TØI report 1850/2021

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Double-track railway between Oslo and Gothenburg

An analysis using the Norwegian Freight Transport model

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Sammendrag:

I denne rapporten modellerer vi effektene i godssektoren for å implementere dobbeltspor for jernbanen for hele distansen mellom Göteborg og Oslo, noe som reduserer transporttidene fra 7,5 timer til 4 timer. Tidsbesparelsene fører til kostnadsbesparelser som vil gangne alle transportkjeder som allerede bruker jernbane på denne fraktrelasjonen. Muligheten for raskere jernbanefrakt vil også tiltrekke seg godsvolumer fra andre transportkjeder som per nå bruker andre ruter eller konkurrerende transportmidler, det vil si sjø- og veitransport, da det åpner for å redusere kostnadene. Å "trekke" godsvolumer bort fra veitransport vil føre til lavere CO_2-utslipp og eksterne kostnader. Vi modellerer også scenarier med høyere drivstoffbeskatning for veitransport. Her vil noen transportkjeder gå over til å benytte jernbanetransport, det vil si at volumer blir "skjøvet" bort fra veitransport for å redusere kostnadene. Disse scenariene resulterer også i lavere CO_2-utslipp og eksterne kostnader.

Summary:

In this report we model the effects in the freight sector of implementing double-track railway for the entire distance between Gothenburg and Oslo, reducing transport times from 7.5 hours to 4 hours. The time savings lead to cost savings, benefitting transport chains that are already using rail on this freight relation. The possibility of improved rail freight will also attract freight volumes from some other transport chains using competing routes and modes, i.e. sea and road transport, as it opens up for reducing costs. “Pulling” freight volumes away from road transport will lead to lower CO_2-emsissions and external costs. We also model scenarios with higher fuel taxation for road transport. Here, some transport chains will shift to competing modes such as rail, i.e. “pushing” away volumes from road transport in order to reduce cost. These scenarios also result in lower CO_2 emissions and external costs.

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Preface

In February 2021 representatives from STRING and the Institute of Transport Economics (TØI) met to discuss the possibility of analyzing the likely effects for the freight sector of upgrading the rail connection between Oslo and Gothenburg to a double-track railway. The main, overarching research question in this report is:

- What are the impacts in the freight sector from upgrading the railway between Oslo and Gothenburg so that the entire line has double-tracks, keeping fuel tax policies unchanged?
    - How will it affect the cost of freight transport between these two regions?
    - How will this impact the demand for road freight transport, and what will be the associated reductions in CO_2-emissions?
    - How will this impact the demand for rail freight transport?
    - What will be the system-wide gross economic benefits for the freight sector of implementing double-track railway on the entire distance?

We answer these research questions by using the Norwegian Freight Transport Model, along with the benefit calculating tool GodsNytte for our analysis. It has ensured a comprehensive and stringent analysis, with a well-established and well-documented modeling tool.

We have adapted the models to this specific case and simulated multiple scenarios for analysis. In addition to the main research question, we have also investigated the impact of more aggressive fuel tax policies that are more in line with climate ambitions in Norway and Sweden than current taxes are.

The research team has consisted of Paal Brevik Wangsness (project leader and main author), Nina Hulleberg (main modeling expert), Anne Madslien and Inger Beate Hovi. Daniel Pinchasik also contributed with a short text in the discussion section of this report (Box A).

Contact person at STRING was Rebecca Rosenquist Elliot. STRING was given a draft version of the final report for commenting. We are thankful for their excellent cooperation, good meetings and constructive feedback.

The internal quality assurance of this report was done by Chief Research Economist Askill Harkjerr Halse.

Oslo, August 2021
Institute of Transport Economics

Bjørne Grimsrud	*Askill Harkjerr Halse*
Managing Director	*Research Director*

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Contents

Summary

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Authors: Paal Brevik Wangsness, Anne Madslien, Inger Beate Hovi & Nina Hulleberg
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In this report we model the effects in the freight sector of implementing double-track railway for the entire distance between Gothenburg and Oslo, reducing transport times from 7.5 hours to 4 hours. The time savings lead to cost savings, benefitting transport chains that are already using rail on this freight relation. The possibility of improved rail freight will also attract freight volumes from some other transport chains using competing routes and modes, i.e. sea and road transport, as it opens up for reducing costs. "Pulling" freight volumes away from road transport will lead to lower CO_2-emsissions and external costs. We also model scenarios with higher fuel taxation for road transport. Here, some transport chains will shift to competing modes such as rail, i.e. "pushing" away volumes from road transport in order to reduce cost. These scenarios also result in lower CO_2 emissions and external costs.

The main focus of this report has been to assess the likely effects in the freight sector of implementing double-track railway for the entire distance between Gothenburg and Oslo. We stress that we have not made any assessment of the necessary investment costs and operations and maintenance costs of implementing double-track railway for the entire distance. We also stress that we only look at the freight sector, so any benefits to passenger travel, will be additional.

Our main scenario is where double-tracks are introduced in 2040 and transport times for freight trains are reduced from 7.5 hours as it is in the current situation, down to 4 hours. We use the Norwegian Freight Transport Model to simulate the effects this infrastructure improvement would have for the freight sector. The modeled impacts can be summarized as follows:

- **Reduced transport time for rail** freight leads to a reduction in the cost of using rail for transporting goods on the freight relations between the Gothenburg and Oslo areas.
- It is the time-based transport costs (salaries etc.) and cargo time costs (the owner of goods' willingness to pay for receiving the goods faster) that are reduced when the speed of rail transport is increased. We assume unchanged distance-dependent costs, e.g., no changes in distance-dependent rail user fees for capital cost recovery for the infrastructure owner/operator.
- These cost reductions are a benefit to transport operators and their customers (the owners of goods) who are already using rail on these freight relations.
- The new opportunity of faster rail transport allows for e-optimization for all agents in the freight transport sector, in the pursuit of minimizing their overall costs. This increased competitiveness for rail transport leads to rail freight **"pulling" goods from competing modes** and competing routes.
- Some transport chains that before the infrastructure improvements would have used either road transport with heavy goods vehicles (HGVs) or sea transport, will find it beneficial to switch to rail transport for parts of their transport chain. Those

who make the switch are reducing their costs. **The net effect is more demand for rail freight and lower costs in the freight sector.**

- The model finds that amount of goods transported by train over the Norwegian-Swedish border at Kornsjø **increases by roughly 40%** compared to the baseline.
- As some parts of transport chains switch from HGVs and sea transport, which are largely powered by fossil fuels, to rail freight, which is powered by electricity, CO_2-emissions from the freight sector are reduced.
- Other external costs, such as accidents and local pollution, are also reduced.

Although faster rail freight would lead to changes in various transport chains in other parts of the freight sector, the largest changes will be on the directly affected relations between the Gothenburg and Oslo areas. The main change is that parts of some transport chains make a shift to rail transport, away from road transport. The model finds that implementing double-tracks here will reduce the number of HGVs crossing the Norwegian-Swedish border at Svinesund by about 2% in 2040 compared to the baseline. While this may seem like a small number in relative terms for road transport, which transports many times more volume than rail transport between Oslo and Gothenburg, the mode shift would represent a significant percentage increase in freight volumes by rail.

As the reduced transport time makes the use of freight train more attractive, we find that in this scenario the amount of goods by train transported over the Norwegian-Swedish border at Kornsjø increases by roughly 40% compared to the baseline.

This would be the result of the freight transport sector re-optimizing when facing this new transport improvement, i.e. how much rail freight will "pull" from road and sea transport.

The **main social benefits of this transport improvement** are transport user benefits, i.e., reductions in overall costs in the freight sector, and the reductions in external costs. With regards to user benefits, the freight transport sector reduces its overall costs, both for existing users of rail freight and new users.

The shift to rail away from HGVs and sea transport for some transport chains leads to lower external costs, mainly those stemming from CO_2-emissions. The reduction in HGVs on the distance between Oslo and Gothenburg alone leads to an estimated reduction in CO_2-emissions of about 66,000 tons over the period 2040-2062[1].

- When summing up, the gross benefits of this transport improvement (for the years 2040-2079) has a present value of **776 MNOK** in the year 2021. This is shown in Table 1.
- The largest benefit component is the reduction of CO2 costs, with a present value of **483 MNOK**, which represents a reduction of about **289 000 tons of CO_2** over the period 2040-2079[2]. These are the sum of reductions in the entire transport chain, from both road and sea transport, reductions occurring in Norway, Sweden and other countries involved in the transport chains.

[1] Opening year of the double-tracks is assumed to be 2040, and 2062 is the year furthest into the future for which there was made projections for the Norwegian Freight Transport Model in the analyses underpinning the National Transport Plan 2022-2033.

[2] Note that we have not done any calculations of the increase in CO_2-emissions from the construction phase of implementing double-track railway.

Table 1: Present value of gross freight sector benefits from introducing double tracks between Gothenburg and Oslo.

Benefit category	Present value, MNOK
Transport user benefits	278
Government finances	-22
Revenues of toll and ferry companies	-23
Reduced CO_2 costs	483
Reductions in other external costs (in Norway)	69
Cost of public funds	-9
Present value of benefits	776

What happens if fuel taxes increase?

Most countries in the world, including Norway and Sweden, have ratified the Paris Agreement. In order to fulfill this agreement, more assertive climate policy will be needed. Some of the most efficient climate policy is to tax the emissions directly, e.g., through fuel taxation. By using the Norwegian Freight Transport Model, we investigate different scenarios with major increases in fuel taxation for road transport, and how this can be expected to affect mode choice for freight between Gothenburg and Oslo.

We expect Swedish fuel prices to be reflected in the cross-border transport costs between Sweden and Norway. Extrapolating the fuel tax trajectory in the past years, with some additions for more aggressive climate policy, we apply fuel prices that are 36% higher in 2040 than in 2018. At the same time, we expect continued fuel efficiency improvements, with fuel use per km for HGVs to be 21% lower in 2040 than in 2018. The modeled impacts can be summarized as follows:

- With fuel taxes rising faster than efficiency improves, the cost of transporting goods by road increases.
- This change costs for the road sector compared to the baseline, forces the agents in the sector to e-optimize in order to minimize their overall costs. This leads to a "push" away from road transport and over to other modes, i.e., sea and rail transport.
- This switch away from road transport to other modes, in particular where shifting to electricity powered rail transport, leads to relatively large reductions in CO2-emissions from the freight sector.
- Other external costs from road transport, such as accidents and local pollution, are also reduced.

In this scenario HGV traffic over Svinesund is reduced by 4.4% in 2040, and further to 5.7% in 2062, compared to the corresponding years in the baseline simulations. Removing these HGVs leads to the removal of 226,600 tons of CO_2 (tCO_2) between 2040 and 2062. And the reduced competitiveness for HGVs leads to a mode shift that implies a 22% increase in the amount of goods transported by train over Kornsjø in 2040, and 32% in 2062, compared to the baseline.

Our analysis contains additional scenarios with higher fuel taxation. In one scenario, we add the implementation of double-tracks into the high fuel tax scenario, we get additional reductions in HGVs crossing at Svinesund and corresponding emission reductions. Compared to the baseline, HGV traffic over Svinesund will be reduced by 5.1% in 2040 and 6.4% in 2062, with total emission reductions for this period totaling 245,000 tCO_2. Freight volumes by train over Kornsjø will also be 59% higher in 2040 and 75% higher in 2062 compared to the baseline.

We also had a stress-test where we assumed higher fuel taxes, but no efficiency improvements, which from a modeling perspective is equivalent to simply more aggressive fuel tax policy. With 36% higher fuel prices in 2040 and no increased fuel efficiency over time, we get 20% lower HGV traffic over Svinesund in 2040 and 40% lower HGV traffic in 2062 compared to corresponding years in the baseline. The aggressive fuel taxation will also drive increases in freight volumes by train over Kornsjø, pushing these to be 60% higher in 2040 and 110% higher in 2062 compared to the baseline. The modeled effect on transported volumes by rail is shown in Figure 1.

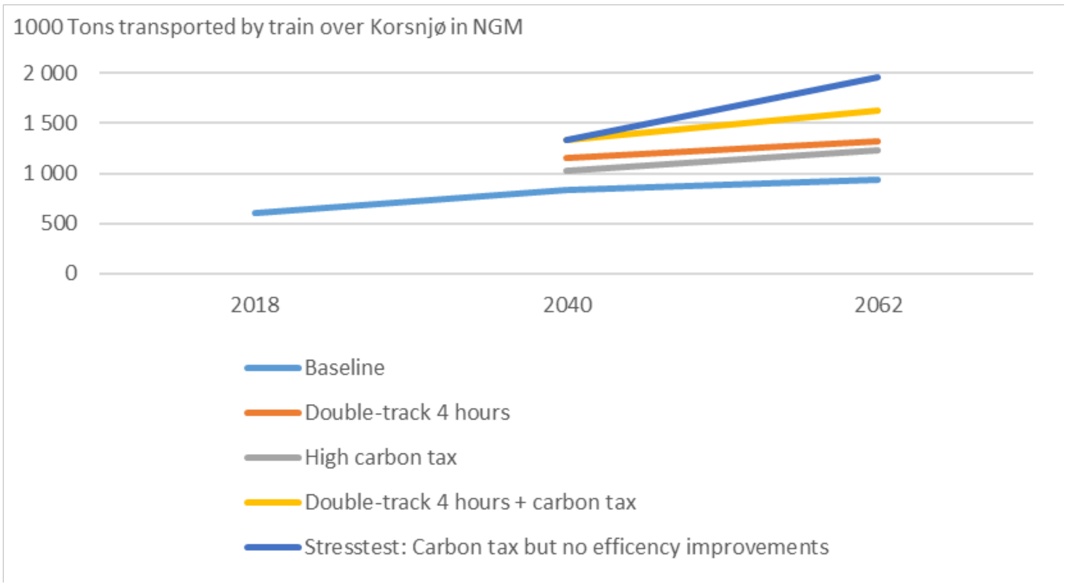

Figure 1: Freight transport volumes (1000 tons) per year transported by freight train over Kornsjø (both directions) in different scenarios.

Figure 1 shows us that **both shorter rail transport times and higher fuel taxes contributes to a shift to rail freight**. The former "pulls" volumes from other modes, whereas the latter "pushes" goods away from road transport. If both are implemented, even higher volumes will be shifted to rail transport. And as the stress-test shows, the more aggressively carbon is priced, the more drastic the changes in the freight sector will be.

Sammendrag

Dobbeltsporet jernbane mellom Oslo og Gøteborg: En analyse ved hjelp av Nasjonal Godsmodell

TØI rapport 1850/2021
Forfattere: Paal Brevik Wangsness, Anne Madslien, Inger Beate Hovi & Nina Hulleberg
Oslo 2021, 39 sider

I denne rapporten modellerer vi effektene i godssektoren for å implementere dobbeltspor for jernbanen for hele distansen mellom Göteborg og Oslo, noe som reduserer transporttidene fra 7,5 timer til 4 timer. Tidsbesparelsene fører til kostnadsbesparelser som vil gagne alle transportkjeder som allerede bruker jernbane på denne fraktrelasjonen. Muligheten for raskere jernbanefrakt vil også tiltrekke seg godsvolumer fra andre transportkjeder som per nå bruker andre ruter eller konkurrerende transportmidler, det vil si sjø- og veitransport, da det åpner for å redusere kostnadene. Å "trekke" godsvolumer bort fra veitransport vil føre til lavere CO2-utslipp og eksterne kostnader. Vi modellerer også scenarier med høyere drivstoffbeskatning for veitransport. Her vil noen transportkjeder gå over til å benytte jernbanetransport, det vil si at volumer blir "skjøvet" bort fra veitransport for å redusere kostnadene. Disse scenariene resulterer også i lavere CO2-utslipp og eksterne kostnader.

Hovedfokuset i denne rapporten har vært å vurdere de sannsynlige effektene i godssektoren ved å implementere dobbeltspor hele togstrekningen mellom Göteborg og Oslo. Vi understreker at vi ikke har gjort noen vurdering av nødvendige investeringskostnader og drifts- og vedlikeholdskostnader ved implementering av dobbeltspor for hele strekningen. Vi understreker også at vi bare ser på godssektoren, så eventuelle nyttevirkninger for passasjerreiser, vil komme i tillegg.

Vårt hovedscenario er hvor dobbeltspor innføres i 2040 og transporttidene for godstog reduseres fra 7,5 timer som det er i dagens situasjon, ned til 4 timer. Vi bruker Nasjonal godstransportmodell til å simulere virkningene denne infrastrukturforbedringen vil ha for godssektoren. De modellerte virkningene kan oppsummeres som følger:

- Redusert transporttid for jernbanefrakt fører til en reduksjon i kostnadene ved å bruke jernbane til transport av varer på godsrelasjonene mellom Göteborg- og Oslo-områdene.
- Det er de tidsbaserte transportkostnadene (lønn etc.) og frakttidskostnader (eieren av varenes betalingsvillighet for å motta varene raskere) som reduseres når hastigheten på jernbanetransporten økes. Vi antar at de distanseavhengige kostnadene er uendret i dette scenarioet, bl.a. ingen endring kjørevegsavgift for å dekke eier/operatør av infrastrukturens kapitalkostnader.
- Disse kostnadsreduksjonene er en fordel for transportoperatører og deres kunder (vareeierne) som allerede bruker jernbane på disse fraktrelasjonene.
- Den nye muligheten for raskere jernbanetransport gir mulighet for re-optimalisering for alle aktører i godstransportsektoren, i jakten på å minimere de totale kostnadene. Denne økte konkurranseevnen for jernbanetransport fører til at jernbanefrakt "trekker" varer fra konkurrerende transportmidler og konkurrerende ruter.
- Noen transportkjeder som før infrastrukturforbedringene ville ha brukt enten veitransport med vogntog eller sjøtransport, vil finne det gunstig å bytte til jernbanetransport for deler av transportkjeden. De som bytter reduserer kostnadene.

Nettoeffekten er mer etterspørsel etter jernbanefrakt og lavere kostnader i godssektoren.
- Modellen finner at godsmengden som transporteres med tog over grensen på Kornsjø øker med om lag 40% sammenlignet med referansebanen.
- Etter hvert som deler av transportkjedene skifter fra vogntog og sjøtransport, som i stor grad drives av fossilt brensel, til jernbanefrakt, som drives av elektrisitet, reduseres CO_2-utslippene fra godssektoren.
- Andre eksterne kostnader, som ulykker og lokal forurensning, reduseres også.

Selv om raskere jernbanefrakt vil føre til endringer i ulike transportkjeder i andre deler av godssektoren,vil de største endringene være på den direkte berørte relasjonen mellom Göteborg og Oslo. Hovedendringen er at deler av enkelte transportkjeder gjør et skifte til jernbanetransport, vekk fra veitransport. Modellen finner at implementering av dobbeltspor her vil redusere antall vogntog som krysser den grensen ved Svinesund med om lag 2% i 2040 sammenlignet med referansebanen. Selv om dette kan virke som et lite antall relativt sett for veitransport, som transporterer mange ganger mer volum enn jernbanetransport mellom Oslo og Gøteborg, vil transportmiddelskiftet representere en betydelig prosentvis økning i godsvolumet med jernbane.

Etter hvert som den reduserte transporttiden gjør bruken av godstog mer attraktivt, finner vi i dette scenariet at mengden gods med tog som transporteres over den norsk-svenske grensen på Kornsjø øker med om lag 40 % sammenlignet med referansebanen. Dette vil være et resultat av at godstransportsektoren re-optimaliserer når den står overfor denne nye transportforbedringen, det vil si hvor mye jernbanefrakt som vil "trekke" fra vei- og sjøtransport.

De viktigste nytteøkningene ved denne transportforbedringen er økningen i operatør- og transportbrukernytten, det vil si reduksjoner i de samlede kostnadene i godssektoren, samt reduksjoner i eksterne kostnader. Når det gjelder operatør- og transportbrukernytten, reduserer godstransportsektoren sine samlede kostnader, både for eksisterende brukere av jernbanefrakt og nye brukere.

Overgangen til jernbane bort fra vogntog og sjøtransport for enkelte transportkjeder fører til lavere eksterne kostnader, som for eksempel de som stammer fra CO_2-utslipp. Reduksjonen i vogntog på avstanden mellom Oslo og Gøteborg alene fører til en estimert reduksjon i CO_2-utslipp på om lag 66 000 tonn i perioden 2040-2062.[3]

- Når vi summerer opp brutto nyttevirkninger fra denne transportforbedringen (for årene 2040-2079) får vi en nåverdi på 776 MNOK i 2021. Dette vises i Tabell 1.
- Den største nyttekomponenten er reduksjonen av CO_2-kostnader, som har en nåverdi på 483 MNOK. Dette representerer en reduksjon på om lag 289 000 tonn CO2[4]. Dette er summen av reduksjoner i hele transportkjeden, både fra vei- og sjøtransport, med utslippsreduksjoner i Norge, Sverige og andre land som er involvert i transportkjedene.

[3] Åpningsåret for dobbeltsporene antas å være 2040, og 2062 er året lengst inn i fremtiden som det ble gjort anslag for Nasjonal Godstransportmodell for i analysene som ligger til grunn for Nasjonal transportplan 2022-2033.

[4] Vi bemerker at vi ikke har gjort noen beregninger av økningen i CO_2-utslipp fra byggefasen av implementeringen av dobbeltsporet jernbane.

Tabell 1: Nåverdi av brutto nytte knyttet til godstransportsektoren av å oppgradere til dobbeltspor mellom Oslo og Göteborg.

Nyttekategori	Nåverdi, MNOK
Transportbrukernytte	278
Offentlige inntekter	-22
Inntekt til ferge- og tollselskaper	-23
Redusert CO_2-kostnader	483
Reduksjoner i andre eksterne kostnader (i Norge)	69
Skattefinansieringskostnader	-9
Nåverdi av nyttevirkninger	**776**

Hva skjer om drivstoffavgiftene øker?

De fleste land i verden, inkludert Norge og Sverige, har ratifisert Parisavtalen. For å oppfylle denne avtalen vil det være behov for mer aggressiv klimapolitikk. Noe av den mest effektive klimapolitikken er å skattlegge utslippene direkte, for eksempel gjennom drivstoffbeskatning. Ved hjelp av Norsk Godstransportmodell undersøker vi ulike scenarier med store økninger i drivstoffavgiften for veitransport, og hvordan dette kan forventes å påvirke transportmiddelvalget for gods mellom Göteborg- og Oslo-områdene.

Vi forventer at de svenske drivstoffprisene gjenspeiles i transportkostnadene over landegrensene mellom Sverige og Norge. Ved å ekstrapolere drivstoffavgiftsbanen de siste årene, med noen tillegg til mer aggressiv klimapolitikk, bruker vi drivstoffpriser som er 36 % høyere i 2040 enn i 2018. Samtidig forventer vi fortsatt forbedringer i drivstoffeffektiviteten, med drivstofforbruk per km for vogntog som 21 % lavere i 2040 enn i 2018. De modellerte virkningene kan oppsummeres som følger:

- Når drivstoffavgiftene øker raskere enn effektiviteten, øker kostnadene ved å transportere varer med bil.
- Denne endringen kostnader for veisektoren sammenlignet med referansebanen, tvinger aktørene i sektoren til å re-optimaliseree for å minimere sine samlede kostnader. Dette fører til et "push" vekk fra veitransport og over til andre transportmidler, det vil si sjø- og jernbanetransport.
- Denne overgangen fra veitransport til andre transportmidler, spesielt der overgang til elektrisk jernbanetransport, fører til relativt store reduksjoner i CO_2-utslippene fra godssektoren.
- Andre eksterne kostnader fra veitransport, som ulykker og lokal forurensning, reduseres også.

I dette scenariet reduseres vogntogtrafikken over Svinesund med 4,4 % i 2040, og videre til 5,7 % i 2062, sammenlignet med tilsvarende år i referansebanen. Fjerning av disse vogntogene fører til fjerning av 226 600 tonn CO_2 (tCO_2) mellom 2040 og 2062. Og den reduserte konkurranseevnen for vogntog fører til et transportmiddelskifte som innebærer en 22% økning i godsvolum som transporteres med tog over Kornsjø i 2040, og 32% i 2062, sammenlignet med referansebanen.

Vår analyse inneholder flere scenarier med høyere drivstoffbeskatning. I ett scenario legger vi til implementering av dobbelt-spor i secenarioet med høye drivstoffavgifter. Da får vi ytterligere reduksjoner i vogntogpasseringer på Svinesund og tilsvarende utslippsreduksjoner. Sammenlignet med referansebanen vil vogntogpasseringer bli redusert med 5,1 % i 2040 og 6,4 % i 2062, med totale utslippsreduksjoner for denne perioden på totalt 245 000 tCO_2. Godsvolumet med tog over Kornsjø vil også være 59 % høyere i 2040 og 75 % høyere i 2062 sammenlignet med referansebanen.

Vi hadde også en stresstest der vi antok høyere drivstoffavgifter, men ingen effektivitetsforbedringer, som fra et modelleringsperspektiv tilsvarer rett og slett mer aggressiv drivstoffavgiftspolitikk. Med 36% høyere drivstoffpriser i 2040 og ingen økt drivstoffeffektivitet over tid, får vi 20% lavere vogntogtrafikk over Svinesund i 2040 og 40% lavere vogntogtrafikk i 2062 sammenlignet med tilsvarende år i referansebanen. Den aggressive drivstoffbeskatningen vil også føre til økte godsvolumer med tog over Kornsjø, noe som presser disse til å bli 60% høyere i 2040 og 110% høyere i 2062 sammenlignet med referansebanen.

Oppsummert viser analysen oss at både kortere togtransporttider og høyere drivstoffavgifter bidrar til et skifte til mer jernbanetransport. Førstnevnte "trekker" volumer fra andre transportmidelr, mens sistnevnte "skyver" varer bort fra veitransport. Hvis begge implementeres, vil enda høyere volumer bli flyttet til jernbanetransport. Og som stresstesten viser, jo mer aggressivt karbon er priset, jo mer drastiske blir endringene i godssektoren.

1 Introduction

1.1 Background

In February 2021 representatives from STRING and the Institute of Transport Economics (TØI) met to discuss the possibility of analyzing the likely effects for the freight sector of upgrading the rail connection between Oslo and Gothenburg to a double-track railway. STRING is a political member organization in Northern Europe, with members representing cities, counties and national regions from Germany, Denmark, Sweden, and Norway. The overarching vision of the organization is to create a megaregion in Northern Europe to combat climate change while improving lives of citizens. To reach this vision, one of their strategic priorities is "To assure high-quality sustainable transport connectivity from Hamburg to Oslo". The upgrade of the railway between Oslo and Gothenburg is one of several initiatives under this strategic priority.

The railway connection between Oslo and Gothenburg across Kornsjø was opened in 1879. Large parts of the route have been largely unchanged since that time. Of a total railway line of approx. 350 km, 138 km has double track. The last section that was extensively upgraded was Gothenburg-Öxnered, where 75 km of double track opened in 2012. There are significant speed limitations on parts of the rail line, especially due to poor curvature, but also due to high frequency of commuter trains near the big cities (Trafikverket & Jernbaneverket, 2016).

Upgrading the railway connection between Oslo and Gothenburg has been on the transport policy agenda for decades. Just going back to the 1990s, we find several reports investigating the possibilities for the railway connection between Oslo and Gothenburg, such as:

- Dubbelspårutbyggnad Göteborg-Kornsjø-Halden [Construction of double-tracked railway Gothenburg-Korsjø-Halden] by Banverket (1991)
- Høyhastighet Oslo-Kornsjø-(Göteborg) [High-speed rail Oslo-Kornsjø-(Gothenburg)] by NSB (1992)
- Samarbeid om infrastruktur Oslo-Göteborg [Infrastructure cooperation Oslo-Gothenburg] by Jernbaneverket (2005)
- Høyhastighetsutredning Oslo-Göteborg [Assessment of high-speed rail Oslo-Gothenburg] by Jernbaneverket (2011)
- Oslo – Göteborg på 3:30 [Oslo-Gothenburg in 3:30] by Jernbaneverket (2012)
- Oslo–Göteborg: Utvikling av jernbanen i korridoren [Oslo-Gothenburg: Developing the railway through the corridor] by Trafikverket & Jernbaneverket (2016)

The latest assessment from 2016 mainly focused on the investment needs and likely costs for upgrading key parts of the railway link between Oslo and Gothenburg. They also looked at the potential for reduced travel and freight time and increases in transport capacity. They did not conduct any analysis of the benefits from such a railway upgrade, neither for the transport users, the environment, or other parts of society. In this report we will be able to shed some light of parts of the benefit calculation, namely the benefits for the freight transport sector and the associated reductions in external costs.

The assessment from 2016 documents the transport time advantage that road transport has on the distance between Oslo and Gothenburg. In the assessment, the expected transport time for a truck (hereafter HGV - heavy goods vehicle) from the Alnabru terminal in Oslo to the Port of Gothenburg was 3 hours and 35 minutes under normal conditions (i.e. low congestion), which seems to roughly correspond to transport times on Google Maps in 2021 (see Figure 2). They contrast this to the expected transport times for freight train, which in 2016 was assessed to be 6 hours and 45 minutes (see Figure 3).

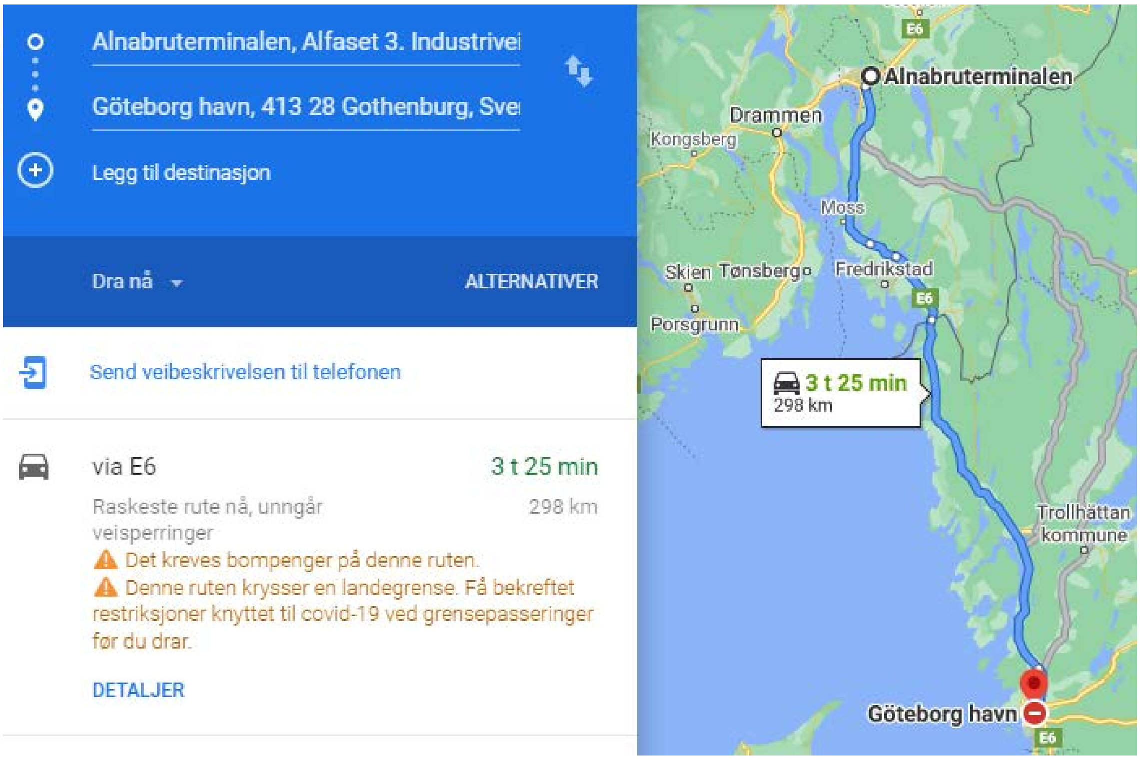

Figure 2: Distances and travel time between Alnabru and the Port of Gothenburg, spring 2021. Source: Google Maps. Accessed May 30th, 2021.

Trafikverket and Jernbaneverket (2016) present three scenarios for improving the train connection between Oslo and Gothenburg. The first scenario is simply implementing the already decided polices on the Swedish side, which will lead to some improvements in transport time for train transport, bringing transport times for freight transport down to 6 hours and 30 minutes. The second scenario involves further improvements and investments, where transport times for freight train could be brought down to 4 hours and 50 minutes during the night, but transport times would be about the same as in the current situation during the daytime. In the third scenario there will be made additional improvements and investments to ensure double track railway between Oslo and Gothenburg, which they expect to give transport times for freight train of about 5 hours to 5 hours and 20 minutes in the daytime, and about 4 hours in the nighttime.

For the purpose of this report, we focus on the third scenario from Trafikverket and Jernbaneverket (2016), where transport times for freight train are 5 hours during the day and 4 hours during the night, compared to the current transport times, as summed up in Table 2.

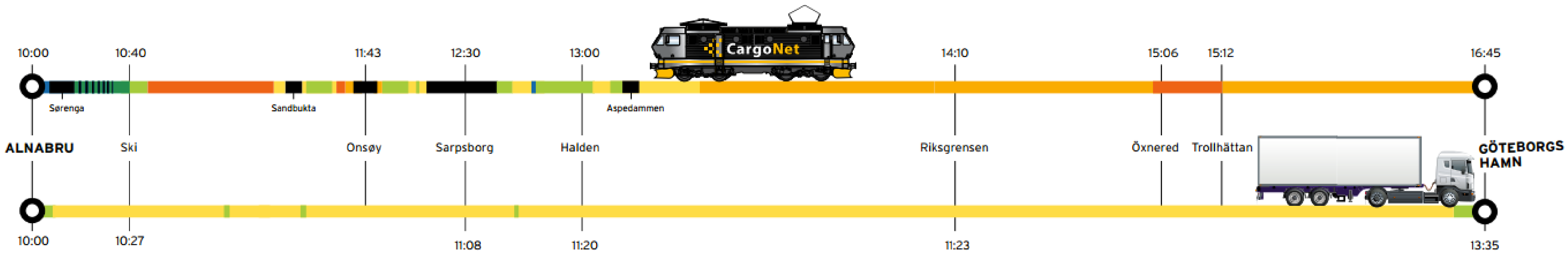

Figure 3: Comparison of speed and driving time for freight trains and road transport Oslo - Gothenburg. Black indicates stop, blue and light green indicate speeds up to 70 km / h, while dark green, yellow, orange and red mark indicate signposted speeds of respectively 70-100, 100-130, 140 and 160-200 km/h. Trafikverket and Jernbaneverket (2016) referring to Jernbaneverket (2012).

Table 2: Transport times between Alnabru and Port of Gothenburg, from Trafikverket and Jernbaneverket (2016).

	Freight Train	Road transport
Current situation	6 hours, 45 minutes	3 hours, 35 minutes
Double track solution, daytime	5 hours	3 hours, 35 minutes
Double track solution, nighttime	4 hours	3 hours, 35 minutes

The transport time in the current situation from Trafikverket and Jernbaneverket (2016) are shorter than transport time for CargoNet in the spring of 2021, which is 7 hours and 51 minutes. This is closer to the transport time in the Norwegian Freight Transport Model, which is 7 hours and 30 minutes. For the purpose of this report, our baseline scenario has a transport time of 7.5 hours between Alnabru and the port of Gothenburg. We can also mention that the transport time for HGVs for this freight relation in the model is 3 hours and 34 minutes, quite close to that in Trafikverket and Jernbaneverket (2016).

1.2 The context of climate policy

As the valuation of CO_2-emissions plays an important role in this analysis, we have decided to devote a section of the report to provide important background and explain some central concepts.

Human-caused climate change is a huge, global threat to life and health for both humans and ecosystems. The welfare (and perhaps even existence) of future generations requires that climate change be limited from the very catastrophic outcomes that can occur with very high temperature rises. There is broad political agreement on recognizing this threat. Therefore, both Norwegian and Swedish authorities have committed themselves on several fronts to making major cuts in their national greenhouse gas emissions.

Most countries in the world, including Norway and Sweden, have ratified the Paris Agreement. It aims to limit the global temperature increase to well below 2 degrees Celsius and strive to limit it to 1.5 degrees. Norway has ratified the Paris Agreement in accordance with the Royal Decree of 17 June 2016 following a decision in Parliament on 14 June 2016.

The different countries that have ratified the Paris Agreement decide for themselves how large emission cuts they are willing to pledge, and they will report accordingly. Norway has announced that it is committed to reducing its greenhouse gas emissions by at least 50% and up to 55% by 2030 compared with the 1990 level. This is an upward adjustment of the original pledge set in 2016. Fulfillment of these obligations will be crucial for Norway's transition to a low-emission society by 2050. By low-emission society is meant that Norway's emissions will be reduced by 90% -95%, as specified in the Government's climate report (Klimameldingen) in 2021 (Klima- og Miljødepartementet, 2021).

Norway's emission obligations are also specified as obligations to the EU, which builds on the EU's/EEA's ambitions to comply with the Paris Agreement. It is useful to distinguish between the sectors that fall under the EU Emissions Trading System (ETS), which we will refer to as ETS-sectors, and non-ETS-sectors. The ETS-sector includes energy, industry, and aviation. The total number of emission permits, i.e., the quota ceiling, for all these sectors will be reduced by 43% compared with 2005. Between 2020 and 2030, the annual quota ceiling will be lowered by a so-called linear reduction factor of 2.2% per year.

Road transport, whose emissions are a prime focus of this report, is not a part of the ETS-sector. In the non-ETS-sector, Norway has committed to reducing emissions by 40% compared to 2005 in its climate agreement with the EU. In its Granavold declaration, the current government plans to over fulfill this pledge by stepping up their emissions reductions to 45% by 2030. This intention is formalized in *Norway's National Plan related to the Decision of the EEA Joint Committee* (Klima- og Miljødepartementet, 2019).

Finally, both Norway and Sweden have committed to working towards carbon neutrality along with the other Nordic countries. This was covered in the Declaration on Nordic Carbon Neutrality (Sipilä, Jakobsdóttir, Solberg, Lövin, & Lilleholt, 2019). The work towards carbon neutrality at home will be combined with Nordic climate diplomacy in international forums in order to drive forward emission-reducing solutions.

The commitments have been made in order to avoid the costs of future climate catastrophe, but the costs of adapting to a low emission society will be high. This cost is often referred to as the abatement cost, i.e., the cost of abating the greenhouse gas emissions so to avoid future damages. There is a high degree of uncertainty of how high this cost will become. Different modeling groups have applied different Integrated Assessment Models (IAMs) under different future scenarios, in order to calculate the necessary carbon price that can drive the necessary emission reductions in order to comply with the Paris Agreement, *at the lowest cost possible*. This carbon price can be referred to as a shadow price. Numerous analyses have been submitted to the IAMC-database (Huppmann et al., 2018), and applied in the special report by the International Panel on Climate Change (IPCC) on the 1.5°C target.

There is a huge spread in carbon price trajectories from these model analyses, as can be shown in Figure 4. Here we display the median values of 50 model calculations of carbon prices consistent with the Paris Agreement, along with the inter-quartile range.

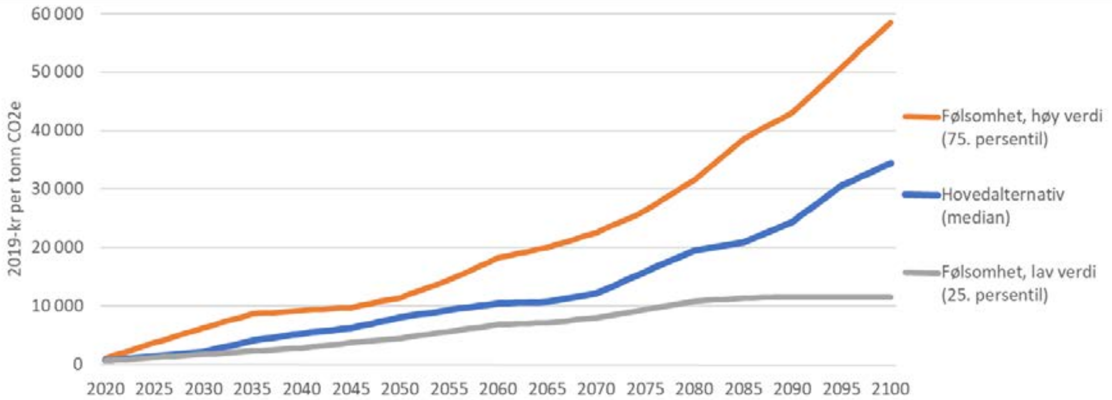

Figure 4: Carbon price trajectories consistent with fulfilling the Paris Agreement based on 50 IAM modeling scenarios used in IPCC (2018).

Even though there is large uncertainty in *how* large the cost of complying with the Paris Agreement will be, it is clear that abatement measures and associated cost of carbon will have to become many times higher than current carbon taxation in most sectors. Norwegian carbon taxation is, on average, among the highest in the world. However, there is a large tax difference between sectors, as can be seen in Figure 5, with the highest in domestic aviation the lowest in agriculture. The former pays for its carbon emissions both in terms of the national carbon tax and the ETS quotas. The latter does not pay for its greenhouse gas emissions at all (quite the opposite, the most emission intensive parts of it is heavily subsidized). In 2021 the road transport sector in Norway has a carbon tax component on fuel that corresponds to a price of 593 NOK per ton of CO_2. This is high compared to international standards, but it is low compared to necessary future prices on carbon depicted in Figure 4.

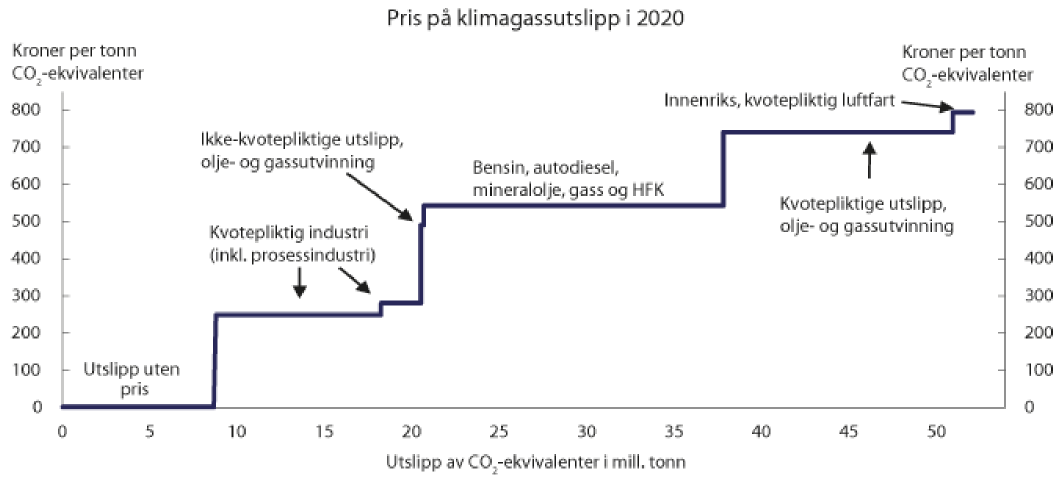

Figure 5: Pricing of carbon in different sectors in Norway in terms of NOK per ton CO_2-equivalent in 2020. The ETS quota price is set at 250 NOK in the figure. The volume of emissions is based on 2018-data. The figure is from Prop. 1 LS - Skatter, avgifter og toll (Finansdepartementet, 2020).

The government's 2021 climate report sets out a plan for the carbon tax to grow to 2000 NOK per ton in 2030. This is roughly in line (slightly lower) with the median carbon price trajectory depicted in Figure 4. However, the growth would need to continue at a fairly high pace throughout the 21st century in order to induce the emission reductions necessary.

Capturing such policy in our freight modeling is key for the analysis in this report. The price of carbon enters the analysis on multiple points, both with regards to prediction and valuation.

The use of carbon pricing for valuation in cost-benefit analysis (CBA) is straightforward. Any change in emissions calculated in model scenarios is to be valued in the cost-benefit analysis according to the carbon price recommended by the Ministry of Transport for emissions in Norway (Samferdselsdepartementet, 2020), and from the Transport Administration for emissions in Sweden (Trafikverket, 2020) for changes in emissions in each country, respectively. These different carbon price trajectories are shown in Figure 6.

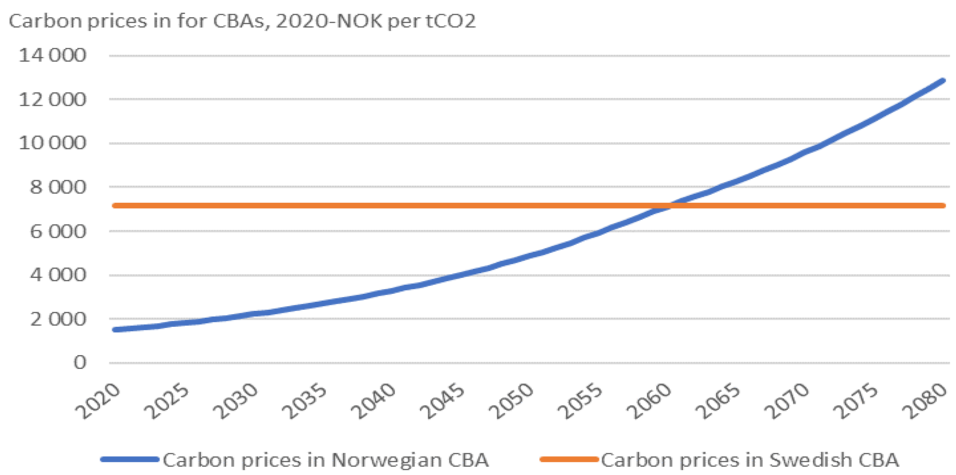

Figure 6: Carbon prices applied in Norwegian and Swedish cost-benefit analysis

The use of carbon pricing for making predictions on how it will affect the transport market requires a specific assumption in the transport modeling of how much fuel will be taxed, and how the road transport sector, notably heavy goods vehicles (HGVs), will respond. Given that the after-tax price of fuel is expected to grow over time, the freight sector can respond in multiple ways:

A. The freight transport can be shifted to other modes, such as freight trains, as they become more competitive when fuel costs increase.
B. The HGV fleet is continuously renewed, and with higher fuel costs the more fuel efficient or zero-emission HGVs become competitive, so we should expect higher carbon taxation to drive average emissions per km downwards.
C. Higher fuel costs can translate into higher transport costs, to which consumers will respond with less demand, leading to lower overall freight transport.

In reality, we can expect a combination of all three responses from the freight sector. If there is a strong response in making the HGV fleet less emissions intensive (response B), then this should be reflected in the transport modeling. It will counteract any shift to other modes (response A). However, response B will to a large extent depend on technological developments in the next decades, which by definition will be highly uncertain. We will have to rely on forecasted efficiency improvements, which we will come back to in the scenario descriptions. Response C is not included in the modeling, as the trajectory of freight volumes remains constant over time, but changes in policies (or other changes affecting the freight market) can affect the choices of modes and routes in the transport sector.

1.3 Research questions

Based on STRINGs strategic priorities of assuring high-quality sustainable transport connectivity from Hamburg to Oslo, also put in the context of high cost of carbon necessary to fulfill the Paris agreement, we formulate the following research questions for this report.

The main, overarching research question is:

1. What are the impacts in the freight sector from upgrading the railway between Oslo and Gothenburg so that the entire line has double-tracks, keeping fuel tax policies unchanged?
    a. How will it affect the cost of freight transport between these two regions?
    b. How will this impact the demand for road freight transport, and what will be the associated reductions in CO_2-emissions?
    c. How will this impact the demand for rail freight transport?
    d. What will be the system-wide gross economic benefits for the freight sector of implementing double-track railway on the entire distance?

We also want to investigate the impact of more aggressive fuel tax policies that are more in line with climate ambitions in Norway and Sweden than current taxes are. This leads to the following research questions:

2. What are the impacts on the freight sector on the relations between the Oslo and Gothenburg areas if fuel tax policies in Norway and Sweden are adjusted more in line with climate ambitions?
    a. How will it affect the cost of freight transport between these two regions?
    b. How will this impact the demand for road freight transport, and what will be the associated reductions in CO_2-emissions?
    c. How will this impact the demand for rail freight transport?

3. What are the impacts on the freight sector on the relations between the Oslo and Gothenburg areas if fuel tax policies in Norway and Sweden are adjusted more in line with climate ambitions, *at the same time as the railway between Oslo and Gothenburg is upgraded* so that the entire line has double-tracks?
    a. How will it affect the cost of freight transport between these two regions?
    b. How will this impact the demand for road freight transport, and what will be the associated reductions in CO_2-emissions?
    c. How will this impact the demand for rail freight transport

We believe that the best way to answer these research questions is to use the Norwegian Freight Transport Model for our analysis. It will ensure a comprehensive and stringent analysis, with a well-established and well-documented modeling tool. We will elaborate more on the modeling in section 2.

1.4 Limitations

This analysis will only concern itself with freight transport, so passenger transport is out of scope. Furthermore, we will not give any considerations to investment cost, or associated operations and maintenance costs, of upgrading the railway between Oslo and Gothenburg so that the entire line has double-tracks. Neither have we given any consideration to CO_2-emissions stemming from the construction phase of upgrading the railway to double-tracks. In other words, we will only focus on the impact that the upgrade to double track railway, and changes in fuel taxation, has on route and mode choice in the freight sector, and the associated environmental impacts and the economic benefits to the freight sector.

The analysis is in essence a modelling exercise using The National Freight Model to calculate how changes in infrastructure and fuel tax policy affect the freight sector and the GodsNytte model to calculate gross benefits. The freight sector projections for the model baseline are the same as those used for freight sector analyses for the National Transport Plan 2022-2033 in Norway. Gathering of new data and new projections have been out of scope for this project. For example, there is no consideration of current or future effects from the covid-19 pandemic on the freight sector.

1.5 Structure of the Report

The report is structured as follows:

In section 2 we go through the methods we apply in this report, namely the Norwegian Freight Transport Model and the associated Excel-tool GodsNytte. In section 3 we describe the scenarios we implement in our modeling framework. We present the results from the modeling in section 4 and provide discussion and conclusions in section 5.

2 Method and Analysis

2.1 The Norwegian Freight Transport Model

In the early 2010s, the Norwegian transport authorities (The Norwegian Public Roads Administration, The Norwegian Railway Directorate and The Norwegian Coastal Administration) and Avinor have developed a national model for all freight transport within and to and from Norway. The latest documentation is found in Madslien, Steinsland, and Grønland (2015). The newest version of The Norwegian Freight Transport Model has been updated for analyses done for the preparation of the Norwegian National Transport Plan 2022-2033 (Ministry of Transport, 2021).

The model system consists of a set of origin-destination matrices for commodity flows (base matrices), cost functions and a detailed logistics model for the choice of transport solution. The base matrices and cost features are input to the logistics model, which is an independent application developed by the Dutch company Significance (Jong, Ben-Akiva, Baak, & Grønland, 2013). The model is normally run through a user interface implemented in the transport planning program CUBE[5].

The logistics model calculates transport solutions for 39 aggregated commodity groups. For each commodity group, a base matrix has been established that specifies how much goods should be transported between all zones in the model. This means that the total amount of goods in the model is constant for a given set of base matrices. The base matrices are established on the basis of a commodity flow analysis, foreign trade statistics, as well as statistics on the production and consumption of goods. The base matrices are projected to different forecast years using the PINGO general equilibrium model and projected growth rates for demography and economic activity from the Norwegian Government long term projections (Finansdepartementet, 2021).

Other key inputs to the logistics model are data files on transport costs, terminal costs, and the value of the goods. Using a network model implemented in CUBE Voyager, matrices of transport time, distances and costs of tolls and ferries are generated between the model's different zones, so-called Level of Service (LoS) data. Such matrices are established for all the different modes of transport, and a large number of vehicle types within each mode of transport. These matrices are multiplied by unit costs for transport time and distance, and together with information on various forms of terminal costs, the total transport costs of all transport solutions (i.e. combinations of vehicle types) between two given zones are presented. Together with other logistics costs, such as holding costs, order costs, etc., the calculated transport costs are used to find the optimal transport solution for all transport flows within and to/from Norway.

[5] https://www.bentley.com/en/products/brands/cube

2.2 Excel-tool GodsNytte

GodsNytte is an Excel-based tool that uses results from simulations in The Norwegian Freight Transport Model (NFM) to calculate gross benefits from changes in infrastructure and policy related to the Norwegian freight sector. These calculations can then be further included in standard cost-benefit analyses (CBAs), as it complies with the guidelines from the Ministry of Finance (2014). The latest documentation of GodsNytte is found in Caspersen, Wangsness, Østli, and Madslien (2015). The newest version of GodsNytte has been updated for analyses done for the preparation of the Norwegian National Transport Plan 2022-2033.

The key inputs are all the changes in the components of the logistics costs, and changes in transported tons, vehicle-kilometers and ton-kilometers for all the modes of transport and vehicle types in NFM for the baseline scenario and a variety of policy scenarios. These inputs are used to construct a timeline for the development in freight sector impacts and other economic impacts, grouped in the following five categories:

- Transport user and transport operator benefits: This represents the changes in total logistics costs for transport operators and the owners of the transported goods. These contain multiple cost components, e.g., time-based costs, distance-based cost, loading costs etc.
- Government finances: This represents the net changes in government revenue from taxes and fees in the transport sector due to the changes in the freight transport equilibrium.
- Revenue to toll and ferry operators.
- External costs: This represents changes in costs related to CO_2 and local emissions, accidents, noise, wear and tear on infrastructure, congestion, and accidental spills into water.
- Cost of public funds: A 20% additional social cost on any contribution a project has to the government deficit (which also includes covering the long-term deficit of ferry and tolling companies), as long-term budget neutrality would force an increase in taxes that increases inefficiencies in capital and labor markets.

The gross benefits discounted to the base year, 2021 in this analysis, which gives us the present value of gross benefits from the infrastructure and/or policy change. All benefit calculations are done automatically when the NFM result files are entered in GodsNytte.

3 Scenario descriptions

3.1 The baseline scenario

The Institute of Transport Economics have conducted many analyses with the Norwegian Freight Transport Model (NFM) that have underpinned many of the analyses for the latest National Transport Plan – NTP 2022-2033. In this work, the baseline scenario has been calculated for a number of key years over the next decades, the latest being in for 2062. This future scenario is based on the existing road, rail, sea and aviation network (including completion of started and some decided infrastructure projects), projections for growth in trade volumes for different goods and completion of currently running road toll schemes (except in the cities), as documented in Madslien, Hulleberg, and Kwong (2019). It is against this baseline all changes in policies and infrastructure are calculated.

For our analyses, the key features of the baseline scenario is that transport times by freight train remain the same as in the current situation, modelled at 7.5 hours between Gothenburg and Oslo, and that distance-based costs, in terms of NOK per km, for Heavy Goods Vehicles (HGVs) remain constant. This implies that in the baseline scenario the projected increases in fuel efficiency are exactly cancelled out by relatively moderate fuel tax increases. We will get back to this issue in the scenarios with higher carbon taxes.

3.2 The double-track scenario

In essence, this is the scenario where double-tracks are introduced between Gothenburg and Oslo, driving down transport time for freight trains in the model[6]. In the report from Trafikverket & Jernbaneverket (2016), they assessed that transport times would be 5 hours during the daytime and 4 hours during the night. We therefore set up scenarios for both 5-hour and 4-hour transport times. Since the changes in the 5-hour scenario are only slightly smaller than in the 4-hour scenario, we focus on the results from the 4-hour scenario.

The reduction in transport time is the only assumed change in this scenario. We assume unchanged distance-dependent costs, e.g., no changes in distance-dependent rail user fees for capital cost recovery for the infrastructure owner/operator.

This reduction in transport times has a first-order effect on driving down time-based costs of transport and the time-costs of cargo (more on this in the results section) for transport by freight train between Gothenburg and Oslo, and nothing else. The second-order effect of this cost-reduction on that link is that all freight relations in the model can now re-optimize their transport choices. The origins and destinations of the goods, and the annual freight volumes are the same, but transport users may now choose different routes and different modes to minimize transport costs. This means that many more freight relations

[6] A minor challenge with modelling this scenario is that cross-border freight transport by wagonload transport is largely transported through the Hallsberg terminal and crosses the border at Charlottenberg. Due to the design of the model, we had to manually make changes in the model set-up so that goods that we assess to be highly likely to only cross between countries at Charlottenberg and be unaffected by shorter transport times over Kornsjø, were taken out of the model simulations.

than those who have origins and/or destinations in the Oslo and Gothenburg-area can be affected, and freight train increases its competitiveness not only compared to HGVs, but also compared to sea transport.

3.3 High fuel tax scenario

In this scenario we make changes to cost functions in the model for the different types of road transport in the model; small lorries, HGVs, HGV-EMS (European Modular System) etc. These changes reflect increases in fuel taxation, which in turn has a first-order effect of driving up the distance-based costs for road transport. The second-order effect is that transport users re-optimize and change their route- and mode choices to best adapt to these higher fuel costs.

A challenge in modelling this scenario is to adapt the model and set the right assumptions regarding fuel efficiency improvements and fuel taxation over time. We want to capture the future developments in fuel taxation and fuel technology, and the interaction between taxation and technology in a consistent model scenario. Technological developments have over time driven down emissions per km for road transport, and is expected to continue to do so (Fridstrøm, 2019). The taxation of CO_2, either directly on fuel or at vehicle purchase has been a major driver of reducing emissions per km (Fridstrøm & Østli, 2021). Given the commitment to fulfil the Paris Agreement, cost efficient climate policy would imply continuous growth in carbon taxation that reflects how increasingly more expensive measures need to be undertaken to reach the target (Rødseth et al., 2020). The implied carbon tax from this carbon price trajectory (the shadow price of the Paris Agreement targets) will become extremely high compared to today's levels (see Figure 4), and it is not guaranteed that there are enough voters behind parties that are willing to apply such carbon taxes, even if it is necessary to reach the targets. A case in point is that key parties on different parts of the political spectrum are voicing opposition[7] to the policies announced in the Norwegian Government's 2021 climate report (Klima- og Miljødepartementet, 2021).

A major uncertainty pulling in the other direction is that technological developments that bring down the cost of emission reductions, may lead to more stringent carbon targets, or increase the likelihood of politicians sticking to their targets (Perino, 2018).

Even if high fuel taxes were increased in one country, it is not certain that fuel taxes will be similarly high in neighboring countries. If the fuel taxes were lower in one country compared to a neighboring country, than there will be incentives for fuel tankering (going out of the way to fill fuel in a cheaper area or deliberately carrying excess fuel in order to reduce or eliminate refueling at the destination)[8]. This also means that it is the fuel price in the neighboring country with the lowest tax that in most cases of cross-border traffic will be the paid fuel price that is reflected in actual costs per kilometer. If Sweden maintains a significantly lower fuel tax than Norway, we can expect the cross-border road transport will mainly refuel in Sweden.

The NFM focuses on the freight transport sector and cannot incorporate complex interactions with technological development and taxation. However, the model analysis needs to be aware of the general trend that can be summarized by the stylized facts:

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[7] Klimameldingen er klar for Stortinget. To partier har satt bremsene på. (bt.no)

[8] As this is common for sea transport, we therefore assume that fuel costs for sea transport remain unchanged in this scenario, and that the increases in fuel taxation will only affect road transport.

- The real value tax rate on fossil fuels can be expected to grow over time
- Emissions per km from HGVs can be expected to decline over time

We have therefore decided to split the fuel tax scenario into what we consider a fairly likely scenario, and a stress-test. In the likely scenario, we consider the Swedish fuel tax to be lower than the Norwegian one in the future, meaning that it will be the Swedish fuel price that will affect the cost per kilometer for HGVs involved in cross-border freight. We also expect the fuel efficiency for HGVs to continue, and consider the rate of improvement projected in Fridstrøm (2019) to be a reasonable assumption. This means that average fuel use per km in 2040 will be 21% lower than in 2018.

On the Norwegian side, an anchor for the fuel tax scenario is the carbon tax announced by the Norwegian government (Klimameldingen) in the winter of 2021 (Klima- og Miljødepartementet, 2021). This implies a carbon tax of 2000 NOK per tCO_2, or 5,32 NOK per liter of diesel by 2030. Contrast this with a tax of 1,58 NOK per liter of diesel in 2021.

Assuming that between 2021 and 2030 the carbon component of the fuel tax will rise according to the stated goal and the road user component remains constant, it will be a formidable tax rise. It will be part of the stimulation to more fuel-efficient HGVs, which will mitigate the logistics cost for road transport in face with such a tax rise. We consider that a plausible and implementable scenario will be that the fuel tax will rise according to the stated plan in 2030, which the road freight sector in the model will take as a cost rise without being able to respond with fuel efficiency. The fuel costs will be 32% higher in 2030 than 2021.

On the Swedish side, there has not been any stated future carbon tax to which we can anchor our scenarios. The fuel tax trajectory the Swedish government held before 2021 does give guidance to a likely fuel tax scenario. For years the fuel tax was first adjusted for inflation, and then adjusted for GDP-growth, which was mechanically set at 2% per year. In 2021, and likely in 2022, this adjustment for GDP-growth is put on pause[9]. The stated reason for this pause is because the mandate of reducing the CO2-content of fuel through the blending in of biofuels, is driving up the production costs of fuel and fuel prices. In spite of the paused GDP-based price reduction, the government expects net emissions to decrease due to lower CO_2-content and higher prices.

Our assessment is that we can expect Swedish policies to drive up fuel prices over time, both through higher taxes and mandating biofuels. We expect the government's climate policy to be at least as aggressive as in the past, with a 2% real-price adjustment per year, but increased ambitions and the cost of the biofuel mandate can drive this tax effect up to 2,8% per year. This results in fuel prices that in The Norwegian Freight Transport Model are 3.47 NOK (excluding VAT) higher in 2040 than in 2018, measured in 2018-prices. In the model this means that fuel prices in Sweden will be 36% higher in 2040 than in 2018. That will affect the distance-based costs of HGVs, and result in changes in route- and mode choice.

To sum up, what we consider to be the likely scenario is where Swedish fuel prices will be 36% higher in 2040, at the same time as average fuel usage per kilometer is 21% lower. The modelling scenarios do not contain any major disruptions with regards to either technology (such as a rapid switch to zero-emission HGVs in the 2040s) or policy (such banning fossil-fueled HGVs). The scenarios assume gradual change, although at a pace somewhat faster than what we have seen in the past. We consider this to be good modelling practice, and

[9] Pausad BNP-indexering av drivmedelsskatten år 2022 - Regeringen.se

we will discuss the robustness of the modelling results to different disruptions that may occur in the future.

In addition to the likely fuel tax scenario, we add a stress-test where the Swedish fuel tax trajectory is upheld, but the fuel efficiency is the same in 2040 as in 2018. Adding a realistic growth in fuel taxation over time without adding realistic fuel efficiency improvements over time, will lead to unrealistic cost increases for HGVs. This will in turn lead to unrealistically large shifts away from HGVs used in freight. However, from a modeling point of view it can be interpreted the same way as a more aggressive tax policy that drive up prices faster.

3.4 Fuel tax and double-track combined

In this scenario we investigate the combined effect of introducing double-tracks for the entire stretch between Gothenburg and Oslo, in a world where fuel taxes have increased significantly. With regards to fuel taxes, we apply what we in the previous subsection considered to be the likely scenario where Swedish fuel taxation, assumed to have a real-price increase of 2,8% per year, will affect the costs per kilometer for cross-border freight, leading to 36% higher fuel prices in 2040 compared to 2018. At the same time there have been improvements in average fuel efficiency so that fuel use per km in 2040 is 21% lower than in 2018.

4 Results

The model calculates how the changes in infrastructure and policies in the scenarios lead to a change in the relative use of the different freight transport modes. In this section we walk the reader through the results in the following steps:

1. Treatment: Impact on the cost of freight transport between Gothenburg and Oslo
2. Shifting modes: How will HGV traffic change?
3. Shifting goods: How will freight volumes on trains change?
4. Shifting carbon: How will emissions from HGVs change, and how much to value it
5. System-wide effect attributed to double track – GodsNytte-analysis

4.1 Impact on the cost of freight transport between Gothenburg and Oslo

There are many cost components for freight transport that add up to the total cost. In the comparison between rail and road transport, the total cost of a shipment is in the Norwegian Freight Transport Model (NFM) broken down into the following cost components:

- Loading costs (loading and unloading)
- Transfer costs (unloading from one transport mode and loading onto another)
- Time-based costs
- Distance-based costs
- Road toll costs
- Cargo time costs (the owner of goods' willingness to pay for receiving the goods faster)

The size of the cost components for a given shipment will vary for the different mode combinations, for different types of shipments, and for different origins and destinations in the Gothenburg and Oslo areas. From all the freight relations in the NFM, we have chosen a straightforward and fairly representative freight flow between Gothenburg and Oslo as a means of comparison, namely the transport of beverages. To put this freight relation in context: In NFM this adds up to 594 tons of beverages transported from Gothenburg to Oslo annually, over 17 shipments. The average shipment contains 35 tons of beverages. The modeled year is 2040, the assumed opening year for the double-track.

We will here compare the cost calculated in the NFM for HGVs (heavy goods vehicles), and by freight train (in a container, with a need for road transport to and from the rail terminal). The cost comparison is done for two scenarios for freight train (baseline and with double-track) and three scenarios for HGVs (baseline, and scenarios with different carbon taxes and levels of efficiency improvements). Since the distance is so short, it is usually uneconomical to send shipments from the Gothenburg area to the Oslo area by ship, from port to port and all the transfer costs that that would entail. However, for some origins and destinations in those two areas it could make sense to use the ferry between Strömstad and Sandefjord along with HGV transport. We therefore add the baseline calculation for that mode choice (transport chain) for context. All the examples are shown in Figure 7.

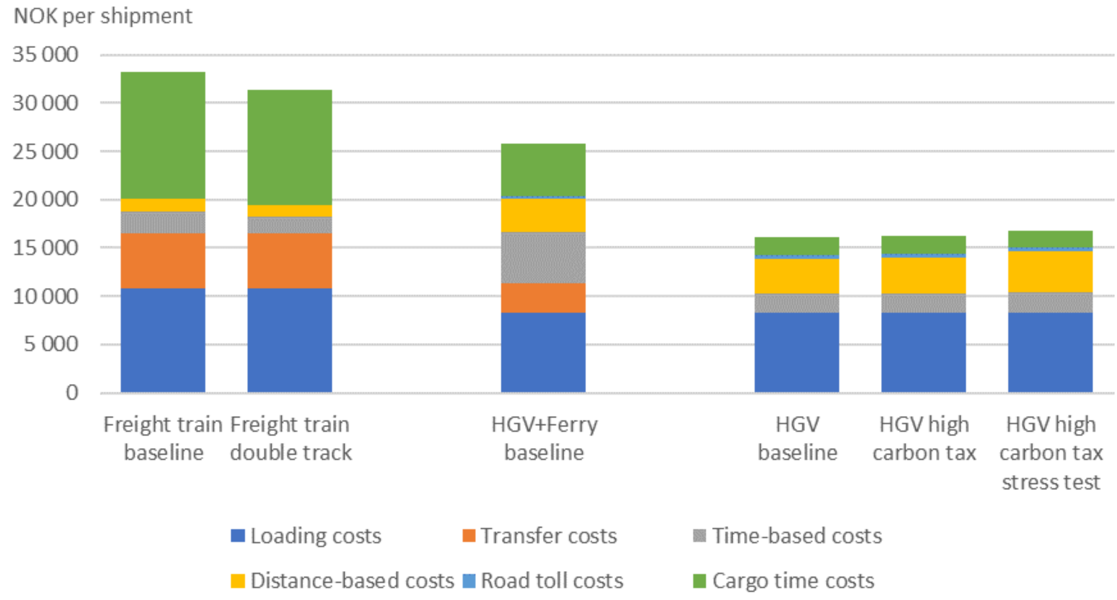

Figure 7: Cost for a representative example shipment ("Other foodstuffs/ beverages") between the Gothenburg area and Oslo area by different modes under different scenarios.

We go through the results in the figure from left to right. The baseline costs for the shipment by freight train is calculated to about NOK 33,000. The largest cost components are the cargo time cost, which makes up 40% of the total. This is mainly based on the willingness to pay estimates from Halse et al. (2019) for cargo owners to reduce transport times. There is a huge spread in willingness to pay for reduced transport times for different cargo types, where the highest was found to be fresh fish and the lowest to be lumber. The cargo category in our example here, "other foodstuffs" falls relatively close to the average value. The cargo time costs stem from the time spent on the train and on lorries to and from the terminal. This time also underpins the time-based transport costs, which mostly consist of labor costs. The time-related costs are the ones that will be reduced by a shortening of travel time by rail between Oslo and Gothenburg. However, other major components, like loading costs (33% in the baseline) will be unaffected. The same goes for the third largest cost component, transfer costs (17%) due to the loading and unloading from HGV to train and train to HGV.

The second bar shows the benefits of reducing the transport time for train between Gothenburg and Oslo down to 4 hours. We see a 26% reduction in time-based costs (salaries etc.) and a 10% reduction in cargo time costs. The total cost of the shipment has been brought down to about 31,000, about a 6% reduction in total. This may seem low when considering that the transport time for the train itself is reduced by about 46%. The reasons are that waiting times, loading times and transport times to and from the rail terminal are unaffected. In addition, the loading costs and transfer costs are unaffected.

For context, we look at the combination of road and sea transport, when HGV transport is combined with ferry transport for the distance between the Gothenburg area and the Oslo area. This is the third bar in Figure 7. The cost for the entire shipment comes to about 26,000 NOK, with the largest share of the cost being attributed to loading costs (32%). Cargo time costs and the time-based cost for the transport itself are of about the same importance, comprising 21% and 20% of the total shipment costs, respectively. While the combination of HGV and ferry has a lower cost than freight train in this example, door-to-door transport with HGV will have even lower cost, as the right side of Figure 7 shows.

The shipment costs of using HGV is about NOK 16,000 in the baseline, less than half of the cost of using the freight train. The largest portion consists of loading costs (55%). The second largest component is the distance-based costs (22%), which include fuel costs, lubricants, and tires. These are the costs that will be affected by any changes in fuel taxation, as is seen in the next scenarios.

The next scenario is the main "High fuel tax scenario" where Swedish fuel taxation follows the path of 2.8% real annual increases. With the underlying cost of fuel assumed to be unchanged in the model, the price at the pump will then be 36% higher in 2040 (in real terms). At the same time fuel usage per km will be 21% lower, due to efficiency improvements. As the other distance-based cost components (e.g., lubricants, maintenance, capital depreciation) are not affected by the change in fuel prices, the net effect on distance-based costs is a 4.5% increase. The total cost of the shipment increases by 1%.

The last bar is the stress-test where we assume that HGVs do not enjoy any of the projected fuel efficiency improvements, but Swedish fuel taxes still follow the same trajectory as in the previous scenario. When the entire 36% fuel price increase is taken in on the distance-based costs, the distance-based costs increase by 21%. For the entire shipment, that results in a 5% cost increase.

To sum up this subsection, we see that the reduction in transport time due to the upgrade to double-tracks reduces the cost advantage gap that HGVs have over freight train in this representative example of a shipment between the Gothenburg area and the Oslo area, but does no eliminate it. Even in the stress-test with a fuel price increase of 36% between 2018 and 2040, and no improvements in HGVs fuel efficiency is assumed, we still find that HGVs maintain a total cost advantage over freight train.

When the model runs through the scenarios for the freight sector as a whole, the changes do result in some shifting from road transport to rail. Compared to the representative example, these shifts will typically be where the cost advantage for HGVs were not so large to begin with. This could be for longer transports than just between the Gothenburg and Oslo area, where the cost disadvantage for rail is less. For longer transport chains, the relative importance of loading costs and transfer costs become less for trains, and the distance and time-costs will become of relatively higher importance for HGVs. Shifts will also occur for shipments where the distance from rail terminals are short at both origin and destination for the goods in question, so that the benefits of reduced transport time make a larger dent into reduced transport costs.

4.2 Shifting modes: How will HGV traffic change?

We are interested in seeing what impact the different scenarios have for shifting away freight transport from HGVs, as they have relatively large external costs per ton-km. In particular we want to see the impact on HGVs crossing the border between Norway and Sweden at Svinesund. The average number of vehicles longer than 16 meters[10] crossing per day in the years 2016-2019 were about 1700, summing up both directions. This number

[10] As border-crossing road freight at Svinesund is dominated by trucks and European modular trucks (with a maximal length of 25,25 meters and maximal weight of 60 tons), we restrict our comparison to counted vehicles that are longer than 16 meters.

includes buses. The modeling of the base year 2018 for this project gives us a daily average of about 1600 HGVs crossing the border at Svinesund when summing up both directions, giving a good fit. The light blue line in Figure 8 shows the development in HGV-traffic across Svinesund in the baseline scenario, from the base year and in the simulation years 2040 and 2062 [11]. The modeled growth in HGV traffic is based on projections in trade patterns and freight volumes as documented in Madslien et al. (2019). If the current infrastructure and policies are continued according to business-as-usual, then HGV traffic is expected to reach over 2370 per day in 2040 and over 3560 in 2062.

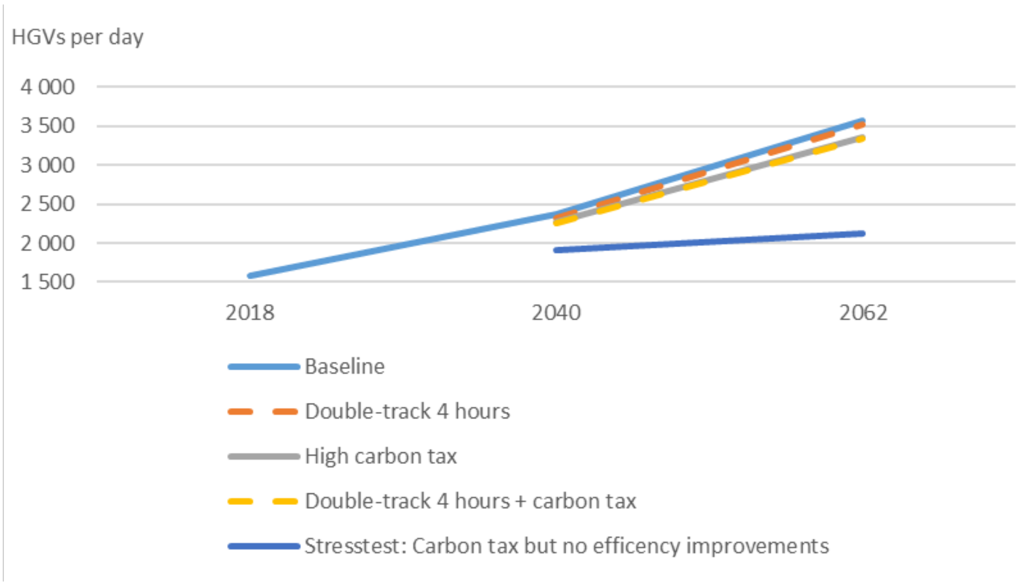

Figure 8: HGV traffic per day over Svinesund (both directions) in different scenarios

Figure 8 displays how HGV traffic is affected in the different scenarios described in the previous subsection. Due to the scaling in the figure, not all changes are easy to see, but we will describe them in the following.

In the double-track scenario, represented by the orange dashed line, the model finds that load shifting away from HGVs results in a drop of 2% in HGV traffic across Svinesund in 2040 compared to the baseline. The simulation results in 48 fewer HGVs per day, summing both directions. The gap between the baseline and the double-track scenario, in numbers of HGVs, is about the same in 2062.

In the scenario with high Swedish fuel taxation (but also fuel efficiency improvements), represented by the grey line, the model calculates a drop in HGV traffic of 4.4% in 2040 (104 HGVs per day). The difference between this scenario and the baseline increases to 5,7% in 2062 (204 HGVs per day). The model finds that adding double-tracks to this scenario (represented by the yellow dashed line) gives an additional decrease of 9 HGVs per day in 2040 and 12 HGVs per day in 2062. This means that HGV traffic levels would be 5.1% and 6.4% lower in the respective modeling years.

More dramatic changes are found in the stress-test, the high fuel tax scenario with no fuel efficiency improvements, represented by the dark blue line in Figure 8. This scenario has 20% lower HGV traffic in 2040 compared to the baseline, and 40% lower in 2062. If HGVs' distance-based cost can be affected strongly, the model will expect a relatively large mode shift as a reaction from transport users.

[11] 2062 is the year furthest into the future for which there was made projections for the NFM in the analyses underpinning the National Transport Plan 2022-2033.

4.3 Shifting goods: How will freight volumes by rail change?

Another way of assessing the mode shifting in the freight patterns crossing over Svinesund is to look at the increases in freight volumes for trains as their competitiveness increases in the various scenarios, either through reduced transport time for trains, or higher fuel taxes for HGVs. We show these aspects of the model results in Figure 9.

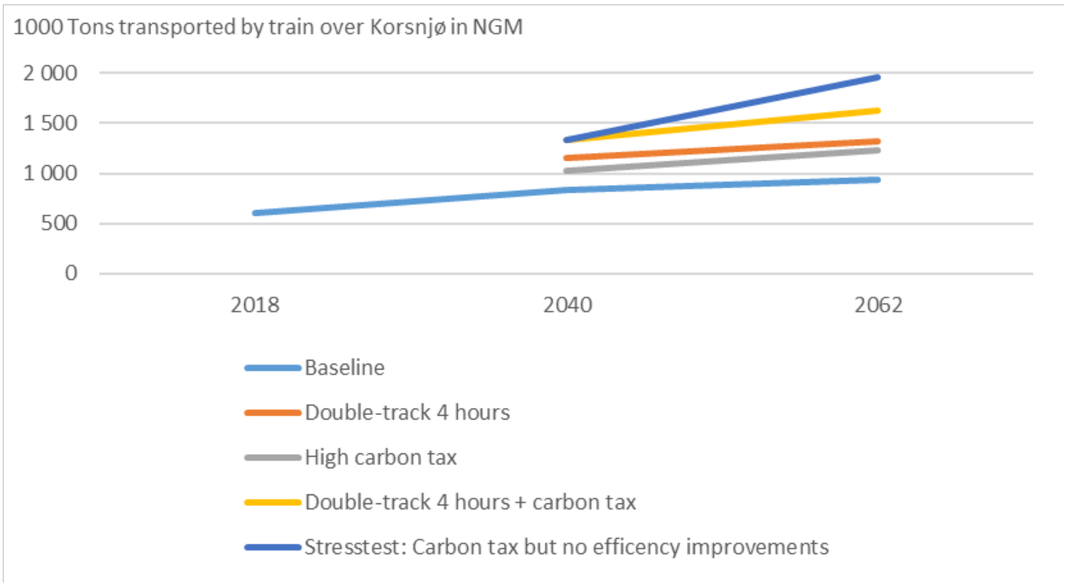

Figure 9: Freight transport volumes (1000 tons) per year transported by freight train over Kornsjø (both directions) in different scenarios.

The light-blue line represents the baseline calculations. The projections for trade patterns and freight volumes give rise to expected growth in transported tons by freight train over Kornsjø. In this business-as-usual-scenario, transported tons by freight train is expected to steadily grow from about 600,000 tons in 2018 to about 930,000 tons in 2062.

In the double-track scenario, represented by the orange line, the model calculates an increase in demand for freight train that results in 39% increase in freight volumes by train over Kornsjø compared to the baseline. This relative increase in freight volumes compared to the baseline increases to 41% in 2062. It is notable that the changes in Figure 9 seem more dramatic than the changes in Figure 8. This is because the relative share for freight transport by HGVs is so much larger than that for trains, that minor reductions in HGV freight that shifts over to rail transport, will imply relatively large increases in freight volumes by train. In addition, we also find some load shifting from sea to rail transport.

In the scenario with high Swedish fuel taxation (but also fuel efficiency improvements), represented by the grey line, the model calculates a 22% increase in freight volumes by train compared to the baseline. This increase corresponds to more than 260,000 tons og goods per year. The difference between this scenario and the baseline increases to 32% in 2062 (over 470,000 tons per year). The model finds additional increases in freight volumes by train when double-tracks are added to this scenario (yellow line). The freight volumes by train over Kornsjø are in this scenario 59% higher in 2040 and 75% higher in 2062 compared to the baseline.

In our stress-test with high fuel taxes and no fuel efficiency improvements, represented by the dark blue line, we get even larger shifts of freight volumes over to train. The model finds that freight trains will transport 60% more goods over Kornsjø in 2040 and 110% more in 2062 compared to the baseline. It is assumed in the model that both railway terminals and railway lines have the capacity to cope with this increase in demand for rail freight.

4.4 Shifting carbon: How will emissions from HGVs change, and how much to value it?

The introduction of double-tracks between Gothenburg and Oslo or aggressive increases in fuel taxation will affect not only the transport between the two cities, but the transport system as a whole. The reductions in emissions these policies cause will not only come from their reductions in HGVs crossing the border, but from all the changes they cause in the freight sector. In particular the scenarios with higher fuel taxation will have large implications for the sector and emissions, both in Norway and Sweden.

For the purpose of this report, we will zoom in on the emission impacts from the reductions in HGV traffic crossing over Svinesund. The value of the system-wide emissions reductions stemming from introducing double-tracks will be covered in the analysis of gross economic benefits in the next subsection.

The analysis in this subsection will be a bit simplified. The reduction in HGV traffic presented in subsection 4.2 will be assumed to have an average transport length that corresponds to the driving distance between the Port of Gothenburg and the Alnabru terminal in Oslo. Some removed trips will be longer, and some will be shorter. We also here ignore any added driving to and from terminals. To extract each transport length from the model calculations would be a laborious task that is out of scope of this report.

The total driving distance between the Port of Gothenburg and the Alnabru terminal is 299 km, with 181 km on the Swedish side between Gothenburg and Svinesund, and 118 km on the Norwegian side between Svinesund and Alnabru. We will calculate the total emission impact from this reduction in HGV-kilometers, but we value the emission reductions according to the carbon prices for CBA-analysis in the respective countries. As discussed in section 3, the time profile of carbon prices for analysis in Norway and Sweden are quite different.

In Figure 10 we present the reduction in emissions from HGVs over the time period 2040-2062 in the three main policy scenarios. In Figure 11 we present the corresponding valuation (undiscounted) of these emission reductions. Emissions occurring in each country are valued according to the carbon prices in each respective country. As most of the HGV-kilometers on the distance of interest are on Swedish ground, and Swedish carbon prices for CBA are substantially higher than those in Norway for most of this time period, most of the emission reductions and its value is on the Swedish side of the border.

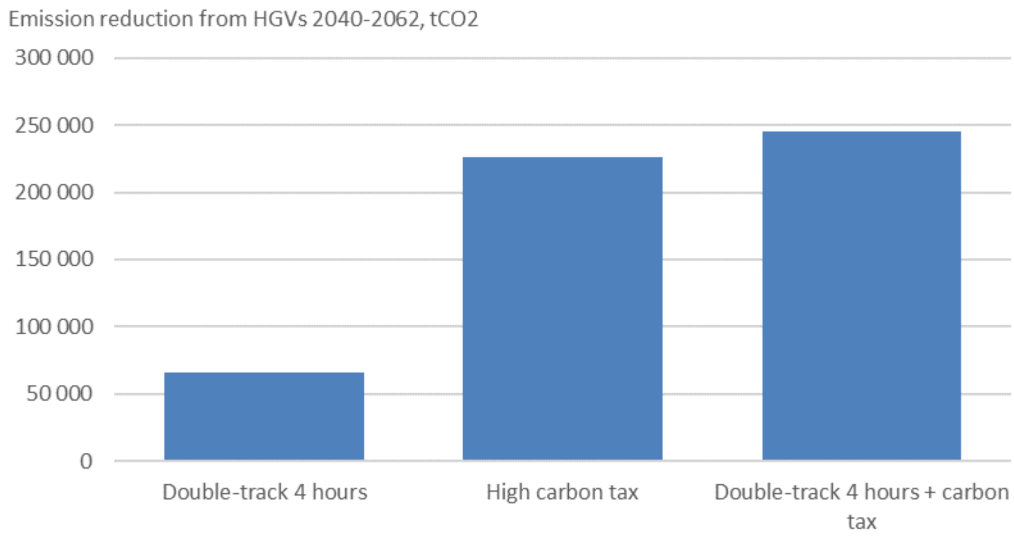

Figure 10: Reductions in CO_2 emissions (tons) from reduced HGV traffic over Svinesund (both directions), between Gothenburg and Oslo) in different scenarios for the time period 2040-2062.

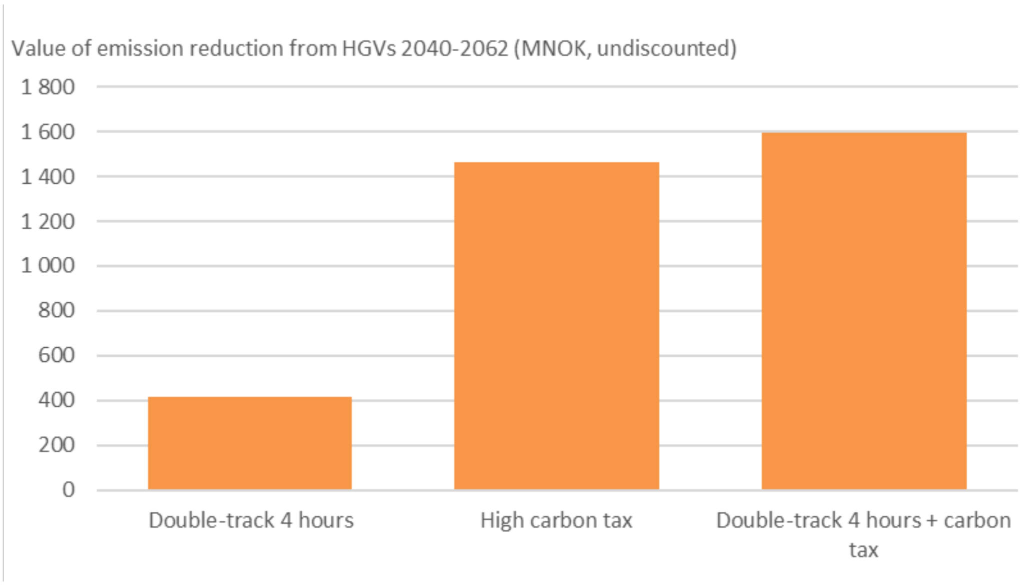

Figure 11: Value of reduced CO_2-emissions from reduced HGV traffic over Svinesund, between Gothenburg and Oslo in different scenarios for the time period 2040-2062. Values in million NOK, undiscounted.

In the double-track scenario the reduction in HGVs between Gothenburg and Oslo solely attributed to the reduction in transport time for freight trains, results in 1,400 fewer tCO_2 on the Norwegian side and 2,100 fewer tCO_2 on the Swedish side in 2040. When we sum up the emission reductions compared to the baseline between 2040 and 2062, it adds up to 66,000 tons in total. The undiscounted value of this stream of emission reductions sums up to 416 MNOK.

In the scenario with high Swedish fuel taxation (but also fuel efficiency improvements), we get a dramatically larger emission reductions from HGV traffic between Gothenburg and Oslo. The emission reductions sum up to more than 7,700 tCO_2 in 2040 and more than 11,500 tCO_2 in 2062. The accumulated emission reductions for this period totals up to more than 226,600 tCO_2 and has a total undiscounted value of 1,463 MNOK. 67% of the emission reduction value is on the Swedish side.

Emissions are reduced by an additional 8% when adding double tracks to a scenario with a high fuel tax, which brings the total emission reduction for the period 2040-2062 up to about 245,000 tCO_2 for the distance between Oslo and Gothenburg. The undiscounted value of these reductions over this period sums up to 1,594 MNOK, with about 70% of this value attributing to emission reductions on the Swedish side of the border.

All these model scenarios end up with relatively large emission reductions for a relatively short transport distance, in the scenarios where high fuel taxes are implemented. We stress, however, that we in this subsection have made very simplified calculation where we only look at the emission reductions from reduced HGV traffic between Gothenburg and Oslo. And these simplifications already come on top of the uncertainty in the model simulations of scenarios far into the future.

4.5 System-wide effects attributed to double-tracks – GodsNytte-analysis

In the final results-subsection we calculated the gross economic benefits for the entire freight sector from introducing double tracks between Gothenburg and Oslo. In the previous subsection we only looked at the impact on traffic and emissions from HGVs crossing Svinesund. In this subsection we zoom out and look at how the impacts of double tracks ripple through the entire freight sector, causing multiple changes in the owners of goods' and freight operators' mode choices and route choices.

We only look at the scenario where double-tracks lead to 4-hour transport time between the Port of Gothenburg and Alnabru, as the scenario with 5-hour transport time is very similar but with scaled down benefits. We also only focus on the scenario where there are no drastic increases in fuel taxes (i.e. distance based costs remain constant for HGVs), as such tax increases has a large effect on the entire freight transport system in Norway, where transport between Gothenburg and Oslo is just one part.

Benefits in 2040

Adding the double-tracks changes the calculus of thousands of transport users, both transport operators and the owners of goods to be transported. They may switch mode if there is net gain, i.e. the cost reduction of moving away from one mode (e.g., HGVs) is higher than the cost increase of moving onto new one (e.g., freight train). In the Excel-model GodsNytte, where we use the output from the Norwegian Freight Transport Model (NFM) to calculate gross economic benefits, the costs in the NFM are aggregated up to 20 components. In the double-track scenario, some of these cost components will increase as a result of the adaptations in the sector to the availability of 4-hour train transport between Gothenburg and Oslo, and some will decrease. As transport operators and owners of goods will always optimize to find solutions that minimize their own cost, the net effect of the availability of faster freight train will lead to net reduction in cost for the sector, as can be seen in Figure 12.

The key message from Figure 12 is that the model finds a net cost saving for the freight transport sector of about 25 MNOK for the year 2040 when double-tracks are introduced (represented by the green column). When operators and owners of goods adapt their transport plans given the new opportunities, this is the gain in the opening year. We will get to the gross benefits over a 40-year time period later in this section, but first we break down the net savings into its major components.

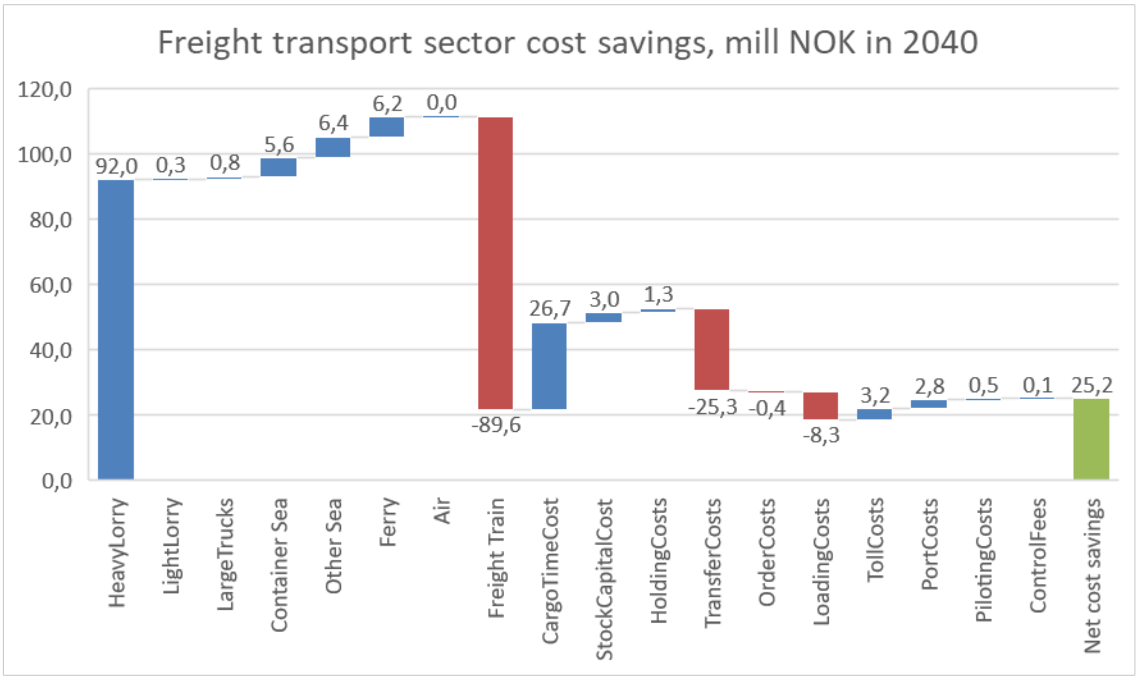

Figure 12: Cost savings in the freight transport sector in 2040 from upgrading to double track between Gothenburg and Oslo, broken down into different cost components. Blue columns represent cost savings. Red columns represent cost additions. The green column represents net cost savings. Values in 2020-kroner.

The largest cost saving is the reduction in the use of HGVs (HeavyLorry in Figure 12), totaling up to 92 MNOK in 2040. There is also some reduction in the use of lighter lorries and European Modular System HGVs (LargeTrucks in Figure 12), the latter with a maximal length of 25,25 meters and allowed weight of 60 tons. As the model also finds some shifting of goods from sea to rail transport, we see cost savings in the form of somewhat less use of container ships, ferries, and other ships. Freight by air transport is found to be unaffected.

As freight trains (mostly container trains) get an increase in activity, it therefore takes on the largest share increase in the sector's costs, about 90 MNOK in 2040. This mode has absorbed goods from all the other modes that have experienced a reduction in activity. The direct activity of the transport modes carry transport costs in terms of distance-based costs and time-based cost, as explained in section 4.1. We here point out that higher cost of more freight train activity in this scenario, also reflects higher revenues to freight train operators.

Figure 12 also shows changes in other major cost components in the sector. A major saving due to double-tracks is the reduction in Cargo Time Costs, which reflects the owner of the goods willingness to pay to receive the goods quicker. There are also some savings for the goods owners in the form of lower holding costs (less need for warehousing), and lower stock capital costs (lower costs of having goods not utilized in a warehouse).

More use of freight trains implies more intermodal transport chains, which inevitably drives up the transfer costs, the costs of moving goods between modes, which is the case in Figure 12. This scenario also gets an increase in loading costs, the costs of loading and unloading at both the sending and the receiving end. These cost increases, along with a minor increase in order costs, drive down the net savings. Finally, as goods have shifted from road transport, the sector ends up paying less in road tolls, and as goods have shifted from sea transport, the sector is also paying less in the form of port costs, piloting costs and control fees.

Benefits over a 40-year period

Following guidelines for cost-benefit analysis in Norway (and default settings in the GodsNytte model), we calculate the benefits over a 40-year period (2040-2079), and discount the values back to 2021 using a discount rate of 4% between 2021 and 2060 and 3% between 2060 and 2079. This follows the guidelines from the Ministry of Finance (2014). This gives us the net present value of future benefits, evaluated in 2021. We also apply the distinction between the main affected groups; the transport users, government finances, toll- and ferry companies and other social costs. "Transport user benefits" is the catch-all name for all the changes that sum up to net benefits in the transport sector described in the first part of this subsection. It is important to remember that reduced costs for tolls, ferries and fuel taxes when goods are shifted from HGVs to freight trains, means less revenue for ferry and toll companies and the government, a transfer effect that we capture explicitly in our benefit calculation based on affected groups. The changes in "other social costs" are broken down into external costs (changes in CO2 emissions, local pollutants, road wear, noise, accidents, congestion etc.) and the cost of public funds. The latter is a 20% additional social cost on any contribution a project has to the government deficit (which also includes covering the long-term deficit of ferry and tolling companies), as long-term budget neutrality would force an increase in taxes that increases inefficiencies in capital and labor markets.

The present values of the components of the gross benefit calculation are given in Table 3:

Table 3: Present value of gross freight sector benefits from upgrading to double-tracked railway between Gothenburg and Oslo.

Benefit category	Present value, MNOK
Transport user benefits	278
Government finances	-22
Revenues of toll and ferry companies	-23
Reduced CO2 costs	483
Reductions in other external costs (in Norway)	69
Cost of public funds	-9
Present value of benefits	776

The net present value of gross freight sector benefits sums up to 776 MNOK[12]. More than a third of this value is attributed to transport user benefits, which we covered in the first part of this subsection, depicted in Figure 12. The present value of 278 MNOK is the net gain for transport operators and goods owners in the freight transport sector due to the availability of shorter transport times by train between Gothenburg and Oslo. Some of this gain is also a loss to ferry and toll companies (present value of 23 MNOK), and it generates less tax revenue (present value of 22 MNOK). These transfers must be included in the economic calculus. This need for government financing elsewhere also leads to higher costs of public funds (present value of 9 MNOK), which also lowers the net gain from this transport improvement.

[12] We stress that we do not count the added costs of maintenance and reinvestments from higher train traffic levels as an external cost in this analysis, as that would be a part of the investment and operation cost of investing in double tracks between Gothenburg and Oslo in any future cost-benefit analysis of such a project.

Another major contributor to gross benefits is the reduction in CO_2 costs, with a present value of 483 MNOK, which represents a reduction of about 289 000 tons of CO_2. These are the sum of reductions in the entire transport chain, from both road and sea transport, reductions occurring in Norway, Sweden and other countries involved in the transport chains[13].

These reductions in other external costs within Norway's borders add up to 69 MNOK. This is mostly from reduced HGV traffic, but also some due to less transport by ship and ferry. This reduction in external cost is due to less local pollution, fewer accidents, and less road wear. The model finds that the net decrease in noise costs is small, as the reduced noise costs from road transport is almost counterbalanced by the increase in noise costs from rail transport.

To summarize this subsection, it is clear that the model finds substantial benefits from reducing transport times between Gothenburg and Oslo. The freight transport sector itself will have large gains from getting double tracks from the entire distance between the two cities. However, under current assumptions about future fuel efficiency for HGVs (which is highly uncertain) and the valuation of CO_2 in Norwegian and Swedish cost-benefit analysis, it is the value of the CO_2 emission reductions that make up the largest share of gross benefits.

If further planning of upgrading to double tracks for the entire distance between Gothenburg and Oslo is undertaken, these gross benefits can be added in a first round of cost-benefit analysis of such a project. We stress that our analysis in this report has not made any calculations of likely investment and maintenance cost for such a project, so no part of the cost-side of the cost-benefit analysis is included. Our analysis also covers only parts of the benefit side, as no analysis for passenger transport has been undertaken. More analysis is needed to get a more complete picture.

[13] GodsNytte was mainly developed for analysis for Norwegian transport policy, meaning that external cost calculations in GodsNytte are designed to focus on Norway. Calculating changes in external costs outside of Norway with the same detail be beyond the scope of the GodsNytte model and would require model developing project. In this report however, we can use the output from NFM to make rough calculations of reductions in CO_2 emissions outside of Norway. We apply the simplifying assumption that all of these reductions occur in Sweden and are therefore valuated at the relatively high carbon price applied in Swedish cost-benefit analysis. As some of these emission reductions will occur in other countries, this will somewhat overstate the valuation of these reductions, as the Swedish carbon price is exceptionally high (Thune-Larsen, Ukkonen, Hammes, & Jensen, 2021). On the other hand, we are not able to calculate the value of the changes to other external costs in the freight sector outside of Norway, which in isolation is an understating of the social value of the transport improvements. We therefore argue that our calculated value of CO_2-reductions outside of Norway will give reasonable completeness to the gross benefit calculation with regards to external costs.

5 Discussion and conclusions

5.1 Conclusions

The main focus of this report has been to assess the likely effects in the freight sector of upgrading to double-track railway for the entire line between Gothenburg and Oslo. Our main scenario is where double-tracks are introduced in 2040 and transport times for freight train are reduced from 7.5 hours as it is in the current situation, down to 4 hours. The modeled impacts can be summarized as follows:

- Reduced transport time for rail freight leads to reduction in the cost of using rail for transporting goods on the freight relations between the Oslo and Gothenburg areas.
- It is the time-based transport costs (salaries etc.) and cargo time costs (the owner of goods' willingness to pay for receiving the goods faster) that are reduced when the speed of rail transport is increased.
- These cost reductions are a benefit to transport operators and their customers (the owners of goods) who are already using rail on these freight relations.
- The new opportunity of faster rail transport allows for e-optimization for all agents in the freight transport sector, in the pursuit of minimizing their overall costs. This increased competitiveness for rail transport leads to rail freight "pulling" goods from competing modes and competing routes.
- Some transport chains that before the infrastructure improvements would have used either road transport with heavy goods vehicles (HGVs) or sea transport, will find it beneficial to switch to rail transport for parts of their transport chain. Those who make the switch are reducing their costs. The net effect is more demand for rail freight and lower costs in the freight sector.
- As some parts of transport chains switch from HGVs and sea transport, which are largely powered by fossil fuels, to rail freight, which is powered by electricity, CO_2-emissions from the freight sector are reduced.
- Other external costs, such as accidents and local pollution, are also reduced.

Although faster rail freight would lead to changes in various transport chains in other parts of the freight sector, the largest changes will be on the directly affected relation between Gothenburg and Oslo. The main change is that parts of some transport chains make a shift to rail transport, away from road transport. The model finds that implementing double-tracks here will reduce the number of HGVs crossing the Norwegian-Swedish border at Svinesund by about 2% in 2040 compared to the baseline. While this may seem like a small number in relative terms for road transport, which transports many times more volume than rail transport between Oslo and Gothenburg, the mode shift would represent a significant percentage increase in freight volumes by rail.

As the reduced transport time makes the use of freight train more attractive, we find that in this scenario the amount of goods by train transported over the Norwegian-Swedish border at Kornsjø increases by 39% in 2040 and 41% in 2062 compared to the baseline. This would be the result of the freight transport sector re-optimizing when facing this new transport improvement, i.e. how much rail freight will "pull" from road and sea transport.

The main social benefits of this transport improvement are transport user benefits, i.e., reductions in overall costs in the freight sector, and the reductions in external costs. With regards to user benefits, the freight transport sector reduces its overall costs, both for existing users of rail freight and new users. The shift to rail away from HGVs and sea transport for some transport chains leads to lower external costs, such as those stemming from CO_2-emissions. The reduction in HGVs on the distance between Oslo and Gothenburg alone leads to an estimated reduction in CO_2-emissions of about 66,000 tons over the period 2040-2062[14]. When summing up, the gross benefits of this transport improvement (for the years 2040-2079) has a present value of 776 MNOK in the year 2021, as shown in section 4.5.

What happens if fuel taxes increase?

We investigate different scenarios with major increases in fuel taxation for road transport, and how this can be expected to affect mode choice for freight between Gothenburg and Oslo. We expect Swedish fuel prices to be reflected in the cross-border transport costs between Sweden and Norway. Extrapolating the fuel tax trajectory in the past years, with some additions for more aggressive climate policy, we apply fuel prices that are 36% higher in 2040 than in 2018. At the same time, we expect continued fuel efficiency improvements, with fuel use per km for HGVs to be 21% lower in 2040 than in 2018. The modeled impacts can be summarized as follows:

- With fuel taxes rising faster than efficiency improves, the cost of transporting goods by road increases.
- This change cots for the road sector compared to the baseline, forces the agents in the sector to e-optimize in order to minimize their overall costs. This leads to a "push" away from road transport and over to other modes, i.e., sea and rail transport.
- This switch away from road transport to other modes, in particular where shifting to electricity powered rail transport, leads to relatively large reductions in CO_2-emissions from the freight sector.
- Other external costs from road transport, such as accidents and local pollution, are also reduced.

In this scenario HGV traffic over Svinesund is reduced by 4.4% in 2040, and further to 5.7% in 2062, compared to the corresponding years in the baseline simulations. Removing these HGVs leads to the removal of 226,600 tCO_2 between 2040 and 2062. And the reduced competitiveness for HGVs leads to a mode shift that implies a 22% increase in the amount of goods transported by train over Kornsjø in 2040, and 32% in 2062, compared to the baseline.

Our analysis contains additional scenarios with higher fuel taxation. In one scenario, we add the implementation of double-tracks into the high fuel tax scenario, we get additional reductions in HGVs crossing at Svinesund and corresponding emission reductions. Compared to the baseline, HGV traffic over Svinesund will be reduced by 5.1% in 2040

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[14] Opening year of the double-tracks is assumed to be 2040, and 2062 is the year furthest into the future for which there was made projections for the Norwegian Freight Transport Model in the analyses underpinning the National Transport Plan 2022-2033.

and 6.4% in 2062, with total emission reductions for this period totaling 245,000 tCO_2. Freight volumes by train over Kornsjø will also be 59% higher in 2040 and 75% higher in 2062 compared to the baseline.

We also had a stress-test where we assumed higher fuel taxes, but no efficiency improvements, which from a modeling perspective is equivalent to simply more aggressive fuel tax policy. With 36% higher fuel prices in 2040 and no increased fuel efficiency over time, we get 20% lower HGV traffic over Svinesund in 2040 and 40% lower HGV traffic in 2062 compared to corresponding years in the baseline. The aggressive fuel taxation will also drive increases in freight volumes by train over Kornsjø, pushing these to be 60% higher in 2040 and 110% higher in 2062 compared to the baseline. In other words, the more aggressively carbon is priced, the more drastic the changes in the freight sector will be.

5.2 Caveats and alternative scenarios

We have already mentioned the difficulty of valuing emissions with different carbon prices according to in which country they are emitted. The simplified solution in this analysis was to price all emission changes from Norwegian territory as Norwegian, and all emission changes outside of Norway as Swedish. Attributing emissions to countries is a complicated exercise, in particular with regards to sea transport, and we know the chosen solution in this analysis is imprecise and will likely overestimate the value of the emission reductions. On the other hand, we also underestimate the non-CO_2 changes in external costs outside of Norway.

All of the modeled scenarios are very stylized, as the only thing changing in the future compared to the baseline is the reduction in transport time and/or increases in distance-based costs for road transport. The model itself, by definition, is a simplified and tractable representation of the real world, meaning that it will capture most developments of interest in the freight transport sector, but not all. Many of the model parameters are uncertain and obtained from limited data. So, although this analysis uses the newest of analytical tools used for transport appraisal in the freight transport sector in Norway, e.g., providing analysis for the National Transport Plan, the exact numbers from this analysis should be interpreted with some caution.

Key uncertainties include the long-term baseline projections into the future for the freight sector. The projected volumes of goods transported within, and to and from Norway, will be highly dependent on economic, demographic, and technological developments, all of which is very uncertain over a timespan of multiple decades. These developments will also be linked to future policies, which also will be highly uncertain, not least in terms of the political will to price greenhouse gas emissions (in all sectors) so that the Paris Agreement is fulfilled.

There are alternative developments that may drastically change the magnitude of gross benefits for the freight sector of reducing transport times between Gothenburg and Oslo down to 4 hours.

Some scenarios will imply lower gains from upgrading to double track:

Faster decarbonization of road transport: If improvements in fuel efficiency or the development of zero-emission solutions (e.g., electricity or hydrogen) for HGVs goes faster than assumed in the scenarios in this report, then the gains from double track will be lower as the absolute impact on carbon emissions will be lower. This is related to the argumentation in the Expert Committee on Technology and Future Transport Infrastructure (Størdal et al., 2019). The opposite also holds, if the improvements in emissions per km for road transport take a longer time than assumed in this report, the gains from upgrading to double track will be higher.

Increased use of low-cost labor in the road transport sector: If the road transport sector continues to be able to keep its costs low by increasing its use of low-cost labor, e.g., from Eastern Europe, the cost advantage for using road transport will grow for many transport chains. In such a scenario, the reduction in transport time from 7.5 hours to 4 hours between Oslo and Gothenburg, a relatively short distance for many transport chains, will induce less change among transport operators and owners of goods then simulated in our model scenarios. An increased cost advantage to road transport would therefore mute the effect of improved transport times for freight trains.

On the other hand, some scenarios will enhance the gains from upgrading to double tracks:

A future with larger transport chains on rail: There are possible future developments in the global freight system that could lead to large transport chains on rail, e.g., the Belt and Road Initiative from China. If this gets integrated into the Northern European rail system, then it would lead to higher demand for using rail freight for the distance between Gothenburg and Oslo as well, to avoid the cost of transferring goods between modes. In such a scenario, the gains from reducing freight train transport times between Gothenburg and Oslo will be larger than what we estimate in this report using the Norwegian Freight Transport Model. This would be a promising venue for future research. See Box A for more background and discussion on the subject.

Although not at the same scale as the Belt and Road Initiative, the underwater tunnel that is currently being constructed between the German island of Fehmarn and the Danish island of Lolland, the Fehmarn Belt Fixed Link, is also expected to increase the demand for rail freight transport in the Nordics. The report "Policy measures for modal shift of freight transport in the Nordic countries" by Mjøsund, Pinchasik, Grønland, and Hovi (2019) uses the Norwegian Freight Transport Model to assess the expected effect Fehmarn Belt Fixed Link when it opens. The model calculations result in an increase of about 100,000 tons more goods transport by rail on Norwegian territory in 2030 compared to the baseline. This would be a national increase in rail transported tonnage of about 0.2%. Such an increase in demand for rail freight would increase the benefits of an upgrade to double-track railway between Oslo and Gothenburg. However, it is also worth noting that the model calculations found similar increase in transported tonnage by road transport due to the Fehmarn Belt Fixed Link. This infrastructure improvement is in other words expected to result in a shift away from sea transport to rail and road transport.

Box A: growing rail transport between Asia and Europe

Regular rail freight services between China and Europa started in 2011, and have since become part of China's so-called 'Belt and Road Initiative'. Initially, regular departures connected Chongqing in China with Duisburg in Germany, but services have since been expanded to a number of cities and regions both on European and Chinese side.

Currently, rail freight between China and Europe primarily runs along one of two main corridors:

- The Northern corridor, connecting trains from North-East and Central-East Chinese regions with Europa through the Trans-Siberian Railway, either directly via Russia or through Mongolia.
- The Central corridor (also called the Southern corridor), where freight trains run through China before first crossing the Kazakh border on their way to Russia.

Both routes then run through Belarus and, depending on one of multiple sub-routes to other European countries, through Poland and Germany.

A third route (the 'Transcaspian route', and often also called the Southern corridor) runs through Kazakhstan and towards the Caspian Sea, where trains drive onto a ferry and have possible sub-routes via e.g. Turkey or Ukraine. This Transcaspian route has been tested but is not used to the same extent as the two main routes above, due to logistical and geopolitical challenges (Schramm & Zhang, 2018).

On the Chinese side, there are now over 60 cities directly or indirectly connected to this railway initiative, while the route network on European side in later years has expanded to a variety of cities either forming the freight's final destination or serving as intermodal terminals, e.g. Polish Malaszewicze and Warsaw, German Duisburg and Hamburg, but also e.g. Riga, Kaliningrad and Rotterdam. Several of these stops yield possibilities for further transport to for example Norway, either by rail or ship, using European short sea networks (Schramm & Zhang, 2018).

Today, China-Europe freight trains are run by several operators, amongst others DB Schenker and DSV, with transit times of ca. 18 days. As an example, DB Schenker operates with a capacity of about 15 trains per week and with a capacity of 50 40-ft. containers per train. Even though rail transport is more expensive, this yields a considerable time advantage compared to container transport by sea, which takes between 30-45 days from China to Europe. At the same time, rail freight is (much) cheaper than air and road transport, where the latter is rarely used on intercontinental distances and with transit times averaging 14 days has only a limited time advantage versus rail.

Over the past decade, rail freight between China and Europe has increased strongly, reaching over 12.000 departures in 2020. Growth was especially strong during the Covid-19 pandemic. Amongst others, this was due to considerable capacity constraints and delays within both air and container-based maritime transport and consequent surges in freight rates for these modes.

Today, much of the freight with Norway as destination and arriving through the Swedish port of Gothenburg is transported via Nordic central warehouses in Southern Sweden. This logistics approach yields both economies of scale due to a central warehouse, but also cost advantages in the sense that goods can be transported to their final Norwegian destination using road operators from low cost countries. For much of this freight segment it seems unlikely that the construction of a double track rail link from Gothenburg will make rail transport competitive, despite is potential advantages.

At the same time, there has in recent years been some rail freight transport from China to Norway, through a hub in Germany and onward via Gothenburg, or alternatively by ship from Eastern-Europe to Gothenburg after coming in by rail from China. The growth potential for these freight routes is amongst others dependent on rail capacity between Gothenburg and Oslo (and, where applicable, onwards to other parts of Norway). Double rail tracks from Gothenburg can yield faster and more reliable (onward) rail freight transport to Norway. This goes both for sea transport arriving to the port of Gothenburg and for direct rail transport from other parts of Europe and Asia with trains running via Gothenburg.

Similarly, improved regularity and reliability on the rail link to Norway can affect how maritime transport with Norway-destined goods is carried out and also open up for some freight modal shift from sea to rail. Currently, the port of Gothenburg for example receives direct calls from intercontinental container ships. Nevertheless, for overseas container transport to Norway it is most common that containers arrive in a port on the European continent, where they are transferred onto feeder ships for onward transport. Regarding the latter, it is pointed out that feeder ships for short sea transport from European ports are often not prioritized in the main ports in Europe. This means that capacity problems in these ports can result in feeder ships being sent out before they are fully loaded, yielding considerable delays for the Norway-destined freight that is left behind. Improved rail links from Gothenburg to Norway may make it more viable for container transport with Norway as final destination to go through Gothenburg. Likewise, improved rail links on this stretch would remove some of rail freight's disadvantages, and as such open up for modal shifts.

Higher economic growth than projected: An optimistic scenario with high economic growth will increase demand for goods and freight transport, which also will increase demand for freight train service. If this higher demand is met with shorter rail transport times than in the baseline, the benefits of double-track railway will be higher. In addition, if such scenario includes higher wage growth (in particular in low-cost countries) the cost advantage for road transport may decrease. Higher incomes would also increase the willingness to pay for sooner deliveries (higher unit prices for cargo time costs), which would imply higher gains from reducing freight train transport times (and other time-consuming activities in the transport chain).

Stricter policies towards road congestion in and around Oslo and Gothenburg: As with all road transport, HGVs contribute to congestion when the traffic volumes on the road becomes large relative to capacity. As road freight volumes are expected to grow and expanding road capacity in and around the larger cities become increasingly expensive and politically difficult, the question of whether to accept congestion or putting a higher price on it becomes more pressing. More road congestion in itself will increase the competitiveness of rail transport, in particular if they manage to reduce transport times e.g., by implementing double-tracks. Rail freight would also gain some advantage if road congestion is more accurately priced (and therefore curbed) through some form of road pricing. This could come in the form of peak-tolls, as is the case with Oslo and Gothenburg in the current situation, or a more sophisticated form of distance-based road pricing, where the price per kilometer depends on where and when the driving is taking place, and with what kind of vehicle. We return to this in the concluding discussion. If road congestion is limited through pricing, then goods with very high cargo time values would benefit and still use HGVs, but operators transporting goods with lower cargo time values would be relatively more inclined to choose rail transport, in particular if rail transport times between Oslo and Gothenburg are reduced.

5.3 Concluding remarks

Ensuring double-track railway for the entire distance between Gothenburg and Oslo and bringing down transport times will have substantial gross benefits for the freight sector. The gross benefits will be even larger when passenger transport is included in the analysis. However, policy makers would have to balance these benefits against the investment, operations, and maintenance costs of ensuring double-track railway. That would be a long-term policy decision, as such a major project is unlikely to begin any sooner than after the current National Transport Plan, which ends in 2033. That is why our model scenarios assume that the transport time benefits would first occur in 2040[15].

In the shorter term, our model scenarios show that greenhouse gases can be reduced, and the relative competitiveness of rail can be increased through higher fuel taxation. From a climate policy perspective, the scenario shows the strength of pricing emissions directly, as it both stimulates the uptake of more fuel-efficient HGVs and shifts to less polluting modes. The effect of pricing emissions directly is stronger if both countries coordinate their fuel taxation, so not to give any incentive to tankering, but instead incentivize reducing emissions from the entire transport chain.

It is also worth mentioning that since there are other external costs than CO_2 emissions, there are gains to be made to develop a system of distance-based road pricing. Here the price per kilometer could vary according to the social cost of driving that kilometer, which would vary according to *where* the driving takes place (in cities vs rural areas), *when* the driving takes place (during congested peak hours or on uncongested roads) and according to *what type* of car (e.g. emissions standard of the HGV). A huge body of transport economic literature shows that this would be possibly the most efficient transport policy to implement, and recent studies argue that it would be efficient to implement for HGVs both in Norway (Rasmussen et al., 2020) and in Sweden (SOU, 2017). Of course, this would also have to be balanced against investment and operations costs and privacy concerns. It is also likely that it would be preferable that such a system was developed and implemented on EU-level, as there probably would be economies of scale. However, a coordination of developing a road pricing system within Scandinavia would still be likely to be preferable to the various countries developing it alone and independently.

Cross-border cooperation and deeper integration between neighboring countries in Northern Europe is not only a means to enable a more sustainable freight sector. It can enable more integrated labor markets that again can enable higher productivity and faster economic growth with a smaller environmental footprint. It can also foster more cohesion and enable better solving of transnational problems. Such issues are not easy to include in a cost-benefit analysis, but they are still a valuable pursuit.

[15] In the appendix we discuss the implications if the double-track railway for the entire distance between Oslo and Gothenburg hypothetically were to be implemented in 2021

6 References

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Appendix:

What if the upgrade to double-tracks happened today?

Upgrading the remaining parts of the railway between Oslo and Gothenburg to double-tracks would be a major project would be unlikely to begin any sooner than after the current National Transport Plan, which ends in 2033. That is why our model scenarios assume that the transport time benefits would first occur in 2040. However, from our point of view in 2021, the benefits of the upgrade to double-tracks would more valuable if happened this year instead of in 19 years. The two main reasons are:

1. Future benefits are discounted at the recommended discount rates (4% for the first 40 years, and 3% for the following 35 years). When the stream of benefits will first occur in 19 years, a large part of the value will be discounted.
2. Road transport may become more fuel efficient over time, but that means that they are relatively inefficient now, and the benefits in terms of reduced emissions will be higher. When this is combined with relatively high carbon prices for Swedish cost-benefit analysis for emissions outside of Norway, with less discounting, the valuation of these reduction will be significantly higher.

We do an extra modeling exercise where we assume that the upgrade to double-tracks is completed in 2021. The agents in the freight sector will re-optimize right away and make changes in modes and routes as they exploit this new opportunity to minimize costs. From 2040 and out the model results will be the same as those in the main scenario as before, but benefits will have accumulated in the 19 years before.

How will HGV traffic change, and what will be the change in emissions?

The relative effect on HGV traffic over Svinesund of completing the upgrade to double-tracks is roughly the same as in the other modeling years 2040 and 2062. The model finds that load shifting away from HGVs results in a drop of 2% in HGV traffic across Svinesund in 2040 compared to the baseline. The simulation results in 28 fewer HGVs per day in 2021, summing both directions.

This reduction in HGVs between Gothenburg and Oslo, assuming that the average trip corresponds to the distance between the Port of Gothenburg and the Alnabru terminal in Oslo, results in 1,060 fewer tCO_2 on the Norwegian side and 1,630 fewer tCO_2 on the Swedish side in 2021. When we sum up the emission reductions compared to the baseline between 2021 and 2060, it adds up to 121,000 tons in total. The undiscounted value of this stream of emission reductions sums up to 695 MNOK.

How will freight volumes by rail change?

The increased competitiveness for rail transport attributed to reduced transport times in 2021 leads to rail freight "pulling" goods from competing modes and competing routes. The model calculates an increase in demand for freight train that results in 33% increase in freight volumes by train over Kornsjø compared to the baseline in 2021. This corresponds to about 198,000 tons of goods in the first year. This increase compared to the baseline, both in absolute and relative terms, gets larger over time, as shown in section 4.3.

What are the system-wide effects attributed to upgrading to double-tracks in 2019?

Similar to the results described in section 4.3, the main social benefits of this transport improvement are transport user benefits, i.e., reductions in overall costs in the freight sector, and the reductions in external costs. With regards to user benefits, the freight transport sector reduces its overall costs, both for existing users of rail freight and new users. The shift to rail away from HGVs and sea transport for some transport chains leads to lower external costs, such as those stemming from CO_2-emissions. We calculate the benefits over the 40-year period 2021 to 2060 and discount the values back to 2021. The present values of all the components of the gross benefit calculation; the transport users, government finances, toll- and ferry companies and other social costs, are given in Table 4

Table 4: Present value of gross freight sector benefits from upgrading to double-tracked railway between Gothenburg and Oslo already in 2021.

Benefit category	**Present value, MNOK**
Transport user benefits	474
Government finances	-55
Revenues of toll and ferry companies	-52
External costs in Norway	295
CO2 costs outside of Norway	487
Cost of public funds	-21
Net present value	1,128

The net present value of gross freight sector benefits sums up to 1,128 MNOK, which is considerably higher than the gross benefit calculation of getting the upgrade to double tracks completed in 2040. More than 40% of this value is attributed to transport user benefits, which we covered in the first part of subsection 4.5, depicted in Figure 12. The present value of 474 MNOK is the net gain for transport operators and goods owners in the freight transport sector due to the availability of shorter transport times by train between Gothenburg and Oslo. Some of this gain is also a loss to ferry and toll companies (present value of 52 MNOK), and it generates less tax revenue (present value of 55 MNOK). These transfers must be included in the economic calculus. This need for government financing elsewhere also leads to higher costs of public funds (present value of 21 MNOK), which also lowers the net gain from this transport improvement.

The main reason why these numbers are so much larger than in the scenario where rail transport times are not reduced before 2040 is mainly due to discounting. When the stream of benefits (and costs to government finances and tolling companies) is closer in time, it is discounted less. The toll revenue is also more affected in the scenario with early upgrading to double-tracks, as analysis assumptions for the National Transport Plan 2022-2033 state that there will be less and less highway tolling after 2040.

As in the main scenario calculation, there are major reduction in external costs as more goods are shifted from road and sea to rail. These reductions in external costs within Norway's borders add up to 295 MNOK, mainly due to reduced CO_2-emissions from road and sea transport. This is higher than in the main scenario calculation because the HGV trips and containership trips replaced in the 2020s and 2030s are less fuel efficient than the ones that will be replaced after 2040. A reduction in HGV kilometers now means a larger reduction in emissions compared to removing an HGV kilometer decades later. However, the relative increase in the value of emission reductions is not as large for this scenario as the increase in the value of user benefits. This is because the Norwegian carbon price trajectory used for cost-benefit analysis (CBA) starts relatively low and grows at the same rate as the discount rate. Hence, there is little effect on the present value.

As with the main scenario calculation, we use the output from NFM to make rough calculations of reductions in CO2 emissions outside of Norway. We apply the simplifying assumption that all of these reductions occur in Sweden and are therefore valuated at the relatively high carbon price applied in Swedish cost-benefit analysis. The present value of these CO2 reductions sums up to 487 MNOK. This is considerably higher than in the main scenario calculation, and a higher relative increase in value compared to external costs in Norway. This is due to reduced discounting of future benefits as they would occur earlier, and the fact that the Swedish carbon price of 7000 SEK (2018-SEK) for all the years of analysis. As shown in Figure 6, the Swedish carbon prices for cost-benefit analysis is higher than the Norwegian carbon price until about 2060.

To summarize this appendix, it is clear that there are substantial benefits from reducing transport times between Gothenburg and Oslo, and the present value of these benefits will be higher the sooner these improvements materialize. We again stress that these model calculations do contain a lot of uncertainty and that we have made no assessment of the likely costs of investment, operations, and maintenance for upgrading to double-track railway between Oslo and Gothenburg. A more complete picture would require more analysis.

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