LANDSVERK

REMOVING THE ISLAND **BARRIER**

Pilot Study for a **New Route** to Suðuroy, Faroe Islands

FAROE ISLANDS

Location	Archipelago in the North Atlantic Ocean
Geography	18 islands, all but one are habited
Geology	Basalt series
Population	54,000 inhabitants
GDP per capita	54,000 EUR
Sovereign state	Kingdom of Denmark
Legislature	Løgting (Parliament)
Capital	Tórshavn
Language	Faroese
Currency	Faroese króna (DKK)
Climate	3°C winter, 11°C summer
Main industries	Fishery, fish farming and tourism
Stretch of road	1,000 km country road
Infrastructure	18 mountain tunnels, 3 bridges, 3 subsea tunnels

Landsverk
(The Faroese Agency for Public Works)

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Publisher: Landsverk 2022

MOBILITY HAS MOVED THE FAROES INTO THE FUTURE

In 1963, the first Faroese tunnel was taken into use. On this day, nearly 60 years ago, the route between Hvalba and Tvøroyri changed from walking over mountains to a road and tunnel where cars could drive. The travel time and opportunities changed drastically.

Since 1963, the Faroese have prioritised tying cities and villages together using roads, tunnels and bridges. Today, there are 21 tunnels in the Faroes; 18 on land tying cities and villages together and three subsea tunnels tying islands together. In 2023, the 22th tunnel will be taken into use, the subsea tunnel between Sandoy and Streymoy, tying another island to the mainland.

The continuously improving road grid has tied the country together, improved mobility – socially, commercially and not least for the working power. A continuous road grid with easy transport benefits the competitive power in the country.

The tunnel to Suðuroy is a huge investment for our little country. Landsverk published this study last year, analysing the social, economic and environmental outcomes of a new route to Suðuroy.

This pilot study has elevated the discussion to a higher level. The study analyses complex matters which give us insight into the social, economic and environmental challenges of the project. This is good news.

Despite the discussion, there seems to be political concord that the country should be tied together so that most Faroese can travel in an easy, quick and safe manner in the Faroes.

Step by step we are approaching a connected archipelago.

Uni Rasmussen
Minister of Finance and Transportation

DARING TO DREAM

A big part of courage is breaking large challenges into smaller challenges in order to achieve a line of solutions. When I got this job at Landsverk, I also received the dreams of those before me. As an institution, Landsverk has played a united part in the development of the Faroese society. Landsverk has been part of building this country.

This pilot study of connecting the southernmost and last large island to the road network is in many ways a gift. Landsverk has been able to use its technical abilities to analyse the social, economic and environmental outcomes of the project. Landsverk has gone in depth using new knowledge and models in our work. By this holistic study we can better estimate the effects of improving the connectivity in Faroe Islands. This study could therefore also be relevant for other island communities.

This is our proposition of how the Faroese society can tie Suðuroy in with the other islands whilst taking all necessary precautions to the people who live across our islands.

The investment into a tunnel to Suðuroy is close to the entire Faroese national budget and as such will impact the whole society for a long time. Therefore, such projects demand consideration and thorough preparation. The rock debris from the tunnel, for example, will create great possibilities with recycled value when 3-4 million cubic metres of debris must be utilised. Perhaps as an apartment- or industrial area in the middle of the Atlantic.

When we started working on this project, the tunnel to Suðuroy was only a dream of tying the country together. Challenge by challenge solved, the tunnel has now emerged from fantasy to the drawing table. But we are not there yet. In case of fire in the tunnel, we must ensure solutions to get travellers to safety. That is our current challenge.

But we dare to dream, and we know we will succeed.

Sigurd L. Lamhauge
CEO of Landsverk

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1. INTRODUCTION

Over the last 70 years, infrastructure in the Faroe Islands has developed significantly, despite the geographic challenges associated with being a remote archipelago (fig. 1). With each new road, tunnel, ferry, bridge, dam and subsea tunnel, commutes have shortened considerably.

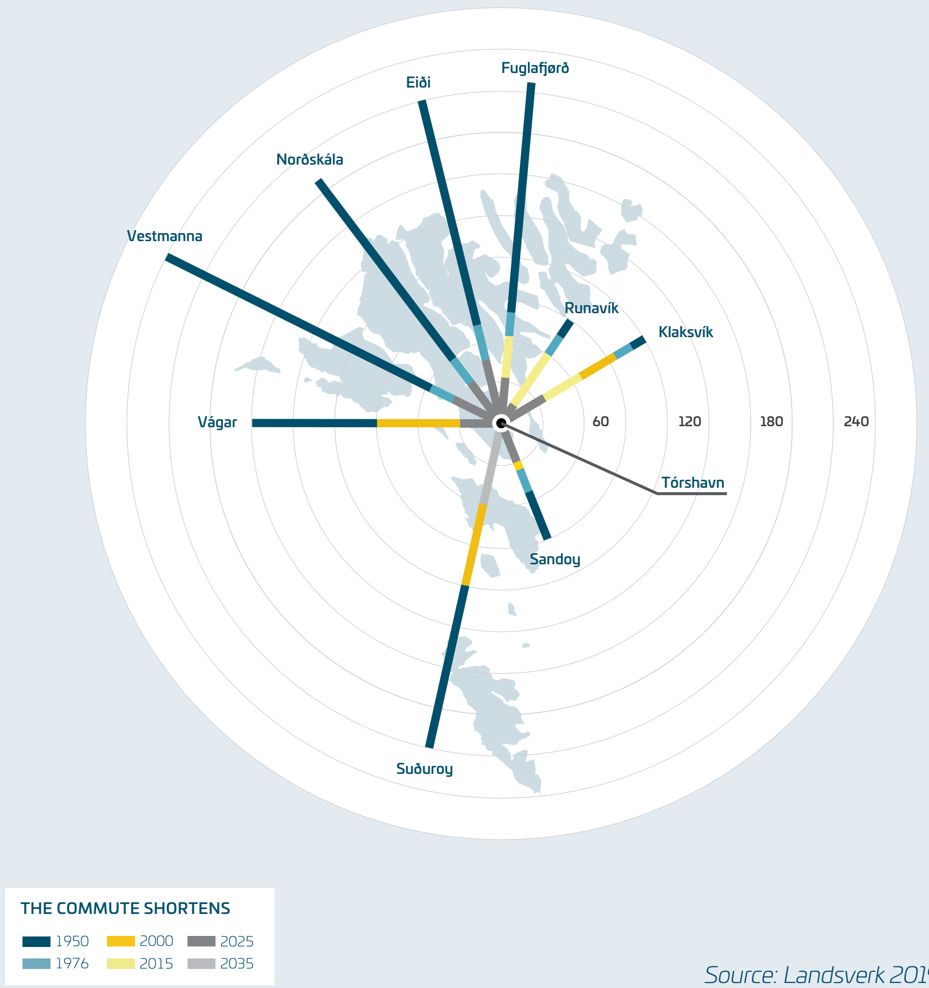
The total main road stretch has reached approximately 480km, amounting to over nine metres of road per inhabitant (Statistics Faroes). In tunnels alone, there is more than a meter per inhabitant, with around 11% of the entire Faroese main road system being underground. In comparison, Denmark and Norway have 13% and 11% of main road per inhabitant respectively, and Norway has 0.2m of tunnel per inhabitant (dst.dk, ssb.no).

The famous Faroese writer Heðin Brú once said of the Faroe Islands: 'We don't live here for practical reasons.' This is apparent in the national budget, with 6-11% spent annually on infrastructure over the last 20 years, excluding subsea tunnels and the part funded by commuter fees. Compared to neighbouring countries, our infrastructure expenses are relatively high, but not higher than other island countries (Appendix D5).

Expansions in infrastructure have played a key role in the welfare of our country in easing everyday life for people and businesses as well as creating economic growth. Research from other countries also shows that infrastructure investments contribute to increased production and economic growth (Bhattacgarya et al., 2015, Stupak, 2018). However, as a society, we need to ask ourselves: With a well-developed infrastructure, will continued investments keep contributing to development and growth? Are the benefits from continued investment greater than the costs? And does further expansion lower CO_2 emissions?

This pilot study will discuss and answer these questions with respect to a new route to Suðuroy. The main purpose of the study is to provide politi-

FIGURE 1: ADJUSTED COMMUTE TO AND FROM THE CAPITAL OVER TIME.



Source: Landsverk 2019, p.5

FIGURE 1: NUMBERS IN A BROADER SENSE, ROUNDED NUMBERS.

Project	Billion DKK	Population 2021	Per Capita	Suðuroy 2021	Sandoy 2021	Per Capita	Ratio
Tunnel to Suðuroy	5.4	53,000	102,000	4,700		1,200,000	9%
GDP 2019	20.9						26%
Annual budget 2021	5.8						93%
Tunnel to Sandoy	1.3	53,000	25,000		1,300	1,000,000	2%
GDP 2019	20.9						6%
Annual budget 2021	5.8						22%
The Great Belt Bridge	38.1	5,800,000	7,000				15
Funen		500,000	76,000				9%

Landsverk, EST, Statistics Faroes, Dst.dk and Sund & Bælt

cians with information based on sustainability. An additional benefit would be a discussion about this particular project and the future infrastructure of the Faroe Islands.

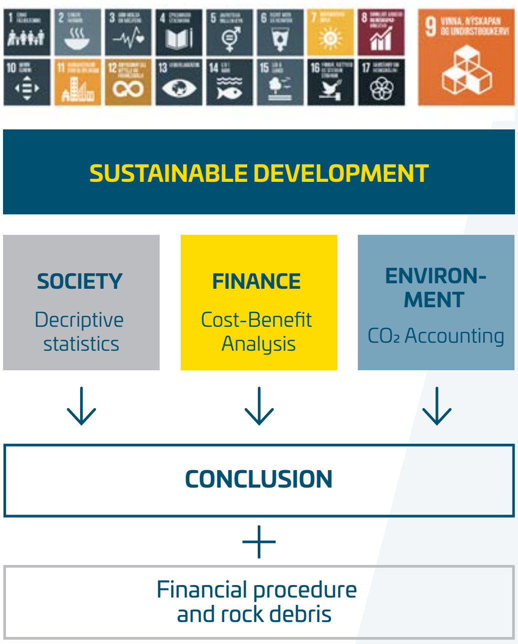
A possible tunnel to Suðuroy would no doubt be the biggest infrastructure investment in Faroese history, both in terms of length and cost. Table 1 shows that a tunnel is estimated at 5.4 billion DKK, which is equivalent to 1.2 million DKK per capita in Suðuroy. This amounts to 26% of the GDP or most of the annual budget (93%). The investment in the tunnel to Sandoy is nearly as large, costing around one million DKK perinhabitant on the island. The number of people benefitting from a tunnel to Suðuroy far exceeds the number for Sandoy, as the proportion of the national population is 9% on Suðuroy and 2% on Sandoy.

If we compare the tunnel to Suðuroy with the Great Belt Bridge connecting Zealand and Funen, the investment amounts to 15 Great Belt Bridges. The proportional population of Suðuroy is similar to that of Funen where anything but a connecting road seems unimaginable. These numbers suggest that the cost of this project is relatively high. It also shows the importance of a broad and thorough analysis of the project.

THE UN'S MODEL OF ANALYSIS USED IN THE PILOT STUDY

The pilot study of a new route to Suðuroy is based on the UN's definition of sustainable development, taking into account society, economy and the environment, see Figure 2 (the Brundtland report, 1987). The conclusion will therefore be based on a balance between these three components.

FIGURE 2: MODEL OF ANALYSIS FOR THE PILOT STUDY



THE STRUCTURE OF THE PILOT STUDY

The study starts with a general summary where conclusions from individual studies will be discussed and compiled into a joint analysis. This section assesses which route to Suðuroy proves best suited according to the social, economic and environmental analyses. After the summary, the study will discuss each of these analyses.

Part 1 contains a social analysis based on statistics showing the effect that investment into modern infrastructure has on the local community. Part 2 contains an economic analysis based on cost-benefit analyses where the costs and benefits are weighed against each other. Part 3 contains an environmental analysis based on CO_2 accounts comparing emissions from a new route to Suðuroy with the current ferry, Smyril. Finally, part 4 contains the additional analyses, first discussing financing, followed by a proposal for utilising the rock debris from the possible construction of a tunnel.

1.2 SUMMARY

ANALYSES PERFORMED TO SHOW DIFFERENT ASPECTS

Investing in a tunnel to Suðuroy is a big social decision. It requires careful consideration and should be based on a solid foundation, taking into account the many and varied factors involved in such a large project. The study will show possible routes to Suðuroy based on social, economic and environmental aspects. These aspects will then be merged into an estimation of the best possible solution.

The social analysis estimates the extent to which the local community in Suðuroy, as well as in the whole of the Faroe Islands, can expect to benefit from an expanded infrastructure. The study reviews experience gained from previous large projects, particularly the tunnels to Vágar and Borðoy. These projects suggest a positive effect on local communities historically, including a growing population, better age distribution, as well as increased work and salaries. The effect varies between communities, as the tunnel to Vágar showed a greater effect on the local community than the tunnel to Borðoy. However, the effect is not necessarily positive. Norwegian examples show the need for certain conditions to be in place in order for investments made in infrastructure to result in regional development. Quite a few of these seem to be in place regarding Suðuroy. This supports the social argument for a tunnel to Suðuroy. However, the benefit to the community depends on commuter fees, i.e., the fees for passing through the tunnel. Higher fees can diminish the social benefits.

The economic analysis compares potential solutions for a new route by looking at the cost and the investment's usage value. The usage value must outweigh the cost before it is advisable to support such an investment. The study suggests that the best financial solution is a ferry, either as it is today from Tórshavn or one from Sandoy when the tunnel is completed. According to the calculations, a subsea car tunnel provides a negative net present value of c. minus 1.6 billion DKK and should not be carried out from an economic point of view. Despite the social and consumer advantages, as well as relatively low running costs compared to a ferry, it still does not outweigh the enormous cost of a subsea tunnel. Even with considerable adjustments to conditions, a subsea tunnel still does not produce a positive present value. Neither do other possible benefits such as increased business and tourism possibilities correct the economic imbalance.

The environmental analysis compares potential solutions regarding CO_2 emissions. The study shows that a tunnel produces considerably lower CO_2 emissions compared to a ferry, with only a third of the emissions of a ferry. This amounts to approx. 231,000 tonnes less for the project period. Even though subsea tunnels produce higher emissions during construction, they produce considerably less when in use. The tunnel solutions all share similar figures for emissions. As with the economic analysis, changes have been made in calculations and conditions, confirming a subsea tunnel as the most sustainable solution.

A COMBINED ESTIMATION OF POTENTIAL SOLUTIONS

After discussing potential solutions socially, economically, and environmentally, an attempt will be made to provide a combined evaluation of solutions. The differing results make it difficult to combine the solutions. Socially and environmentally, a subsea tunnel is the best option, while the enormous cost of a tunnel points to a ferry instead. It is therefore a question of priority, i.e. which of the factors carries the most weight. Some consider the social factor the most important, while others focus on economy and environmental impacts.

In order to reach a combined conclusion, a multi-factor analysis will be used. This aims to intertwine various factors in support of an enlightened decision. In this particular study, the social, economic and environmental aspects need to be considered together. An everyday example of such an analysis can be buying a car. The buyer probably has thoughts on make, model, price, condition, colour, etc. that must all be weighed and considered in order to reach a decision.

Table 2 shows a multifactor analysis of the three analyses with possible routes. Each route is assigned a value where 5 is the best option and 0 is the worst. Good results are colour coded in green and poor results in red. Other options include light green, yellow and orange.

The multifactor analysis shows many interesting results. The current route has a high economic value and thus scores a green 5, while it has the lowest social and environmental value, resulting in two red zeros. The current route therefore scores 5 points which is relatively low compared to other options. A new ferry to Suðuroy scores equally well economically but low socially and environmentally. A rail tunnel scores highest environmentally but low socially and economically.

The conclusion of the multifactor analysis is that from the point of view of sustainability, car tunnels are the best solution. They get high scores socially and environmentally but a low economic score. The reason for the variation in the tunnel via Skúvoy is that it is estimated to provide greater social benefits on account of including one more island, but at the same time, it is likely to disrupt the birdlife in the island. A degree of uncertainty clouds these scores without, however, affecting the result. Similar factors might affect the tunnel from Skarvanes due to its beautiful, unspoilt nature.

The principle of sustainable development is the balance between the three aforementioned factors. Therefore, these carry the same weight in figure 2, meaning that they were equal in the combined evaluation. It is, however, quite possible that political parties will prioritise differently. Below, an attempt is made to differentiate the value.

Table 3 shows how different weight distribution changes results. If the social value is doubled compared to the other two aspects, car tunnels remain the best solution. The same applies if the environmental value is doubled. However, if the economic value is doubled, a ferry between Sandoy and Suðuroy would be the best solution, although it would not score that much higher than the current ferry or the tunnel solutions.

CONCLUSIONS FROM ADDITIONAL ANALYSES

Regardless of whether we talk about tunnels or a new ferry, the investment is extensive and expensive. Therefore, the possible financing of a tunnel has been looked into.

The expected expenses for a possible tunnel to Suðuroy are estimated at 172 million DKK a year. Expense expectation is therefore so high that it cannot only be financed with commuter fees or by adjusting loan conditions. This study therefore investigated specific compound financing if the project is to be carried out. One of the conclusions is that leaving the current commuter fee unchanged would only finance 10% of the investment, leaving the rest to be funded by deposits or public financial support. Another conclusion suggests that by extending the lending period and letting the government play a bigger role in taking up the loan and thus reducing interest rates compared to previous tunnels, the annual financial requirements can be reduced from 172 million to 69 million DKK a year. This solution should reduce commuter fees as well as relieving the burden on the national purse.

Finally, this study looks at the possibilities of utilising the rock debris from the tunnel. A possible tunnel project produces c. 3.8 million m^3 of debris that can either create new possibilities or new challenges. The possibilities lie in new projects that would otherwise require rather expensive debris. A high supply of debris can therefore open possibilities for other projects to take place during the construction of the tunnel. The debris can also be a challenge due to the vast amount of it and limitations in quality. This study stresses the importance of determining where to put the debris, or what to use it for, before the project is commenced. This study presents nine suggestions for utilising the debris, where environmental as well as archaeological aspects must be considered before any other measures are implemented.

TABLE 2: MULTIFACTOR ANALYSIS, VALUE 0-5

Options	0 Current ferry	1 Tunnel from Skarvanes	2 Tunnel from Sandur	3 Tunnel via Skúgvoy	4 Rail tunnel	5 New ferry
Soocial	0	4	4	5	2	1
Economic	5	1	1	1	0	5
Enviromental	0	4	4	3	5	0
TOTAL	5	9	9	9	7	6

TABLE 3: MULTIFACTOR ANALYSIS, VALUE 0-5

Social value doubled

Options	0 Current ferry	1 Tunnel from Skarvanes	2 Tunnel from Sandur	3 Tunnel via Skúgvoy	4 Rail tunnel	5 New ferry
Soocial	0	8	8	10	4	2
Economic	5	1	1	1	0	5
Enviromental	0	4	4	3	5	0
TOTAL	5	13	13	14	9	7

Economic value doubled

Options	0 Current ferry	1 Tunnel from Skarvanes	2 Tunnel from Sandur	3 Tunnel via Skúgvoy	4 Rail tunnel	5 New ferry
Soocial	0	4	4	5	2	1
Economic	10	2	2	2	0	10
Enviromental	0	4	4	3	5	0
TOTAL	10	10	10	10	7	11

Environmental value doubled

Options	0 Current ferry	1 Tunnel from Skarvanes	2 Tunnel from Sandur	3 Tunnel via Skúgvoy	4 Rail tunnel	5 New ferry
Soocial	0	4	4	5	2	1
Economic	5	1	1	1	0	5
Enviromental	0	8	8	6	10	0
TOTAL	5	13	13	12	12	6

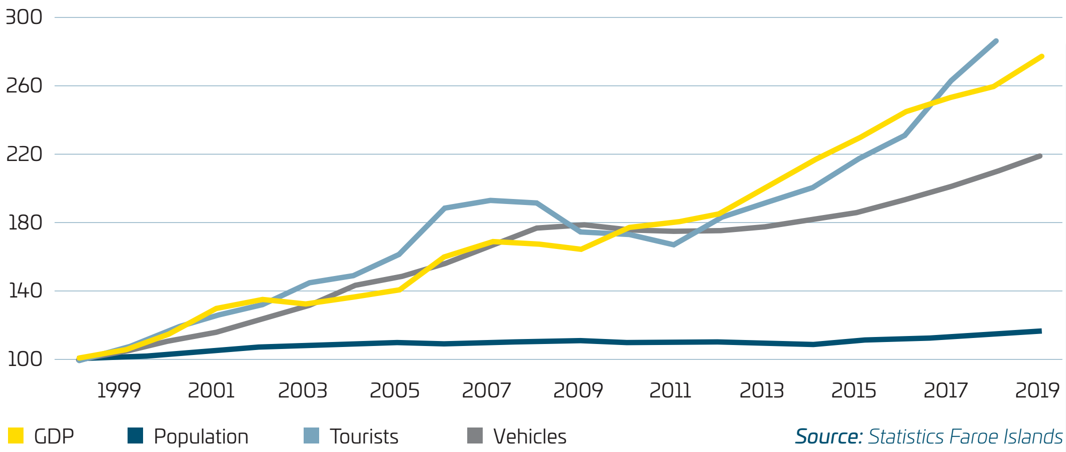
2. THE SOCIAL ANALYSIS

The social analysis shows the importance of infrastructure, including the social effect of connecting islands by road. Suðuroy is compared with other islands that have or will have connecting roads: Vágar, Borðoy and Sandoy. The primary method of analysis is descriptive statistics based on data from Statistics Faroes. The use of descriptive statistics prevents significant results but rather provides qualified indications. Furthermore, visible changes to a connecting road may be affected and/or delayed by sociological factors (e.g. culture) that cannot be measured in statistics.

As Graph 1 shows, major changes have taken place in Faroese society over the last 20 years. The purpose of such investments is primarily to create growth in the region (Rietveld, 1989).

It is difficult to assess whether the Faroese attempts at regional development have succeeded; and equally whether infrastructure investments are the best course of action. Firstly, it is difficult to assess the alternative situation had the investments not been made. Secondly, there are no clearly defined objectives for local and regional development. The latter is a challenge, because, as researcher in regional development, Gestur Hovgaard said: 'When a concept holds everything, it really says nothing.' (Hovgaard, 2001). It is worth mentioning that the Ministry of Culture prepared a regional development report in 2001 which was discussed, but no specific developmental policy was drafted or adopted (Ministry of Culture, 2001). According to the regional development report, industry, settlement and infrastructure are closely associated. Very few Faroese studies discuss the effects of infrastructure investments on local communities. Statistics on this topic are also scarce, particularly regarding the effects on commerce. Despite the lack of developmental policy, the following section will analyse how infrastructure investments affect local communities regarding demography, work, and income. Finally, a summary will follow as well as an assessment of the extent to which a connecting road changes the circumstances in Suðuroy.

GRAPH 1: SELECTED PARAMETERS, 1998-2019



Source: Statistics Faroe Islands

According to the graph, the population has increased, as have the numbers of vehicles and tourists, and the economy has grown. All these factors add to the pressure on the Faroese infrastructure, and the growth requires development and additional maintenance of the infrastructure.

EXTENSIONS FOR REGIONAL DEVELOPMENT

Historically, various conditions have impacted how and to what extent Faroese infrastructure has developed. A report on future Faroese infrastructure from the Ministry of Industry showed that historical and economic factors, as well as a political will towards local and regional development, have affected which infrastructure investments have been made (Ministry of Industry, 1999). Extensions have therefore not merely been economically motivated but have also been chosen in order to strengthen a region. The term for this approach is active investment strategy.

2.1 DEMOGRAPHY

INFRASTRUCTURE CAN GREATLY AFFECT POPULATION

Faroese demographics also show the international tendency towards centralisation. Inhabitants move from smaller places to larger areas and from villages to cities. From 1985-2019 the metropolitan area has increased most in population and has grown proportionally by 6.4%. In the same period, most other areas have decreased accordingly (Appendix A1).

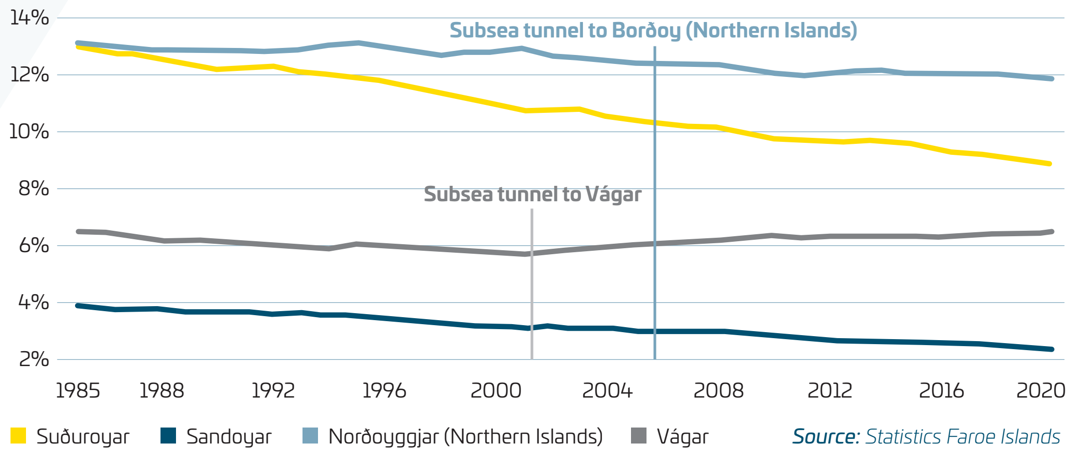
Looking at selected areas, it is clear that the demographics outside the metropolitan area vary greatly. Graph 2 shows that Vágar and Sandoy demographics were very similar before work on the subsea tunnel to Vágar commenced. Just before the tunnel came into use in 2002, the population in Vágar started to grow. Suðuroy had 13% of the population in 1985 which had dropped to just 9% in 2019. In that same period, the Northern Islands have managed to maintain a stable population of about 12%; however, the Borðoy subsea tunnel does not seem to have impacted the population. Despite differing tunnel effects, this would suggest that a connecting road has a positive effect on the population, about 700 people in Vágar and just over 200 in Northern Islands.

A closer look at the demographic change in Suðuroy reveals that the population diminished by 1,264 people in the years 1985-2019 as a result of national and international emigration. Graph 3 shows that a larger part of those who emigrated, did so within the Faroes rather than going abroad. This would support the claim that a subsea tunnel could maintain or even increase the population.

Connecting roads improve the distorted age and gender distribution

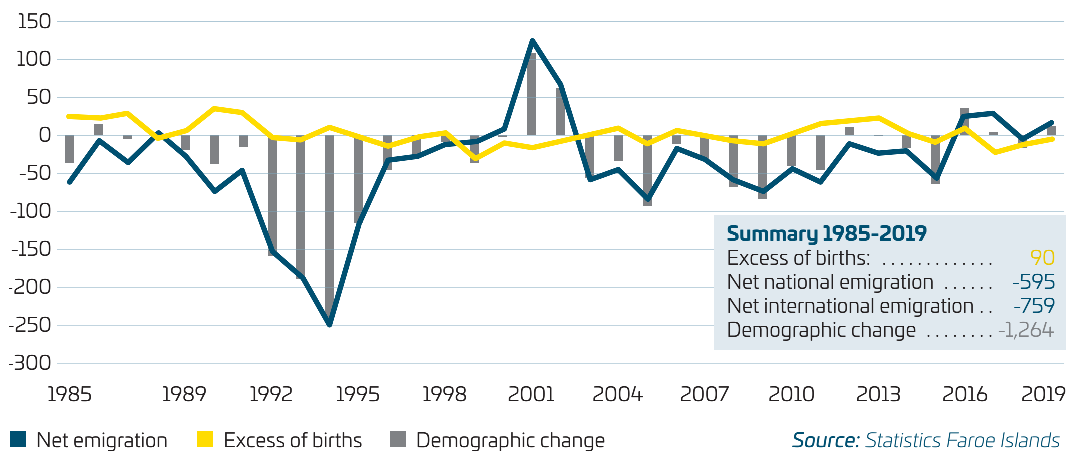
As in our neighbouring countries, the average age is increasing. People are getting older and having

GRAPH 2: PROPORTIONAL POPULATION FOR SELECTED AREAS, 1985-2019



Source: Statistics Faroe Islands

GRAPH 3: DEMOGRAPHIC CHANGES IN SUÐUROY, 1985-2019



Source: Statistics Faroe Islands

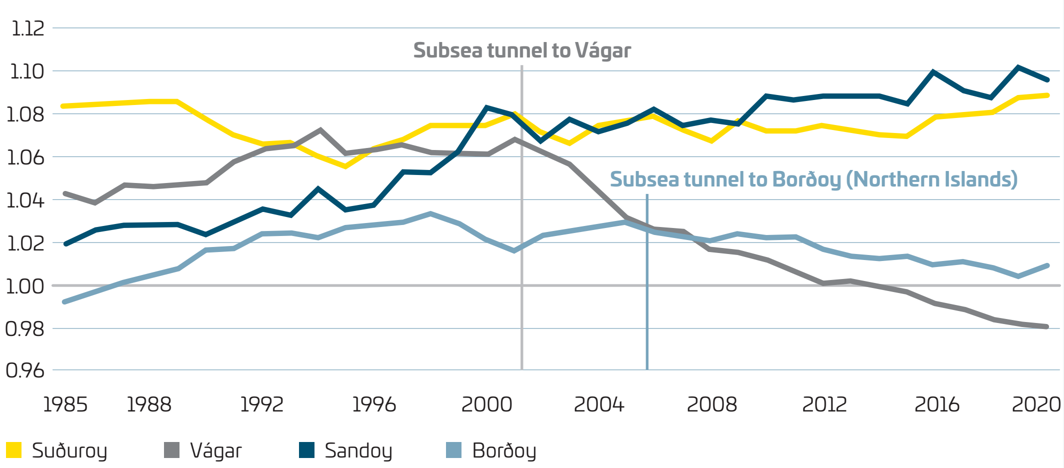
fewer children. The term demographic imbalance is commonly used in this context.

Demographic imbalance is particularly apparent in Suðuroy and Sandoy, as in the previously mentioned period, these islands shared a relatively high average age compared to the rest of the country (Appendix A2). In 2020, the average age in Suðuroy was 3.5 years above the national average. Graph 4 below shows a similar tendency to Graph 2, i.e. a significant change in the average age in Vágar after the subsea tunnel came into use in 2002. Graph 4 suggests a correlation between a connecting road and average age, as average age dropped in both Vágar and the Northern Islands after their respective tunnels came into use. The evidence is particularly strong in Vágar, as their average age was 6% higher than the national average before the tunnel came into use, and today it is 2% lower than the national average. This would suggest that the increase in population caused by the tunnel consists of young people or young families.

A closer look at Suðuroy demographics shows that not only has the population decreased over time, but the demographic imbalance increases as well. Specifically, the younger age groups get smaller and the age group over 67 years of age grows in Suðuroy compared to the national demographics (Appendix A3).

This imbalance in Suðuroy becomes particularly apparent in the population pyramid in Graph 5 below, where the older age groups are proportionately larger, and the age groups 20-40 years and 0-4 years are small. This imbalance gets worse over time and applies to women in particular. Gender distribution in Suðuroy was proportionally better balanced from 1985-1996. After 1996, gender distribution becomes distorted compared to the period beforehand and the national gender distribution (Appendix A4).

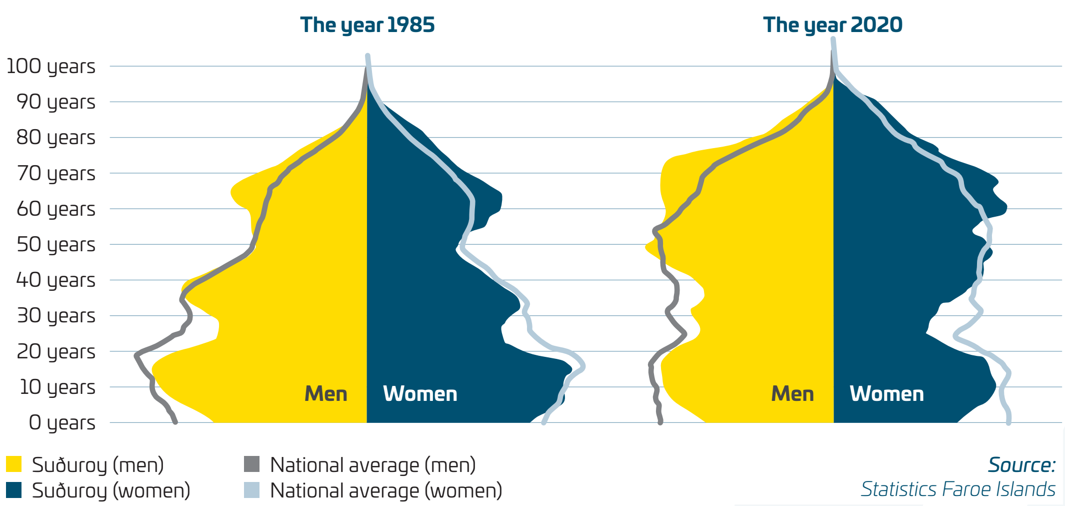
GRAPH 4: PROPORTIONAL AVERAGE AGE FOR SELECTED ISLANDS, 1985-2020



Comment: The tunnel to Vágar opened on 10 December 2002, and the tunnel to Borðoy on 29 April 2006 (tunnil.fo)

Source: Statistics Faroe Islands

GRAPH 5: AGE AND GENDER DISTRIBUTION IN POPULATION PYRAMIDS IN 1985 AND 2020



Source: Statistics Faroe Islands

A close look at age and gender distribution compared to demographic change in Suðuroy, reveals strong indicators that young women are leaving the island. The imbalance gets worse when women of child-bearing age leave the island (also called a self-perpetuating effect). Faroese and Scandinavian studies show that young women often leave smaller places due to limited employment opportunities (Nielsen et al., 2020). Studies in Iceland also show that improved commute and travel links result in a more balanced gender distribution, because more women work in the service industry which is typically based in the metropolitan area (Karlsson, 2004).

2.2 WORK

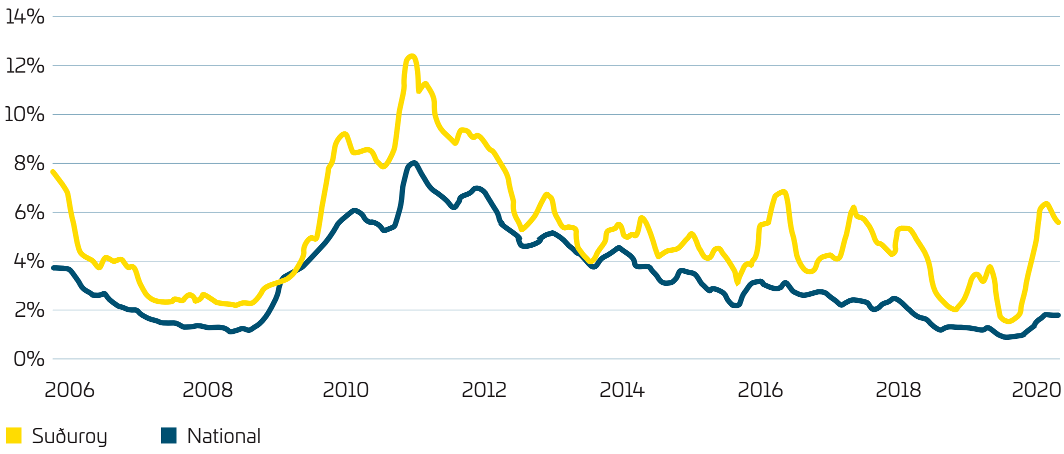
A CONNECTING ROAD UNITES THE LABOUR MARKET

Looking at the course of unemployment in these areas, it appears that the subsea tunnels have had varying effects on the areas (Appendix A5). The tunnel to Vágar has clearly affected unemployment, as rates subsequently dropped compared to the rest of the country. This particularly applied to men, which might suggest that men benefit more from a connecting road – either because they commute more, or because the local industry changes in their favour with the tunnel. Apart from the financial crisis, when, for example, the fish factory Kósin went bankrupt, the tunnel to Borðoy also appears to have reduced unemployment in the Northern Islands.

Compared with the rest of the country, unemployment rates in Suðuroy are considerably higher throughout the period, on average about 2% higher. The fact that unemployment rates are higher in Suðuroy than in the rest of the country suggests two separate labour markets. In other words, the work force in Suðuroy is separate from the national work force. However, this is not unexpected, because the current infrastructure separates Suðuroy from the rest of the country and limits commuting opportunities. We see this in the statistics from Manntal 2011, as a very limited number of people commute to and from Suðuroy (Appendix A12). Infrastructure investments improve these conditions according to socioeconomic theory, because the better the mobility of capital and work force, the better they are utilised. Ceteris paribus, increased mobility increases work supply and agglomeration, as travelling is an expense for the commuter and lost production for businesses. A connecting road therefore improves flexibility and conjoins the needs of the industry and the ability of the work force, resulting in improved production power (Combes et al., 2012), Bernard et al., 2019). Keeping this in mind, a tunnel to Suðuroy would not only benefit Suðuroy but the whole industry.

If we then look at duration of unemployment, in Suðuroy it tends to last shorter compared with the national average. There are more short-term unemployed workers and fewer long-term unemployed workers in Suðuroy (Appendix A6). One of the reasons might be seasonal unemployment, which applies more to Suðuroy. Graph 6 shows that unemployment is relatively irregular in Suðuroy.

GRAPH 6: UNEMPLOYMENT BY AREA, MONTHLY 2005-2020



Comment: *Varðin Pelagic (fish factory) opened in July 2012 (vardin.fo)*

Source: *Statistics Faroe Islands*

2.3 INCOME

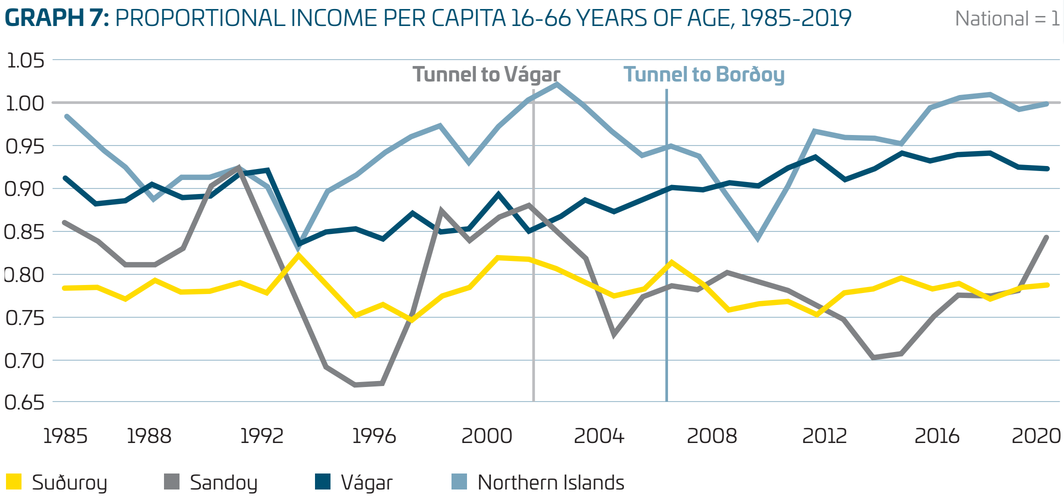
A CONNECTING ROAD INCREASES INCOME

Looking at local economies in the same areas, tax income grows throughout the period (Appendix A7). Even though Suðuroy gets its share of economic growth, the island's tax income tends to be lower than that of other islands. The difference seems to increase over time where the annual tax income per capita in Suðuroy was 1,529 DKK lower than the national average in 1993 and 4,597 DKK lower in 2019. These numbers may, however, be affected by factors such as varying tax rates and child deduction rates across time and areas. The tunnels do not seem to have the same effect as they did on population and average age. One explanation might be that if most of the immigration consists of young families, that may have a levelling effect, as children count in the population but do not generate tax income until they start working. In other words, the effect is delayed and only visible long term. Tax income can also affect local work and population over time. Higher tax income may improve conditions for business activity as well as the level of public services, which both contribute to better living conditions in a local community.

The median income for these areas has increased over time across all areas (Appendix A8). The areas without connecting roads, however, have relatively lower median income. The difference does not seem to grow over time, because the annual average median income for this period is 231,269 DKK nationally and 202,780 DKK for Suðuroy, i.e. 28,489 DKK lower on average. The challenge regarding median income is that statistics are only available since 2009 after both subsea tunnels were in use. Therefore, annual income per capita will be looked at instead. Graph 7 shows a similar tendency as with median income, i.e. that Sandoy and Suðuroy have proportionately lower annual incomes per capita. Incomes in Suðuroy are a stable 20% lower compared to the rest of the country. The imbalance in Suðuroy particularly affects men, and the income gap widens over time (Appendix A9). In Vágar, incomes have increased steadily since the opening of the tunnel in 2002. Numbers in the Northern Islands, on the other hand, have not been as stable during the financial crisis but have now reached the national standard. Even though the effect of the tunnels is not as visible as with population and age, this would suggest a positive effect on annual income per capita.

Regarding median income and annual income, field of work, education and work hours should be considered. The division of fields of work has not changed much over the last 10 years, i.e. the work force in each field has stayed roughly the same. Yet, there is a difference across areas. The great difference between Suðuroy and the rest of the country is in fishing and the private service industry (Appendix A10). The fishing industry in Suðuroy is relatively large compared to the rest of the country, but the private service industry is rather limited. Economic theory suggests that economic growth typically causes an industrial shift from raw material industry to service industry which overall

GRAPH 7: PROPORTIONAL INCOME PER CAPITA 16-66 YEARS OF AGE, 1985-2019



Comment: *The tunnel to Vágar came into use on 10 December 2002, and the tunnel to Borðoy on 29 April 2006 (tunnil.fo)*

Source: *Statistics Faroe Islands*

demands higher education and provides higher income (Strauss and Maisonneuve, 2007).

Suðuroy has different educational conditions than other areas. Unfortunately, the only educational statistics are from 2011. These statistics show considerably lower education levels in Suðuroy than in other parts of the country. In work hours, however, Sandoy is the only area that differs from the rest (Appendix A11). Lower incomes in Suðuroy might therefore come from a different industrial structure as well as lower levels of education.

2.4 CONDITIONS

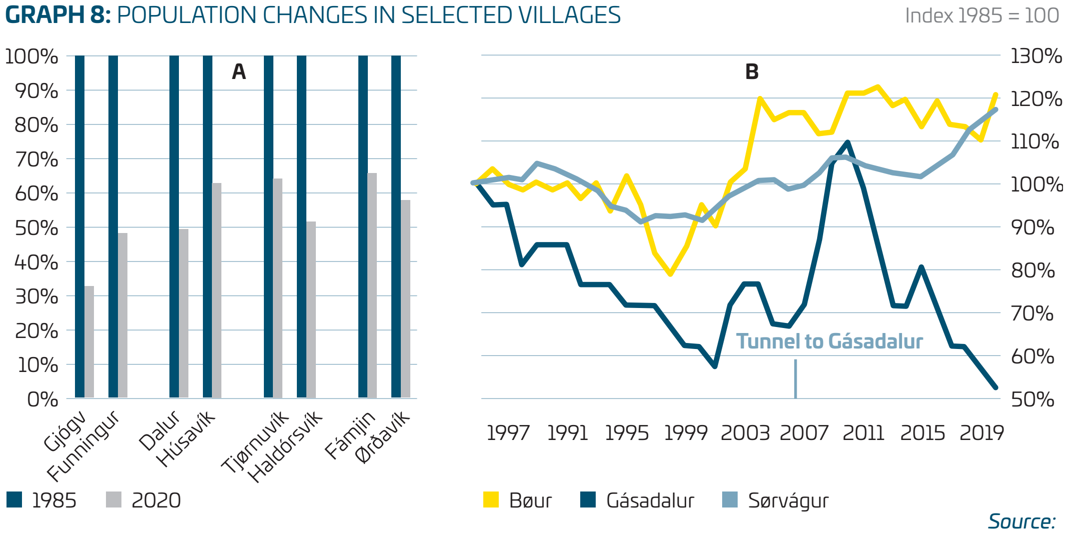
As statistics have shown, connecting roads have a positive effect on local communities within various social parameters, such as population and age. This is more apparent for the tunnel to Vágar which suggests that results vary. The question is therefore: what conditions must be in place in order for infrastructure investments to generate social benefits?

Demographic changes for selected villages and neighbouring villages with and without infrastructure challenges are demonstrated below. In 2006, the tunnel to Gásadalur was taken into use, and currently, plans for tunnels to Gjógv, Tjørnuvík, Fámjin and Dalur are on the table. Graph 8(A) shows despite poor accessibility, Gjógv and Dalur are the only villages to see a considerable decrease in population compared to neighbouring villages, while the same does not apply for Tjørnuvík and Fámjin. Graph 8(B) shows clear population growth in Gásadalur after the tunnel was opened followed by a drop after 2010 with today's population being even smaller than pre-tunnel. This shows that infrastructure investments do not necessarily generate regional development, but other conditions may prove relevant.

Norwegians have worked hard and systematically on regional development. Their studies show that the following three criteria need to apply for an infrastructure investment to generate socio-economic growth in the region (Markussen and Samstad, 2001).

1. The poorer the conditions of existing infrastructure, the greater the chances of economic growth. This particularly applies to improvements that can create new opportunities and not mere improvements on existing infrastructure.
2. Areas that are connected to the metropolitan area should have clear development potential.
3. The political system in the area should be well developed, and there should be at least one industry/custom for foundation and/or one market to inspire growth potential.

GRAPH 8: POPULATION CHANGES IN SELECTED VILLAGES



Source: Statistics Faroe Islands

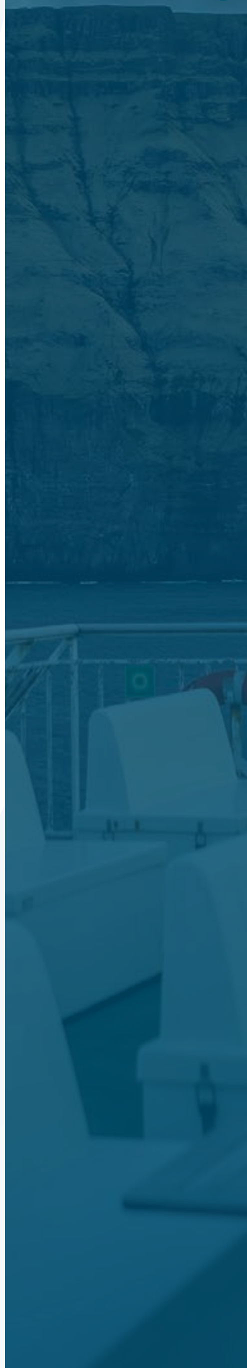
Comment: *The tunnel to Gásadalur came into use on 21.12.2006 (landsverk.fo)*

The question is: Do these criteria apply to Suðuroy? A potential subsea tunnel would meet the first condition, as it would improve flexibility and drastically reduce travelling time. Additionally, a tunnel would add a new means of transport – from public sailing to private driving. Regarding the second point, local businesses claim that a tunnel would increase their competitive strength, as a connecting road provides better and safer connection to the metropolitan area. Money saved on transportation would improve the competitive strength of local businesses (Ministry of Transportation, 2019) which would in turn benefit the local consumers in Suðuroy. Icelandic studies showed that lower transportation costs reduced prices on goods and increased the assortment of goods. Food prices, for example, went down by 3% (Karlsson, 2004). Additionally, better travel connections would mean considerably improved growth potential for tourism and adventure industry in Suðuroy (VFI, 2020). Regarding the third point, it has already been said that the fishing industry and particularly the pelagic industry is doing well in Suðuroy. Studies in neighbouring countries show that solid preparation work is key to seizing growth opportunities and that those who prepare for increased competition do better (Karlsson, 2004). All in all, an investment in a tunnel to Suðuroy seems to meet all three criteria for socioeconomic growth.

These three conditions were also in place for the other two tunnels but the effect on those areas seems quite different. Vágar became a commute friendly area that was suddenly quite close to the capital. As a result, the population grew. The Northern Islands, on the other hand, have quite a strong industry and need outside workers. The question is whether a tunnel would change the commuting situation to the capital and/or the local industry. These situations are difficult to predict, but foreign and Faroese statistics show that most people commute no more than 30-60 minutes to work (Appendix A12). The tunnel to Suðuroy would make the commute about 60 minutes (Landsverk, 2019). Thus, the commute would make the 60-minute cut. If Suðuroy can become a commute friendly area, i.e. if the project is to generate regional development, the travelling cost plays an important part. This will be discussed further in the report on how the tunnel would be financed.

2.5 CONCLUSION

The social analysis shows a certain centralisation of the Faroese population where people move from villages to cities. This particularly applies to Suðuroy with a net emigration of 1,264 over the past 35 years, while the Faroese population has grown by 6,806 inhabitants. Additionally, Suðuroy has an imbalance in distribution of age and gender compared to the national average, and the situation gets worse over time. The analysis showed that infrastructure investments have a positive effect on local communities regarding population, age distribution and work. However, there are exceptions. Norwegian studies show that certain criteria need to be met for infrastructure investments to lead to regional growth. A connecting road to Suðuroy seems to meet these conditions, so from a purely social perspective focusing on regional development, one could argue that the investment should be made with a manageable travelling cost.



3.

COST-BENEFIT ANALYSIS

AN ACKNOWLEDGED ANALYTICAL METHOD

The economic analysis is based on socioeconomic theory, including cost-benefit analysis where benefits and costs of the project are continuously made comparable. In other words, the analysis compares the benefits and the costs to find the net result. A cost-benefit analysis is very similar to financial analyses, as both calculate the net result of an investment. The main difference is that financial analyses focus on the business while the cost-benefit analysis focuses on the community as a whole. The main objective of the analysis is to show the socioeconomic effect before choosing a solution. Even though the main conclusion focuses on the net result, the benefit of a cost-benefit analysis is to provide an organised and acknowledged analytical process which provides the basis for reaching an informed decision.

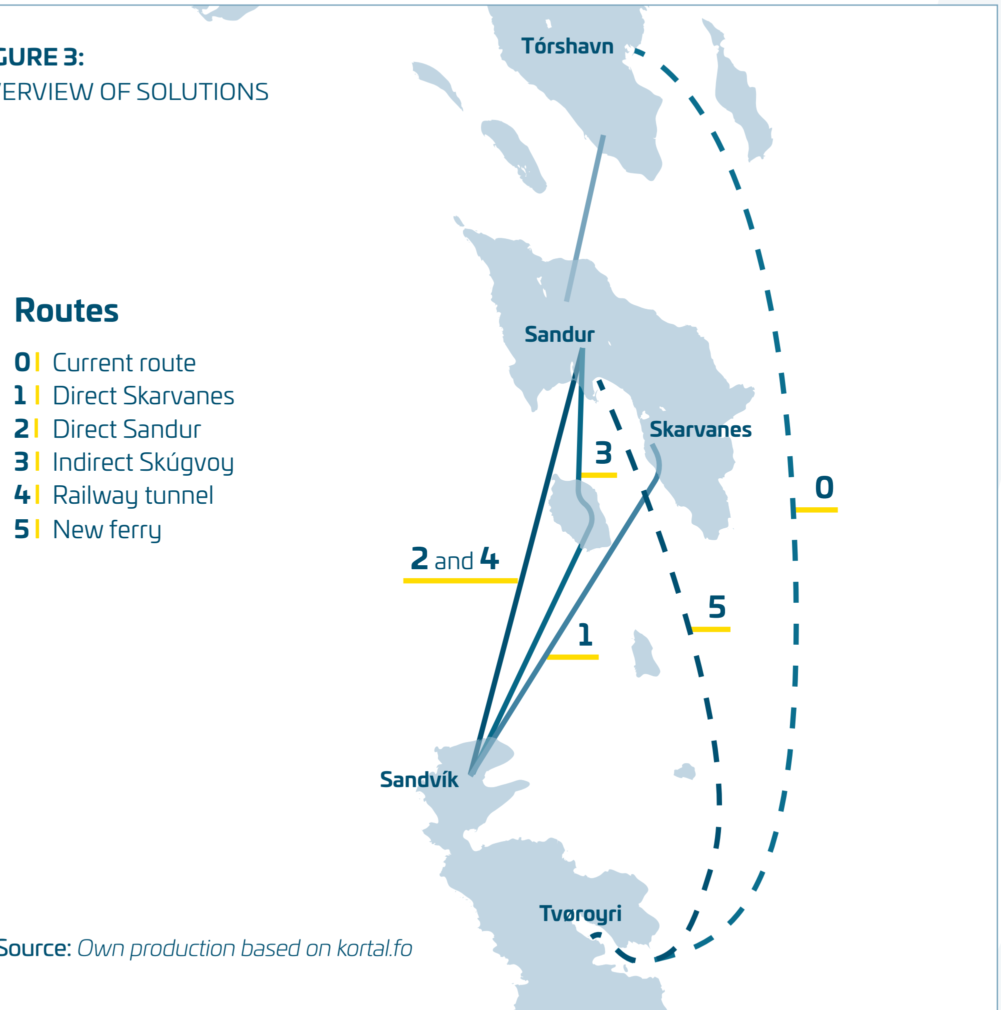
A cost-benefit analysis does not account for everything and has its limitations, but this is an internationally used method to analyse public infrastructure investment. This analysis uses TERESA which is commonly used in Northern Europe. The calculation settings in the programme are Danish but have been adapted to Faroese conditions where possible (about 50%).

3.1 PROJECT OUTLINES

FIVE SEPARATE PROJECTS ANALYSED

Cost-benefit analyses are performed for five potential solutions which are all compared to the existing route, i.e. the ferry, Smyril (Fig. 3). The solutions consist of car tunnels with three sep-

FIGURE 3:
OVERVIEW OF SOLUTIONS



Source: *Own production based on kortal.fo* arate routes (1, 2 and 3), a train tunnel (4) and a new ferry between Sandoy and Suðuroy (5). In figure 3, the new ferry sails from Sandur to Krambatangi. Another option would be for the new ferry to sail from Sandur to Hvalba. This would shorten the sailing time. If this becomes relevant, further studies are required. The purpose of analysing several potential solutions is to present a thoroughly thought-out project.

3.2 ESTIMATION OF OUTCOMES

SIX GROUPS OF OUTCOMES ESTIMATED.

In this part of the analysis, only relevant outcomes that are quantifiable and monetized are discussed. Some project outcomes are more quantifiable and evaluable than others. Outcomes with a market price to estimate, such as money saved on fuel and time cost in business are easier to estimate. Leisure and delays on the other hand prove more difficult as there is no market price for these outcomes. Unquantifiable outcomes will be discussed in 3.5 Qualitative Outcomes.

Outcomes are grouped in six categories: building cost, operation and maintenance, user profit, externality, other outcomes and additional outcomes. This part will briefly discuss the conditions for these categories which are the basis for the cost-benefit analysis. A more in-depth overview of calculation settings including the adjustments to Faroese conditions is found in Appendix B1.

3.2.1 BUILDING COST

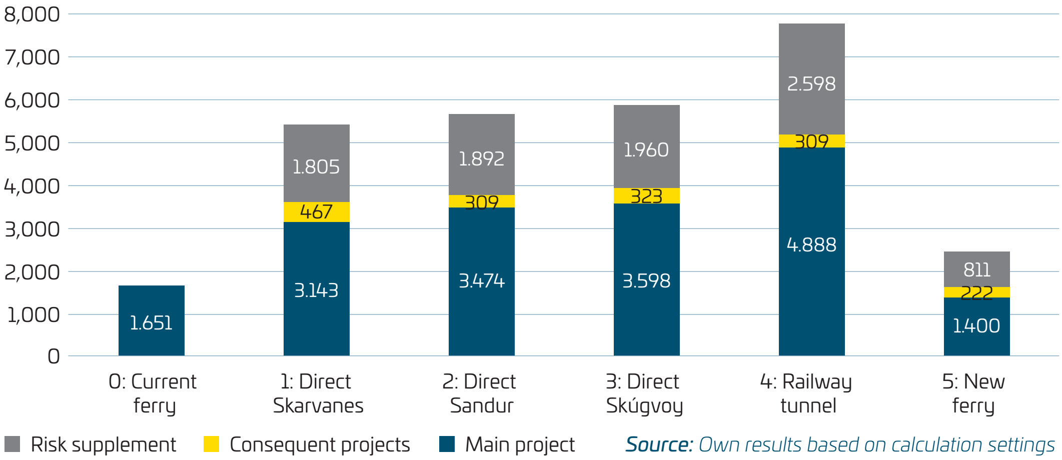
THE INVESTMENT COST FOR TUNNELS IS CONSIDERABLY HIGHER THAN FOR FERRIES

Building cost or investment cost is the cost of construction and the ferries. Building cost contains the primary project, consequent projects and a risk supplement. This is to ensure that all costs are covered, including accessibility. The building cost for subsea tunnels is based on the cost of the tunnels to Eysturoy and Sandoy which was 138 million DKK per kilometer (2021 prices). SSL has estimated the cost of a new ferry to be 800 million DKK for the current route and 700 million DKK for a new route between Sandoy and Suðuroy as that ferry could be smaller. The consequent projects are estimated at 222-467 million DKK without a risk supplement (Appendix B2 shows consequent projects). Uncertainties due to the early-stage result in a risk supplement of 50% for all projects (more on risk supplement in part 5, Financing Model). Safety solutions on the new route are one of the more uncertain factors. Examining safety procedures or risk assessment can set the security level for a subsea tunnel.

Graph 9 shows a considerably higher investment cost for tunnels than ferries, particularly in the case of the train tunnel due to railways and railway cars. The challenge in comparing investment costs is that a train tunnel is maintained periodically. Tunnels last for the whole investment period of 50 years while ferries and trains need to be replaced after 25 years, and therefore the investment cost for the ferries is included twice (SSL 2021, COWI 2021a). The analysis has accounted for each investment period.

At the end of the investment period, the facilities and ferries have a value known as remaining value. This value is calculated on the condition that it has been maintained well, leaving the value unchanged but discounted to period nil. For example, a project priced at 5.6 billion DKK has a remaining value of 1.1 billion DKK after 50 years (about 20%). This shows how future outcomes are discounted over time.

GRAPH 9: OVERVIEW OF INVESTMENT COST (MILLION DKK, 2012 PRICES)



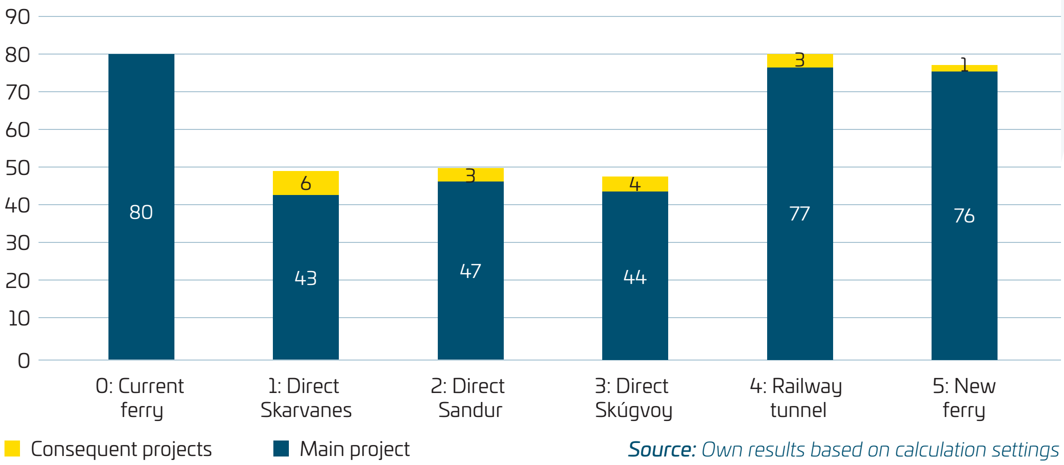
Source: *Own results based on calculation settings*

3.2.2 OPERATION AND MAINTENANCE

OPERATION COSTS FOR FERRIES IS CONSIDERABLY HIGHER THAN FOR SUBSEA TUNNELS

Operation cost and maintenance are settled annually in the investment period. Current cost is used for ferries and previous tunnel costs for tunnels. Operation cost for the train tunnel is based on previous tunnel costs as well as maintenance of railway installations in our neighbouring countries (COWI, 2021). Graph 10 shows an overview of operation costs for each potential solution. Operation costs are the opposite of building costs, i.e. the ferries cost c. 30 million DKK more to run annually than the tunnels.

GRAPH 10: OVERVIEW OF OPERATION COSTS (MILLION DKK, 2012 PRICES)



Source: *Own results based on calculation settings*

3.2.3 USER PROFIT

USER PROFIT IS MADE UP OF THE DIFFERENCE BETWEEN TIME SAVED AND INCREASED TRAVELLING COST

The obvious and definitive parameter regarding an expanded infrastructure is increased user profit, i.e. saved time and travelling cost. In this case, all solutions save time and increase travelling cost, as commuters go from sailing to driving themselves. Commuters between Suðuroy and Sandoy will save time and money, but most people are going to the capital. Thus, the net user profit will be the difference between the saved time and the increased travelling cost. The user profit on a train tunnel or a ferry is increased travel frequency, making commuting more flexible. This user profit is limited compared to car tunnels, as the user is still confined to a timetable and a change in transportation which adds a new fee.

The driving cost (i.e. fuel and wear) is relatively easy to price but travelling time is more challenging. The Trade-Off method is internationally used to price travelling time. In this case, it is based on hourly pay (Boardman, 2018). The value of the time saved is therefore estimated by the Faroese salary scale.

Table 4 shows an overview of some of the defining calculation settings required to calculate the user profit of the project. The table shows that those who travel most with most people in the car are those who do not commute or travel for business. On the other hand, the time of the commuters and business travellers is the most valuable, including delays, as these cause greater disturbances. The price per kilometer for large cars is considerably higher than that of passenger cars, as can be expected.

TABLE 4: CALCULATION SETTINGS FOR USER PROFIT

Travel purpose	Commuting	Business	Other
Ratio	26.5%	9.6%	63.9%
Passengers per car	1,07	1,09	1,52
Travel time per hour			
On time	DKK 64	DKK 322	DKK 64
Delays (+50%)	DKK 96	DKK 483	DKK 96
Driving cost per km.			
Passenger car	DKK 2,78	DKK 2,69	DKK 2,78
Lorry	DKK 3,69	DKK 3,69	DKK 3,69

Source: *COWI, Statistics Faroe Islands and MAGN*

Even though a user fee is a tangible cost for the user and affects user profit, it is not taken into account in a cost-benefit analysis, because the user fee is an income for the country and a fee for the user which even each other out. This does not apply to passengers, however, whose user fee is accounted for as income, but the user profit is not. More on user fees and user profit in part 5, Financing Model.

3.2.4 EXTERNALITY

EXTERNALITY IS BASED ON INTERNATIONAL PRICING

In addition to the obvious outcomes, previously discussed, the new travel pattern has also affected other external circumstances, better known as externality. These include traffic accidents, noise, air pollution and environment (CO_2). These outcomes are compared to the current ferry, such as changes in noise levels from sailing to driving. The externality is primarily based on international statistics and estimations of human lives, noise, air pollution and CO_2. Air pollution and CO_2 are discussed in more detail in the environmental analysis.

3.2.5 OTHER OUTCOMES

THE PROJECTS INCREASE THE PUBLIC INCOME BUT HAVE A NEGATIVE TAX DISTORTION

Other outcomes include changes to public income and the Faroese labour market. Despite excluding user fees, other public incomes are included, such as fuel tax. If the user ends up driving more, public tax income will increase.

Developing infrastructure changes the labour market, as was shown in the social analysis. The socioeconomic effect on the industry includes tax distortion and an increased work force. One way or another, a large part of the public investment will be financed by income tax. An increased income tax produces a negative tax distortion because higher taxes reduce the motivation to work. This is often called the tax distortion factor and is set at 1.1. This means that the net public sector borrowing requirements have a tax distortion of 10%. On the other hand, infrastructure investments increase work supply, as people spend less time commuting and part of that time is spent working more. Finally, the net distortion of public investments is typically negative, i.e. negative tax distortions are relatively higher than the increased working power (DTU, 2015). This also applies to these projects.

3.2.6 ADDITIONAL OUTCOMES

A TUNNEL BENEFITS THE ELECTRONIC INFRASTRUCTURE

Additional outcomes in this cost-benefit analysis include vast and definitive areas, such as how potential solutions save current route operation costs and benefit the electronic infrastructure. It should be kept in mind that two new ferries need to be bought in the project period at 800 million DKK each, with their relatively high operation costs (approx. 30 million DKK more annually than tunnels). Additionally, tunnels are not affected by poor weather conditions, estimated as statistical cancellations on the current route.

One additional outcome of the tunnel (solution 1-4) is the possibility of running electronic infrastructure through the tunnel rather than through submarine cables which are considerably more expensive with shorter durability. This would benefit the electricity grid and internet. Suðuroy is currently separated from the rest of the Faroese electricity grid, but a tunnel would make it possible to add Suðuroy to the combined electricity grid. According to SEV, this is a defining step towards the green transition, as the addition of Suðuroy would strengthen and further advance the Faroese electricity grid. Internet in Suðuroy is currently provided through submarine cables which occasionally snap and have a high repair cost. According to NET, a subsea tunnel would improve these conditions. The savings earned by running electricity and internet cables through a subsea tunnel compared to submarine cables are estimated at c. 10 million DKK annually.

Other additional outcomes that are also worth considering include tourist income and lost salmon income in sailing via Sandur (solution 5). These are all tangible outcomes but due to large uncertainties or lack of significance in the bigger picture, these outcomes are only included in the sensitivity analysis.

3.3 NET PRESENT VALUE

A NEW FERRY IS THE ONLY SOLUTION WITH A POSITIVE NET PRESENT VALUE

The cost-benefit analysis assumes a 50-year project period, because the investment typically provides benefits for a longer time. Nevertheless, an end date is set at 50 years after the investment project is complete. It is not without importance when in the project timeline the benefits occur. Even if the positive outcomes are estimated at 2 million DKK annually, this does not mean that the utility after 50 years is 100 million DKK. There are two reasons for this. Firstly, users estimate outcomes higher the sooner they benefit from them. This is commonly called positive time preference. Secondly, if the investment was not implemented, it could have been spent differently to boost the economy. A discount interest of 3.5-2.5% is applied to reflect the cost of postponing the out-

TABLE 5: NET PRESENT VALUE (NPV), MILLION DKK, 2021 PRICES

Route	**1** Direct Skarvanes	**2** Direct Sandur	**3** Indirect Skúgvoy	**4** Railway tunnel	**5** New ferry
Building cost:	**-4,517**	**-4,734**	**-4,906**	**-5,962**	**-809**
Construction cost	-5,638	-5,909	-6,124	-7,442	-1,023
Remaining value	1,121	1,175	1,218	1,480	214
Operation and maintenance:	**-1,101**	**-1,051**	**-1,094**	**-1,573**	**-1,625**
Operation, road	-1,101	-1,051	-1,094	-	-1,625
Operation, railway	-	-	-	-1,573	-
User profit:	**736**	**957**	**933**	**422**	**105**
Saved travel time, people	1,740	1,897	1,895	922	478
Saved travel time, goods	22	24	24	10	6
Driving cost	-1,025	-964	-986	-510	-379
Externality:	**86**	**91**	**88**	**155**	**26**
Road accidents	-54	-52	-53	-27	-19
Noise	-70	-67	-68	-35	-24
Air pollution	159	159	159	162	53
Environment (CO_2)	50	50	50	55	17
Other outcomes:	**-82**	**-101**	**-109**	**-447**	**55**
Fee outcomes	203	194	198	99	71
Tax distortion	-335	-358	-368	-573	-26
Increased work force	51	62	61	27	10
Additional outcomes:	**3,200**	**3,200**	**3,351**	**3,200**	**2,319**
Savings of current route	2,892	2,892	3,044	2,892	2,319
Ferry cancellations	15	15	15	15	
Improved electricity grid, energy	251	251	251	251	-
Improved electricity grid, internet	41	41	41	41	-
NPV	**-1,678**	**-1,638**	**-1,735**	**-4,205**	**72**
IRR	2.1%	2.2%	2.2%	1.0%	3.5%
Net usage per public DKK*	-	-	-	-	1.65

**Only significant if the project has a positive NPV* come. The discount interest is used to calculate the cost and estimated outcomes into a present value to facilitate comparability of cost and benefit. The net present value is therefore the difference between the recalculated cost and benefit.

Table 5 shows an overview of the whole NPV for each potential solution. Positive numbers signify increased benefit compared to the current route, and negative numbers signify an increased cost compared to the current route.

The cost-benefit analysis shows greatly differing results with NPVs between -4,205 and 72 million DKK. The only solution to produce a socio-economic positive NPV is the new ferry between Sandoy and Suðuroy. Thus, from an economic point of view, this is the only viable solution. This solution offers a very limited NPV of 72 million DKK and therefore is not much better than the current route. More on this in the sensitivity analysis. The cost-benefit analysis shows quite similar results for all three car tunnel solutions while the railway tunnel shows a much greater socio-economic loss. When divided into public and user result, NPV for all potential solutions reaches a public economic loss and user profit (Appendix B3). However, these results are redundant in a socioeconomic analysis that takes public effect as well as user profit into account.

Despite negative NPVs for most potential solutions, all of them have a positive internal rate of return (IRR) of between 1 and 3.5%. IRR tells us the rate of the discount interest in order for NPV to be positive. The IRR interest rate is closely tied to the investment profile, i.e. when benefits and cost apply. This emphasises the weight of the discount interest and its effect on NPV.

Looking at individual outcomes shows a positive user profit for all solutions, i.e. that the saved travelling time is higher than the increased driving cost. Externality is also positive across all solutions while the net outcomes for fees and labour market are only positive in solution 5. Additional outcomes are positive across all solutions as expected.

3.4 SENSITIVITY ANALYSIS

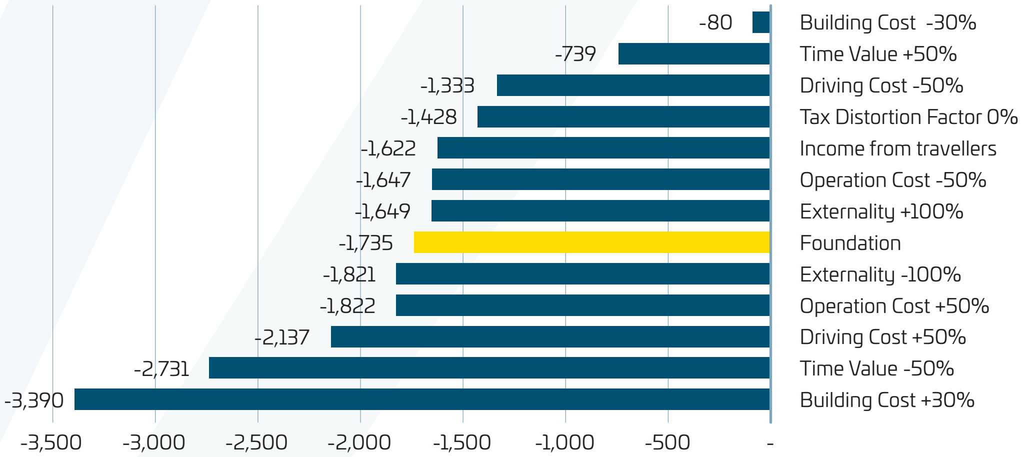
This part presents a sensitivity analysis to examine how durable NPV is to changes in these calculation settings. Despite a wide selection of calculation settings in a cost-benefit analysis, only the most defining settings are considered in the sensitivity analysis. Only one setting is changed at a time while the others remain the same in order to see each outcome for the selected setting. The sensitivity analysis is only carried out for solutions 3 and 5, as the new ferry was the only one with a positive NPV and all three car tunnels had very similar NPVs (Appendix B4). The NPV for the railway tunnel was very negative which excludes that option.

3.4.1 TUNNEL SOLUTION

CONFIRMATION THAT A TUNNEL SOLUTION IS NOT ECONOMICALLY PROFITABLE

Graph 11 shows how NPV changes when selected settings are changed. The graph shows that despite a basis sensitive to changes in settings, the conclusion sticks as each altered setting causes a negative NPV. In other words, this makes a tunnel a poor solution economically. The analysis also confirms that the NPV is particularly sensitive to changes in building cost and assigning time value, i.e. how much the saved travelling time is worth.

GRAPH 11: SENSITIVITY ANALYSIS FOR SOLUTION 3: INDIRECT VIA SKÚVOY, NPV IN MILLION DKK, 2021 PRICES

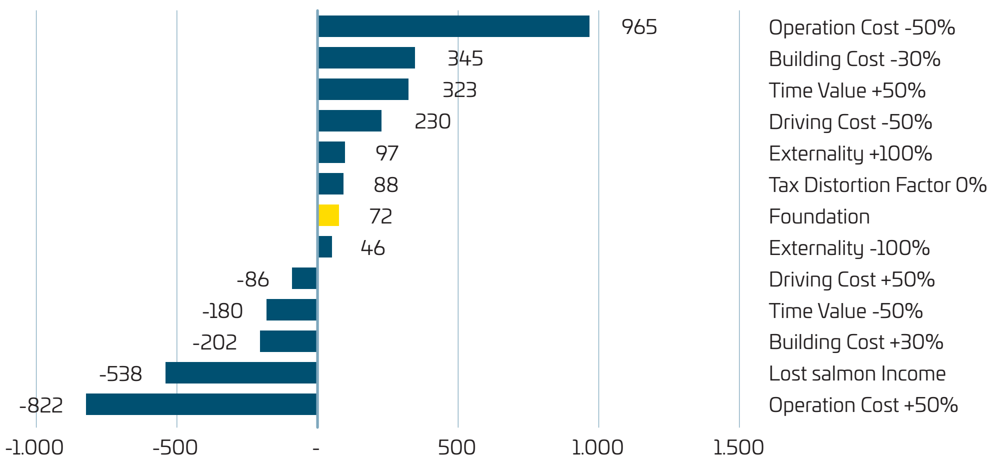


3.4.2
NEW FERRY ROUTE

A NEW FERRY ROUTE SEEMS UNCONVINCING

By changing a single setting, the NPV for solution 5 can go from -822 million DKK to 965 million DKK. This questions the conviction of a new ferry route, which should be considered with caution. If the lost salmon income is entered, the NPV changes from 72 million DKK to -538 million DKK. Unlike the tunnel solution, changes to operation cost affect the outcome greatly. This is not unexpected as the cost of a ferry is relatively high compared to a tunnel.

GRAPH 12: SENSITIVITY ANALYSIS FOR SOLUTION 5: NEW FERRY ROUTE, NPV IN MILLION DKK, 2021 PRICES.



3.5 QUALITATIVE OUTCOMES

QUALITATIVE OUTCOMES DO NOT CHANGE PREVIOUS RESULTS

Having looked at the durability of the cost-benefit results, this part will look at the qualitative outcomes, i.e. outcomes that are confirmed but cannot be quantified and monetized. These outcomes are included so that they can affect previous conclusions. For example, if calculations show that a given project has a negative result of 100 million DKK but simultaneously opens the harbour up to other opportunities and improves tourism opportunities, a sufficient outcome may support going ahead with the project after all.

Table 6 shows an overview of the qualitative outcomes from each potential route and their effects. The table shows that car tunnels have more effects, both positive and negative, than railway and ferry. It is worth mentioning that the tunnel via Skúvoy is thought to have a negative effect on bird life on the island and may result in breaches of the Ramsar Convention to which the Faroes are bound. If it becomes relevant, an environmental study should be conducted to determine the best route (Faroese Environment Agency, 2020). Another significant outcome that is difficult to value is rock debris. All the debris from the tunnel to Eysturoy was utilised in other projects while only ¼ of the debris from the tunnel to Sandoy was utilised (EST, 2021). The trouble in estimating the debris is that the quality is low, limiting its usage, and the volume is huge compared to the demand (c. 3.8 million m^3). On the other hand, the debris proves useful in facilitating projects that would otherwise not be possible. This will be discussed further in part 6.

The qualitative analysis shows no change in previous NPV results. The only outcome with a positive NPV has hardly any qualitative outcomes.

TABLE 6: OVERVIEW OF QUALITATIVE OUTCOMES

Marking	
+++	Excellent outcome
++	Good outcome
+	Small improvement
0	Neutral
-	Small setback
--	Bad outcome
---	Very bad outcome

Route	1 Direct Skarvanes	2 Direct Sandur	3 Indirect Skúgvoy	4 Railway tunnel	5 New ferry
Cost					
Lower credit rating	-	-	-	--	0
Disturbance in building period	--	-	--	-	-
Effect on wildlife	0	0	---	0	0
Increased road maintenance	-	-	-	0	0
Utility					
Use of debris	++	++	++	++	0
Harbour opportunities	+	+	+	+	0
Improved tourism opportunities	+	+	++	+	0
Lower cost of patient transportation by helicopter	+	+	+	0	0
Saved operation cost of helipad and helicopter schedule	+	+	+	0	0
Potential changes in social benefit system	+	+	+	0	0

3.6 CONCLUSION

The conclusion of the cost-benefit analysis is that from a socioeconomic perspective, the best solution is using ferries from Tórshavn or Sandoy. Although a connecting road would provide increased user benefit and have a relatively low operation cost, it does not add up to the building cost of a potential tunnel. This applied in particular to the railway tunnel because of the high investment cost. The sensitivity analysis confirmed the durability of this conclusion, because a subsea tunnel with changes in the parameters remained negative. But the car tunnel projects all had a positive IRR of about 2.2% which shows that the conclusion is sensitive to changes in discount interest. This is to be expected because the investment cost remains the same from the onset while the usage, i.e. user benefit and savings from current route, remains the same for the whole period where the discount interest is significant.

The last project with a positive NPV of 72 million DKK was a new ferry between Sandoy and Suðuroy. However, the sensitivity analysis showed that this conclusion was unconvincing with changes in the calculation settings. On the other hand, a ferry is the best economic solution. The fact that the car tunnels do not generate a socioeconomic profit is to be expected considering that the project is expected to cost more than 5 billion DKK and is mainly intended for 5,000 people. Therefore, other considerations than economic must be documented if a tunnel project is carried out.

The qualitative outcomes are not estimated to affect the conclusion, neither for a tunnel nor for a new ferry. On the other hand, the cost-benefit analysis also showed that a connecting road improves the electronic grid which can have a greater significance than estimated in the analysis.

4. CO_2-ACCOUNT

POLITICAL WILL TO CUT CO_2 EMISSIONS

In 2020, the Faroese Environment Agency published a report on Emissions Inventories 1990-2019. The report states that emissions in the Faroes come from three main sources: Energy (88%), industrial processes (10%) and agriculture (2%). Thus, Faroese emissions primarily come from polluting energy. This becomes apparent in import data, as 14.2% of Faroese imports is grouped as fuel (Faroes Statistics).

For some time, the Faroese political system has expressed a will and an aim to cut emissions. The aim is to cut CO_2 emissions on land by 45% by 2030 compared to 2010 emissions (Ministry of Health and Domestic Affairs, 2019). However, it is proving difficult to reach this target and it may seem like all words and no action. The same applies in our neighbouring countries.

In 2020, rather remarkably, an extension of Heathrow Airport was legally stopped. The reason was that the project was thought to breach the Paris Convention for the Protection of Industrial Property (2). Something similar happened to the petroleum company Shell when they considered expanding. This project was also thought to breach the Paris Convention (3). These examples demonstrate an international trend to legally cut emissions. It is quite possible that the same trend will reach the Faroes. The export industry certainly senses a growing interest in sustainable goods.

THE CURRENT ROUTE RESULTS IN HIGH CO_2 EMISSIONS

A CO_2 account has been carried out for the new route to Suðuroy which would be the biggest infrastructure project in Faroese history. The account is carried out due to a political will and aim for the Faroes to be greener. Additionally, legal ties play a part in the decision.

The current route to Suðuroy is the diesel run ferry, Smyril. On average, Smyril uses about 18,000 litres of diesel a day (SSL, 2021). This makes 2.6% of the total fuel usage in 2019 (Ministry of Health and Domestic Affairs, 2019) and 15.5% of vehicle fuel usage (Ministry of Finance, 2021). An average sized detached house uses approx. 3,000 litres of oil annually (Effo). As such, the oil usage of Smyril corresponds to c. 2,190 households annually, 6 households daily or 17,200 tonnes of CO_2 annually, which is 1.6% of the total emissions in the Faroes, 15.8% of the vehicle emissions or 14.4% of household emissions. In other words, this route has a high cost in CO_2 which is why it is discussed further in relation to the five potential solutions discussed in the cost-benefit analysis.

THE ANALYSIS IS BASED ON AN ACKNOWLEDGED CO_2 PROGRAM AND DATABASE

The environmental analysis provides a CO_2 account where the CO_2 emissions for the whole project duration of 50 years are systematically categorised for each potential solution so they can be compared. A CO_2 account is similar to an annual account as both reveal the net result. The difference is that while an annual report hopefully provides a net profit, a CO_2 account should provide a negative net result, as it would mean lower emissions compared to the current route. The analysis uses the program TEMA (4) which is commonly used in northern Europe. The calculation settings are Danish but where possible, they are adjusted to Faroese conditions (c. half the settings). The limitation on TEMA is that it does not account for emissions from construction. An expanded edition of TEMA which also accounts for construction is being developed, but unfortunately is not yet available (COWI, 2021a). This can provide a distorted emissions result. Therefore, the project construction (e.g. drilling a tunnel compared to building a new ferry) has been included. Project construction data are primarily based on data from the acknowledged German database OKOBAUDAT (5). Pollution data are considered transparent and easily transferable to Faroese conditions because construction and installation in the Faroes is primarily based on international standards. An overview of the settings is found in Appendix C1.

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[2] https://www.forbes.com/sites/davidrvetter/2020/02/27/heathrow-third-runway-ruled-illegal-on-climate-grounds/?sh=1be4946d618f

[3] https://www.ecowatch.com/shell-climate-lawsuit-paris-agreement-2653115543.html

[4] https://www.cta.man.dtu.dk/modelbibliotek/co2-beregningsmodel

[5] https://www.oekobaudat.de/no_cache/en/database/search.html

4.1 CONSTRUCTION

SUBSEA TUNNEL CONSTRUCTION HAS A HIGH CO_2 COST

Table 7 below shows the calculation of CO_2 emissions when building new ferries and railways. The calculation is relatively simple and is based on how many tonnes of steel are used. The current route renews a ferry like Smyril while a new ferry between Sandoy and Suðuroy is 25% smaller (SSL, 2021). For a tunnel, the calculations are based on previous tunnels.

The table shows a summary with subcategories where drilling and disposal of debris and other materials have a high CO_2 cost. In tunnel materials, most of the CO_2 comes from tarmac and sprayed concrete. The calculations also show that tunnel construction has a higher CO_2 cost than ferry construction. Considering that the construction time for all solutions is rather lengthy, building ferries and tunnels amounts to c. 1% and 5% respectively of the annual Faroese CO_2 emissions.

4.2 OPERATION

Estimating CO_2 emissions for the usage time across the whole project timeline of 50 years is difficult as annual projections are required for various conditions (e.g. traffic numbers, car park, ferries and electricity production). It can be difficult to estimate the extent of these important conditions. Therefore, the effect of the changes in conditions will be discussed in the sensitivity analysis.

PROJECTIONS OF FERRIES AND VEHICLE POPULATION

Table 8 shows an overview of projections of energy usage for the ferries used in the analysis. The table shows that the new Smyril which is due to be completed in 2030 is estimated to have a higher functionality and will thus use 25% less diesel compared to the current Smyril. When the new Smyril is due for replacement in 2055, the development of long distance ferries is estimated to be able to provide a green ferry. The new ferry for the new route is estimated to maintain the energy usage even though the route is one third shorter. The saved sailing time will be balanced out by additional trips, thus not saving energy. Sildberin, the ferry to Skúvoy, is the only ferry that is expected to be electrically driven in 2030.

TABLE 7: CO_2 EMISSIONS FOR CONSTRUCTION SPLIT INTO SUBCATEGORIES. TONNES OF CO_2

Route	0 Current ferry	1 Direct Skarvanes	2 Direct Sandur	3 Indirect Skúgvoy	4 Railway tunnel	5 New ferry
Group						
Drilling	-	13,840	15,297	15,843	15,297	-
Debris disposal	-	8,826	9,712	10,044	9,712	-
Completion	-	1,857	2,053	2,126	2,053	-
Energy use on building site	-	5,546	6,130	6,348	6,130	-
Materials	-	23,408	23,206	25,324	23,206	-
Recycling potential	-	-4,606	-4,288	-4,613	-4,288	-
Steel	13,657	102	102	-	1,227	10,268
Total	**13,657**	**48,973**	**52,211**	**55,072**	**53,335**	**10,268**
Percentage of annual Faroese CO_2 emissions	1.3%	4.5%	4.8%	5.1%	4.9%	0.9%

The projections for the vehicle population in graph 13 are based on Danish statistics, as there are no Faroese statistics available. Despite this being a small inconvenience, the proportion of the Faroese vehicle population is similar to the Danish one, thus deeming it a viable comparison. Graph 13 shows the projection proportion of power sources for passenger cars and lorries. The numbers show that most passenger cars currently run-on diesel and petrol, but the number of electric cars is growing. The numbers also show that around the year 2060 all passenger cars are predicted to be electric. The numbers for larger vehicles differ as electric lorries are not available for another few years and by 2060 the proportion between diesel and electric lorries will be half and half. Producing projections for a Faroese vehicle population is difficult as the green transition has only just begun. A technological breakthrough can revolutionise the car market as we know it. Traffic projections are based on Faroese numbers and the traffic model Visum where traffic increases 0.5-1% annually.

FERRY OPERATION HAS A HIGH CO_2 COST

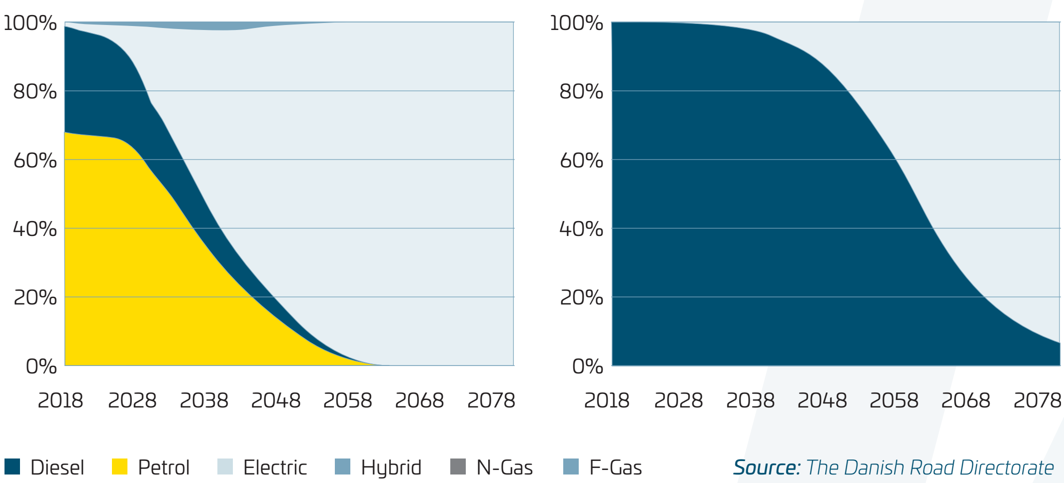
In table 9, operation between 2030-2080 has been calculated regarding CO_2 emissions using the potential solutions mentioned in this study. Four subcategories include: tunnel, vehicle, railway and ferry.

The table shows that ferries have a rather high CO_2 emissions in operation. Tunnel operation, e.g. light and pumps, does not. The reason is that projections of the Faroese electricity grid show that energy will become more sustainable with time. If the total Faroese emissions are locked in, the annual average operation for the solutions amounts to between 0.6% and 0.1% of the annual emissions. In other words, ferry operation is on average six times higher than tunnel solutions.

TABLE 8: ENERGY USAGE PROJECTIONS FOR FERRIES

Ferries	Description	Number	Unit	Source
Sildberin 2030	Electric ferry	0	litres	SSL/COWI
Current Smyril	Daily diesel usage	18,000	litres	SSL/COWI
Smyril 2030	Daily diesel usage	13,500	litres	SSL/COWI
Smyril 2055	Electric ferry	0	litres	SSL/COWI
New ferry 2030	Daily diesel usage	13,500	litres	SSL/COWI
New ferry 2055	Electric ferry	0	litres	SSL/COWI

GRAPH 13: PROJECTIONS FOR THE VEHICLE POPULATION



Source: The Danish Road Directorate

TABLE 9: OPERATION 2030-2080, TONNES CO_2

Route	0 Current ferry	1 Direct Skarvanes	2 Direct Sandur	3 Indirect Skúgvoy	4 Railway tunnel	5 New ferry
Group						
Tunnel	-	2,407	2,660	2,755	2,660	-
Vehicle	-	55,342	53,181	54,264	27,479	19,292
Railway	-	-	-	-	638	-
Ferries	329,498	-	-	-	-	329,498
Total	**329,498**	**57,749**	**55,842**	**57,019**	**30,777**	**348,790**
Annual average emissions in operation	6,590	1,155	1,117	1,140	616	6,976
Proportion of annual emissions in the Faroes	0.6%	0.1%	0.1%	0.1%	0.1%	0.6%

4.3 NET RESULT

Like the cost-benefit analysis, the CO_2 account so far confirms that tunnel construction has a higher emissions cost than a ferry. Additionally, the tunnel operation has a lower emissions cost than a ferry operation. A discussion of the total result will follow.

THE TUNNEL SOLUTIONS HAVE LOWER TOTAL EMISSIONS THAN FERRIES

Table 10 shows an overview of total emissions for the construction and operation of solutions 0-5 for the entire project period. The table shows that all tunnel solutions cut emissions by -259,043 to -231,063 tonnes compared to the current route. A railway tunnel has the biggest cut as it has environmentally friendly operation while the net result for car tunnels is quite similar. The new ferry increases emissions by 15,904 tonnes of CO_2 compared to the current route. Operation will pollute more as the ferry will sail as much while the user will need to drive more.

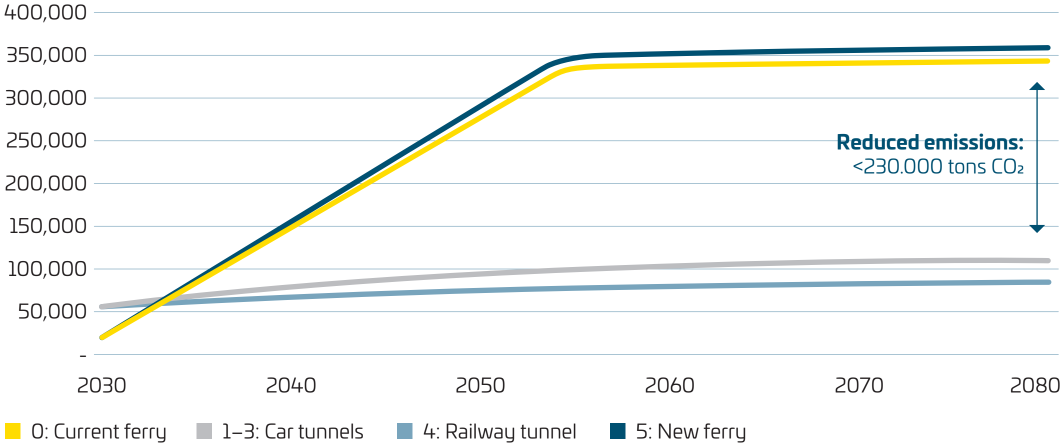
In graph 14, emissions for solutions 0-5 have accumulated over time. The graph shows that ferries have lower emissions from the start due to lower emissions in construction. However, already in the fourth year 2034 the ferries catch up to the tunnels due to higher emissions in operation. When the ferries are replaced in 2055, they are expected to use green energy, and there is a clear change in emissions as the curves nearly align horizontally. Emissions for the railway tunnel decrease over time compared to the car tunnels due to greener operation.

This shows that despite the relevance of CO_2 emissions for construction, that particular aspect is of lower importance in the big picture. This will be discussed further in the sensitivity analysis below.

TABLE 10: NET RESULT FROM CO_2 ACCOUNT, TONNES CO_2

Route	0 Current ferry	1 Direct Skarvanes	2 Direct Sandur	3 Indirect Skúgvoy	4 Railway tunnel	5 New ferry
Construction	13,657	48,973	52,211	55,072	53,335	10,268
Operation	329,498	57,749	55,842	57,019	30,777	348,790
Total	343,155	106,722	108,052	112,092	84,112	359,059
Net (compared to the current route)		**-236,434**	**-235,103**	**-231,063**	**-259,043**	**15,904**

GRAPH 14: ACCUMULATING EMISSIONS OVER TIME, TONNES CO_2



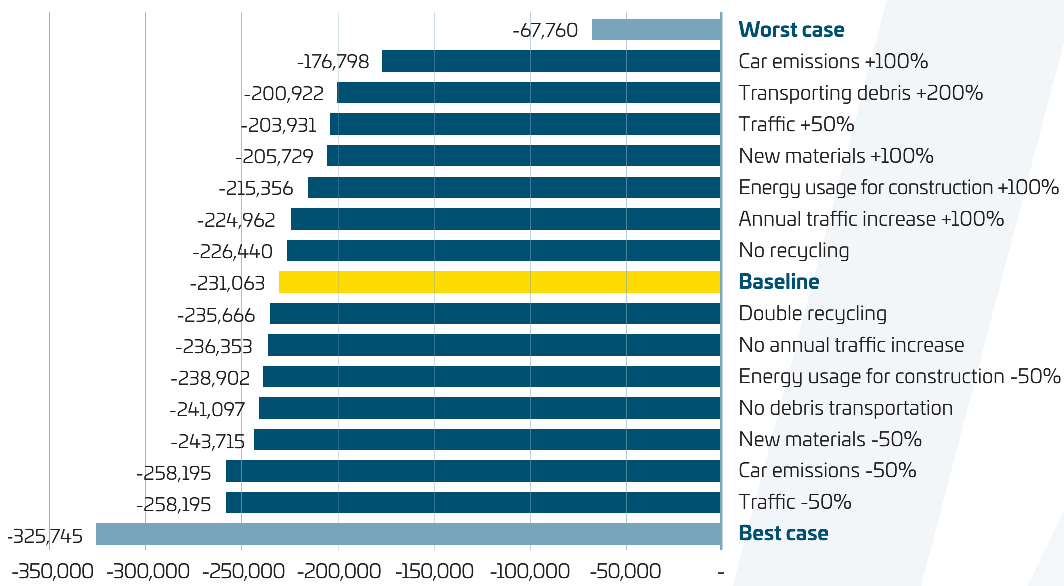
4.4 SENSITIVITY ANALYSIS

This part presents a sensitivity analysis to show the sensitivity of the CO_2 account result to changes in the chosen settings. This is done by altering one condition at a time while the others remain unchanged. The net result showed that both ferry solutions were quite similar, and there is hardly any difference between the three car tunnels. Therefore, the sensitivity analysis will only be based on one car tunnel solution comparing the level of CO_2 emissions saved to the current ferry. This will be performed twice, once altering the tunnel conditions and once altering the ferry conditions.

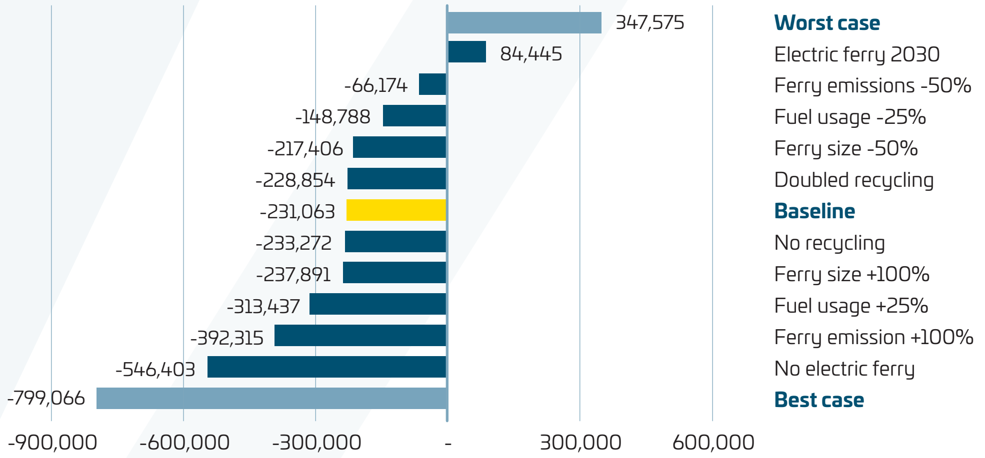
The sensitivity analysis confirms that tunnels are more environmentally friendly

Graph 15 shows that despite large changes in the tunnel conditions, this does not change the net re-

GRAPH 15: NET RESULT FOR TUNNEL SOLUTION (3) WITH ALTERATIONS IN TUNNEL CONDITIONS, TONNES CO_2



GRAPH 16: NET RESULT FOR TUNNEL SOLUTION (3) WITH ALTERATIONS IN FERRY CONDITIONS, TONNES CO_2



sult much. This is apparent in the worst-case net result, where all the changes combined still result in a CO_2 reduction of -67,760 tonnes CO_2. This confirms that a tunnel solution is clearly better for the environment.

Graph 16 on the other hand shows that the net result for a tunnel solution is quite heavily affected by the alterations in ferry conditions and is sensitive to alterations in ferry emissions. For example, if the ferry is replaced by a green ferry already in 2030, the emissions for the tunnel solution would be 84,445 tonnes CO_2 higher than the ferry. This indicates that the result might not be as conclusive as previously shown but on the other hand, it is rather unlikely that long distance ferries will be green by 2030 (SSL/COWI).

4.5 CONCLUSION

The CO_2 account shows that the current ferry has relatively high CO_2 emissions using 2.6% of the total fuel usage and 1.6% of total emissions in the Faroes. The results show that a subsea tunnel has a high CO_2 cost during construction but much lower emissions in operation. The tunnel solutions all share relatively similar emissions except for the railway tunnel with lower energy operation.

If we look at construction and a usage period of 50 years, a tunnel solution has lower net emissions of about 230,000 tonnes CO_2, amounting to 21.2% of the annual CO_2 emissions in the Faroes compared to the year 2019 (annual average for the entire project timeline amounting to 0.4% of total emissions in the Faroes). The sensitivity analysis thus confirms to a large extent that a subsea tunnel is more environmentally friendly than the current route.

5.

FINANCING MODEL FOR A TUNNEL TO SUÐUROY

5.1 TRAVELLING COST

USER FEES CAN LIMIT USER PROFIT

Historically, many large infrastructure investments have been publically financed, meaning that all citizens pay for a service regardless how much they use it. Subsea tunnels, however, are such expensive projects that other financing options have been deemed necessary, such as user fees. User fees have the advantage of changing user behaviour, including towards more sustainable solutions. In this case, additionally, it has been considered an advantage that users pay part of the project, including foreign tourists who would otherwise not pay.

The question of how to finance subsea tunnels is regularly discussed politically. As well as being a political debate, other factors can also play a part. Claims are sometimes made that user fees limit user benefit resulting in a social loss. This is not always the case. User fees result in a lower tax distortion as they distort work supply or the will to work less than income tax (Appendix D2).

One common way to analyse social projects is to look at which project proves most useful compared to the cost without accounting for how the project is financed (DTU, 2015). The exception is when projects are fully or partially funded by user fees, mainly because user fees limit user profit due to higher travelling cost reducing traffic.

Appendix D1 'Travelling Cost' shows that the total traffic benefit of an infrastructure investment is calculated using changes in travelling cost including driving cost to the commute itself, the cost that comes with travel time and potential user fee (TERESA). Additionally, overhead charges (debt collection etc.) are tied to user fees. Nevertheless, user fees are commonly used in infrastructure, because as Milton Friedman said, there is no such thing as a free lunch. [6]

5.2 BORROWING REQUIREMENTS

THE ESTIMATE OF THE INVESTMENT COST IS BASED ON PREVIOUS TUNNEL PROJECTS

ÍIn the Faroes, four infrastructure projects are in place and are operated by PPPs. All four are subsea tunnels shown briefly in table 11. The table shows that between 15-59% of these projects is publically funded. If the investment cost is recalculated to 2021 prices, it varies from 99-138 million DKK per kilometer. The tunnels to Eysturoy and Sandoy are expectedly more expensive due to higher safety standards over time, and the tunnel to Eysturoy has a roundabout that increases the cost of the project (Tunnil, 2021).

No final decision has been made about a tunnel to Suðuroy and pilot studies have just started. Based on Figure 4, the project is still in phase 1.

TABLE 11: SUBSEA TUNNEL PROJECTS, MILLION DKK

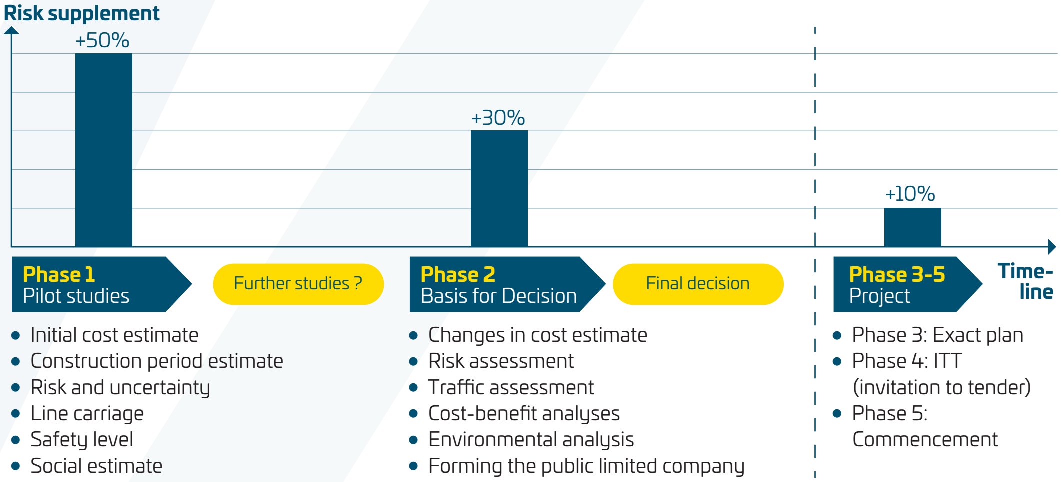
Subsea tunnel projects							
Project	**Year**	**Km**	**Investment Cost**	**Share Capital**	**Ratio**	**Investment Cost 2021**	**Million/km**
Tunnel to Vágar	2002	4.9	295	160.3	54%	517	106
Tunnel to Borðoy	2006	6.2	395	235	59%	615	99
Tunnel to Eysturoy	2020	11.4	2,640	400	15%	3,060	138
Tunnel to Sandoy	(2023)	10.8					

** Formula: FV=PV*(1+3%)^t*

Source: Tunnil

[6] "There's no such thing as a free lunch" eftir amerikanska búskaparfrøðingin Milton Friedman

FIGURE 4: RELATION BETWEEN PROJECT PHASES AND RISK SUPPLEMENT



Source: *Own results based on the Danish Ministry of Transportation 2017*

Defining circumstances have still not been discussed or executed, such as geology, line carriage and safety levels. Reliable cost estimates cannot be carried out until these are in place. An initial cost estimate is based on a line carriage of 26 km, the most recent projects for 138 million DKK per km. as well as with and without a risk supplement of 50% for various uncertainties.

RISK SUPPLEMENT IS USED IN THE INITIAL PHASE

A risk supplement is added to the initial cost because the tunnel to Suðuroy is in the initial phase without an extensive pilot study. Therefore, the uncertainty is higher. Figure 4 shows that further studies and better insight reduce the risk. Our neighbouring countries typically use a risk supplement of 50% for subsea tunnels and bridges in the first project phase based on initial cost and empirical data (Danish Ministry of Transportation 2017, Norwegian Public Road Administration 2014). Unfortunately, our database is an insufficient basis for a reliable risk supplement, so we use the risk supplement level of our neighbours. In the last 20 years, tunnel projects in the Faroes have had an additional cost without inflation of about 30% compared to cost estimates (Appendix D3). The cost estimates for a new route to Suðuroy are therefore in phases 1-2 and thus fit the applied risk supplement. This is relevant for the tunnel to Suðuroy as the safety level has not yet been established. It has not been decided whether there will be a single or dual tunnel and other details while the initial cost estimate is based on a single tunnel without additional safety measures.

Based on these conditions, the investment cost for a tunnel to Suðuroy is about 3.6 billion DKK and 5.4 billion DKK with a risk supplement. A share capital of 800 million DKK is based on cost estimates of a substitute ferry for Smyril (SSL, 2021) as well as the same risk supplement.

Both cost estimates will be used here with emphasis on the estimate including a risk supplement, as the project is at such an early stage and that estimate is deemed more reliable. The cost of derivative projects is not included in this case but is included and discussed in the cost-benefit analyses.

TABLE 12: COST ESTIMATE FOR A TUNNEL TO SUÐUROY, MILLION DKK .

Cost estimate for a tunnel to Suðuroy						
Project	**Km**	**Million DKK/km**	**Risk supplement**	**Investment cost**	**Share capital**	**Ratio**
Excluding risk supplement	26	138	0%	3,588	800	22%
Including risk supplement	26	138	50%	5,382	1,200	22%

CONSTRUCTION METHOD

The cost estimates are based on the construction cost for the tunnels to Eysturoy and Sandoy where the Drill and Blast method was used. So far, all car tunnels in the Faroes are blasted, but an alternative method is of Tunnel Boring Machines (TBM). TBM uses machines that bore the tunnels in one go like a large round hole. This drilling method is commonly used in other countries, particularly for long water and railway tunnels (COWI, 2021a). In the Faroes, the electrical company SEV has successfully used TBM to drill 34 km of water tunnel. These tunnels have other diameters and purposes than the car tunnel intended for Suðuroy. Therefore, Landsverk has requested an offer for TBM as well as prices for similar projects in Norway (Appendix D4). The conclusion was that the construction cost of TBM is estimated at double the cost but at half the drilling time. In other words, TBM is more expensive but much faster. The estimates are based on experiences in other countries and are therefore not entirely comparable. The choice of construction method should therefore be analysed further.

5.3 PAYMENT AND FINANCE

AN ANNUAL INVESTMENT COST OF 172 MILLION DKK

Table 13 shows an overview of calculation settings and examples of potential payment methods for a tunnel to Suðuroy. Based on these calculation settings, the loan payment will be 206 million DKK annually (interest and repayment). In order to simplify the example, a fixed interest annuity loan was used to ensure the same repayment for the whole period. The interest and term were based on the conditions for the most recent tunnels to Eysturoy and Sandoy with security from the treasury. The operation and administration of the tunnel is estimated at 43 million DKK annually (Tunnil, 2021), while the operation cost for the current route of 76.5 million DKK annually (SSL, 2021) is calculated as an annual operation supplement. In other words, the operation cost of a tunnel would be 33.5 million DKK lower for a tunnel compared to a ferry. The annual investment cost is therefore 172 million DKK.

THE PROJECT CANNOT BE FUNDED WHOLLY BY USER FEES

Below are some examples of payment methods that fully cover the project cost; each with its advantages and disadvantages, which is why they are often combined. Note that the toll is based on a traffic estimate of 1,300 cars a day and that average fees, charges and taxes are used. A user fee for a tunnel to Suðuroy has not been discussed politically and has not yet been settled. The user fee was therefore based on the calculation settings used.

TABLE 13: CALCULATION SETTINGS FOR THE TUNNEL TO SUÐUROY, MILLION DKK

	Including risk supplement	Excluding risk supplement
Investment cost	5,382	3,588
Share capital	1,200	800
Borrowing requirements	4,182	2,788
Interest	2.73%	2.73%
Repayment term	30 years	30 years
Annual instalments	206	137
+ Annual operation	43	43
- Operation supplement	76.5	76.5
Annual cost	**172**	**104**

Table 14 demonstrates that an annual income of 172 million DKK would mean a one-way toll of 369 DKK. Additionally, there is no certainty that the traffic estimate is reliable, which would mean that the toll would not cover the cost. Another income solution for funding the project would be raising income tax by 1.4%, the equivalent of 308 DKK a month at an average pay of 264,000 DKK (Statistics Faroes) or increasing fuel taxes by 0.69 DKK per liter, petrol, and diesel by 4.11 DKK per litre or increasing road charges for each vehicle by 4,284 annually. This shows a clear cost difference including and excluding risk supplement, confirming the importance of limiting the investment cost for the project. This will be discussed further in the sensitivity analysis.

If we look at the tunnel to Sandoy which also has limited traffic, one-way toll is set at 376 DKK on average (Appendix D6). The tunnel to Sandoy is therefore comparable to the tunnel to Suðuroy in many ways. If the traffic from the tunnel to Suðuroy (+1,300) is added to the tunnel to Sandoy, the one-way toll is reduced to 89 DKK which is similar to that of the tunnel to Eysturoy. The same applies to the user fees in the tunnels to Vágar and Borðoy, which using 2021 prices were also considerably cheaper from the start (Appendix D7). User fees for these tunnels are undoubtedly lower due to cheaper investment cost and greater share capital (table 11).

TABLE 14: POTENTIAL FINANCING OF THE TUNNEL TO SUÐUROY

Payment method for the tunnel to Suðuroy		
Payment method	**Including risk supplement**	**Excluding risk supplement**
One-way toll	369 DKK	222 DKK
Private income tax	1,4%	0,8%
Business income tax	5,9%	3,5%
Oil tax per liter	0,69 DKK	0,42%
Fuel tax for vehicles per litre	4,11 DKK	2,48 DKK
Road charge	4.284 DKK	2.578 DKK

OTHER USER FEES

In the Faroes, user fees have only been used for physical transport, i.e. transporting people and goods. But in other countries, it is not uncommon to charge for other installations that go through a tunnel, such as water, internet and electricity (footnote 7). The cost-benefit analysis showed that the electricity grid can benefit greatly from a tunnel where the saving compared to submarine cables is estimated at 10 million DKK annually (Net 2020, SEV 2020). If this saving reflects cost and willingness to pay, it could count as a potential tunnel income. An additional 10 million DKK amounts to about 6% of the required annual income. This is a political question that has not yet been discussed.

Another potential finance solution is debris. In other tunnel projects, the debris has been given to other projects at no cost. The challenge is that despite a debris recycling value, the limited quality and the excessive amount decreases its value. This will be discussed further in part 6.

5.4 SENSITIVITY ANALYSIS

USER FEE PARTICULARLY SENSITIVE TO FINANCE DEMAND AND TRAFFIC NUMBERS

A sensitivity analysis will now follow, measuring how sensitive the calculations are to the settings. In the first part, only one setting will be altered while the others remain unchanged. A break-even analysis will follow, altering settings until they balance a previously set user fee.

Graph 17 shows how changes in settings affect the user fee. If the daily traffic is 1,050 vehicles rather than 1,300, the user fees increase to 599 DKK. If traffic increases to 1,550 vehicles, the user fee is reduced to 266 DKK.

If the project had relatively as large a share capital as the tunnel to Borðoy, i.e. 59%, the toll would be set at 161 DKK on average. If there is no share capital, the toll would be 495 DKK.

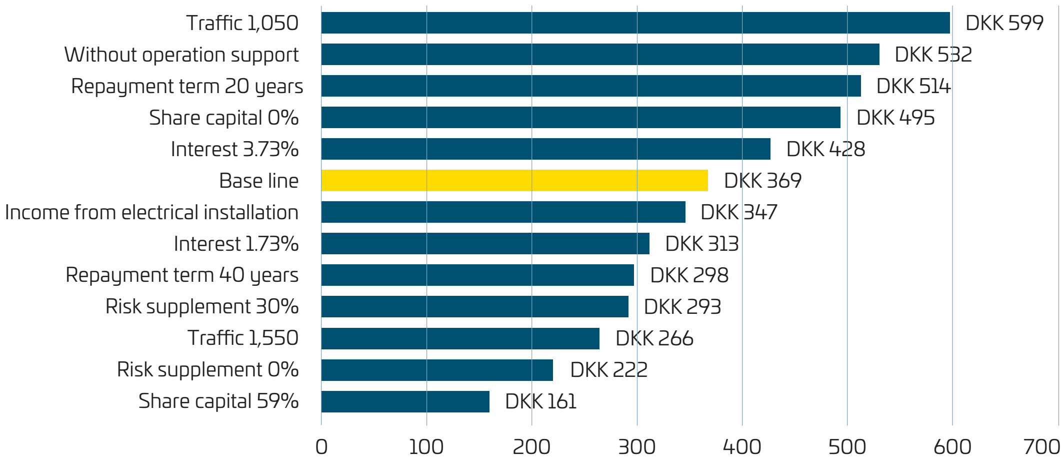
The borrowing requirements for the tunnel also greatly affect the user fee. If the loan period increases to 40 years, the user fee drops to 298 DKK. Similarly, an interest cut of 1% would reduce user fees to 313 DKK.

All in all, this analysis shows that the user fee is sensitive to realistic changes in the calculation settings with the cost nearly doubled or reduced by half. The analysis also shows that the fee is particularly sensitive to changes in the investment cost, finance demand and traffic numbers.

Without an operation supplement, only 10% can be financed by user fees

[7] https://www.irf.global/event/pf-ppp21-march-online-training/

GRAPH 17: SENSITIVITY ANALYSIS OF AVERAGE USER FEE



In table 15, the previous sensitivity has been turned upside down using the break-even analytic method. This method analyses how conditions can be altered to reach a toll of 150 DKK on average. This amount was based on a study where informants seemed willing to pay around 150 DKK (Gallup, 2021). Additionally, this cost matches the current cost on board the ferry Smyril. The table shows that for this to be realistic, the investment cost can only be 3.3 billion DKK, borrowing requirement and thus also instalments reduced by half, i.e. only 2.1 billion DKK or 104 million DKK annually can be financed with user fees. The ratio of share capital must be 61% which is higher than previous tunnels. Without risk supplement, the share capital would have to be 90%, which confirms the importance of an operation supplement. Additionally, the traffic should count c. 3,200 cars (as many as through the tunnel to Borðoy) which is far from realistic.

The analysis shows that neither the loan interest nor loan period alone can allow the project to apply a user fee of 150 DKK. An interest cut of 1% would reduce annual instalments by c. 26 million DKK which would amount to the income from 481 cars daily if the one-way toll was set to 150 DKK. Borrowing conditions and interest rates thus play an important part if this project is to become reality. This topic will be discussed further later.

TABLE 15: BREAK-EVEN ANALYSIS WITH A TOLL OF DKK 150, MILLION DKK

	With risk supplement			Without risk supplement		
	Base case	**Break-even**	**Δ%**	**Base case**	**Break-even**	**Δ%**
Investment cost	5,382	3,305	-39%	3,588	2,905	-19%
Financial requirements, million DKK	4,182	2,105	-50%	2,788	2,105	-24%
Loan payment, million DKK	206	104	-50%	137	kr. 104	-24%
Share capital	24%	61%	154%	28%	41%	48%
Traffic	1,300	3,194	146%	1,300	1,923	48%
Interest	2.73%	-1.81%		2.73%	0.72%	-74%
Repayment term	30	Never		30	49	64%

5.5

FORMING THE PUBLIC LIMITED COMPANY

A JOINT AND MULTI SOLUTION LOWERS THE COST BUT LIMITS USER BENEFITS

This part will discuss how tunnel companies can be arranged. It will look at what conditions are relevant if the tunnel to Suðuroy is financed as a single company as opposed to a joint and multi solution where all tunnels are merged in one parent company.

Table 16 shows that with the traffic in all tunnels, of which only tunnels to Eysturoy, Sandoy and Suðuroy have debt, the average one-way toll would be 67 DKK. In other words, the debt free tunnels would help finance the new tunnels. But as we have seen, increased user fees often reduce user profit, particularly if the fee does not affect the target user or when a user is cost sensitive. Another solution could therefore be to leave existing fees unchanged, and the surplus could help finance the new tunnels. The problem is that the surplus from the older tunnels is only 7-8 million DKK annually and would therefore not make much of a difference (Tunnel to Vágar 2019, Tunnel to Borðoy 2019).

A limited company remains a political issue, but we can still look at the Norwegian approach. The parent company provides all projects with security, but the user fee is cancelled when the debt for each particular project has been repaid[8]. This should provide better security and therefore also better financing opportunities and conditions.

TABLE 16: DIFFERENT TUNNEL COMBINATIONS AND ONE-WAY TRAVELLING COST ON AVERAGE, MILLION DKK

Tunnel combination	Tunnel to Suðuroy	All subsea tunnels
Daily traffic	1.300	13.780
Borrowing requirements	4.182	6.382
- Annual instalment	206	314
- Annual operation	43	93
+ Operation supplement	76,5	76,5
Annual income minimum	172	330
One-way toll	**369 DKK**	**67 DKK**

5.6

CREDIT SOLUTIONS

A PUBLIC LOAN IS ADVISED

With a financial requirement of 4.2 billion DKK, good borrowing terms and conditions are essential if the project is to become a reality. The sensitivity analysis showed the project was sensitive to variable interest rates. Credit solutions are briefly discussed below and conditions that should be studied further will be pointed out.

Four potential credit solutions are:

1. The tunnel is financed as a public investment on the National Budget.
2. The government takes out the loan and re-lends it to the tunnel company t.
3. The tunnel company takes out the loan with security from the government.
4. The tunnel company takes out the loan without government security.

*(**Source**: Government Bank 2021. Note on credit solutions.)*

[8] https://www.nyeveier.no/

Advantages and disadvantages follow for each solution. Solutions 1 and 4 are deemed unlikely due to the scale of the project, making financing as a public investment on the National Budget difficult, while a loan without government security would be too expensive.

Due to the scale of the project, it might be sensible to use a 100% public limited company as with previous tunnels. For the least expensive solution, the Government Bank recommends solution 2. The tunnel company would then borrow the money on the same conditions as the Government Bank, which would thus be cheapest.

It is difficult to say exactly how the credit conditions change for solutions 2 and 3, but increased security for solution 2 means better credit conditions. The difference also depends on the details of the government security. The Government Bank estimates that the additional cost for solution 3 will be 1% higher than for solution 2. A drop in interest by 1% with other calculation settings intact would save the project 25 million DKK annually or c. 765 million for the whole repayment period. Another advantage of solution 2 is that the Government Bank can provide several smaller loans creating more flexible financing that can adjust to the project cash crunch. The problem is that this may involve interest rate hikes which would not affect the project in a fixed interest loan from the start.

INTERNATIONAL DEMANDS FOR FINANCE

Because the Faroes are not part of the EU and our infrastructure is not tied to other countries, the Faroes are not bound by international road standards. Instead, the Faroes adhere to legal requirements used in neighbouring countries, and with regard to tunnels, Norway has been a good example (Landsverk). According to Landsverk, this has been a good approach, as it ensures the quality of our roads while routes can still be adjusted to suit local conditions. However, EU and Norwegian standards require tunnels over 10 km to be dual carriageway which would increase the cost of the project considerably. Creditors can require international standards, so this becomes even more relevant if credit is to come from the international capital market, which is quite likely for this project. This should therefore be examined further.

5.7 EXAMPLE OF FINANCING MODEL

In the financing model analysis, it became clear that the loan requirement for this project is 172 million DKK annually which cannot simply be financed through individual methods or by altering calculation settings. Therefore, it is necessary to look at other combined solutions if the project is to become a reality.

There are many potential solutions and table 17 shows four examples of combinations with altered conditions where the one-way toll will be between 71-154 DKK, which is close to the cost of the current route with and without the cost of the tunnel to Sandoy (provided that the cost is the same as for the tunnel to Eysturoy).

The original calculation settings are largely based on the tunnels to Eysturoy and Sandoy, i.e. 2.73% interest over 30 years. Additionally, the share capital is set at the same amount as a new ferry would cost and the operation supplement is equal to that of the current route.

If the government takes out the loan and re-lends the tunnel company the required amount and considering that the interest rates have fallen since 2016, the estimated interest is 1%. This would mean that the toll could be reduced by 56 - 64 DKK depending on the share capital.

Another solution is extending the repayment term to 40 or 50 years, which is not uncommon in large infrastructure projects (COWI 2018). With an extension from 30 to 40 or 50 years, the toll would be reduced by 83 to 115 DKK. However, despite a lower toll, this saving would not be free, as the extension would have additional interest costs of 1.54 billion DKK at an interest rate of 2.73% and 886 million DKK at an interest rate of 1.73%.

TABLE 17: ALTERATIONS IN COMBINED CONDITIONS, MILLION DKK

Original		Example 1		Example 2		Example 3		Example 4	
Investment cost	5,382	5,382		5,382		5,382		5,382	
Share capital	1,200	**600**	DKK 63	1,200		**1,000**	DKK 21	**600**	DKK 63
Credit requirements	4,182	4,782		4,182		4,382		4,782	
Interest	2.73%	**1.73%**	-DKK 64	**1.73%**	-DKK 56	**1.73%**	-DKK 58	**1.73%**	-DKK 64
Term	30	30		**50**	-DKK 115	30		**40**	-DKK 83
Annual instalment	206	206		126		188		167	
+annual operation	43	43		43		43		43	
-annual operation supplement	76.5	**176.5**	-DKK 214	**100**	-DKK 50	**176.5**	-DKK 214	**176.5**	-DKK 214
Required annual income	172	72		69		55		33	
Annual traffic	468,000	468,000		468,000		468,000		468,000	
One-way toll	**DKK 369**		**DKK 154**		**DKK 147**		**DKK 117**		**DKK 71**

The third solution is reducing the share capital or increasing the operation supplement. In other words, this means whether the government finances the project from the start or over the usage period. Table 17 shows that this would also affect the toll. One of the challenges with a project of this scale is the difficulty in fitting it into the annual investment framework. Aa more flexible solution might therefore be to increase the annual operation supplement rather than increasing the share capital. The share capital must increase by c. 500 million DKK to reduce the toll as much as when the annual operation supplement is increased by 23.5 million DKK (to 100 million DKK).

6.

POSSIBILITIES WITH ROCK DEBRIS FROM A TUNNEL TO SUÐUROY

This section analyses the importance of deciding where to place rock debris from the tunnel or how best to utilise it. So far, the debris from tunnel projects is accounted for as a cost, both in the cost-benefit analysis and in the CO_2 account. In fact, the debris has a recycling and a practical value.

In the past years, debris from tunnel projects has been welcomed by both private and public entrepreneurs because the increased volume of rock debris has meant that projects can be carried out. In some cases, not finding a suitable location or use for the debris has been a problem and it has mostly been because of a lack of preparation. What we can derive from this is that the debris can open up project possibilities, if supply and demand can be balanced. Furthermore, if supply and demand are not balanced, a large pile of debris is considered a challenge for the environment. The challenge of getting the debris question right from the beginning is greater in this tunnel than it has been previously. Therefore, it is even more pressing to plan for the usage of the debris at the beginning of the project.

The proposals in the analysis are examples of how the debris can be used. This means that specific projects are not analysed and can only be outlined in general. Environmental and archaeological aspects of the specific projects need to be specified before taking it further.

The Faroese geology is basaltic. When rock is blasted for tunnel projects, a relatively large amount of explosives is used. Consequentially, most of the rock is converted into debris. The heavy explosion also compromises the strength of the rock. The type, quality and size of the debris limits its usage. Table 18 outlines how debris from other subsea tunnel projects and related road projects has mainly been used. The amount is in bulk materials[9].

The debris is useful as filling in harbour construction or harbour expansions. Smaller amounts have also been used in other types of projects. These examples can be used as inspiration for the use of debris from the tunnel to Suðuroy.

The amount of debris from this tunnel is much larger than in previous projects. The tunnel to Suðuroy also means that a new tunnel must be made from the village of Sandvík, in northern Suðuroy.

The Drill & Blast (D&B) method has been used in previous tunnel projects in the Faroes, while Tunnel-boring machine (TBM) is a relatively new method and has been widely used in Norway. TBM has its advantages and is a possibility but based on experience, D&B is more likely to be used.

As seen in table 19, the challenges finding a location or usage for the debris when using the D&B method in the tunnel to Suðuroy are twice those of the tunnel to Eysturoy and three times those of the tunnel to Sandoy. If the debris was piled onto a football field, the pile would be almost 600 meters high. An average lorry takes around 10 m^3 of debris per load. It could be worth exploring the possibilities of having a conveyor belt in the tunnel for debris removal. This would limit the number of lorries and machines inside the tunnel and reduce the risk of work-related accidents and fire hazards in the construction period.

It is to be expected that the proportion of debris is half and half from Sandoy and Suðuroy, if Skúvoy is surpassed. The current building projects in the pipeline for the next 10 years do not need as

TABLE 18: AMOUNT AND USAGE OF DEBRIS FROM PREVIOUS SUBSEA TUNNELS

	Amount [m^3]	Usage
Tunnel to Vágar	600,000	Harbour construction, Kollafjørður
Tunnel to the Northern Islands	750,000	Harbour expansion, Klaksvík Harbour expansion, Leirvík
Tunnel to Eysturoy	1,800,000	Industrial estate, Sund Harbour construction, Runavík Harbour expansion, Strendur
Tunnel to Sandoy	1,300,000	Harbour construction, Runavík Landfill, Velbastað and Sandur

[9] *Bulk debris takes up around 60-70% more space than solid rock*

TABLE 19: AMOUNT OF DEBRIS FROM THE DIFFERENT ROUTES AND METHODS

	Solution 1 Skarvanes ↔ Sandvík	Solution 2 Sandur ↔ Sandvík	Solution 3 Sandur ↔ Skúgvoy ↔ Sandvík	New tunnel to Sandvík
D&B	3,300,000 m^3	3,600,000 m^3	3,800,000 m^3	350,000 m^3
TBM	4,600,000 m^3	5,050,000 m^3	5,250,000 m^3	N/A

much debris as the tunnel to Suðuroy produces. It is therefore necessary to think about new projects. Table 20 outlines possible projects for the next 10 years.

As shown, new large projects are needed if the debris from the tunnel is to be fully utilised. Calculated amounts and moving costs are approximations and need to be specified, if any of the projects are realised. Moving costs only include moving the debris from the tunnel to its destination and not the costs for the specific project. Other costs therefore need to be included. The moving costs are based on the principle that every load of debris costs 12 DKK per m^3 in addition to distance and method.

RELATED ROAD PROJECTS

We have experience using debris in related road projects, such as in the new tunnel to Hvalba, as the basaltic qualities in Suðuroy are generally of a high standard. Generally, however, the debris quality after explosions in tunnels is below standard. This limits its use to only the lowest layer of a road outside the tunnel. Relatively small amounts of it are also being used for work roads related to the construction site. Depending on the chosen route, the amount needed for related projects is between 70,000 and 130,000 m^3 of debris. This does not include a cost approximation because it is part of the larger project.

SILENCING WALL BY THE ROAD

Basically, this is a high pile of debris, laid by the new roads in Sandvík and Hvalba and, if relevant, also in Skúvoy and Skarvanes. The debris acts as a silencing wall and lowers the noise from traffic in residential areas. If a 2.5 meter high wall is erected, the total amount of debris used on new roads in Sandvík and Hvalba is between 40,000 and 50,000 m^3. In addition to that come the roads in Skarvanes and Skúvoy. The cost of laying the debris by the roads in Sandvík and Hvalba is around 2.25 million DKK.

INDUSTRIAL ESTATE IN GAMLARÆTT

This project entails expanding the current harbour in Gamlarætt. The area is centrally placed in the Faroes, there have been relatively few problems with heavy surf and the area is at least 1.25 km away from residential areas. It is therefore considered to be an appropriate place for a future industrial estate in the southern part of the islands.

TABLE 20:
POSSIBLE PROJECTS FOR THE NEXT 10 YEARS WHERE THE DEBRIS COULD BE USED

Project	Amount [m^3]	Date of project	Moving costs [DKK/m^3]
Related roads	70,000-130,000	Simultaneously	-
Silencing wall by the road	30,000	Simultaneously	50
53,000 m^3 industrial estate in Gamlarætt	275,000	Simultaneously	60
125,000 m^3 industrial estate in Gamlarætt	1,025,000	Simultaneously	60
Industrial estate in Skarvanes	1,300,000	Simultaneously	45-55*
Area near Sandvík	2,050,000	Simultaneously	36-46*
Filling a quarry, Glyvursnes	2,500,000+	Simultaneously	70
Airport and roads, Glyvursnes	200,000	2030+	70
Airport and roads, Søltuvík	150,000	2030+	55

**Debris can be transported both by lorries and ships.*

The distance from the entrance of the tunnel to Suðuroy in Sandoy and to the potential industrial estate is 14 or 22 kilometers, depending on the location of the tunnel entrance.

A jetty must be built and the necessary debris and rocks for it can be collected on site or from a quarry either in Hundsarabotn or Hústoft.

When discussing the tunnel to Sandoy, it was suggested that the area in Gamlarætt was expanded by 53,000 m². The harbour was to be expanded by 35,000 m² and an area of 18,000 m² was to be made to provide material for the required jetty. In addition to the material used from the site, this project would require 250,000 m³ of debris. The moving costs would be 60 DKK per m³, amounting to 16.5 million DKK. That does not include the toll fee and jetty.

Another proposal is to expand the area around the harbour even more. The harbour can be expanded 90,000 m² and another 35,000 m². Rock and debris can be taken on site to be used for the jetty and additional rock and debris can be used from a quarry. This project will need around 1,025,000 m³ and debris and the moving costs would be around 60 DKK per m³, totalling 61.5 mill. DKK. Toll fee and jetty are not included in the cost.

In addition to the above-mentioned projects, debris can also be used to make a new road to the entrance to the tunnel to Sandoy. The current road is very windy.

INDUSTRIAL ESTATE IN SKARVANES

This project is an industrial estate by the village of Skarvanes. When you leave the village of Sandur and approach the village of Skarvanes, there are areas large enough for an industrial estate. Figure 7 shows a potential site, where an estate of around 80,000 m² can be built, which would need large rocks to build a jetty. They can be provided from a local quarry or blasted from the area around the site. The depth of the sea in the area is unknown, but if it is around 20 meters deep on average, 1,300,000 m³ of debris would be needed, in addition to the rocks for the jetty.

The industrial estate is relevant if the tunnel entrance is located by Skarvanes. The distance from the tunnel to the estate would be around 1 kilometer. If the entrance is in Sandur, debris can be moved both by land and by sea. If drilling on the island of Skúvoy, the debris can be moved off the island by sea, but a road would have to be built in an environmentally fragile area, as well as an expansion of the harbour in Skúvoy. The moving costs by sea would be 45 DKK per m³, amounting to 58.5 million DKK. The cost by land would be 55 DKK per m³, amounting to 71.5 million DKK. New roads and jetties are not included.

FIGURE 5: EXPANDING THE AREA AROUND GAMLARÆTT BY 53.000M². SOURCE: KRINGVARP FØROYA

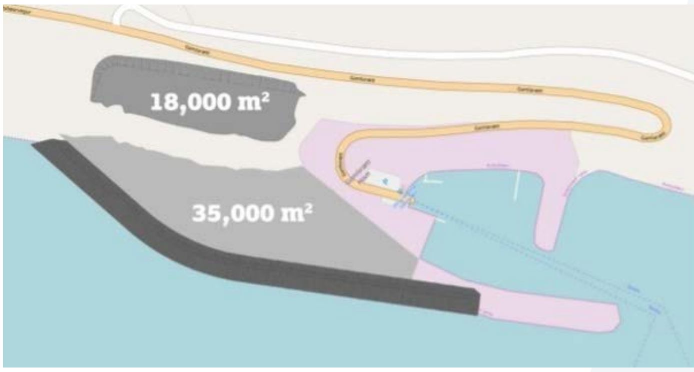
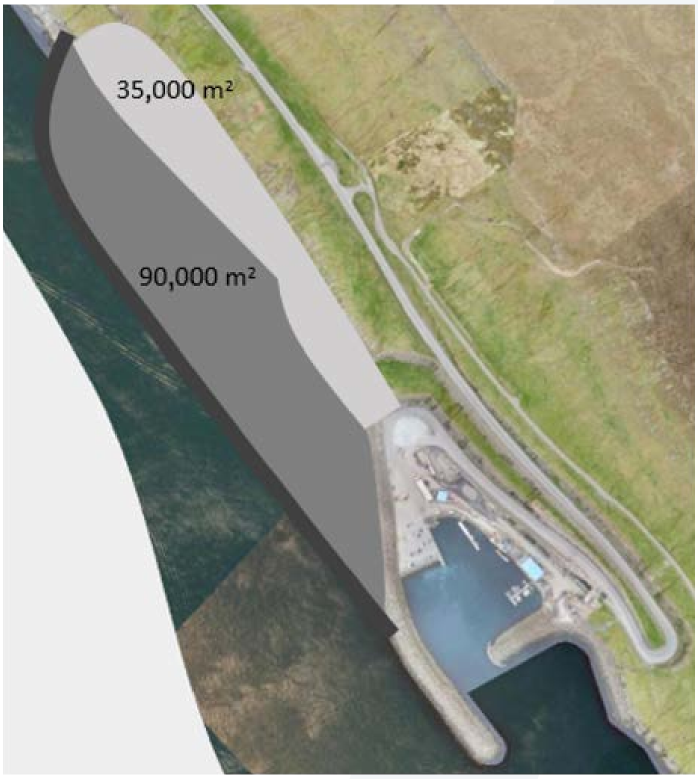


FIGURE 6: EXPANDING THE AREA AROUND GAMLARÆTT BY 125.000 M²



[10] *Havast skal í huga, at tá sprongt verður eftir dekkgróti, útvegast umleið 15% dekkgrót og 85% smágrót.*

FIGURE 7: AREA AROUND THE VILLAGE OF SKARVANES

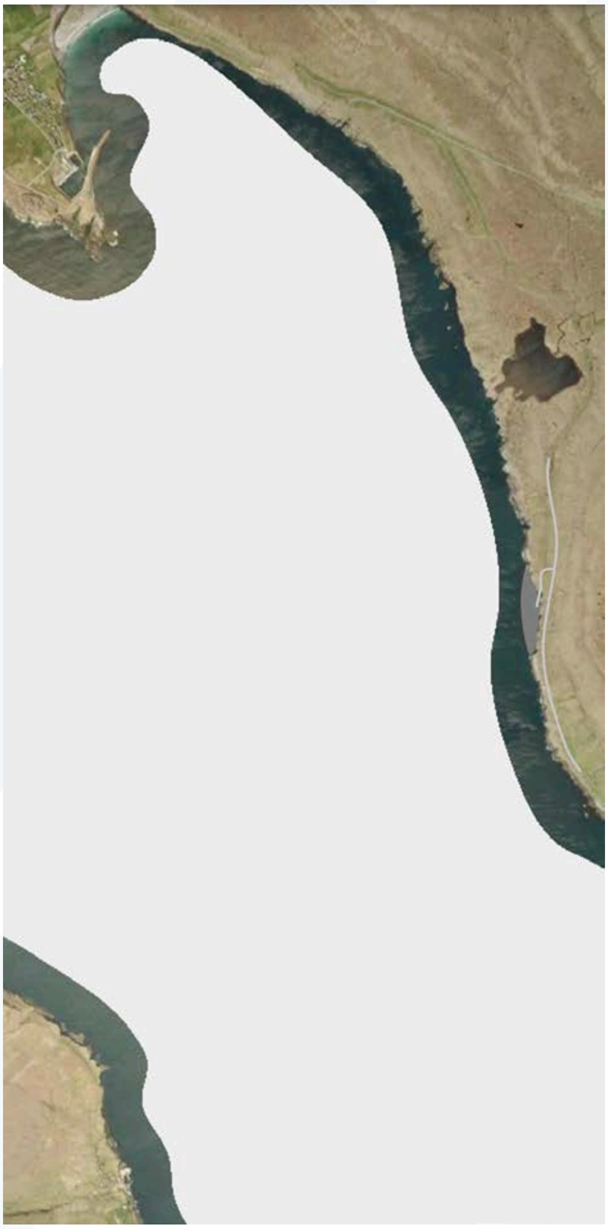
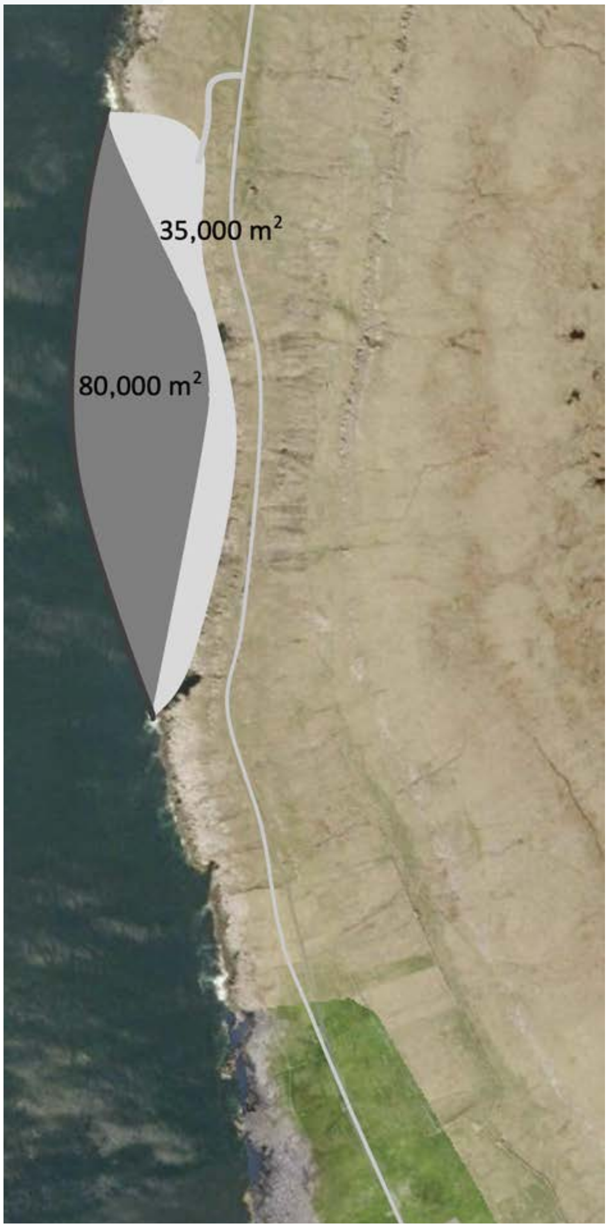


FIGURE 8: LOCATION OF AN INDUSTRIAL ESTATE IN AREA AROUND THE VILLAGE SKARVANES



AREA NEAR SANDVÍK

This project is the expansion of an area along the eastern shore of northern Suðuroy. The area is chosen because of its distance from the tunnel entrance on Suðuroy and because it does not interfere with the daily goings of the residents of Sandvík. The height of waves is also favourable. The area can be used for fish farming, windmills and other activities that require some distance from residential areas.

Figures 9 and 10 illustrate how the area can be expanded by 90,000 m^2 with an average depth of 25 meters. This solution would require an amount of debris of around 1,700,000 to 2,050,000 m^3 depending on the accessibility. In addition, it would be necessary to blast another 35,000 m^2 of rocks. In total, this would create an area of 125,000 m^2.

This project would require either an expansion of the harbour in Sandvík, so the debris can be moved by sea, or a tunnel to the area. It is possible to make a 2.3 km long tunnel from Sandvík or a 1 km long tunnel from the entrance of the subsea tunnel to the area. The former is a better solution than the latter.

Another possibility is to place a conveyor belt in the subsea tunnel and transport the debris directly to the area. This has not been tried in the Faroes before but has been used successfully elsewhere. Under the right circumstances, a conveyor belt can be a less expensive solution than lorries and trucks and it diminishes the risk of work-related accidents and fire hazards. The estimate is that a conveyor belt can save a possible 165,000 to 190,000 trips by different vehicles from the tunnel.

The moving costs using the direct tunnel solution would be 25 DKK per m^3, amounting to a total of 51.25 million DKK. This does not include related projects like a jetty.

It is also possible to find a different location in the area or change the project itself.

The project is expensive but could be beneficial to the larger project. It would also ensure land for projects which require a certain distance from residential areas.

FIGURE 9: THE AREA AROUND SANDVÍK WITH DIFFERENT ACCESS POINTS TO THE AREA

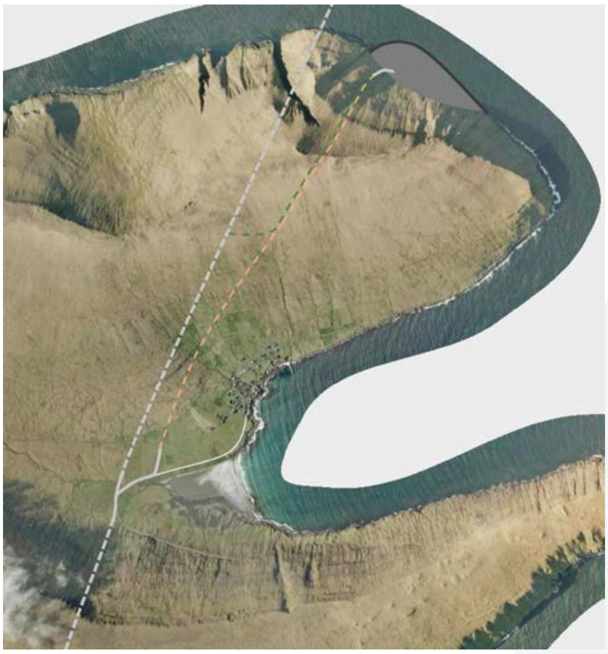


FIGURE 10: THE AREA NEAR SANDVÍK

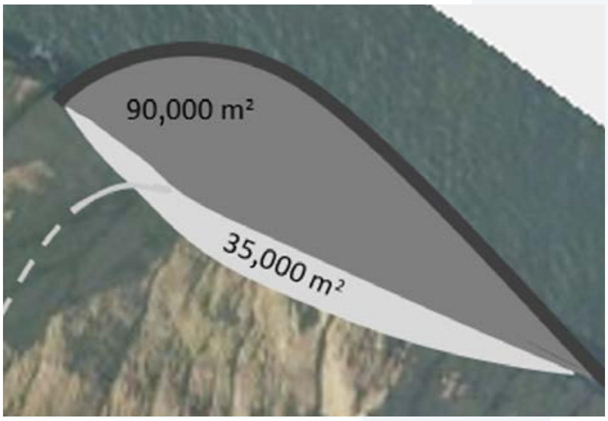
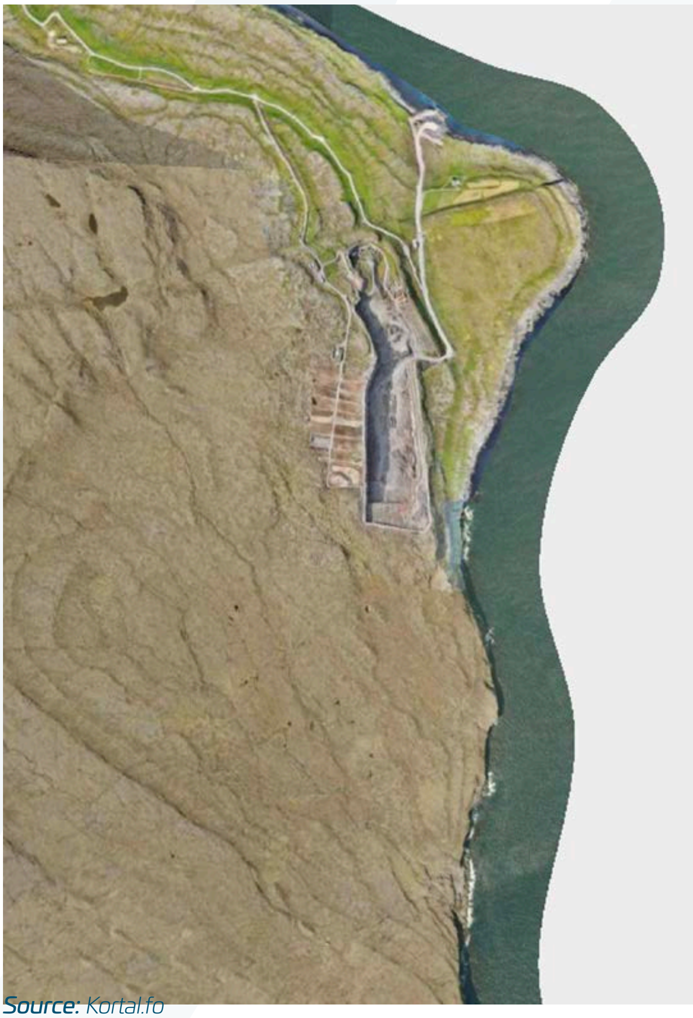


FIGURE 11: THE QUARRY ON GLUVURSNES



Source: Kortal.fo

FILLING A QUARRY, GLYVURSNES

This project is to place the debris in a quarry on Glyvursnes for future use or to improve and repair the area in and around the quarry. The old quarry is 25,000 m² while the new quarry is 82,000 m² with an average height of 30 meters. The quarry can fit more than 2,500,000 m³ of debris from the tunnel to Suðuroy. This solution does not create any additional value and the moving costs would be around 70 DKK per m³. It would also hinder any future activity in the quarry.

AIRPORT AND ROADS, GLYVURSNES

This project entails building a 2,700 meter long airport on Glyvursnes. Landsverk has previously examined the possibility of building an airport on Glyvursnes, as it is considered the best location for an international airport in the Faroes. In order to level the area, part of it would be blasted, thus not requiring much debris. The need would be an approximately 120,000 m^3. The related road is 6.4 kilometers long and would need 80,000 m^3 of debris. It is, however, doubtful whether the debris from the tunnel is of a good enough quality for this project. The moving costs would be around 70 DKK per m^3.

This project is a 2,000 meter long airport in Søltuvík. After Glyvursnes, Søltuvík is the best location for an international airport in the Faroes. The area needs to be levelled and the need for debris would therefore be limited, some 90,000 m^3. The related road is 4.5 kilometers long and would need around 60,000 m^3 of debris. As on Glyvursnes, it is doubtful if the debris from the tunnel is of a high enough quality for this project. The moving costs would be around 55 DKK per m^3.

If the debris is not needed anywhere, the only solution would be to stack it, maybe in a quarry, or conceal it in the ground. These solutions do not add value and can also be an inconvenience for the area where it is located.

As shown, there is not a specific project where the debris can be used. But several projects might be needed for the debris to be fully utilised. In this section, a few solutions have been presented. Some of them have been discussed before. Some of them are more realistic than others, perhaps even possible. What we can say is that we need to think about what to do with the debris. To fully utilise it, lowering the moving costs and to avoid unfortunate placements, we need to decide how to use the debris, before progressing with the actual tunnel.

These are all suggestions, but it is possible to approach Landsverk directly if you have other ideas for how to use the debris.

FIGURE 12: AIRPORT AND ROAD ON GLYVURSNES

Source: Landsverk, 2019

FIGURE 13: AIRPORT AND ROAD IN SØLTUVÍK

Source: Landsverk, 2010

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- Danmarks Statistik, https://www.dst.dk/da/
- Kortal.fo http://www.kortal.fo/
- Statistics Iceland, https://hagstofa.is/
- Statistics Faroe Islands, https://hagstova.fo/fo
- MarineTraffic, https://www.marinetraffic.com/en/ais/home/centerx:-12,0/centery:25,0/zoom:4
- Shetland Islands Council, https://www.shetland.gov.uk/
- Statistics Norway, https://www.ssb.no/
- Sustainable Construction Information Portal https://www.oekobaudat.de/en.html
- Statistics Åland, https://www.asub.ax/sv

PROGRAMMES

- Calculating emissions, Vejdorektoratet.
- Visum trafficmodel https://www.ptvgroup.com/en/solutions/products/ptv-visum/
- TEMA: Transporters EMissioner under Alternative forudsætninger. Transport DTU https://www.cta.man.dtu.dk/modelbibliotek/co2-beregningsmodel
- TERESA: Transport-, Bygdnings- og Boligministeriets Regnearksmodel for Samfundøkonomisk Analysen. Transport DTU https://www.cta.man.dtu.dk/modelbibliotek/teresa

8. APPENDICES

A APPENDICES FOR THE SOCIAL ANALYSIS

APPENDIX A1: CENTRALISATION IN THE FAROES

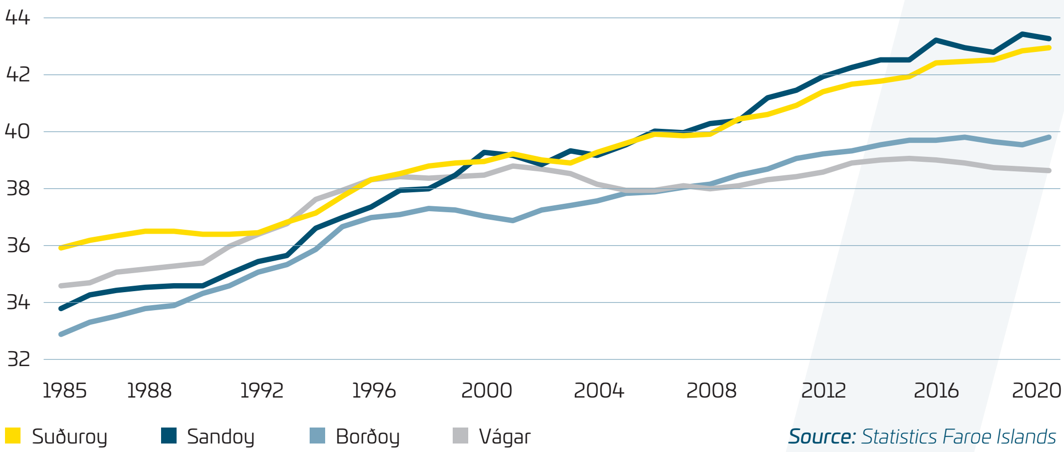
TABLE 21: VILLAGES AND CITIES BY POPULATION

Population	1985	2019	Δ
5,000 +	14,422	19,635	5,213
	31.8%	38.2%	6.4%
2,000 - 4999	4,726	4,839	113
	10.4%	9.4%	-1.0%
1,000 - 1999	7,343	7,358	15
	16.2%	14.3%	-1.9%
5,00 - 999	8,980	9,451	471
	19.8%	18.4%	-1.4%
2,00 - 499	5,255	6,095	840
	11.6%	11.9%	0.3%
1,00 - 199	1,857	1,989	132
	4.1%	3.9%	-0.2%
0 - 99	2,765	1,969	-796
	6.1%	3.8%	-2.3%
Total	**45,348**	**51,336**	**5,988**

Source: Statistics Faroe Islands

APPENDIX A2: AVERAGE AGE

GRAPH 18: AVERAGE AGE FOR SELECTED ISLANDS, 1985-2020



Source: Statistics Faroe Islands

APPENDIX A3: AGE DISTRIBUTION

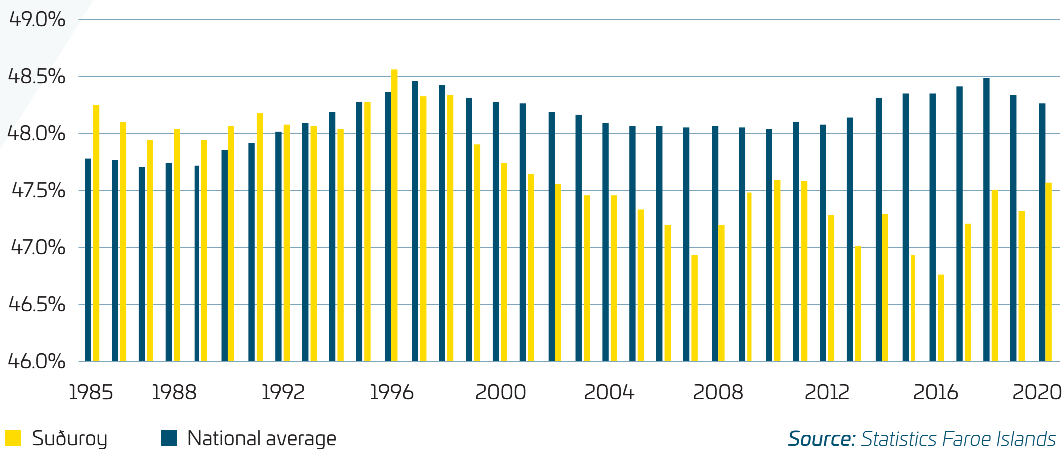
TABLE 22: CHANGES IN AGE DISTRIBUTION FOR SELECTED AREAS, 1985 AND 2020

	Total	0-15 years	16-66 years	>67 years
1985				
National average	45,348	12,399	28,642	4,307
	100.0%	27.3%	63.2%	9.5%
Suðuroy	5,881	1,532	3,618	731
	100.0%	26.0%	61.5%	12.4%
2020				
National average	52,154	11,610	32,448	8,096
	100.0%	22.3%	62.2%	15.5%
Δ%		-5.1%	-0.9%	6.0%
Suðuroy	4,603	898	2,765	940
	100.0%	19.5%	60.1%	20.4%
Δ%		-6.5%	-1.5%	8.0%

Source: *Statistics Faroe Islands*

APPENDIX A4: GENDER DISTRIBUTION

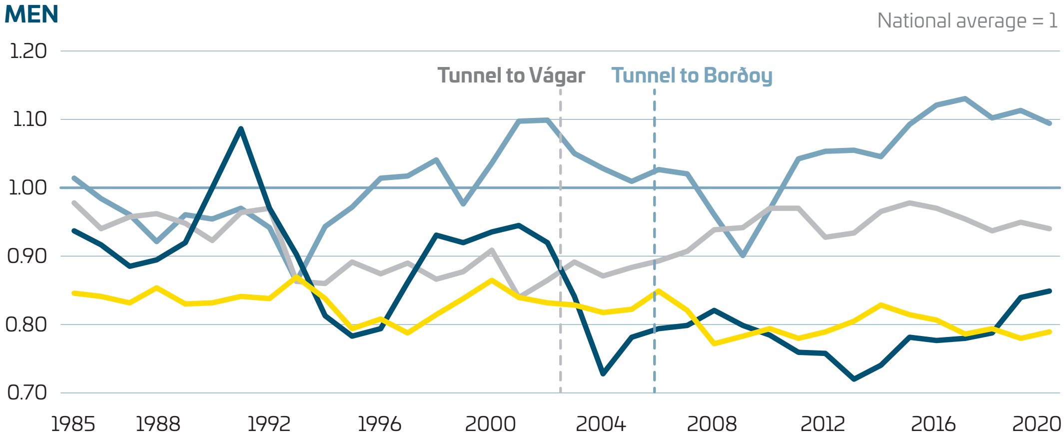
GRAPH 19: DISTRIBUTION OF WOMEN IN SELECTED AREAS, 1985-2020

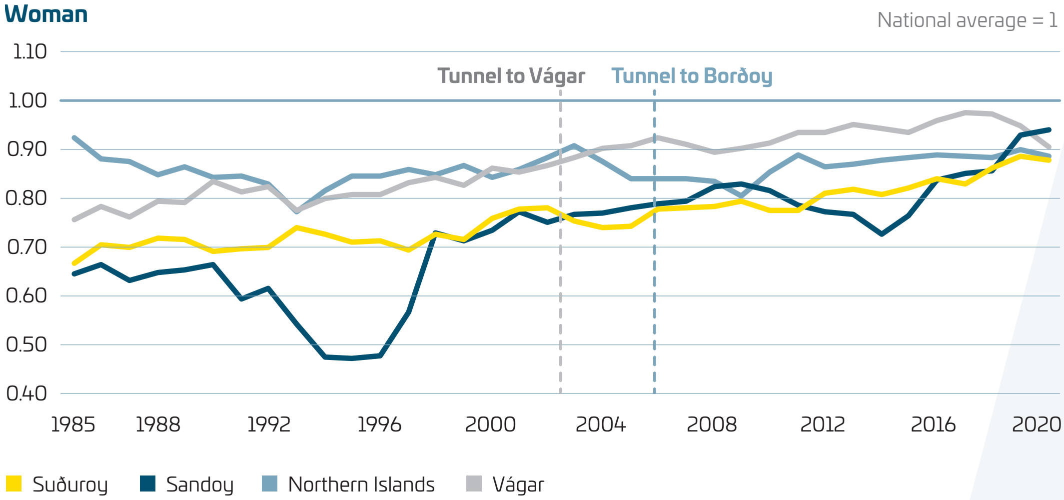


Source: *Statistics Faroe Islands*

APPENDIX A5: PROPORTIONAL UNEMPLOYMENT

GRAPH 20: PROPORTIONAL UNEMPLOYMENT FOR MEN AND WOMEN IN SELECTED AREAS, 1985-2020



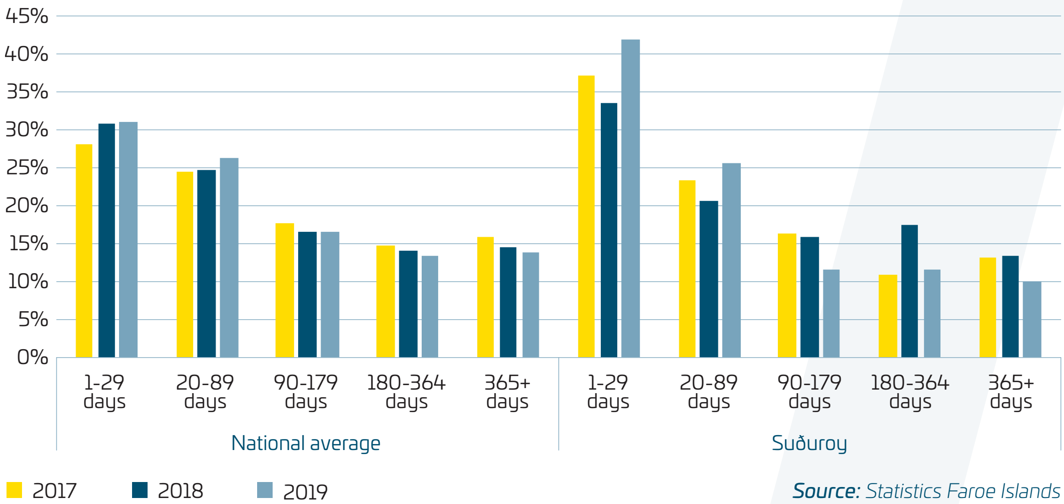


Comment: *The tunnel to Vágar opened on 10 December 2002, and the tunnel to Borðoy on 29 April 2006 (tunnil.fo)*

Source: *Statistics Faroe Islands*

APPENDIX A6: DURATION OF UNEMPLOYMENT

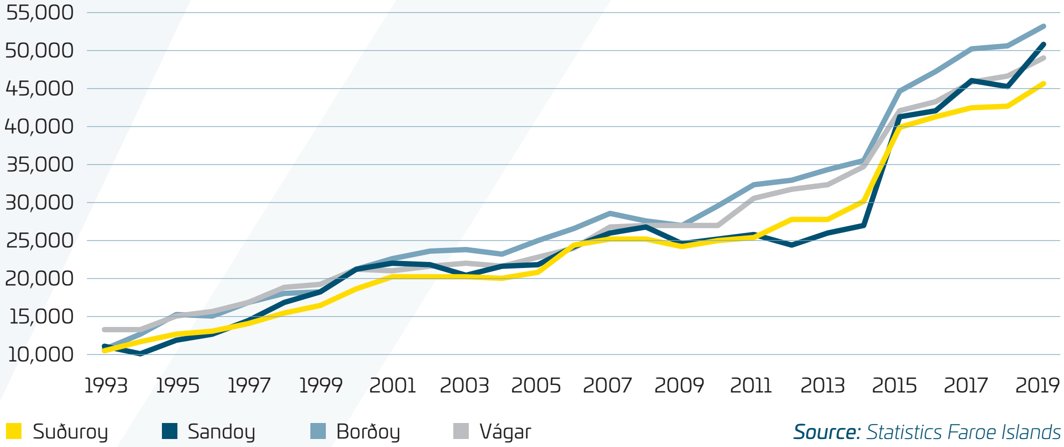
GRAPH 21: PROPORTIONAL DURATION OF UNEMPLOYMENT BASED ON AREAS, 2017-2019



Source: *Statistics Faroe Islands*

APPENDIX A7: LOCAL TAX INCOME

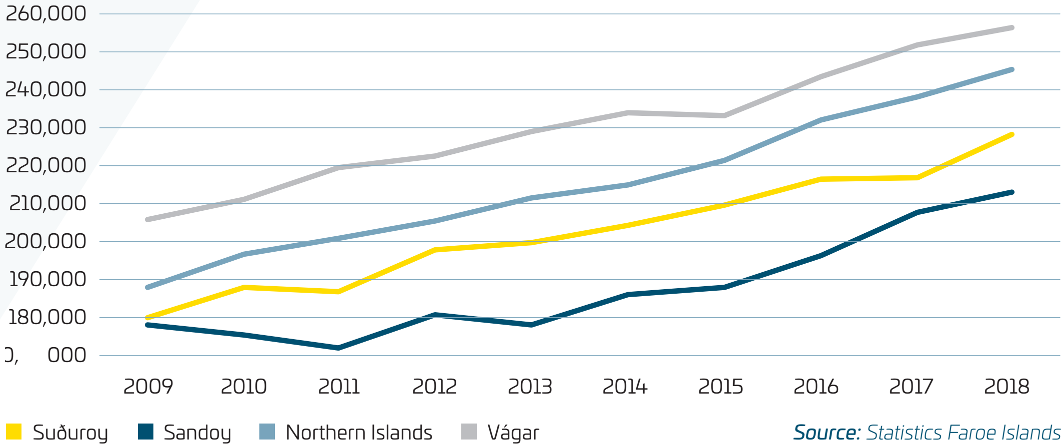
GRAPH 22: LOCAL NET TAX PER CAPITA FOR SELECTED ISLANDS, 1993-2019



Source: Statistics Faroe Islands

APPENDIX A8: AVERAGE INCOME

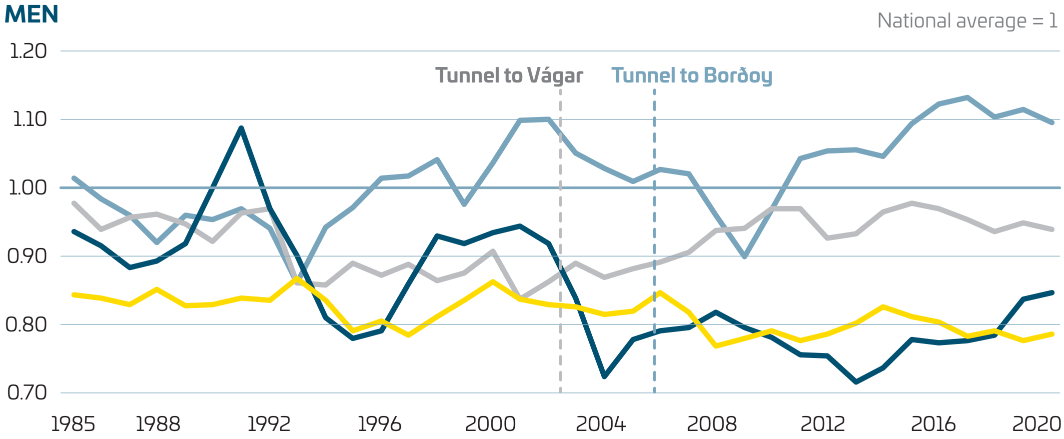
GRAPH 23: AVERAGE ANNUAL INCOME PER CAPITA IN SELECTED AREAS, 2009-2018

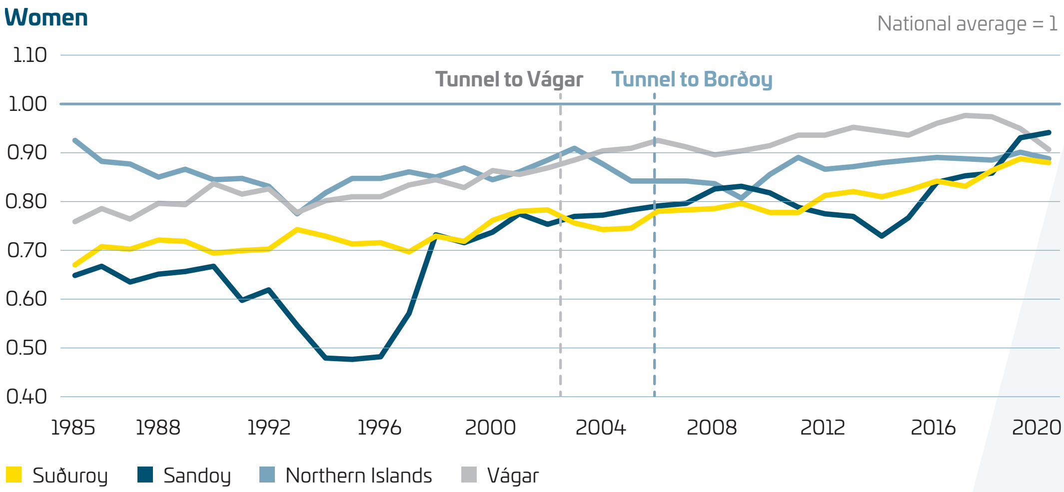


Source: Statistics Faroe Islands

APPENDIX A9: INCOME

GRAPH 24: PROPORTIONAL INCOME BASED ON GENDER IN SELECTED AREAS, 1985-2020



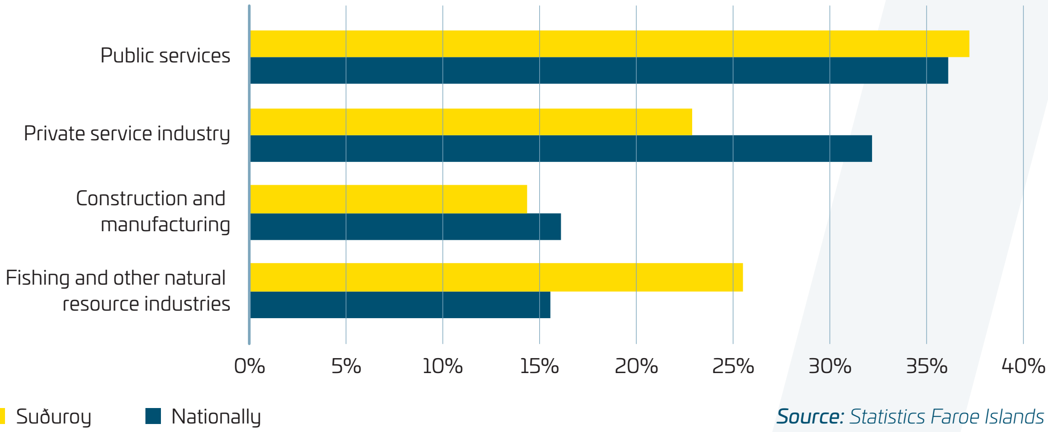


Comment: *The tunnel to Vágar opened on 10 December 2002, and the tunnel to Borðoy on 29 April 2006 (tunnil.fo)*

Source: *Statistics Faroe Islands*

APPENDIX A10: BRANCHES OF INDUSTRY

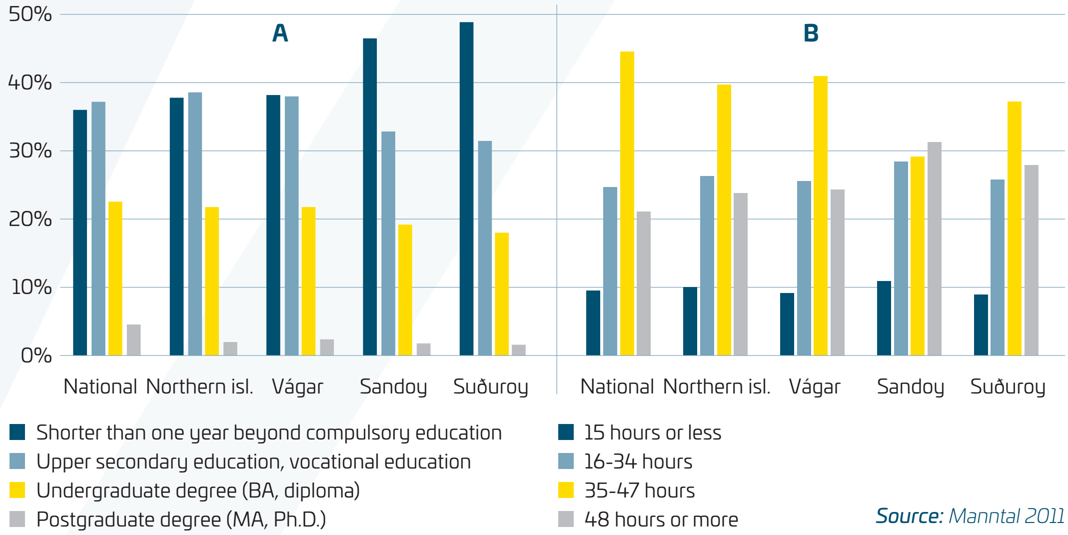
GRAPH 25: PROPORTIONAL SALARY EARNERS BASED ON INDUSTRY BRANCH AND SELECTED AREAS, 2019



Source: *Statistics Faroe Islands*

APPENDIX A11: EDUCATION LEVEL AND WORK HOURS

GRAPH 26: PROPORTIONAL EDUCATION LEVEL (A) AND WORK HOURS (B) FOR SELECTED AREAS, 2011



Source: Manntal 2011

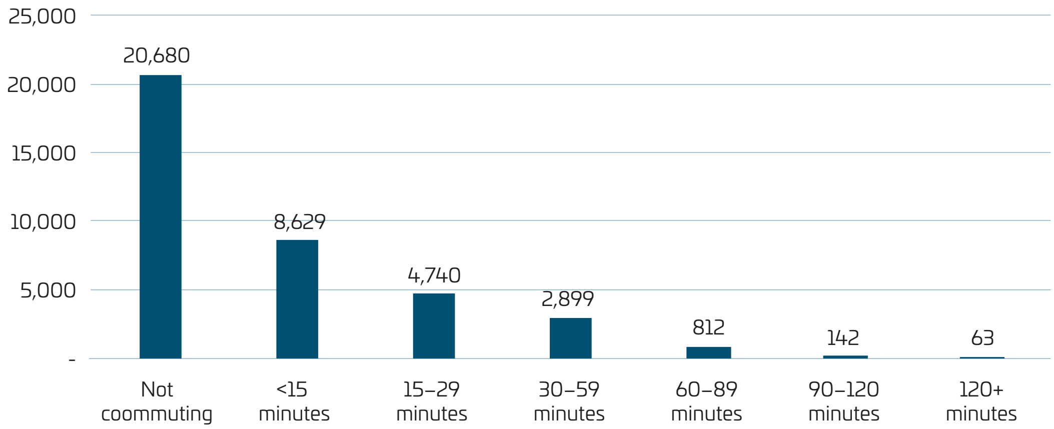
APPENDIX A12: COMMUTING

TABLE 22: COMMUTING TO AND FROM, BASED ON AREAS, 2011

Commuting to	Commuting from: Total	Northern isl.	Eysturoy	Tórshavn	Streymoy	Vágar	Sandoy	Suðuroy
Total	37,965	4,545	8,352	14,153	3,703	2,378	1,063	3,771
Nothern isl.	1,322	1,008	224	55	13	5	...	15
Eysturoy	3,482	250	2,964	78	129	22	17	22
Tórshavn	9,440	199	748	6,772	1,110	359	123	129
Streymoy	1,005	22	219	226	496	32	5	5
Vágar	646	4	26	60	31	512	5	8
Sandoy	208	...	8	21	...	...	177	...
Suðuroy	1,182	13	26	26	14	10	...	1,092

Source: Manntal 2011

GRAPH 27: COMMUTING TIME, 2011



B APPENDICES FOR THE ECONOMIC ANALYSIS

APPENDIX B1: THE ECONOMIC ANALYSIS

TABLE 23: OVERVIEW OF UNIT PRICES FOR INVESTMENTS AND OPERATION, 2012 PRICES

Investment and operation			
Variable	**Investment**	**Operation**	**Source**
Roads	**million DKK/km**	**million DKK/km/year**	
New road	22	0.3	LV
Maintaining road	15	0.3	LV
Passing place per 250 m	3		LV
Crossroads each	2		LV
Roundabout each	4		LV
Tunnels			
Tunnel (T8.5)	87	0.8	LV
Tunnel (T10.5)	104	0.8	LV
Single lane subsea tunnel	138	1.4	EST
Administration of tunnel company		**million DKK/year**	
Administration costs		5	Tunnil
Debt collection		2	Tunnil
Ferries	**million DKK**	**million DKK/year**	
New Smyril	800	75	SSL
New ferry Sandoy-Suðuroy	700	70	SSL
New Sildberi	35	3.5	SSL
Ferry berths			
Krambatangi	12	1	LV
Skúvoy	5	0.5	LV
Sandur	120	0.8	LV
Railway	**million DKK/kr/track**	**million DKK/year**	
Track	20	30	COWI
Current conductors	8		COWI
	million DKK/each		
Track changers	4		COWI
Transformer	8		COWI
Communication devices	10		COWI
Safety inspection	5		COWI
SCADA	5		COWI
Train			
Railway car	40		COWI
Locomotive	45		COWI
Freight car	4		COWI
Rescue train	5		COWI
Buildings			
Railway station	12		COWI
Workshop and storage	30		COWI

Estimates in the analysis are based on the unit price above, which is based on trial prices and estimates from sources in table 24.

TABLE 24: OVERVIEW OF ALL COMMON CALCULATION SETTINGS IN THE COST-BENEFIT ANALYSIS

Common calculation settings				
Variable	**Report**	**Number**	**Unit**	**Source**
Price level	**2021 prices**			
Annual inflation in construction		3	%	LV
Project term	incl. remaining value	50	years	FM
Discount interest	years 0-35	3.5	%	FM
	years 36-50	2.5	%	FM
Net repayment factor		1.28		FM
Tax distortion factor		1.1		FM
Annual tax increase	years 2030-2040	1	%	Visum
	years 2041-2080	0.5	%	Visum
Driving cost	Passenger cars	2.78	DKK/km	COWI
	Lorries	3.69	DKK/km	COWI
Travel purpose	Commuting	26.5	%	COWI
	Business	9.6	%	COWI
	Other	63.9	%	COWI
Time cos	Foundation	322	DKK/hour	COWI
	Business	1	factor	COWI
	Commuting	0.3	factor	COWI
	Other	0.3	factor	COWI
	Delays	1.5	factor	COWI
Estimated daily traffic 2030	Solution 1	1,240	vehicles	Visum
	Solution 2	1,260	vehicles	Visum
	Solution 3	1,370	vehicles	Visum
	Solution 4	1,160	vehicles	Visum
	Solution 5	1,060	vehicles	Visum
Traffic ratio	Passenger cars	90.4	%	Visum
	Larger cars	9.6	%	Visum
Annual ferry cancellations	Smyril	13	trips	SSL
	Sildberin	16	trips	SSL
Average number of passengers	Business	1.09	passengers	COWI
	Commuting	1.07	passengers	COWI
	Other	1.52	passengers	COWI
Emissions cost	CO_2	0.27	DKK/kg	COWI
	Particles	880	DKK/kg	COWI
	Nox	123	DKK/kg	COWI
	SO_2	13	DKK/kg	COWI
Noise		33,306	DKK/SBT/year	COWI
Accidents	Death	36,344,620	DKK	COWI
	Serious damage	5,665,544	DKK	COWI
	Minor damage	723,277	DKK	COWI

APPENDIX B2: CONSEQUENT PROJECTS

TABLE 25: OVERVIEW OF ALL CONSEQUENT PROJECTS, 2021 PRICES

Route	1 Direct Skarvanes	2 Direct Sandur	3 Indirect Skúgvoy	4 Railway tunnel	5 New ferry
Project in km/amount					
Update road in Sandur	4				2
New road in Sandur		0.6	0.6	0.6	2.5
New road in Skarvanes	3				
New ferry berth in Sandur and update current					1
Tunnel (T8.5) in Skarvanes	0.35				
Crossroads in Skúvoy			1		
New road in Skúvoy			0.4		
Passing place in Skúvoy			1		
New road in Sandvík	0.6				
Tunnel (T8.5) in Sandvík	2.5	2.5	2.5	2.5	
New road in Hvalba	2.5	2.5	2.5	2.5	
Update road in Hvalba	0.4	0.4	0.4	0.4	
Update road in Trongisvágur	1.1	1.1	1.1	1.1	
Project in million DKK					
Update road in Sandur	61	-	-	-	31
New road in Sandur	-	13	13	13	55
New road in Skarvanes	66	-	-	-	-
New ferry berth in Sandur and update current	-	-	-	-	137
Tunnel (T8.5) in Skarvanes	31	-	-	-	-
Crossroads in Skúvoy	-	-	2	-	-
New road in Skúvoy	-	-	9	-	-
Passing place in Skúvoy	-	-	3	-	-
New road in Sandvík	13	-	-	-	-
Tunnel (T8.5) in Sandvík	219	219	219	219	-
New road in Hvalba	55	55	55	55	-
Update road in Hvalba	6	6	6	6	-
Update road in Trongisvágur	17	17	17	17	-
	467	309	323	309	222
Risk supplement (50%)	233	155	161	155	111
Total	**700**	**464**	**484**	**464**	**333**

APPENDIX B3: DIVIDED NET PRESENT VALUE

TABLE 26: NPV DIVIDED INTO PRIVATE AND PUBLIC PROFIT, MILLION DKK

Route	1 Direct Skarvanes	2 Direct Sandur	3 Indirect Skúgvoy	4 Railway tunnel	5 New ferry
Building cost					
Construction cost	-5,638	-5,909	-6,124	-7,442	-1,023
Remaining value	1,121	1,175	1,218	1,480	214
Operation and maintenance					
Operation, road	-1,101	-1,051	-1,094	-	-1,625
Operation, railway	-	-	-	-1,573	-
Externality					
Road accidents	-54	-52	-53	-27	-19
Noise	-70	-67	-68	-35	-24
Air pollution	159	159	159	162	53
Environment (CO_2)	50	50	50	55	17
Other outcomes					
Fee outcomes	203	194	198	99	71
Tax distortion	-335	-358	-368	-573	-26
Increased work force	51	62	61	27	10
Additional outcomes					
Savings of current route	2,892	2,892	3,044	2,892	2,319
Improved electricity grid, energy	251	251	251	251	-
Improved electricity grid, internet	41	41	41	41	-
A: Public	**-2,429**	**-2,610**	**-2,683**	**-4,642**	**-33**
User profit					
Saved travel time, people	1,740	1,897	1,895	922	478
Saved travel time, goods	22	24	24	10	6
Driving cost	-1,025	-964	-986	-510	-379
Ferry cancellations	15	15	15	15	
B: Private	**751**	**972**	**948**	**437**	**105**
NPV (A+B)	**-1,678**	**-1,638**	**-1,735**	**-4,205**	**72**

APPENDIX B4: SENSITIVITY ANALYSES

TABLE 27: INDIRECT SUBSEA TUNNEL VIA SKÚVOY

Route 3: Indirect Skúgvoy	NPV	IRR
Building Cost +30%	-3,390	1.6%
Time Value -50%	-2,731	1.5%
Driving Cost +50%	-2,137	1.9%
Operation Cost +50%	-1,822	2.1%
Externality -100%	-1,821	2.1%
Foundation	**-1,735**	**2.2%**
Externality +100%	-1,649	2.2%
Operation Cost -50%	-1,647	2.2%
Tourist income	-1,622	2.2%
Tax Distortion Factor 0%	-1,428	2.3%
Driving Cost -50%	-1,333	2.4%
Time Value +50%	-739	2.8%
Building Cost -30%	-80	3.2%

TABLE 28: NEW FERRY FROM SANDUR

Route 5: New ferry	NPV	IRR
Operation cost +50%	-822	Negativ
Lost fish-farming income	-538	0.9%
Building cost +30%	-202	2.6%
Time value -50%	-180	2.4%
Driving cost +50%	-86	2.8%
Externality -100%	46	3.4%
Foundation	**72**	**3.5%**
Tax distortion factor 0%	88	3.6%
Externality +100%	97	3.6%
Driving cost -50%	230	4.1%
Time value +50%	323	4.4%
Building cost -30%	345	5.2%
Operation cost -50%	965	6.9%

C APPENDICES FOR THE ENVIRONMENTAL ANALYSIS

APPENDIX C1: CALCULATION SETTINGS FOR CONSTRUCTION, CO_2 EMISSIONS

TABLE 29: CALCULATION SETTINGS FOR CONSTRUCTION, CO_2 EMISSIONS

Calculation settings, construction				
Group	**Description**	**Amount**	**Unit**	**Source**
Ferries				
Tonnes CO_2 per tonne of steel	Tonnes CO_2 eq.	2.56	tonnes	OEKOBAUDAT.DE
New Sildberi	Steel	20	tonnes	SSL
New Smyril	Steel	2,652	tonnes	marinetraffic.com
New ferry	25% smaller than Smyril	1,989	tonnes	SSL
New train	Steel per carriage	20	tonnes	COWI
Tunnels				
Liters of diesel annually	Construction	854,307	Liters	EST
	Finishing	343,980	Liters	EST
Annual energy usage	On building site	1,741,755	kWh	EST
kg CO_2 per litre diesel		2.7	kg	OEKOBAUDAT.DE
kg CO_2 per kWh		0.398	kg	SEV
New tarmac every 20y				LV

Group	Description	kg CO_2/ unit	Unit	Source
Drill & Blast	Explosives	0	tonnes	OEKOBAUDAT.DE
Debris disposal	Amount of debris	0	m^3	OEKOBAUDAT.DE
	Number of lorries	23	$10m^3$ per load	OEKOBAUDAT.DE
Road construction	Subbase course, Fk 22-120, 500 mm	0	m^3	OEKOBAUDAT.DE
	Binder, Fk 22-120 mm, 300 mm	0	m^3	OEKOBAUDAT.DE
	Lower surface course, Fk 2-32 mm, 100 mm	0	m^3	OEKOBAUDAT.DE
	Toop surface course, Ag 16, 60 mm	185	m^3	OEKOBAUDAT.DE
	Wear course, Ab 16, 50 mm	207	m^3	OEKOBAUDAT.DE
	Concrete car protection - Skúgvoy	351	m^3	OEKOBAUDAT.DE
Kerb, both sides	Concrete kerb 0.1x0.4m	252	m^3	OEKOBAUDAT.DE
	Debris for drainage	0	m^3	OEKOBAUDAT.DE
Securing debris	Systematic bolting C/C 2 m	6	Stk.	OEKOBAUDAT.DE
	Sprayed concrete 50 mm	262	m^3	OEKOBAUDAT.DE
Sealing leaks	Concrete	262	m^3	OEKOBAUDAT.DE
Tunnel portal (each)	Concrete	351	m^3	OEKOBAUDAT.DE
	Reinforcement, 4 kg/m^3 concrete	0	Kg	OEKOBAUDAT.DE
Technical instalments	Cable inserts for instalments	3	m	OEKOBAUDAT.DE
	Light per 2.5m	0	pieces	OEKOBAUDAT.DE
	Ventilationo, 2 per 60m	0	pieces	OEKOBAUDAT.DE
	Pumps, 8 pices	0	pieces	OEKOBAUDAT.DE
	Emergency phones per 125m	0	pieces	OEKOBAUDAT.DE
	Fire extinguisher, 2 per 125m	3	pieces	OEKOBAUDAT.DE

TABLE 30: CALCULATION SETTINGS FOR CONSTRUCTION, CO_2 EMISSIONS

Calculation settings, units

Construction and finalising: Tunnel to Suðuroy, T10.5, road width 9.5m				
Group	**Description**	**Unit**	**Per km**	**Source**
Pump station, 8 pieces		m^2		Statens Vegvesen - hb021
Passing place per 500m		m^2	480	Statens Vegvesen - hb021
Side corridor per 2,000m		m^2	223	Statens Vegvesen - hb021
Drill & Blast	Explosives	tonnes	200	tunnil.fo
Debris removal	Amount of debris	m^3	157,660	
	Number of lorries	$10m^3$ per load	15,766	
Tarmac	Binder, Fk 22-120 mm, 300 mm	m^3	3,061	LBF
	Lower surface course, Fk 2-32 mm, 100 mm	m^3	1,020	LBF
	Top surface sourse, Ag 16, 60 mm	m^3	612	LBF
	Wear course, Ab 16, 50 mm	m^3	510	LBF
Kerb, both sides	Concrete kerb0.1x0.4m	m^3	80	EST
	Debris for drainage	m^3	2,520	EST
Securing debris	Systematic boltingC/C 2 m	pieces	10,900	Statens Vegvesen - hb021
	Sprayed concrete 50 mm	m^3	1,143	Statens Vegvesen - hb021
Sealing leaks	Concrete	m^3	90	tunnil.fo
Tunnel entrance (each)	Concrete	m^3	13	
	Reinforcement, 4 kg/m^3 concrete	kg	52	
Technical instalments	Cable inserts for instalments	m	1,000	
	Lithg per 2.5m	pieces	400	Statens Vegvesen - hb021
	Ventilation, 2 per 60m	pieces	33	Statens Vegvesen - hb021
	Pumps, 8 pieces	pieces	-	
	Emergency phones per 125m	pieces	8	Statens Vegvesen - hb021
	Fire extinguisher, 2 per 125m	pieces	16	Statens Vegvesen - hb021

Consequent projects: connecting roads to the tunnel to Suðuroy, road width 8.5m				
Group	**Description**	**Unit**	**Per km**	**Source**
Road construction	Subbase course, Fk 22-120, 500mm	m^3	4,250	LBF
	Binder, Fk 22-120mm, 300mm	m^3	2,550	LBF
	Lower surface course, Fk 2-32mm, 100mm	m^3	850	LBF
	Top surface course, Ag 16, 60mm	m^3	510	LBF
	Wear course, Ab 16, 50mm	m^3	425	LBF
	Concrete car protection – Skúvoy	m^3	240	

TABLE 30: CALCULATION SETTINGS FOR CONSTRUCTION, CO_2 EMISSIONS *(CONTINUED)*

Calculation settings, units

Consequent projects: New tunnel to Sandvík, 2.5km, T9.5, road width 7.5m				
Group	**Description**	**Unit**	**Per km**	**Source**
Passing place per 500m		m^2	36	Statens Vegvesen - hb021
Side corridor per. 2,000m		m^2	13	Statens Vegvesen - hb021
Drill & Blast	Explosives	tonnes	175	tunnil.fo
Debris removal	Amount of debris	m^3	70,890	
	Number of lorries		7,089	
Tarmac	Binder, Fk 22-120, 300mm	m^3	2,265	LBF
	Lower surface course, Fk 2-32mm, 100mm	m^3	755	LBF
	Top surface course, Ag 16, 60mm	m^3	453	LBF
	Wear course, Ab 16, 50mm	m^3	377	LBF
Kerb, both sides	Conocrete kerb0.1x0.15m	m^3	3	
	Debris for drainage	m^3	540	
Securing debris	Systematic boltingC/C 2 m	pieces	10,400	Statens Vegvesen - hb021
	Sprayed concrete 50 mm	m^3	1,088	Statens Vegvesen - hb021
Sealing leaks	Concrete	m^3	135	tunnil.fo
Tunnel entrance (each)	Concrete	m^3	-	
	Reinforcement, 4 kg/m³ beton	kg	-	
Technical instalments	Cable inserts for instalments	m	1,000	Statens Vegvesen - hb021
	Light per 2,5m	pieces	400	Statens Vegvesen - hb021
	Emergency phones per 125m	pieces	8	Statens Vegvesen - hb021
	Fire extinguisher, 2 per 125m	pieces	16	Statens Vegvesen - hb021

Consequent projects: road around Hvalba, 4km, road width 7.5m				
Group	**Description**	**Unit**	**Per km**	**Source**
Road construction	Subbase course, Fk 22-120, 500mm	m^3	4,250	LBF
	Binder, Fk 22-120mm, 300mm	m^3	2,250	LBF
	Lower surface course, Fk 2-32mm, 100mm	m^3	750	LBF
	Top surface course, Ag 16, 60mm	m^3	450	LBF
	Wear course, Ab 16, 50mm	m^3	375	LBF

TABLE 31: CALCULATION SETTINGS FOR OPERATION, CO_2 EMISSIONS AND UNITS

Calculation settings, operation				
Group	**Description**	**Amount**	**Unit**	**Source**
Ferjur				
Sildberin 2030	Electric ferry	0	liters	SSL/COWI
Current Smyril	Daily diesel usage	18,000	liters	SSL/COWI
Smyril 2030	Daily diesel usage	13,500	liters	SSL/COWI
Smyril 2055	Electric ferry	0	liters	SSL/COWI
New ferry 2030	Daily diesel usage	13,500	liters	SSL/COWI
New ferry 2055	Electric ferry	0	liters	SSL/COWI
kg CO_2 per litre diesel		2.7	kg	OEKOBAUDAT.DE
Car park				
Projections for the vehicle population	Passenger cars			VD
	Lorries			VD
Projections for energy production	Energy sources			SEV
Improved energy functionality	Years 2015-2040	1	%	VD
	Years 2041-2080	0.5	%	VD
Traffic				
Increased traffic, 2030	Solution 1	24,754,135	km	Visum
	Solution 2	23,768,165	km	Visum
	Solution 3	24,245,140	km	Visum
	Solution 4	12,224,780	km	Visum
	Solution 5	8,613,870	km	Visum
Annual traffic increase	Years 2030-2040	1	%	Visum
	Years 2041-2080	0.5	%	Visum
Traffic proportion, type	Passenger cars	90.4	%	Visum
	Larger cars	9.6	%	Visum
Traffic proportion, area	City driving	5	%	Visum
	Main road driving	95	%	Visum
Emissions				
Emissions cost	CO_2	0.27	DKK/kg	COWI
	Particles	880	DKK/kg	COWI
	Nox	123	DKK/kg	COWI
	SO_2	13	DKK/kg	COWI

D APPENDICES FOR THE FINANCING MODEL

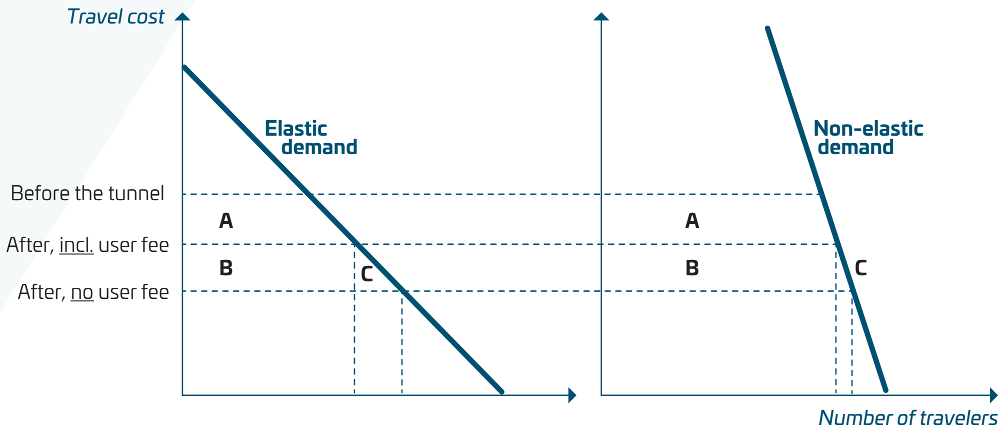
APPENDIX D1: TRAVEL COST

Travel cost = driving cost + travel time + user fee

While the expenses for driving cost (fuel and wear) and user fee are easily estimated, travel time remains more difficult to value. The Trade-Off method is typically used for this estimate which is based on hourly wage (Boardman et al., 2018). The value of time saved is therefore estimated according to the Faroese wage scale.

Belowis a graphic example of the correlation between user profit and user fee in a subsea tunnel.

FIGURE 14: USER PROFIT AND USER FEES



Area A = User profit Δ **Area B** = User fee **Area C** = Social loss *Source: Own production, based on DTU*

Figure 14 shows the demand for a subsea tunnel where the travel cost and number of passengers depends on how the project is financed. The blue lines in each figure show that the higher the fee, the fewer passengers, and the lower the fee, the more passengers. The left figure shows a more horizontal blue line than the one on the right, because the demand is more elastic, i.e. price changes affect the demand.

Before a subsea tunnel, the travel fees are high, partly due to a long travel time. The top dotted line shows this. When the subsea tunnel is there, the cost is reduced, and unless a user fee is added, the cost drops to the lowest dotted line which increases the number of passengers. Thus, users get great profit from the tunnel. Without user fees, the increase in user profit corresponds to areas A+B+C.

User fees increase travel cost where the increase of user profit is limited to area A; area B is the user fee, and area C is the social loss, as fewer people use the tunnel compared to the situation without fees. The social loss (C) depends on the price elasticity of the demand. Users in the figure to the right are less cost sensitive which results in a lower social loss.

APPENDIX D2: USER FEES

FIGURE 15: GRAPHIC AND FORMAL DESCRIPTION OF USER FEES

+	−
• Lower tax distortion (S)	• Administration fees (F) • Reduced user profit (B)

The total outcome of user fee = ΔS - F - ΔB
Advantage of user fee: ΔS > F - ΔB

Source: *Own production based on DTU*

As seen above, user fees result in a lower tax distortion, as user fees distort work supply or the will to work less than income tax. On the other hand, user fees reduce the user profit and result in higher administration fees (debt collection etc.). One might wonder why the user fee itself is not in the figure, but as it is a public income and a private fee, the total outcome is nil. This is commonly referred to as a transfer, where the gain from a toll is transferred from private to public (Boardman et al., 2018).

All in all, user fees are an advantage for a project where administration fees (F) and the reduced user profit (B) are lower than the gain of a lower tax distortion (S). This comes into effect if the user is not too cost sensitive, i.e. the demand is not largely affected by changes in travel cost.

APPENDIX D3: DEVIATION OF PROJECTS

FIGURE 32: DEVIATION OF ESTIMATE AND CONSTRUCTION COST, MILLION DKK

	Estimate					Construction					Deviation		
Cost level	**1999**	**2006**	**2012**	**2018**	**Present value***	**2000**	**2003**	**2006**	**2016**	**2021**	**Nominal**	**Real**	**Average**
Project													
Tunnel to Vágar	206				212	295					43%	39%	
Tunnel to Borðoy	260				293		395				52%	35%	
Tunnel to Hov	95				117			166			75%	42%	39%
Tunnel to Hvalba		155			208				250		61%	20%	
Tunnel to Eysturoy		953			1,281				1,540		62%	20%	
Tunnels 'Norður um Fjall'		251			391					522	108%	33%	
Tunnel to Sandoy		661			888					1,300	97%	46%	30%
Tunnel to Eysturoy			1,130		1,272				1,540		36%	21%	
Tunnel to Hvalba			170		191				250		47%	31%	
Tunnels 'Norður um Fjall'			265		346					522	97%	51%	
Tunnel to Sandoy			800		1,044					1,300	63%	25%	32%
Tunnels 'Norður um Fjall'				393	429					522	33%	22%	
Tunnel to Sandoy				1,000	1,093					1,300	30%	19%	20%
Average	**4**	**12.5**	**6**	**3**							**62%**	**31%**	

**Formula: FV=PV*(1+3%)^t*

APPENDIX D4: COMPARISON OF CONSTRUCTION METHODS

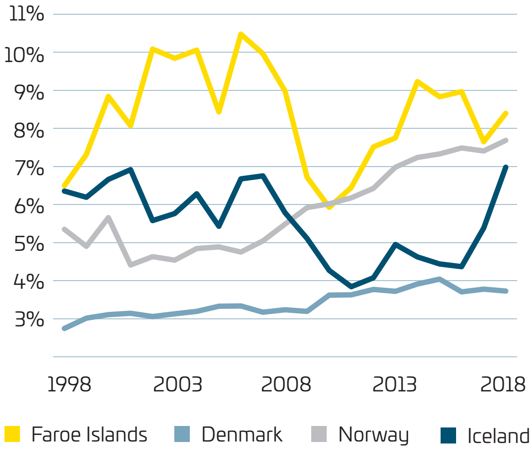
TABLE 33: COST AND TIME ESTIMATE FOR THE TUNNEL TO SUÐUROY

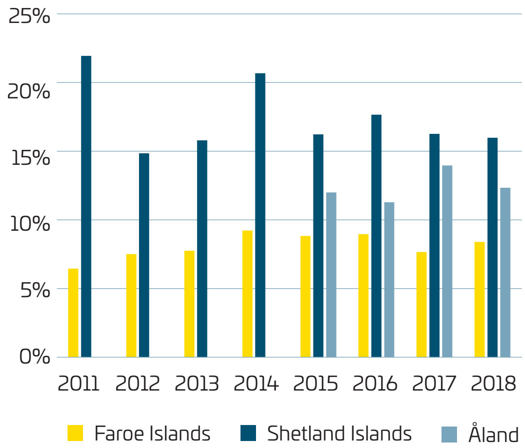
Cost and time estimate for the tunnel to Suðuroy		**Cost (Million)**		**Time**
Km	**26**	**DKK**	**EUR**	**Km/year**
Source	**Drill & Blast**			
Est: 11.4+10.8 km single lane subsea tunnel, T10.5/9.5 m	Total building cost	138	18.4	
	Total: 26km	**3,588**	**478**	**9.1**
	TBM			6
Offer from Herrenknecht: Double shield T10m	TBM investment/piece	210	28	
Follo Line Oslo: 22km dual tunnel, T8.75m	Operation cost/km	172.5	23	
Ratio from tunnels 'Norður um fjall'	Completion/km (35%)	74.3	9.9	
	Total: 26km	**6,837**	**912**	**4.3**

Comment: Estimates are based on sources from various countries.

APPENDIX D5: PUBLIC FINANCE PLAN

GRAPH 28: PROPORTIONAL PART OF NATIONAL BUDGET SPENT ON INFRASTRUCTURE (COFOG)





Source: Statistics Faroe Islands, hagstofa.is, dst.dk, ssb.no, Shetland Islands Council and ÅSUB

APPENDIX D6: CALCULATION SETTINGS FOR THE TUNNEL TO SANDOY

TABLE 34: CONDITIONS FOR USER FEES FOR THE TUNNEL TO SANDOY, MILLION DKK

Calculation settings, tunnel to Sandoy	
Investment cost	1,300
Share capital	200
Borrowing requirements	1,100
Interest	2.73%
Repayment period	30 years
Annual instalments	54
Daily traffic	400
One-way toll	**376 DKK**

APPENDIX D7: AVERAGE PRICES

TABLE 35: AVERAGE PRICES FOR OTHER SUBSEA TUNNELS

	Average prices both ways		
Project	**2003**	**2006**	**2021 prices***
Tunnel to Vágar	DKK 147		DKK 210
Tunnel to Borðoy		DKK 90	DKK 121

**Formula: FV=PV*(1+2%)^t*

This is the average price for the first year after the tunnels were opened; subsequently average prices have dropped significantly and stand at less than 30 DKK both ways (Tunnil, 2021).

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