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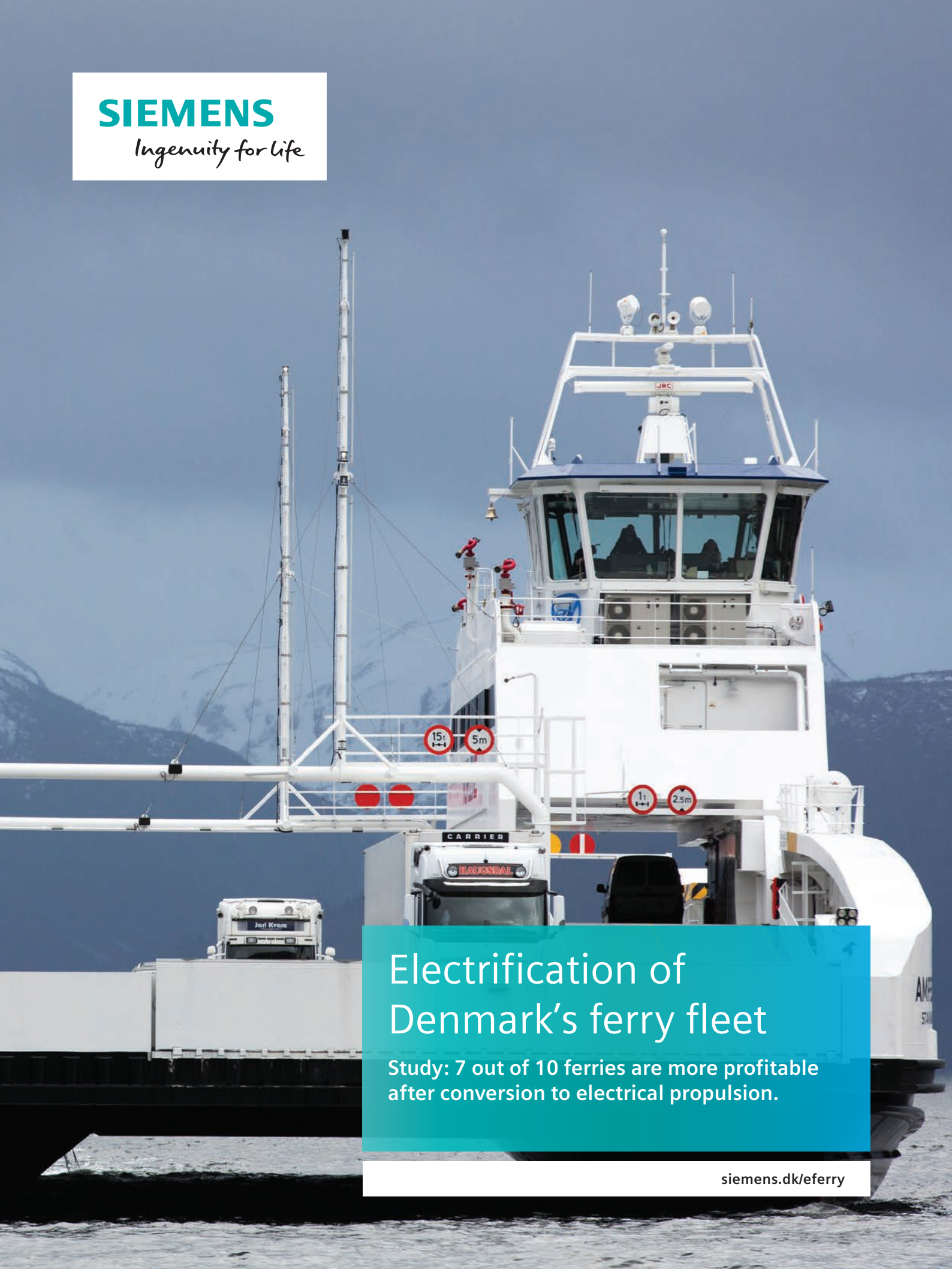


Electrification of Denmark's ferry fleet

Study: 7 out of 10 ferries are more profitable after conversion to electrical propulsion.

siemens.dk/eferry

Introduction

Denmark will be fossil fuel-free by 2050. That is the verdict of a unanimous Danish parliament. But if this goal is to be successful, we must not only convert the fuel used by future transport, we also need a strategy for optimization of the relationship between the transport sector and the energy sector. This study analyzes the possibilities within Denmark's ferry fleet.

In 2015, the world's first electric car ferry began operating in Norway under the name of Ampere. After one and a half years of operation, Ampere's technology has shown that there are only winners in this story; the shipping company gets a cheaper ferry operation, the environmental impact has been minimized and passengers have experienced an increased comfort in their crossings.

Today Denmark has 42 domestic routes along the Danish coast that are trafficked by 52 ferries. Several Danish companies have taken the first step in the direction of greener ferry services, but there is still great potential in replacing traditional diesel propulsion with electric propulsion. The question is; *how many of these ferries would be cheaper to operate if they were electric ferries?*

In order to answer the question, we have analyzed the e-ferry Ampere, which provides valuable insights for the calculation of the electrification potential of Denmark's ferry services, thanks to its many thousands of hours in operation. The conclusion is clear: **7 out of 10 ferries are more profitable as electric ferries.**

Electrification is a prerequisite for Denmark's green transition. And with Denmark's rise in electrical generation from renewable wind resources means there is a possibility of achieving significant economic, as well as environmental gains. But it requires a decision to invest in electrification.

This study intends to provide a constructive contribution to the debate. We hope that the conclusions inspire to further investment in environmentally-friendly, integrated solutions in the maritime sector and in the Danish transport sector in general.

October 2016.

Scope of analysis

This feasibility study investigates Denmark's coastal passenger ferries that carry inhabitants, cars and visitors around in the country. This includes 52 ferries that operate on 42 various domestic routes. The study analyzes the potential for replacing Denmark's traditional diesel-powered ferries with new electrical ferries that are both greener, and also have the potential for delivering a stronger business case.

A third of these ferries were built before 1980, and the oldest dates all the way back to 1930. This means that decisions for replacement are not so far ahead.

Acknowledging that not all ferries must – and should – be replaced tomorrow, we are analyzing the potential of replacing them in year zero to take as long-term a perspective as possible.

Ferries running on fossil fuel will never be environmentally friendly. If we are to achieve Denmark's political climate objectives of being independent from fossil fuels by 2050, we must convert to an carbon-neutral energy source such as electricity generated by renewables.

The following parameters are studied:

Ferry operations
On which ferry routes is it technologically possible to replace traditional diesel ferries with electric ferries?

Economy
What is the financial potential of electric ferries?

Environment
What are the environmental gains from electric ferries?

The potential of clean, electrical operation

With a growing number of initiatives focusing on electrification and the green transition, we now see that it is entirely technologically possible to replace diesel engines with battery-powered electric motors.

Suitable and profitable routes

30 ferry routes will be more profitable with battery operation
Agersø – Stigsnæs
Agger – Thyborøn
Askø – Bandholm
Assens – Baagø
Ballebro – Hardeshøj
Barsø – Barsø Landing
Branden – Fur
Bøjden – Fynshav
Egense – Hals
Endelave – Snaptun
Esbjerg – Fanø
Fejø – Kragenæs
Femø – Kragenæs
Fåborg – Avernakø – Lyø – Fåborg
Hjarnø – Snaptun
Holbæk – Orø
Hou – Sælvig
Hundested – Rørvig
Hvalpsund – Sundsøre
Kleppen – Venø
Mellerup – Voer
Mors – Thy
Omø – Stigsnæs
Rudkøbing – Strynø
Sejerø – Havnsø
Spodsbjerg – Tårs
Svendborg – Skarø – Drejø
Svendborg – Ærøskøbing
Udbyhøj Nord – Udbyhøj Syd
Aarø – Aarøsund

The Danish ferry fleet has for many years had the tradition of being powered by diesel engines that use marine gas oil or the more polluting heavy fuel oil.

Thanks to a growing number of initiatives focusing on the transition to green energy sources and electrification, we now see that it is entirely technologically possible to replace diesel engines with battery-powered electric motors.

Most of the ferries in Denmark today operate over relatively short distances, with an energy consumption of less than 2,000 kWh per trip. They have, therefore, an operational profile that make them suitable for electrical operation.

A battery solution for electrical operation is viable for ferry routes with a high number of trips, because the savings in operating costs become so large that they can cover the investment costs – and even exceed them.

On long journeys, ferries have a need for batteries with higher capacity, which sets greater requirements for charging while they are in port. Hence for long routes, it is more financially and environmentally viable with a hybrid solution, i.e. a combination of batteries and diesel or gas electric propulsion, where it is made possible for internal combustion engines to always operate at their optimum operating point.

Another 5 ferry routes are profitable with a phase-out of PSO levy (Public Service Obligation)
Bogø – Stubbekøbing
Christiansø – Gudhjem
Nekselø – Havnsø
Søby – Fynshav
Søby – Fåborg

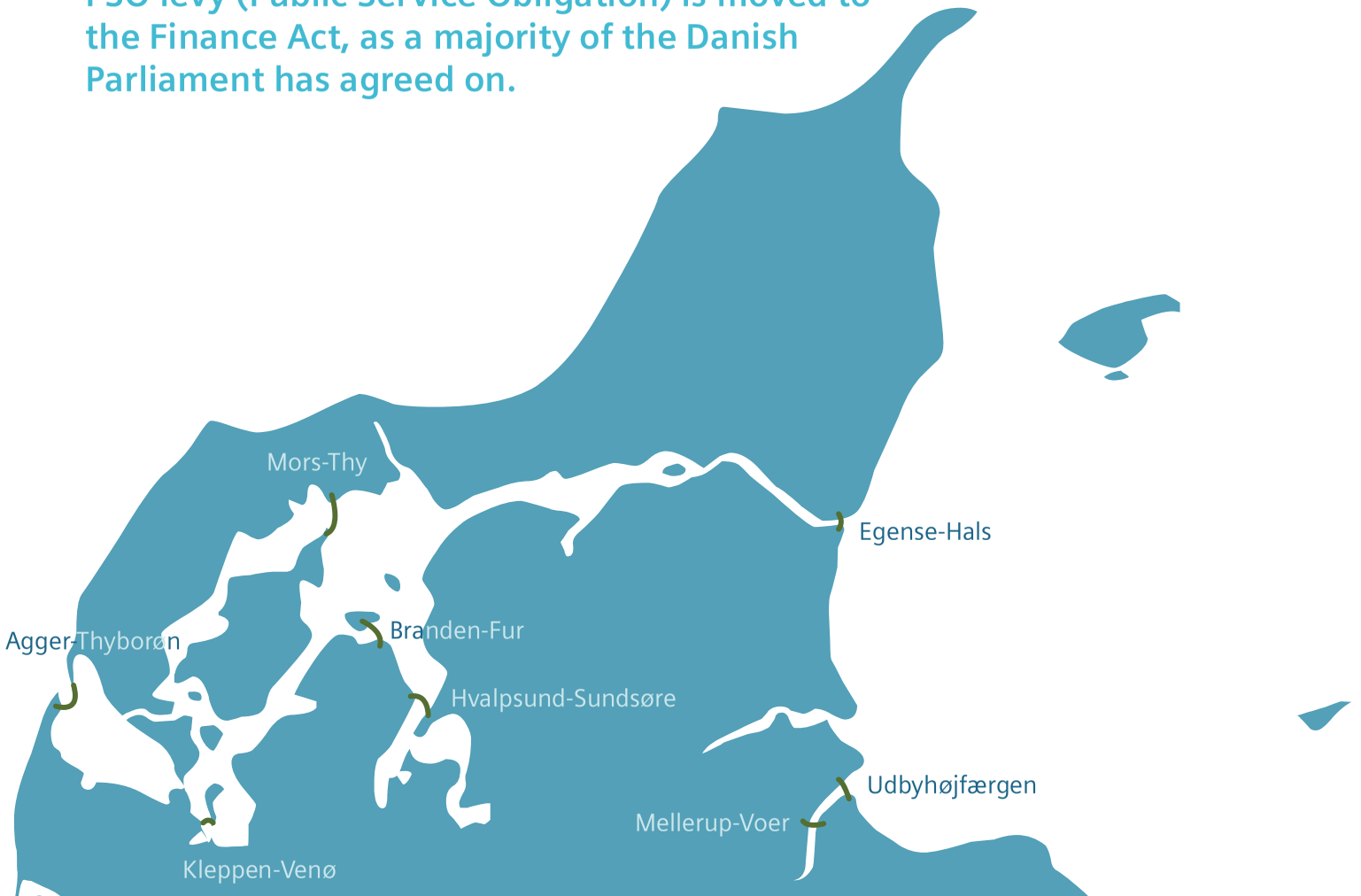
Electrical operation

In Denmark, there are 52 domestic diesel ferries, operating on 42 coastal routes, with an energy consumption of less than 2,000 kWh per trip and a crossing time of less than 60 minutes. This is an operational profile that with current technology can make electrical operation profitable.

Suitable and profitable ferry routes in Denmark

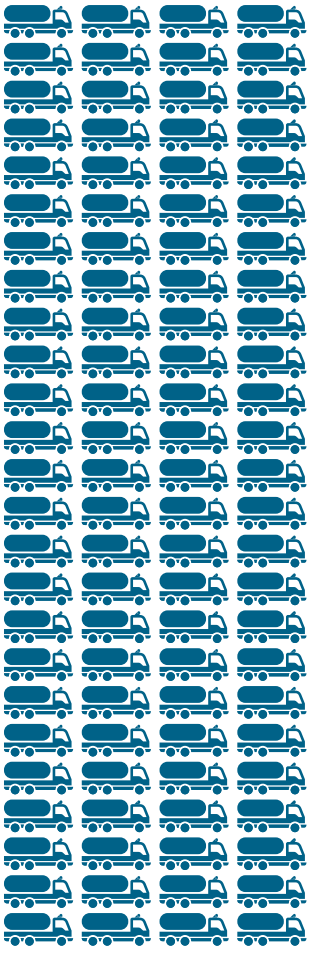
30 of Denmark's ferry routes are more profitable with electric propulsion compared to diesel propulsion.

Another 5 ferry routes become profitable, when the PSO levy (Public Service Obligation) is moved to the Finance Act, as a majority of the Danish Parliament has agreed on.




Hundested-Rørvig
Sejerø-Havnsø
Hou-
Sælvig
Hjarnø-Snaptun
Endelave-Snaptun
Nekselø-Havnsø
Holbæk-Orø
Esbjerg-Fanø
Assens-Baagø
Aarø-Aarøsund
Agersø-Stigsnæs
Fåborg-Avernakø-
Lyø-Fåborg
Bøjden-
Fynshav
Omø-Stigsnæs
Barsø-Barsø Landing
Svendborg-Skarø-Drejø
Spodsbjerg-
Tårs
Femø-Kragenæs
Ballebro-Hardeshøj
Søby-Fynshav
Søby-Fåborg
Rudkøbing-
Strynø
Fejø-
Kragenæs
Bogø-Stubbekøbing
Svendborg-
Ærøskøbing
Askø-Bandholm

Electrification would mean savings of 19,000 tonnes of fuel per year. This will also result in approximately 1,000 fewer fuel tankers driving through port cities to supply ferries.



The climate potential: 50,000 tonnes of CO_2 saved per year

Electrification of Denmark's 52 coastal diesel-powered ferries will result in CO_2 savings of 50,000 tonnes per year.

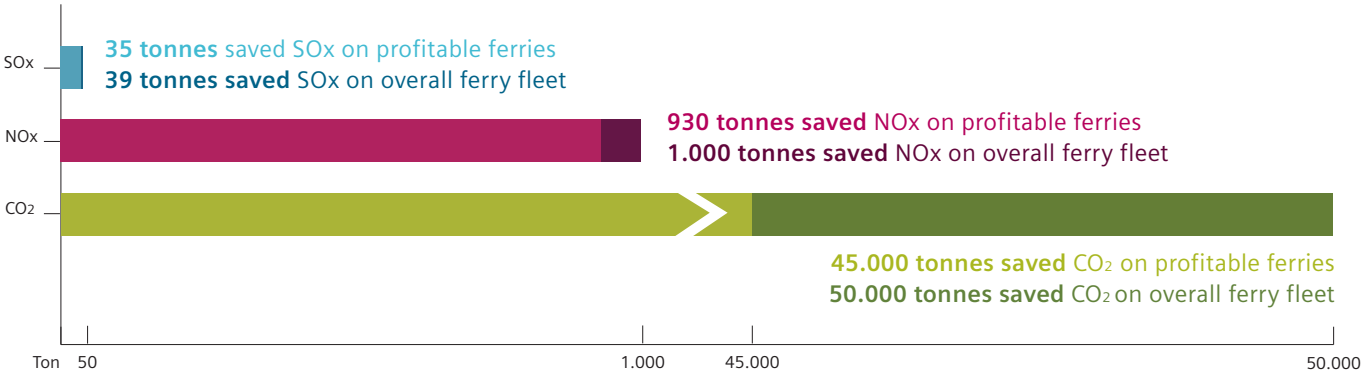
Ferries running on fossil fuel will never be friendly to the environment. They will always emit significant quantities of CO_2, to the detriment of the climate and the environment. The analysis shows that the current ferries can reduce their CO_2 emission by 50,000 tonnes per year.

But ferries' fuel does not just emit CO_2. It is also a serious source of atmospheric pollution, because of the large quantities of emitted substances that are harmful to health, such as sulfur oxide (SOx) and nitrous oxides (NOx).

The air pollution places a heavy burden on the world's oceans, lakes and forests, and it is also considered to be responsible for lung cancer and asthma, among other things.

In order to calculate the full potential of environmental benefits offered by electrification, the study has calculated the conversion of all 52 ferries. By comparing the current diesel ferries with a corresponding number of electrical ferries, we have calculated the environmental potential.

Environmental benefits of electrification:



A cleaner working environment on board

Conversion to fully electrical operation does not only achieve environmental benefits; crew and passengers will also advantage from the electrical ferries.

First and foremost e-ferries result in a better environment on board, as it will no longer be necessary to have fuel as well as large quantities of various lubricating oils on board. The fumes from hot engine rooms will be entirely removed and the air on board will no longer be affected by dangerous substances and particles from the engines running.

The demanding maintenance work needed for internal combustion engines and their auxiliary systems, such as fuel centrifuges and fuel pumps, can be entirely removed from the crew's tasks and the total quantity of maintenance significantly reduced.

As there will no longer be a need for fossil fuels, crew work in connection with refueling is reduced. An added benefit will be less disturbance from heavy truck traffic in port areas and remove the CO_2 emissions from the fuel tankers that are no longer needed.

Crew and passengers will experience an increased level of comfort when e-ferries quietly sail along the Danish coast with far less noise and vibration on board.

Profitability: DKK 81 million saved in operations each year

7 out of 10 Danish coastal ferries are more profitable as e-ferries. The ship owners can obtain operational savings of a total of DKK 81 million per year by replacing diesel-powered ferries by e-ferries.

Required additional investment

39 out of 52 ferries are more profitable after conversion to electrical propulsion. Such restructuring requires investments of approximately DKK 420 million more than investment in an equivalent number of traditional diesel ferries. However, the additional costs are quickly recovered as a result of the e-ferries' operational savings.

The investment consists mainly of building new ferries out of aluminum, a material that makes the ferries lighter, thus lowering the ferry's energy needs. In addition the investments also includes:

- Price of new batteries
- Cost of expanding the existing electricity grid locally to the port mooring
- Transformer costs for building charging stations in the port.

Operational savings

With clean, electrical operation, the ferry covers its entire energy consumption by electricity from the batteries. As the battery-driven aluminum ferries have a lower energy consumption than traditional diesel ferries, large savings are made in the cost of the ferry operation. And it should be noted that this is in a situation in which the prices of fossil fuels are historically low. The price of electricity is, on the other hand, characterized by higher degree of stability.

The shift from diesel engines to electric engines also helps to reduce maintenance costs in the engine rooms significantly and there will be less need for maintenance of the engine rooms along with service checks.

The substitution of 39 electrical ferries provides the following return:

- Operating and maintenance costs are reduced by DKK 81 million per year
- Fuel consumption is reduced from 19,000 tonnes a year to 0.

Total return of DKK 35 million per year

If the required additional investment is compared to the operational savings, the savings exceed the costs. Based on the study's 10-year analysis period, electrification will give a return on investment of DKK 35 million per year.

Increased attractiveness without PSO

The total price of electricity for ferries consists of three parts: the price of pure market electricity, distribution tariffs and public service obligations (PSO). The analysis' calculation of the profitability of the conversion from diesel to battery operation is including the controversial PSO levy, which for the 4th quarter is set at DKK 0.221 per kWh.

As a majority in the Danish parliament has agreed to move the PSO away from electricity bills to the Finance Act, the e-ferries' operating costs are further reduced.

This increases the financial attractiveness of the investment. In the event of phasing the PSO out, even more Danish ferries will become profitable from conversion to electrical operation.

The study's calculations show that in this case as many as 80% of Denmark's coastal ferries will be more profitable when electrically operated. An exemption from PSO will thus result in total operational savings at DKK 91 million per year, and the return on investment increasing to as much as DKK 45million per year.

After 5.5 years, the operational savings will exceed the costs of electrification. It should be noted that this with an electricity price in which the PSO levy has not yet been phased out.

The world's first electric car ferry is already in operation – with more on the way

With investments in electrical ferries in both Norway and Finland, Scandinavia is the first region in the world to be investing in clean and environmentally friendly battery powered ferries.

The world's first fully electric car ferry has been in operation in Norway since March 2015. Installed with batteries and electrical motors, rather than diesel engines, the e-ferry Ampere has now taken passengers back and forth across Sogne Fjord for a distance that is equal to more than 1.5 times around the world.

While the passengers embark and disembark from the ferry, the batteries are quickly charged in port by electricity from renewable energy sources, which means that the ferry is CO_2-neutral. Approximately one million liters of diesel is saved every year.

In the wake of Ampere's success, Siemens has received orders for another three e-ferries in Finland and Norway. Furthermore, the environmentally-friendly solution is now supported at a political level, as the Norwegian parliament has asked the government to take appropriate measures to ensure that all new ferries use emission-neutral technologies.

This makes Scandinavia a world pioneer in investment for battery-powered and environmentally-friendly technologies in the maritime transport sector.

Data collection and method

For the evaluation of the potential of electrical ferries, the actual operating experiences from Ampere's battery technology have been used as a starting point for the analysis of the Danish routes.

In order to be able to evaluate the potential for electric ferries, there has been a need for knowledge of the existing Danish ferries. Information on ferries' timetables, installed power, dimensions, operational profiles and speed has been gathered from the Danish Register of Shipping, Statistics Denmark and from dialog with the individual shipping companies. Based on this information, we have calculated the ferries' energy needs in the form of diesel consumption.

In order to calculate the potential benefits from electrification, started with the real experience from an e-ferry in operation: Ampere.

The experience gained from Ampere's battery technology has been used as a basis for the calculation of costs and savings for its ferry route, which we have scaled out for the Danish routes. As there may be great variation between the ferries, the calculations are estimates and can therefore not be regarded as absolute. In the study, we have excluded international routes and long express routes, where the speed requirement differs from the conditions used in our analysis model.

The study's financial analysis considers the profitability of electrical ferries. We do this by comparing the cost and savings respectively from a diesel ferry and an e-ferry.

The following parameters are included in the economic analysis:

- Investment costs: New aluminum ferries, batteries, establishment of onshore connections in the port, expansion of the electricity grid.
- Operational costs
- Maintenance costs

In the calculation of the additional investment, we calculate from the supposition that all new e-ferries will be built of aluminum, because the lighter material reduces the ferry's energy needs.

These costs are included in the study's conclusion. In the same way, the amount of energy that must be taken from the national grid during fast charging is also reduced, thus providing operational savings.

A prerequisite for the ferries' purely electrical propulsion is that there is access to the necessary amount of energy for charging in the port. A dialog with the power companies has given us data about the distribution network at all ports. From here we have calculated how much the grid needs to be expanded to enable the ferries to charge while docking. Acknowledging that the ferries have different energy needs, our calculation of additional investment has included an estimation of what it will cost to lay cables at a minimum of 10 kV to the dock.

The calculations show that if the ferries are electrified, they will have an annual energy need of 45 GWh. This represents 0.3% of Denmark's electricity production from wind turbines in 2015 – or what can be easily covered by energy production from 2 new 7 MW wind turbines at an appropriate location, such as the Baltic Sea.

In the analysis we have used an inflation-adjusted discount rate of 7.1%. The analysis assumes that all the investment is carried out in the year zero and will be distributed over the analysis period. As the ferry and power grid's lifetimes are estimated to be 30 and 40 years respectively, the investment costs are adjusted with the scrap values at the end of the analysis period.

Conclusion

The study's main conclusion is that 7 out of 10 ferries will be more profitable if current ferries are replaced with green, electrical ferries.

From the calculations, we can conclude that 39 out of 52 of the Danish coastal ferries – operating at 30 different routes – are more profitable on electric operation on their respective routes, compared with diesel operation. In fact, the green conversion will give companies a return of a total of DKK 35 million per year over a 10-year period. The reason is that the operational savings from e-ferries reach as high as DKK 81 million a year, which outweighs the costs of the required additional investment.

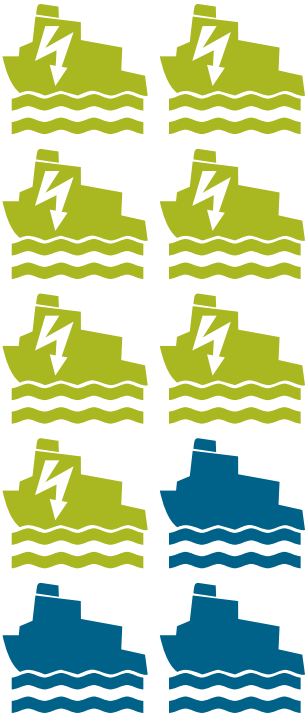
If Denmark succeeds in electrifying these ferries, the environmental gains will be significant. The study shows that the potential for reducing the ferries' CO_2 emissions amounts to 50,000 tonnes per year.

At the same time, the replacement will almost eliminate air pollution from NOx and SOx in coastal towns and natural areas, benefiting the environment and residents.

With the transition to electricity, the ferries will have an annual energy need of 45 GWh, which can be covered by the energy production from just two large wind turbines. This would not only save 19,000 tonnes of fuel per year, but it also illustrates how the energy sector and transport sector in future can collaborate through electrification, while the expansion of renewable energy sources continues.

Several Nordic countries have realized the financial and environmental benefits, and fully electric ferries are already in operation in both Norway, Sweden and soon Finland. It is time that Denmark also exploits the technologies, so the transition to electricity in the maritime transport sector can be implemented. If we are to achieve climate Denmark's political objective to be fossil fuel-free before 2050, there is a need to consider the interaction between energy supply and energy usage. Here, the e-ferries carry an unrealized, realistic potential that simultaneously makes sense financially.

7 out of 10 ferries are more profitable after conversion to electrical propulsion.



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