The Eco-Island ferry project

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During recent years a number of small ferries have been built for the Danish archipelago, and each time shipyards were invited to tender for a contract, we discussed if it was possible to come up with an project for building a ferry of carbon fibre composite (CFRP). We were certain that the weight reduction obtained by using the lightest materials would reduce fuel consumption by one third of that of a comparable steel ferry.

The requirements for new ferries were that they should be built according to the EC Directive 2009/45/EC (the Ferry Directive) [2] [3], which said that they must be built of steel.

These discussions resulted in the ECO-Island project. The ECO-Island Ferry is defined as a ferry built of light weight carbon fibre sandwich materials (CFRP), where the weight savings on the hull are used solely for reducing fuel consumption and thereby lowering the environmental impact (CO_2 footprint).

In late 2010/early 2011 a group of small Danish and Swedish companies set up the ECO-Island project. The aim of the project was to compare an existing steel ferry with the alternative design of the ECO-Island ferry both with the same payload and speed.

1. To demonstrate that by reducing the weight of the hull structure of a smaller vessel a significant reduction in fuel consumption and environmental impact can be achieved (*by designing a new CFRP ferry and calculating the fuel consumption).*

2. To show by calculating the accumulated cost of the vessel in its entire service life, that there will be an economical benefit from selecting the more expensive composite material *(by performing a complete life cycle cost analysis (LCCA) for the two ferries).*

3. To show by calculating the accumulated environmental impact of the vessel in its entire service life – including disposal/decommissioning of the vessels – that there will be a similar reduction compared to the traditional steel vessel *(by performing a complete life cycle analysis (LCA) for the two ferries).*

4. To perform the required and relatively new approval procedure for vessels built from other materials than steel and obtain a formal approval from the maritime authorities *(by performing a full-scale fire risk analysis based on approval of the carbon fibre composite ferry).*

5. To inspire ship owners, shipyards and designers to consider light weight materials when fuel consumption and environmental impact have high priority *(by publishing all project documentation and findings as widely as possible).*

The correlation between the weight of a transported load (ship + cargo) and the required power (horsepower) is well-known. The lighter the vessel, the greater the payload that can be transported using the same amount of power.

Other sectors of the transportation industry has been very well aware of this fact for years and are constantly striving to design lighter transportation vehicles.

Increasing fuel costs and environmental issues have become key factors in modern shipbuilding, and it is therefore relevant to look for new methods to improve efficiency – also for vessels. Upcoming requirements from IMO will classify vessels above 400 GT according to their *energy efficiency design index* – EEDI. The new IMO regulations will be implemented from 2013 to 2025. These requirements will most likely – in a modified form – include smaller vessels too. A lighter vessel will have relatively higher energy efficiency than a heavier one.

Traditionally, vessels have been built in steel or – to a certain degree – aluminium. The choice of composite materials as the main structural materials for a vessel hull is necessary in order to reach higher speeds with the same amount of power, or to carry a larger payload with the same displacement.

A ship hull built of carbon fibre sandwich (CFRP) weighs only approximately 1/3 of a steel hull with the same displacement. Even if the equipment and installations of the ship are the same as those of a similar steel vessel, the lighter vessel will require substantially less engine power to transport the same payload at the same speed. But a carbon fibre ferry has a higher initial cost than a similar steel ferry, and the legislation in general requires or expects vessels to be built from steel or other non-combustible material.

The purpose of the Directive is to implement as many relevant requirements as possible from the SOLAS Convention for smaller domestic passenger vessels. The legal wording of the directive, however, has missed a possibility given in the SOLAS Convention in 2002 [12]. By applying an approval procedure called "risk analysis based approval" it is possible to build vessels in other materials than "steel or equivalent (non-combustible material)". The Ferry Directive stresses that it only applies to vessels built of "steel or equivalent", whereas the use of alternative materials is only mentioned in the Annex.

These conditions have been confirmed by both the Danish and the Swedish shipping authorities. So if we wish to build a modern ferry in carbon materials today there are 3 options:

- To build a ferry according to national legislation, which means the cheapest ferry, but also a ferry that cannot be exported to other EU countries as such.

- To build a ferry according to the requirements of the SOLAS Convention. This means a considerably more expensive ferry, since the set of rules are worded for ferries in world-wide and unrestricted service.

- To build a ferry according to the HSC code rules. A set of rules permitting the use of other materials than steel, but at the same time including the precondition that the ferry can sail at a certain required minimum of (high) speed. Along with the demand for high speed follows the demand of increased manning. Both conditions make the set of rules irrelevant in this context.

Consequently, we conclude that the EU Directive in its present form limits the development of modern energy efficient and environmentally friendly ferries and should be adjusted accordingly in order to provide the same possibility to apply alternative constructions and materials as the SOLAS Convention. It is the intention of the ferry directive to implement as many of the SOLAS requirements and provisions as possible.

The Project

The ECO-Island project was organised under MARKIS, a Scandinavian organisation whose objective is to support sustainable shipping and green growth in the field maritime business and to create attractive maritime innovation environments in the Skagerrak & Kattegat region.

The project group consisted of:
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Kockums, Henrik Johansson
Aalborg Universitet: Henrik Riisgaard
2.-0 LCA Consulting: Jannick H. Schmidt
Danish authorities: Søfartsstyrelsen
Swedish authorities: Transportstyrelsen
MARKIS
Municipality of Odder

Sponsors:
The Danish Maritime Fund
SP Technical Research Institute of Sweden
Region Västra Götaland

Re point 1

We looked for an existing ferry and asked the Municipality of Odder in Denmark, if they would help us by giving us access to the available information on their “Tunøfærgen” (Tun island ferry) as a reference ferry in our project. They accepted and were very helpful.
The ferry was designed and together with the staff from SP and the other partners, the General Arrangement [6] and outline specification [5] was worked out in detail, with fire safety as a first priority.
A catamaran hull was chosen to obtain maximum stability [10], and an acceptable draft with enough lateral resistance to obtain minimum leeway in windy conditions. The draft of the new catamaran hull was 1.4 m, compared to our reference ferry, Tunøfærgen, at 2.1 m.
One of the challenges designing the hull was to avoid too much trim when a lorry was driving on board. When the weight of the ferry is very small, the longitudinal centre of gravity (LCG) is easily moved by moving the cargo. This could give the ferry a disadvantageous trim.
By giving the aft part of the hull an overhang, the change in water plane area with the draft is very big and the consequence is reduction of trim.
The numbers below (fig. 1) were used to compare structural weight. The weight of reference ferry build in steel is shown as 100 %. The same ferry in other materials would have a structural weight in % of the steel ferry as shown below in fig. 1, and for the ECO-Island ferry our estimate began with a structural weight of 31-37 % of a steel ferry with the same capacity.

After a total scantling of the whole structure, the ferry ended up with a structural weight a little lower than expected, and the hull resistance required smaller engines and smaller fuel tanks. Once again additional reduction of weight resulted in smaller displacement.

For the design the light weight ferry three principles were used:

a. Light weight materials all over
b. Minimalistic accommodation and small structures all over
c. Every thing that can be left ashore must be left ashore.

Overall structural weight	[%] [%]
Steel	100
Aluminium	67 - 56
E-Glass/foam sandwich	52 - 43
Carbon/foam sandwich	37 - 31

Fig. 1

The structural design [8] was made according DNV HSLC code. Winter conditions have been taken into consideration, and an ice zone with extra reinforcement of the hull shell and increased density of the core material is part of the design. This will offer protection against impact from ice, and the use of this method for naval ships has been very successful.

The ECO-Island ferry was equipped with a stern ramp. Re point c. this should have been left ashore, but the Tunøfærgen was equipped with a stern ramp, and for the sake of comparability it was included in the design.

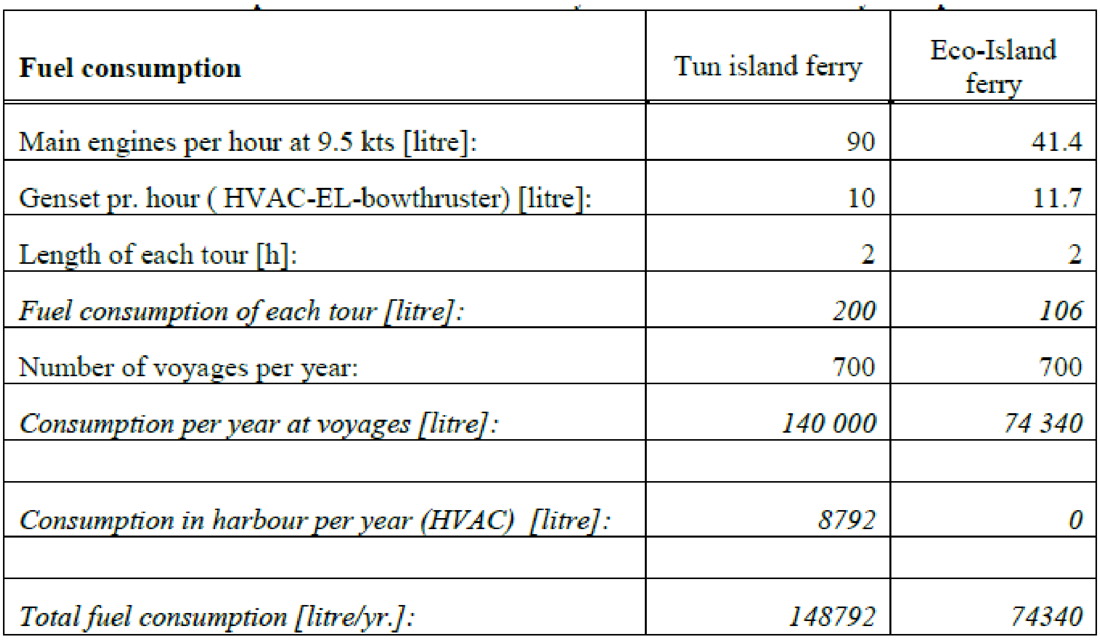
The car deck required special design, because of the big shear loads from the lorry tyres, and a corrugated sandwich was chosen to give the deck sufficient shear strength.

The fuel consumption for the Tunøfærgen was measured over a longer period of time by the chief engineer and the annual purchase was used as a control. For the ECO-Island ferry the fuel consumption was calculated using calculated resistance, the efficiency of the mechanical parts, the efficiency of the propellers and a normal sea allowance for this part of Denmark.

The heating on board was also included in the calculation, and the insulation of the hull shows a much better thermal insulation for the ECO-Island ferry than for the existing ferry. The sandwich core and the fire insulation gave a much smaller thermal loss, so small that there could be a risk of ice on desk in winter. A special design for the car deck construction had to be made, for melting ice on the deck. A thin aluminium plate with heating wires covering the whole surface of the car deck in order to avoid ice on deck was used. This also serves to protect the composite deck against stones in car tyre.

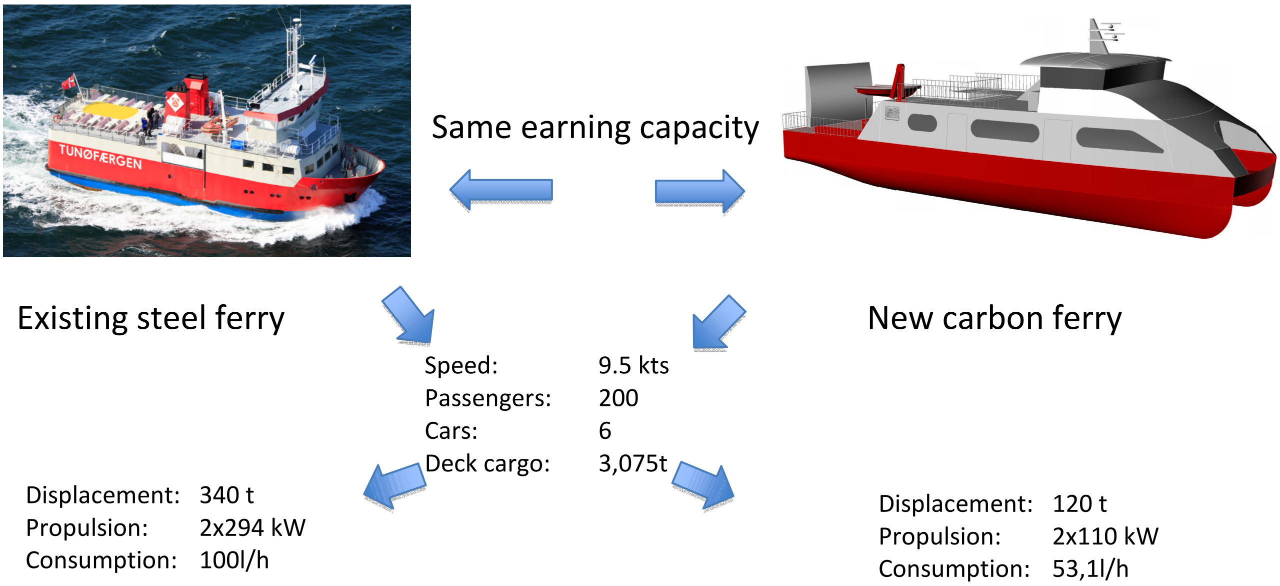
The result of the calculation was a reduction in fuel consumption for the ECO-Island ferry to about half of that of the reference ferry.

Fig. 2 and 3 shows the comparison between the two ferries.



Fuel consumption	Tun island ferry	Eco-Island ferry
Main engines per hour at 9.5 kts [litre]:	90	41.4
Genset pr. hour (HVAC-EL-bowthruster) [litre]:	10	11.7
Length of each tour [h]:	2	2
Fuel consumption of each tour [litre]:	*200*	*106*
Number of voyages per year:	700	700
Consumption per year at voyages [litre]:	*140 000*	*74 340*
Consumption in harbour per year (HVAC) [litre]:	*8792*	*0*
Total fuel consumption [litre/yr.]:	*148792*	*74340*

Fig. 2



Same earning capacity

Existing steel ferry

New carbon ferry

Speed: 9.5 kts
Passengers: 200
Cars: 6
Deck cargo: 3,075t

Displacement: 340 t
Propulsion: 2x294 kW
Consumption: 100l/h

Displacement: 120 t
Propulsion: 2x110 kW
Consumption: 53,1l/h

Fig. 3

Re point 2

A complete life cycle cost analysis (LCCA) for the two ferries was carried out by SP Technical Research Institute of Sweden.
Thus the design group had documentation for the comparison from an independent company.
Danish shipyards were asked to come up with an offer for two newbuildings, and the price for the ferries were 4.6 M€ for the Tunøfærgen and 5.2 M€ for the ECO-Island ferry.

The maintenance costs for the two ferries were quite different, especially after the first ten years, where those of the steel ferry were escalating. The numbers used are 71,000 €/y for the Tunøfærgen and 35,000 €/y for the ECO-Island ferry.

Today the existing Tunøfærgen travels approximately two return trips per day, leading to a daily operating time of 4 hours.

The accumulated costs for the two ferries during the whole life cycle are shown in the diagram below (fig. 5).

As shown in the diagram the Tunøfærgen option has the lowest accumulated costs in the beginning, because of the lower production costs. The break-even point is after 10.6 years, whereof 8.6 are in operation. In total the Eco-Island ferry has the lowest accumulated costs after the total life cycle. The difference at the end of the life cycle in present value is M€ 1.3 in favour of the Eco-Island ferry.

A sensitivity analysis was carried out and the effect of different parameters for the operating phase has been investigated. The interest rate, fuel price, operating hours, maintenance costs and rest value. The Tunøfærgen was found to be the cheapest option in a short perspective. However, after a number of years the accumulated costs of the Eco-Island ferry equal those of the Tunøfærgen, and at the end of the life cycle the lightweight ship was found to have the lowest total cost. The more the ferry is used, and the higher the fuel price, the more favourable the Eco-Island ferry becomes.

One parameter that was not taken into account in the LCCA was the importance of the draft. The fact that the draft of the Tunøfærgen is 2.1 m and 1.4 m for the ECO-Island ferry could lead to alternative choice of route and a saving of 3.2 nm/day. The saving on fuel consumption would have a smaller impact on LCCA.

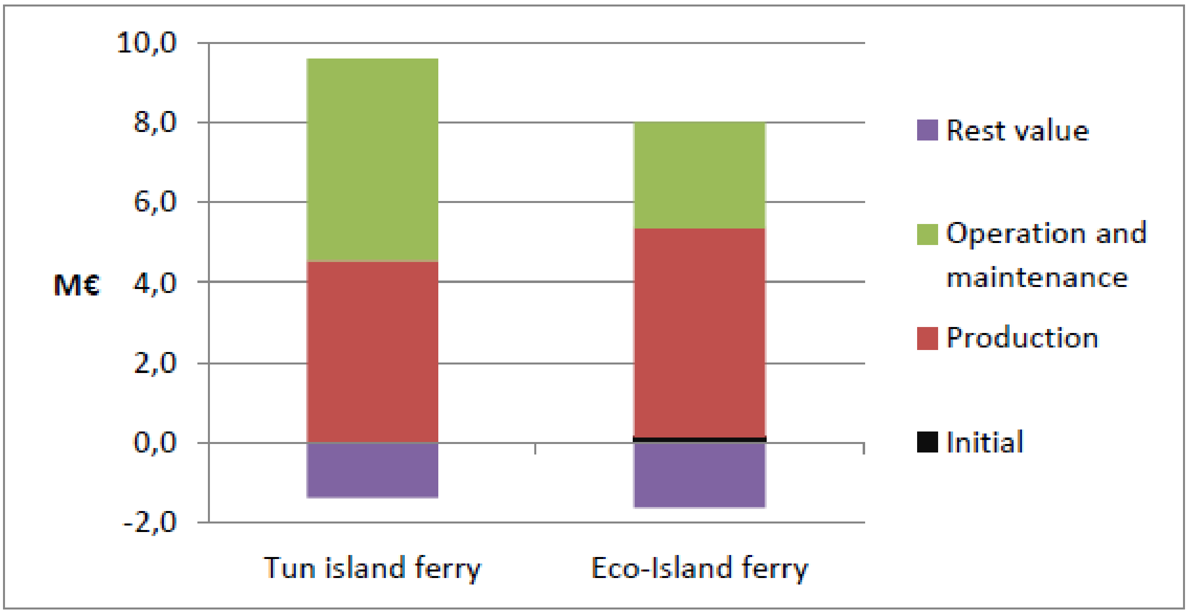


Fig. 4

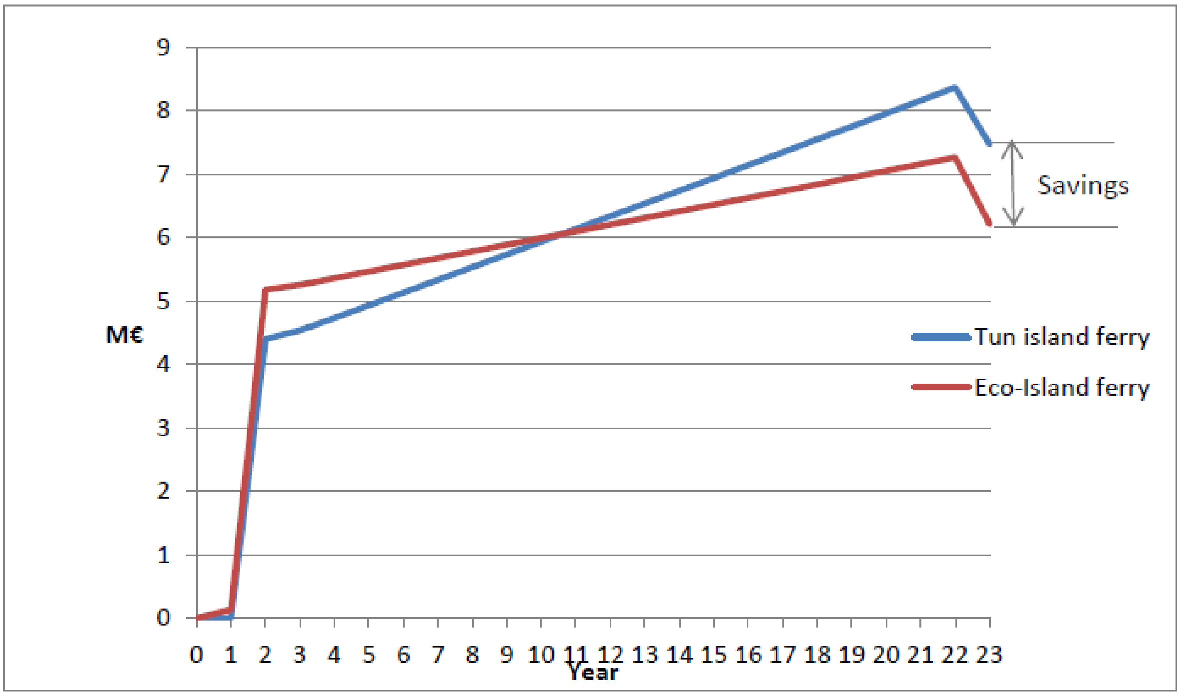


Fig. 5.

Re point 3

2.-0 LCA Consulting: Jannick H. Schmidt carried out the life cycle assessment in accordance with the ISO standards on LCA: ISO 14040 (2006) and ISO 14044 (2006) [13]. In this way the design group had documentation for the comparison from an independent company, and the report is checked by Henrik Wenzel, Professor at University of Southern Denmark.
The report studies the environmental performance of the two ferry alternatives, including the emissions related to the production of construction materials and to engine size, energy savings resulting from the lower weight of the ferry, and the waste handling at the end-of-life of the ferry. The data sources for background data comes from Ecoinvent and DK and EU27 hybrid IO-database.

Generally, the ecoinvent database v2.2 (ecoinvent 2010) was used for the upstream product system relating to the production of materials, energy, capital goods as well as treatment/recycling of waste/scrap. The ecoinvent database is the most comprehensive transparent LCA database on the market. The database is fully linked (no black box processes) in the LCA software (SimaPro), and the full documentation of all data in ecoinvent are publically available at http://ecoinvent.org/.
It appears from the comparison of the overall characterised results that the Eco-Island Ferry performs better than the Tunøfærgen for all impact categories. Generally, the impacts related to the life cycle of the Eco Island Ferry are around half of those of the Tunøfærgen. The reason for this is related to the reduced fuel consumption of the Eco Island Ferry (see fig. 6).
The applied end-of-life scenario (fig. 7) represents the current estimated waste disposal/recycling of a ferry. Two scenarios have been carried out; one in which recycling of polymers is maximised and one in which polymers are sent to landfill. Disposal of other materials (mainly steel) has not been changed, since the current practise of steel recycling is well established. The only new technology/material being introduced is the polymers (the composite materials). It should be noticed that it is assumed that the carbon fibre cannot be recycled for the time being.

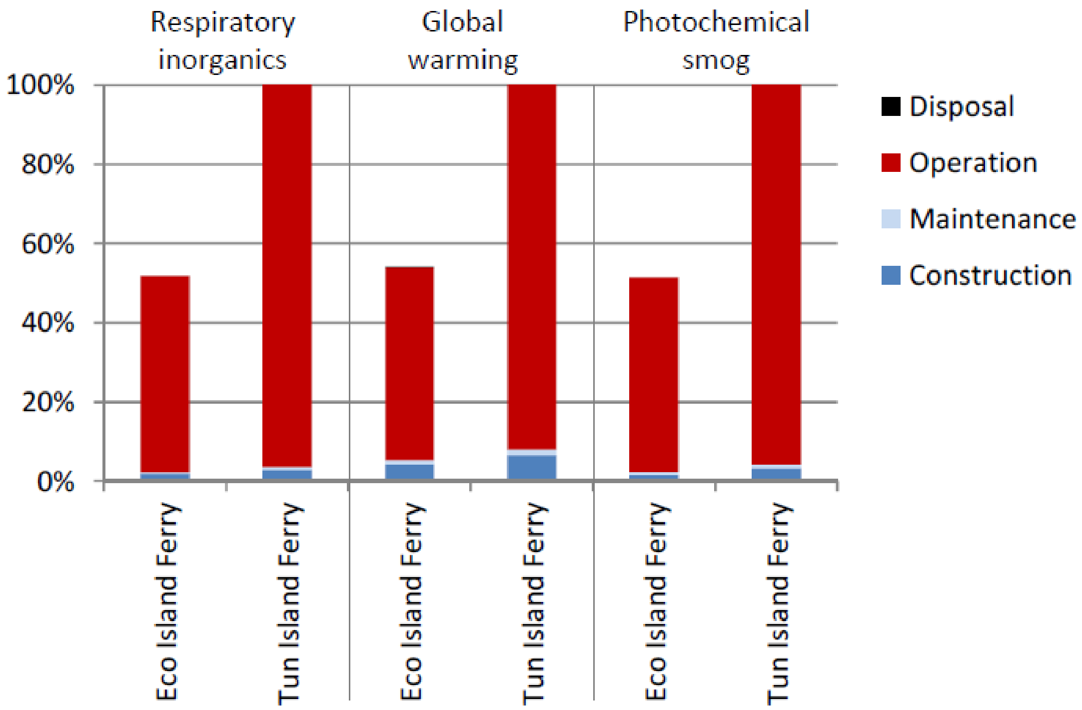

Respiratory inorganics
Global warming
Photochemical smog
100%
80%
60%
40%
20%
0%
Eco Island Ferry
Tun Island Ferry
Eco Island Ferry
Tun Island Ferry
Eco Island Ferry
Tun Island Ferry
Disposal
Operation
Maintenance
Construction

Fig. 6

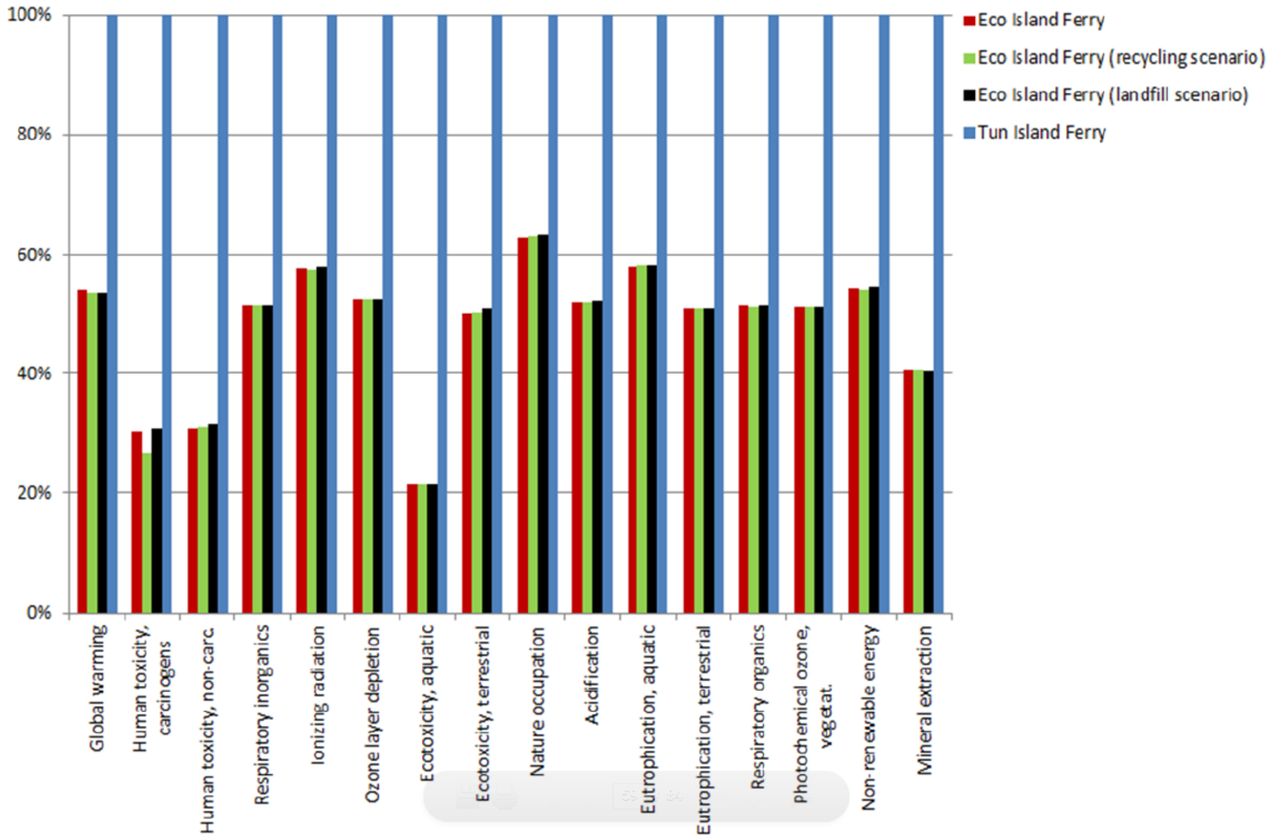

100%
80%
60%
40%
20%
0%
Eco Island Ferry
Eco Island Ferry (recycling scenario)
Eco Island Ferry (landfill scenario)
Tun Island Ferry
Global warming
Human toxicity, carcinogens
Human toxicity, non-carc
Respiratory inorganics
Ionizing radiation
Ozone layer depletion
Ecotoxicity, aquatic
Ecotoxicity, terrestrial
Nature occupation
Acidification
Eutrophication, aquatic
Eutrophication, terrestrial
Respiratory organics
Photochemical ozone, vegetat.
Non-renewable energy
Mineral extraction

Fig. 7

Re point 4

The document: Procedure outline of engineering analysis required by Regulation 17 [4], describes the procedure of the full-scale fire risk analysis:
SOLAS chapter II-2 (part F) Regulation 17 (hereafter referred to as Regulation 17) states that fire safety design and arrangements may deviate from the prescriptive requirements set out in parts B, C, D, E or G, provided that the design and arrangements meet the fire safety objectives and functional requirements of the regulations. When fire safety design or arrangements deviate from the prescriptive requirements, an engineering analysis shall be carried out based on the guidelines in MSC/Circ.1002. These guidelines describe the use of a deterministic performance-based approach based on fire safety engineering to verify that the fire safety of the novel design is at least equivalent to that stipulated in the regulations, often referred to as the “equivalence principle”. Since there are no general explicit criteria for the required level of fire safety, the fire safety in the alternative design needs to be compared to that of a prescriptive design. Accordingly, the prescriptive design is used as a reference design, complying with the fire safety requirements in parts B, C, D, E and G of SOLAS 2009 chapter II-2. The documented level of fire safety of the alternative design is therefore not absolute, but relative to the implicit fire safety of a traditional design, which is likewise a product of the implicit fire safety level in prescriptive regulations. Accounting for uncertainties when comparing levels of fire safety, the engineering analysis based on MSC/Circ.1002 should demonstrate that the alternative design and arrangements with reasonable confidence has a fire safety equivalent to, or better than, that of a prescriptive design.
Briefly, the procedure outline of the engineering analysis outlined in MSC/Circ.1002 and required when laying claim to Regulation 17 can be described as follows:

- *A design team is formed.* Together the members of this design team shall have all necessary competences to perform the engineering analysis.
- *A preliminary analysis in qualitative terms is conducted.* This analysis includes definitions of scope, development of design fire scenarios and development of trial alternative designs.
- The analysis is documented in a Preliminary Analysis Report which shall be submitted to the Administration for consideration before a quantitative analysis is initiated.
- *A quantitative analysis is conducted.* This analysis includes a quantification of the design fire scenarios, development of performance criteria and an evaluation of the trial alternative designs.

The final documentation from the regulation 17 analysis shall demonstrate whether an equivalent safety level has been obtained for the alternative design.

The first part of the regulation 17 analysis “Franz Evegren, Michael Rahm; Preliminary analysis report Eco-Island-Ferry_STA_final; SP Technical Research Institute of Sweden” is finished and accepted by the national authorities. This part of the documentation will not be public in the full content, but will be accessible in a revised edition.
The quantitative analysis is not yet examined by the national authorities, but will subsequently be accessible also in a revised edition.

Re point 5

www.eco-island.dk and
www.eco-island.se

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