POLICY IMPLICATIONS OF CO_2 EMISSIONS FOR ISLAND FERRY SERVICES

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1. INTRODUCTION

1.1 Background

The primary aim of The Climate Change (Scotland) Act 2009[1] is reducing greenhouse gas emissions and transitioning to a low carbon economy with the intention of helping to create a more successful country, through increasing sustainable economic growth. The Act creates a framework for setting reduction targets, putting in place measures to achieve these targets and reporting on progress.

The Carbon Account for Transport[2] meets a commitment contained in the National Transport Strategy[3]. The Carbon Account for Transport helps government to take decisions and develop actions to meet the targets in the Climate Change (Scotland) Act 2009, by providing a structure for monitoring and reviewing progress towards achieving the 'reduced emissions' Strategic Outcome for transport.

In light of this legislation the St Margaret's Hope Pier Trustees (SMHPT) commissioned TRI together with Pedersen Consulting (TRI, 2011a; TRI, 2011b) to undertake research to investigate and compare the relative performance of alternative ferry services between the Scottish mainland and Orkney, together with surface transport connections, in terms of greenhouse gas emissions.

The two principal ways in which passengers may be transported by surface transport modes to/from Orkney are considered. These are:

- By road (i.e. car or bus) or rail to Aberdeen and then by sea to Orkney (Kirkwall), and vice versa, and;
- By road (i.e. car or bus) or rail to either Scrabster or Gills Bay in Caithness and thence by sea across the Pentland Firth to Orkney, and vice versa.

There tends to be a general perception that sea transport is more energy-efficient than land or air transport (Mellin & Rydhed, 2011), though other researchers have questioned this assumption (Eide, et al., 2009). Indeed, Hjelle (2011) found that Ro-Ro (i.e. ferry) transport was not a good alternative to land transport from an energy use and emissions perspective. In fact, this issue requires careful analysis in each situation as specific ship and route emission impacts differ quite significantly and will depend on a range of factors, in particular route distance, ship capacity, service speed, engine

power and average work load, type of fuel used, and fuel consumption (Sjodin et al, 2007). This suggests that each sea transport service has to be evaluated in its individual context which is the approach taken here.

1.2 Methodology

The study first calculates sea transport CO_2 emissions and fuel consumption for specific ferries serving the three sea routes connecting mainland Scotland and Orkney, and apportions this on a per passenger and per car basis calculated using recent ferry load factors derived from available data, (section 2). Then, overland transport CO_2 emissions and fuel consumption levels for each route taking into account a common inland destination (in this instance Edinburgh), are calculated per passenger for public transport (bus and rail) and on a per car basis, for each ferry route option (section 3). To broaden out the analysis we also estimate the comparative CO_2 emissions per passenger for air transport.

Thereafter, by summing both overland and sea transport legs, the overall total level of CO_2 emissions and fuel consumption per trip is calculated on per passenger and per car, bus and train basis for each route (section 4). The results and implications of the findings are summarised and conclusions presented (section 5).

2. SEA TRANSPORT EMISSIONS

2.1 Ship data

The analysis considers CO_2 emissions and fuel consumption for three ships (Figure 1) each serving different routes between mainland Scotland and Orkney (Figure 2), as follows:

- NorthLink's *Hjaltland* (and hence also the respective sister ship *Hrossey*) offering 3 southbound and 4 northbound trips weekly on the 248 km route between Aberdeen (ABZ) and Kirkwall (KOI);

- NorthLink's *Hamnavoe* offering 2-3 return trips daily on the 52 km route between Scrabster (Caithness) (SCR) and Stromness (STR); and

- Pentland Ferries' *Pentalina*, offering 3-4 return trips daily on the 28 km route between Gill's Bay (Caithness) (GBY) and St. Margaret's Hope (SMH).

Table 1 presents ship capacity and engine power data for all three vessels studied. *Hjaltland* has capacity for up to 125 cars and 600 passengers, with installed power of 21,600 kW. *Hamnavoe* has capacity for up to 95 cars and 600 passengers, with installed power of 8,680 kW. *Pentalina* can carry up to 75 cars and 250 passengers, and has installed power of 3,876 kW.

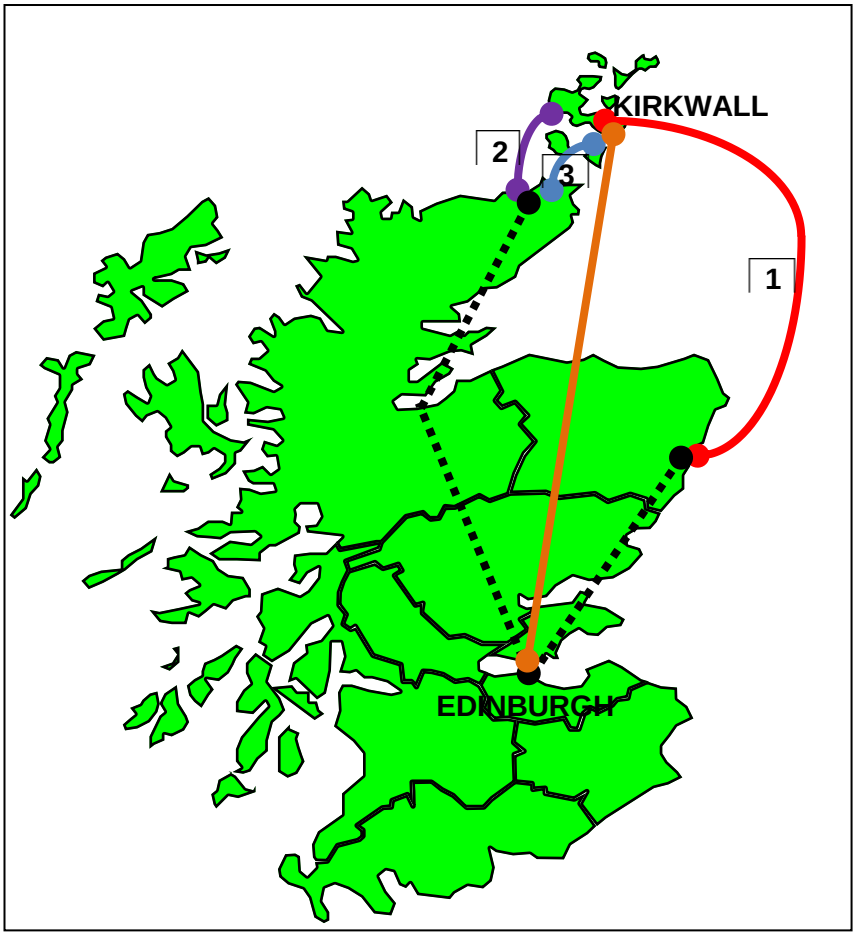
Figure 1: Ships analysed in the study

MV *Hjaltland/Hrossey* (NorthLink Ferries, Aberdeen - Kirkwall/Lerwick)

MV *Hamnavoe* (NorthLink Ferries, Scrabster - Stromness)

MV *Pentalina* (Pentland Ferries, Gill's Bay – St. Margaret's Hope)

Figure 2: Map of routes evaluated



(1) Aberdeen-Kirkwall

(2) Scrabster-Stromness

(3) Gill's Bay-St. Margaret's Hope

Road/Rail (to/from Edinburgh)

Air (Kirkwall-Edinburgh)

Table 1: Vessel capacities, power and speed

Vessel	Route	CAPACITY			Installed	Speed
		Trailers	Passengers	Cars	Power (kW)	(Km/hour)
Hjaltland(N'bnd)	ABZ-KOI	24	600	125	21,600	44
Hjaltland(S'bnd)	KOI-ABZ	24	600	125	21,600	30
Hamnavoe	SCR-STR	20	600	95	8,680	33
Pentalina	GBY-SMH	9	250	75	3,876	30

Sources: Scottish Ferries Review 2010; Pentland Ferries.
ABZ=Aberdeen; GBY=Gill's Bay: SMH=St. Margaret's Hope; KOI=Kirkwall; SCR=Scrabster; STR=Stromness

There is clearly a large engine power difference between *Hjaltland* and the other two ships. *Hjaltland's* installed power of 21,600 kW is over five times as much as *Pentalina*, albeit the latter has 60% of *Hjaltland's* car capacity. The requirement for such a large installed power on *Hjaltland* is due to the decision taken (by those responsible for setting the service specification) for the ship to maintain a high service speed of 24 knots (44 km/hr) on the northbound journey between Aberdeen-Kirkwall. On the southbound overnight crossing between Kirkwall and Aberdeen, *Hjaltland* and sistership take slightly longer running at a lower speed of about 16 knots (i.e. using 2 engines instead of 4).

Looking at ship carrying capacity on a daily basis provides a useful perspective here as the outcomes depend to a great extent on service frequency, which in turn is influenced by route distance as well as ship speed. As *Pentalina* offers up to 8 each way trips per day on the short Pentland Firth crossing compared with *Hjaltland's* single trip per day, this means that, while the latter provides a daily route capacity for 125 cars, *Pentalina* offers a total capacity of up to 600 cars/day (i.e. 8 trips x 75 cars). Moreover, *Pentalina* achieves this using less than one fifth of the installed power. *Pentalina's* daily passenger capacity is by the same token over three times greater than *Hjaltland*.

The ferry *Hamnavoe*, operating the Scrabster – Stromness route, has more than twice the power of *Pentalina*, for just a 22% difference in car capacity. However any car capacity advantage for *Hamnavoe* is also outweighed by the greater service frequency of *Pentalina*, the latter offering more crossings per week. This results in *Pentalina* actually providing about 10% more car capacity per annum than *Hamnavoe*, and with less than half the ship power employed.

Of the three ships in the study, although *Pentalina* is the smallest, she offers greater carrying capacity than the other two, thanks to a higher frequency and shorter route, and achieves this using substantially less engine power. All things being equal, this would be expected to translate into lower fuel

consumption and hence lower CO_2 emissions per car and per passenger carried. The remainder of the study tests this hypothesis.

2.2 Ship fuel consumption and CO_2 emissions by route

Table 2 provides calculations of fuel consumption for each ship per operating hour. The focus here is on main engine power and ignores generators[4]. Fuel consumption is based primarily on the following specific factors:

- Ship installed engine power
- Percentage of ship power applied, noted as 'maximum continuous rating' (mcr)
- Standard rate of fuel consumption of 200 gms/km/hour (or kg/km/hour)[5]
- A slightly higher mcr[6] is applied for ships serving on shorter crossings.

Estimated fuel consumption on this basis for *Hjaltland* northbound is 3,625 lt/hr, for *Hjaltland* southbound 2,034 lt/hr, for *Hamnavoe* 1,772 lt/hr, and for *Pentalina* 755 lt/hr.

Table 2: Calculated fuel consumption for each ship

	Hjaltland Northbound	Hjaltland Southbound*	Hamnavoe	Pentalina
Power-kw	21,600	10,800	8,680	3,700
mcr	73%	82%	89%	89%
kw/mcr	15,803	8,867	7,725	3,293
kg/kw/hr	0.2	0.2	0.2	0.2
kg/hr	3,082	1,729	1,506	642
lt/hr	3,625	2,034	1,772	755

Notes: mcr = maximum continuous rating

**Hjaltland* (southbound) assumed uses 2 of her 4 engines

Source: Own calculations, based on published data

Table 3 calculates CO_2 emissions for each route/ship for a single voyage. For *Hjaltland* and *Hamnavoe*, the analysis provides outcomes based on using either Heavy Fuel Oil (HFO) or Marine Diesel Oil (MDO). Our understanding is that these ships use cheaper HFO, despite HFO being 20% more polluting than MDO in terms of CO_2 emitted. In the case of *Pentalina* the focus is only on MDO as that vessel does not use HFO.

The analysis indicates that fuel consumption for a single trip by *Hjaltland* northbound amounts to 20,228 lt, and for *Hjaltland* southbound at a slower speed using two engines it is 17,024 lt. For *Hamnavoe*, a single crossing consumes 2,757 lt fuel, whilst for *Pentalina* the figure is 708 lt.

When burning HFO, *Hjaltland* northbound between Aberdeen-Kirkwall emits 65,133 kg of CO_2 per trip. If using MDO, *Hjaltland* would emit 54,048 kg CO2 per trip. Sailing southbound between Kirkwall-Aberdeen, *Hjaltland* emits an estimated 54,819 kg of CO_2 using HFO, and 45,489 kg CO_2 if using MDO.

Hamnavoe emits 8,877 kg of CO_2 per trip if burning HFO. If using MDO, *Hamnavoe* would emit 7,366 kg CO_2 per trip. By contrast, *Pentalina* emits 1,892 kg CO_2 per trip.

Thus, compared to *Pentalina* and the shortest sea crossing (i.e. Gill's Bay – St. Margaret's Hope), *Hjaltland's* CO_2 emissions per single crossing are between 28-34 times greater northbound, and 24-28 times greater southbound, while *Hamnavoe's* CO_2 emissions per Pentland Firth crossing are 4-5 times greater than that of *Pentalina*.

Table 3: Comparison of ship fuel consumption and CO_2 emissions by route

Vessel	Route	Sea Dist-km	Service Speed-km/hr	Lt/ Hour	Lt/ Trip	CO_2/Trip HFO (kg)	CO_2/Trip MDO (kg)
Hjaltland(N'bnd)	ABZ-KOI	248	44	3,625	20,228	65,133	54,048
Hjaltland(S'bnd)	KOI-ABZ	248	30	2,034	17,024	54,819	45,489
Hamnavoe	SCR-STR	52	33	1,772	2,757	8,877	7,366
Pentalina	GBY-SMH	28	30	755	708	NA	1,892

Sources: Scottish Ferries Review 2010; Pentland Ferries.
Notes:
ABZ=Aberdeen; GBY=Gill's Bay: SMH=St. Margaret's Hope; KOI=Kirkwall; SCR=Scrabster; STR=Stromness
Conversions by http://www.nef.org.uk/greencompany/ CO_2calculator.htm

MDO kg / litre	2.672	CO_2	MDO = Marine Diesel Oil
HFO kg / lt	3.220	CO_2	HFO = Heavy Fuel Oil

2.3 Ship fuel consumption and CO_2 emissions per car

Table 4 breaks the analysis down further to calculate emissions and fuel consumption per car carried. This assessment is based on actual traffic carried and average ship load factors for all vessels during 2010.

In order to apportion fuel consumption and hence CO_2 emissions across the different traffic carried, we have split fuel consumption into three equal parts as follows:

- One third relating to cars
- One third relating to passengers
- One third relating to freight (albeit freight is not considered here)

The rationale for this is that ship space is allocated, and hence revenues are derived from, these three distinct traffic flows. It is not considered possible to be absolutely precise with this apportionment; however, we consider the split to be broadly representative. We would note that, on *Hjaltland* and *Hamnavoe*,

two decks are used for passengers, whilst one deck (the latter equivalent to the height of two passenger decks) is used for vehicles (cars and trailers). Having a common approach to apportionment of fuel consumption and hence CO_2 emissions also provides for a more standardised assessment for each vessel. In effect the margin of difference identified between vessels will remain the same irrespective of the precise proportion of power allocated to each traffic category.

Table 4: Comparison of ship fuel consumption and CO_2 emissions per car carried

Vessel	Route	Cars/ Trip*	Lt/ Car/trip	CO_2/Car HFO (kg)	CO_2/Car MDO (kg)
Hjaltland(N'bnd)	ABZ-KOI	31	216	696	578
Hjaltland(Sbnd)	KOI-ABZ	31	182	586	486
Hamnavoe	SCR-STR	21	44	142	118
Pentalina	GBY-SMH	18	13	NA	34

ABZ=Aberdeen; GBY=Gill's Bay: SMH=St. Margaret's Hope; KOI=Kirkwall; SCR=Scrabster; STR=Stromness

*Based on following actual average 2010 load factors (%):

ABZ-KOI-LER	25	%
SCR-STR	22	%
GBY-SMH	25	%

Notes: Cars assumed to account for 33.333% of ship power/fuel consumption

Assumes one third fuel cons allocated each for cars, pax and freight.

ABZ-KOI load factor includes traffic for Lerwick carried via Kirkwall (but sea km to Kirkwall only).

For the Aberdeen-Kirkwall route we have included in our analysis traffic flows between Aberdeen-Lerwick so that the total traffic carried (i.e. via Kirkwall or otherwise) is taken into account. We do not consider it reasonable to exclude Shetland traffic as the latter is carried together with Orkney traffic on the Aberdeen-Kirkwall leg and vice versa. However, in our analysis the ship fuel consumption and CO_2 data calculations per passenger and car only relate to the Aberdeen-Kirkwall leg so as to provide a like-for-like comparison with the other by-sea routes between Scotland and Orkney.

Calculations are therefore based on actual average ship load factors for cars carried which we calculate as follows: 25% for Aberdeen-Kirkwall-Lerwick; 22% for Scrabster-Stromness; and 25% for Gill's Bay-St. Margaret's Hope. On this basis we estimate (for 2010) that *Hjaltland* carried an average of 31 cars/trip, *Hamnavoe* 21 cars/trip and *Pentalina* 18 cars/trip.

Assuming one third of ship fuel consumption relates to the transporting of cars (i.e. the car deck), we calculate that *Hjaltland* northbound consumes 216 lt/car, while *Hjaltland* southbound consumes 182 lt/car. On the shorter Pentland Firth crossings, we calculate that *Hamnavoe* consumes 44 lt/car, while *Pentalina* consumes 13 lt/car.

In terms of related CO_2 emissions, *Hjaltland* northbound therefore emits 696 kg CO_2 per car carried if burning HFO (or 578 kg CO_2 per car if burning MDO). Southbound, *Hjaltland* emits 586 kg CO_2 if burning HFO (or 486 kg CO_2 if burning MDO). On the Pentland Firth, *Hamnavoe* emits 142 kg CO_2 per car carried if burning HFO (or 118 kg CO_2 if burning MDO. By contrast, *Pentalina* emits just 34 kg CO_2 per car carried.

This therefore means that *Hjaltland* northbound emits 17-20 more CO_2 per car compared with *Pentalina*, and southbound between 14-17 times. On the shorter Pentland Firth crossing, *Hamnavoe* emits 3-4 times the levels of CO_2 per car carried compared to *Pentalina*.

2.4 Ship fuel consumption and CO_2 emissions per passenger

Assessment of ship CO_2 per passenger carried follows a similar approach to the analysis above for cars. Again we assume one third of total fuel consumption is related to passengers, per single voyage. Similarly we also base the calculations on 2010 traffic volumes carried and estimated load factors.

For *Hjaltland* and the longer Aberdeen-Kirkwall route (inclusive of passengers carried on the Aberdeen-Kirkwall leg then to Lerwick) we calculate an average passenger load factor of 33% which equates to 203 passengers carried/trip. For *Hamnavoe* the load factor of 12% equates to an average of 71 passengers per trip. And for *Pentalina*, a load factor of 18% implies 45 passengers carried per trip. Again these figures are based on actual carryings and number of sailings per annum.

From Table 5 we can see that *Hjaltland* northbound has a fuel consumption rate of 33 lt per passenger, while southbound the equivalent figure is 28 lt per passenger. *Hamnavoe* has a fuel consumption of 13 lt per passenger carried, while *Pentalina* has a figure of 5 lt per passenger.

In terms of CO_2 emissions, *Hjaltland* northbound emits 107 kg CO_2 per passenger carried if burning HFO (or 89 kg CO_2 for MDO). For *Hjaltland* southbound the comparative figure is 90 kg CO_2 per passenger carried if burning HFO (or 75 kg CO_2 for MDO. For *Hamnavoe*, the level of CO_2 emissions equates to 42 kg CO_2 per passenger carried if using HFO (or 35 kg CO_2 for MDO). For *Pentalina* the comparable figure is 14 kg CO_2 per passenger carried.

To calculate ship CO_2 emission for a car and accompanying passenger the data shown above needs to be summed (i.e. to provide an emission figure per car *and* passenger). The result is shown in Table 6.

The combined figure indicates for *Hjaltland* (N'bnd) that a car + Passenger has total ship fuel consumption per trip of 249 lt fuel with CO_2 emissions (for HFO) of 803 kg (666 kg for MDO). For *Hjaltland* (S'bnd) the comparable figures are 210 lt fuel and 676 kg CO_2 (HFO) per car + Passenger (561 kg if MDO).

Table 5: Comparison of ship fuel consumption and CO_2 emissions per passenger carried

Vessel	Route	Pax/ Trip	Lt/ Pax/trip	CO_2/Pax HFO (kg)	CO_2/Pax MDO (kg)
Hjaltland(N'bnd)	ABZ-KOI	203	33	107	89
Hjaltland(Sbnd)	KOI-ABZ	203	28	90	75
Hamnavoe	SCR-STR	71	13	42	35
Pentalina	GBY-SMH	45	5	NA	14

ABZ=Aberdeen; GBY=Gill's Bay: SMH=St. Margaret's Hope; KOI=Kirkwall; SCR=Scrabster; STR=Stromness

*Based on following actual average 2010 load factors (%):

ABZ-KOI-LER	34%
SCR-STR	12%
GBY-SMH	18%

Notes: Passengers assumed to account for 33.333% of ship power/fuel consumption
Assumes one third fuel cons allocated each for cars, pax and freight.
ABZ-KOI load factor includes traffic for Lerwick carried via Kirkwall (but sea km to Kirkwall only).

Table 6: Comparison of ship fuel consumption and CO_2 emissions per car and accompanied passenger carried

Vessel	Route	Lt/Car& Pax/trip	CO_2/Car&Pax HFO (kg)	CO_2/Car&Pax MDO (kg)
Hjaltland(N'bnd)	ABZ-KOI	249	803	666
Hjaltland(Sbnd)	KOI-ABZ	210	676	561
Hamnavoe	SCR-STR	57	184	153
Pentalina	GBY-SMH	18	NA	48

ABZ=Aberdeen; GBY=Gill's Bay: SMH=St. Margaret's Hope; KOI=Kirkwall; SCR=Scrabster; STR=Stromness

*Based on actual average 2010 traffic carried and load factors (%):

Notes: Assumes one third of fuel consumption allocated each for cars, pax and freight.
ABZ-KOI load factor includes traffic for Lerwick carried via Kirkwall (but sea km to Kirkwall only).

For *Hamnavoe* the outcome is 57 lt fuel and 184 kg (if HFO) for a passenger + car (153 kg if MDO). For *Pentalina* the outcome is 18 lt fuel and 48 kg CO_2 per by-sea trip.

The analysis indicates that *Pentalina* offers by a significant margin the lowest fuel consumption and CO_2 emissions per car + accompanying passenger carried. *Pentalina* has only 6-7% of the emissions per car + passenger

compared to the *Hjaltland*. Compared with *Hamnavoe*, *Pentalina* has between 26-31% of the emissions per car + passenger carried.

3. LAND AND AIR TRANSPORT EMISSIONS

3.1 Fuel consumption and CO_2 emissions per car + passenger

Land transport CO_2 emissions are added to sea transport CO_2 emissions in order to develop a clearer picture of total CO_2 emissions for each route. In the calculation of land (and air) transport emissions we assume the following:

- Edinburgh is journey start/end point
- Orkney port of arrival is end point (or airport for air analysis)
- Average car fuel consumption of 0.07 lt/km
- Average car emission of 101 gms CO_2 per km/pax

Table 7: Single car fuel consumption and CO_2 emissions by road, per passenger

Route	Road Dist/km	Lt/ km	Lt/ Trip/Pax	gms CO_2/ km/Pax	kgs CO_2/ Trip/Pax
EDI-ABZ	203	0.07	9	101	21
EDI-SCR	426	0.07	18	101	43
EDI-GBY	438	0.07	19	101	44

Source: DfT and various sources for average car CO_2 emission, 2009
ABZ=Aberdeen; GBY=Gill's Bay: SCR=Scrabster;
EDI=Edinburgh
Road distances from RAC Route-planner
Passenger-car ratio: 1.58 (Scottish Transport Statistics, 2010)

The road distance between Edinburgh and Aberdeen (to connect with *Hjaltland*) is 203 km (Table 7). Average car occupancy applied here is the Scottish average of 1.58 passengers per car trip. An average car on this route therefore has fuel consumption of 9 lt per passenger/trip, and emits 21 kg of CO_2.

The longer road route between Edinburgh and Scrabster (to connect with *Hamnavoe*) involves a distance of 426 km. For a single car this longer road route involves fuel consumption of 18 lt per passenger/trip, and emissions of 43 kg CO_2.

The Edinburgh-Gill's Bay road route for a car (to connect with *Pentalina*) involves fuel consumption of 19 lt per passenger/trip and has CO_2 emissions of 44 kg.

3.2 Fuel consumption and CO_2 emissions per passenger by bus

Table 8 presents calculations for bus (coach) transport. Bus fuel consumption and CO_2 emission calculations are based on a fuel consumption rate of 0.0161 lt per passenger-km.

On this basis, a bus trip between Edinburgh-Aberdeen consumes 3.3 lt fuel per passenger and emits 8.5 kg CO_2. For Edinburgh-Scrabster the comparable figures are 6.8 lt fuel and 17.8 kg CO_2 per passenger journey. And for Edinburgh-Gill's Bay, the figures are 7 lt fuel and 18.3 kg CO_2 per passenger journey.

Table 8: Bus fuel consumption and CO_2 emissions per passenger, by route

Route	Road Dist/km	Lt/ Pax-km	Lt/ Trip/Pax	gms CO_2/ Pax-km	kgs CO_2/ Trip/Pax
EDI-ABZ	203	0.0161	3.3	41.8	8.5
EDI-SCR	426	0.0161	6.8	41.8	17.8
EDI-GBY	438	0.0161	7.0	41.8	18.3

ABZ=Aberdeen; GBY=Gill's Bay: SCR=Scrabster;
EDI=Edinburgh
Source: Transport Watch UK

3.3 Fuel consumption and CO_2 emissions per passenger by train

Train fuel consumption and CO_2 emissions per passenger are presented in Table 9. Calculations are based on a fuel consumption rate of 0.0308 lt per passenger-km.

Table 9: Train fuel consumption and CO_2 emissions per passenger, by route

Route	Rail Dist/km	Lt/ Pax-km	Lt/ Pax	gms CO_2/ Pax-km	kgs CO_2/ Pax/Trip
EDI-ABZ	211	0.0308	6.5	80	17
EDI-SCR*	544	0.0308	16.8	80	44
EDI-GBY*	544	0.0308	17.1	80	44

*Distances include local bus connection for SCR and GBY resp.
ABZ=Aberdeen; GBY=Gill's Bay: SCR=Scrabster; EDI=Edinburgh
Source: Transport Watch UK

Whilst the distance by rail between Edinburgh-Aberdeen is not much different from road, the distance between Edinburgh and the far north by rail is

considerably greater (i.e. about 120 km more) than road. This in turn has an effect on fuel consumption and CO_2 emissions for this mode.

Rail fuel consumption per passenger between Edinburgh-Aberdeen is calculated at 6.5 lt with CO_2 emissions of 17 kg. Rail transport to the far north ports (i.e. inclusive of local bus connections) involves fuel consumption of 17 lt per passenger, with CO_2 emissions of 44 kg per passenger.

3.4 Fuel consumption and CO_2 emissions per passenger by air

Table 10 presents fuel consumption and CO_2 emissions per passenger for air transport between Edinburgh-Orkney (airport to airport only). The flying distance is 340 km. Calculations are based on a fuel consumption rate of 0.084 lt per passenger-km.

The Saab 340 aircraft used by Loganair on Orkney routes has a fuel consumption rate of 1.43 lt/km, giving fuel consumption per trip of 486 lt based on a full load. We assume here an average 50% load factor (i.e. 17 seats occupied). This equates to fuel consumption per passenger trip of 28.6 lt, resulting in a CO_2 emission of 74 kg per passenger trip.

Table 10: Air transport fuel consumption and CO_2 emissions, per passenger

Route	Air Dist/km	Lt/ km	Lt/ Pax-km	Lt/ Pax	gms CO_2/ Pax-km	kgs CO_2/ Pax/Trip
EDI-KOI	340	1.43	0.084	28.6	217	74

Source: http://saabaircraftleasing.com
ABZ=Aberdeen; EDI=Edinburgh
Note: Data is based on 50% average load factor for Saab 340 aircraft (i.e. 17 seats filled)

4. COMBINED SEA + LAND TRANSPORT EMISSIONS

4.1 Ship + road CO_2 emissions and fuel consumption per car + passenger

Table 11 and Figure 3 sum together the sea transport and road transport CO_2 emissions for each route, for a car + passenger between Edinburgh-Orkney. The outcomes are as follows:

- For *Hjaltland* (Aberdeen-Kirkwall N'bnd), CO_2 emissions per car + passenger between Edinburgh-Orkney is 824 kg if ship uses HFO (687 kg if ship uses MDO);

- For *Hjaltland* (Kirkwall-Aberdeen S'bnd), total CO_2 emissions per car + passenger between Orkney-Edinburgh is 697 kg if ship uses HFO (582 kg if ship uses MDO);

- For *Hamnavoe* (Scrabster-Stromness), total CO_2 emissions per car + passenger between Edinburgh-Orkney is 227 kg if ship uses HFO (196 kg if ship uses MDO);

- For *Pentalina* (Gills Bay-St Margaret's Hope), total CO_2 emissions per car + passenger between Edinburgh-Orkney is 93 kg.

Table 11: Combined ship + road CO_2 emissions per car + passenger, Edinburgh-Orkney

		BY SEA		BY ROAD	TOTAL	
Vessel	Route	CO_2(HFO) Car&Pax (kg)	CO_2(MDO) Car&Pax (kg)	CO_2 Car&Pax (kg)	CO_2(HFO) Car&Pax (kg)	CO_2(MDO) Car&Pax (kg)
Hjaltland(N'bnd)	ABZ-KOI	803	666	21	**824**	687
Hjaltland(Sbnd)	KOI-ABZ	676	561	21	**697**	582
Hamnavoe	SCR-STR	184	153	43	**227**	196
Pentalina	GIL-SMH	NA	48	44	NA	**93**

ABZ=Aberdeen; GBY=Gill's Bay: SMH=St. Margaret's Hope; KOI=Kirkwall; SCR-Scrabster; STR=Stromness
Notes: Includes road transport to/from Edinburgh
Bold indicates fuel currently used by each vessel

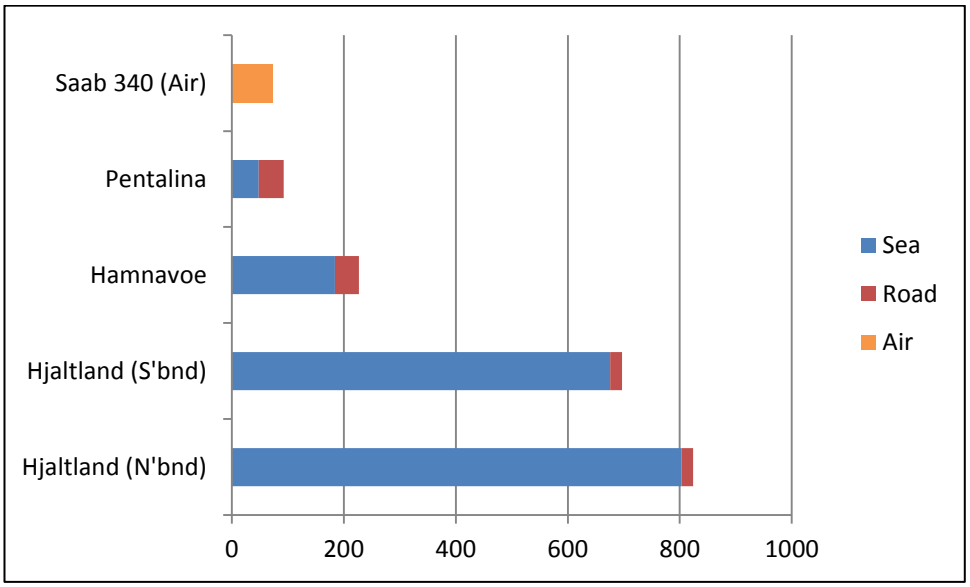


Figure 3: CO_2 (kgs) per car & Passenger, Edinburgh-Orkney, by sea and road
(Based on Hjaltland and Hamnavoe burning HFO, Pentalina MDO)
Ship & Car CO_2 figure is inclusive of carriage of car (and passenger) on the ship. Air CO_2 figure is per passenger only (i.e. excludes car), so not directly comparable.

Road transport followed by the short Pentland Firth ferry crossing (via *Pentalina*) is clearly the best option in terms of reducing CO_2 emissions for cars and passengers travelling between mainland Scotland and Orkney.

Compared with *Hjaltland* (northbound, between Aberdeen-Kirkwall), using the longer road route from Edinburgh to Gill's Bay then *Pentalina* for the short Pentland Firth crossing, a single car + passenger can reduce CO_2 emissions by almost 90%. This exceeds the Scottish Government's objective of an 80% reduction in CO_2 emissions by 2050.

Compared with *Hjaltland* southbound, the alternative routing by *Pentalina* to Gill's Bay and then by road to Edinburgh incurs CO_2 emissions per car + passenger of just one-seventh (14%) of the former. This also exceeds the Scottish Government's objective of an 80% reduction in CO_2 emissions by 2050.

Compared with *Hamnavoe* (using HFO), the latter involving CO_2 emission per car + passenger between Edinburgh-Orkney of 227 kg, the *Pentalina* option has less than half the level of CO_2 emissions (93 kg).

These results demonstrate that:

1. Any of the shorter sea crossings plus long distance road transport is, in terms of CO_2 emissions per car + passenger, by a very considerable margin, a far superior option compared with the longer sea crossing (via Aberdeen) between the Scottish mainland and Orkney, and;

2. Of the two Pentland Firth crossings, the *Pentalina* operating between Gill's Bay-St. Margaret's Hope is clearly the best option (i.e. more than twice as environmentally friendly as *Hamnavoe*), reflecting what is a shorter sea route but also a more efficient ship in terms of payload, power and fuel consumption.

An important finding here concerns the proportion of emissions relating to: a) sea transport, and; b) car (i.e. road) transport, for each ferry alternative. For *Hjaltland* (northbound), emissions per car + passenger by sea of 803 kg CO_2 represent over 97% of the total emissions for a single car + passenger travelling between Edinburgh-Orkney, road transport accounting for just 3% of the overall journey emissions.

By contrast, for the best option, the *Pentalina* and short crossing, the road leg accounts for 47% of emissions (44 kg CO_2) per car + passenger trip between Edinburgh-Orkney, while the sea leg accounts for 53% of emissions (48 kg CO_2).

The main conclusion here is that the longer road trip plus the shortest possible sea crossing results in considerably reduced CO_2 emissions per car + passenger/trip.

Table 12 calculates fuel consumption in respect of a car + passenger travelling between Edinburgh and Orkney. As would be expected, *Hjaltland*

northbound and southbound involves by far the greatest total fuel consumption, at 210-249 lt per car + passenger, of which the vast majority of this fuel is consumed by the ship on the long sea route (i.e. well over 90% in each instance).

Table 12: Combined ship + road fuel consumption per car + passenger, Edinburgh-Orkney

		BY SEA	BY ROAD	TOTAL
Vessel	Route	Lt/ Car	Lt/ Car	Total Lt/ Car
Hjaltland(N'bnd)	ABZ-KOI	249	9	258
Hjaltland(Sbnd)	KOI-ABZ	210	9	219
Hamnavoe	SCR-STR	57	18	75
Pentalina	GIL-SMH	18	19	37

ABZ=Aberdeen; GBY=Gill's Bay: SMH=St. Margaret's Hope; KOI=Kirkwall; SCR-Scrabster; STR=Stromness
Includes road transport to/from Edinburgh

The *Hamnavoe* option has total fuel consumption of 75 lt/car + passenger inclusive of road transport, whilst *Pentalina* offers the lowest total fuel consumption per car + passenger travelling between Edinburgh-Orkney of 37 lt. Again it should be noted that these calculations are based on and hence reflect actual traffic volumes and vessel load factors (2010 levels).

In terms of fuel consumption and hence energy usage, the *Pentalina* option is twice as efficient as *Hamnavoe*, and between 6-7 times more efficient than *Hjaltland* per car + passenger carried.

4.2 Ship + road CO_2 emissions and fuel consumption per passenger by bus

Table 13 and Figure 4 present CO_2 emissions per passenger for ship + bus alternatives between Edinburgh and Orkney.

Hjaltland (N'bnd) has a combined ship + bus CO_2 emission per passenger of 115 kg (using HFO). *Hjaltland* (S'bnd) has combined ship + bus CO_2 emission per passenger of 98 kg (HFO). *Hamnavoe's* CO_2 emission for ship + bus per passenger is 60 kg (HFO). If using MDO, the respective outcomes are 97 kg, 83 kg, and 52 kg CO_2 per passenger trip.

Again the best option by a significant margin is the catamaran *Pentalina* and the shorter Gill's Bay-St. Margaret's Hope route which offers a combined sea + bus emission of 32 kg CO_2 per bus passenger trip between Edinburgh-Orkney. The *Pentalina* therefore reduces by half the CO_2 emission level for a passenger compared with using ship + bus via *Hjaltland* and Aberdeen, and saves between 28-38% the CO_2 emissions compared with *Hamnavoe*.

Table 13: Combined ship + bus CO_2 emissions per passenger, Edinburgh-Orkney

		BY SEA		BY ROAD	TOTAL	
Vessel	Route	CO_2/Pax HFO (kg)	CO_2/Pax MDO (kg)	CO_2/Pax (kg)	Total CO_2/ Pax (HFO)	Total CO_2/ Pax (MDO)
Hjaltland(N'bnd)	ABZ-KOI	107	89	8.5	**115**	97
Hjaltland(Sbnd)	KOI-ABZ	90	75	8.5	**98**	83
Hamnavoe	SCR-STR	42	35	17.8	**60**	52
Pentalina	GIL-SMH	NA	14	18.3	NA	**32**

ABZ=Aberdeen; GBY=Gill's Bay: SMH=St. Margaret's Hope; KOI=Kirkwall; SCR-Scrabster; STR=Stromness

Bold indicates fuel currently used by each vessel

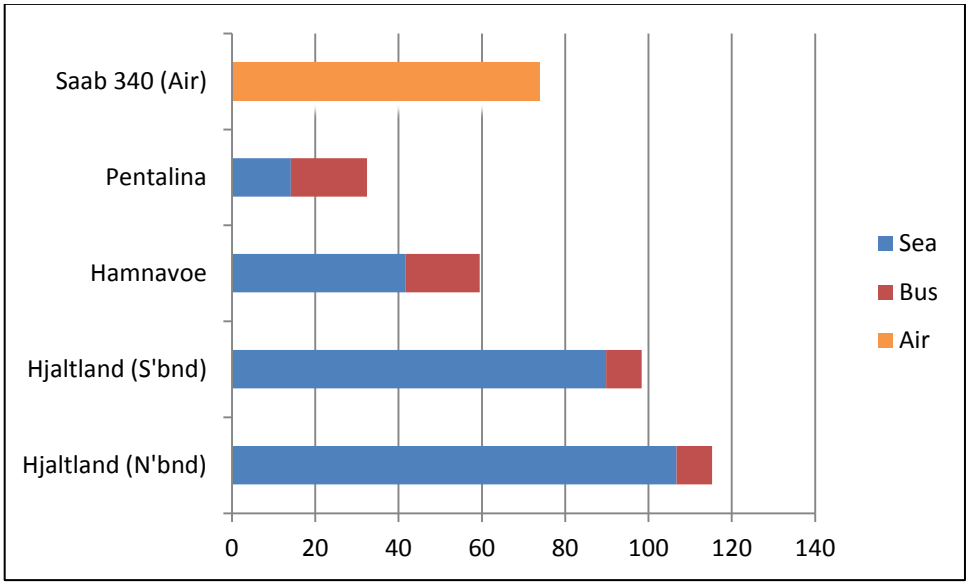


Figure 4: CO_2 (kgs) per Passenger by ship and bus, Edinburgh-Orkney
(Based on Hjaltland and Hamnavoe burning HFO, Pentalina MDO)

In terms of total fuel consumption (Table 14), *Pentalina* again offers the best outcome, with a combined (sea + bus) fuel consumption of 12.3 lt per passenger transported between Edinburgh-Orkney.

The *Pentalina* and short crossing (inclusive of bus to Edinburgh) therefore offers a total fuel consumption saving of over one third (38%) per passenger compared to *Hamnavoe*, with an even greater saving of between 61-66% compared with *Hjaltland*.

Figure 4 illustrates the poor performance of *Hjaltland* even against air transport. A passenger travelling by *Hjaltland* + bus between Edinburgh-

Orkney via Aberdeen is actually emitting considerably more CO_2 than a passenger travelling direct by air (i.e. some one third more - 74 kg CO_2 by air, 115 kg CO_2 via *Hjaltland* + bus). *Hamnavoe* + bus is only slightly better compared to air transport (i.e. 60 kg compared to 74 kg by air).

At 32 kg CO_2 per passenger, *Pentalina* + bus between Edinburgh-Orkney is less than half the emissions per passenger compared to air, about half the *Hamnavoe* emissions, and almost one third that of *Hjaltland*.

Fuel consumption calculations for each option are shown in Table 14. For ship + bus between Edinburgh-Orkney, *Pentalina* offers the lowest fuel consumption of 12.3 lt per passenger, compared with 19.8 lt per passenger for *Hamnavoe*, and well over 30 lt per passenger for *Hjaltland*.

Thus *Hjaltland* + bus has three times greater fuel consumption per passenger trip compared to *Pentalina*, while the *Hamnavoe* option has about one third greater fuel consumption.

Table 14: Combined ship + bus fuel consumption per passenger, Edinburgh-Orkney

		BY SEA	BY ROAD	TOTAL
Vessel	Route	Lt/ Pax	Lt/ Pax	Total Lt/ Pax
Hjaltland(N'bnd)	ABZ-KOI	33.2	3.3	36.4
Hjaltland(Sbnd)	KOI-ABZ	27.9	3.3	31.2
Hamnavoe	ABZ-KOI	13.0	6.8	19.8
Pentalina	GIL-SMH	5.3	7.0	12.3

ABZ=Aberdeen; GBY=Gill's Bay: SMH=St. Margaret's Hope;
KOI=Kirkwall; SCR-Scrabster; STR=Stromness

4.3 Ship + road CO_2 emissions and fuel consumption per passenger by train

Table 15 and Figure 5 provide analysis of ship + train CO_2 per passenger for a journey between Edinburgh-Orkney. The analysis includes a short bus leg between Thurso and the respective ports for both Pentland Firth ship options.

Hjaltland (N'bnd) has ship + train CO_2 emission of 124 kg (HFO) per passenger (105 kg CO_2 if using MDO). *Hjaltland* (S'bnd) has CO_2 emission per passenger of 107 kg (HFO) (91 kg CO_2 if using MDO). *Hamnavoe* is slightly less at 85 kg CO_2 (HFO) (or 78 kg CO_2 if using MDO).

Pentalina again offers the least emission level of 58 kg per passenger using ship and train between Edinburgh and Orkney. This is equivalent to about half the CO_2 level of *Hjaltland*, and a 26-32% saving compared to *Hamnavoe*, per

passenger. So, despite Scrabster being closer to Thurso rail station than Gill's Bay, the latter option using *Pentalina* is superior in terms of lower CO_2 emissions per passenger journey using rail.

Table 15: Combined ship + train CO_2 emissions per passenger, Edinburgh-Orkney

Vessel	Route	BY SEA CO_2/Pax HFO (kg)	BY SEA CO_2/Pax MDO (kg)	BY RAIL CO_2/Pax (kg)	TOTAL CO_2/Pax Car (HFO)	TOTAL Total CO_2/ Pax (MDO)
Hjaltland(N'bnd)	ABZ-KOI	107	89	17	**124**	105
Hjaltland(Sbnd)	KOI-ABZ	90	75	17	**107**	91
Hamnavoe	SCR-STR	42	35	44	**85**	78
Pentalina	GIL-SMH	NA	14	44	NA	**58**

ABZ=Aberdeen; GBY=Gill's Bay: SMH=St. Margaret's Hope; KOI=Kirkwall; SCR-Scrabster; STR=Stromness
Bold indicates fuel currently used by each vessel

Figure 5 illustrates these differences, and compares each sea option with air transport (albeit the latter at a higher load factor). Again the long distance ferry options via-Aberdeen using *Hjaltland* (and then rail) between Edinburgh-Orkney are substantially worse in terms of CO_2 emissions per passenger than air transport. The only ferry option based on using rail transport connections which achieve lower CO_2 emission per passenger than air is *Pentalina*.

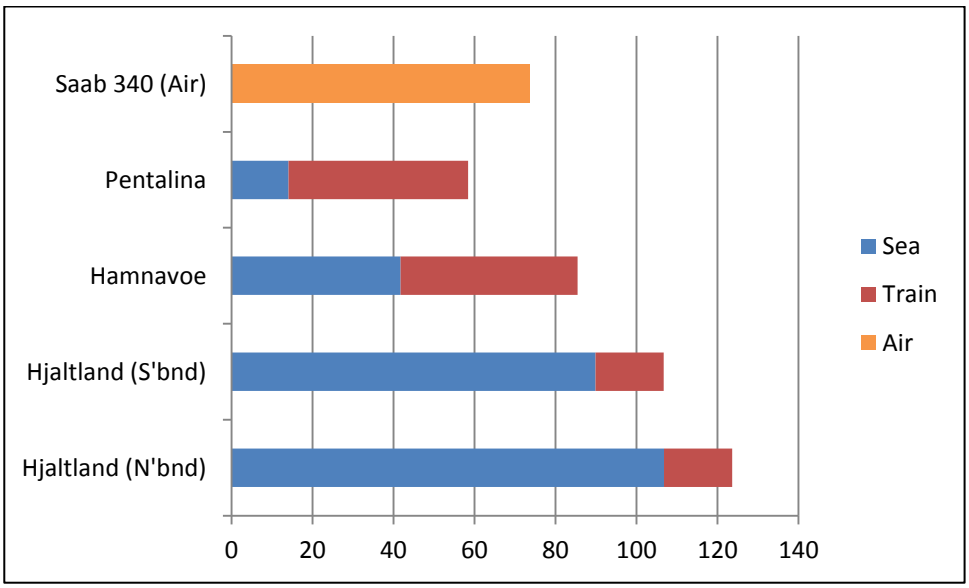


Figure 5: CO_2 (kgs) per Passenger by ship and train, Edinburgh-Orkney
(Based on Hjaltland and Hamnavoe burning HFO, Pentalina MDO)

Fuel consumption calculations for each option are shown in Table 16. Using ship + rail between Edinburgh-Orkney, *Pentalina* has the lowest overall fuel consumption of 22 lt per passenger. This is nearly half the fuel consumption of *Hjaltland* (N'bnd), and saves almost one-third compared to *Hamnavoe*.

Table 16: Combined ship + train fuel consumption per passenger Edinburgh-Orkney

		BY SEA	BY TRAIN	TOTAL
Vessel	Route	Lt/ Pax	Lt/ Pax	Total Lt/ Pax
Hjaltland(N'bnd)	ABZ-KOI	33	6.5	40
Hjaltland(Sbnd)	KOI-ABZ	28	6.5	34
Hamnavoe	ABZ-KOI	13	16.8	30
Pentalina	GIL-SMH	5	17.1	22

ABZ=Aberdeen; GBY=Gill's Bay: SMH=St. Margaret's Hope; KOI=Kirkwall; SCR-Scrabster; STR=Stromness

5. DISCUSSION AND CONCLUSIONS

5.1 Summary of main findings

Table 17 summarises the outcome for CO_2 emissions per passenger for all ferry routes analysed inclusive of combined transport alternatives. The data is also presented in the graph shown in Figure 6. To re-state, the data relates to per passenger or per car + passenger journey between Edinburgh and Orkney.

The lowest CO_2 emission ferry route by a very substantial margin is Pentland Ferries *Pentalina* and Gill's Bay-St. Margaret's Hope, plus any connecting land transport mode, or combination - car, bus and/or train - to/from Edinburgh.

Pentalina has a CO_2 emission of 93 kg per car + passenger between Edinburgh-Orkney, which is less than half the *Hamnavoe* CO_2 level per car + passenger (227 kg), and only 11-13% of the emissions for *Hjaltland* via Aberdeen (607-824 kg).

The lowest CO_2 travel option overall is *Pentalina* + bus, at 32 kg CO_2 per passenger journey between Edinburgh-Orkney. *Hamnavoe* is twice as high as this (60 kg), with *Hjaltland* three times higher in terms of CO_2 per passenger (98-115 kg).

For ship and train *Pentalina* again offers the best travel option, at 58 kg CO_2 per passenger, compared with 85 kg for *Hamnavoe* and between 107-124 kg for *Hjaltland*. This is despite the fact Gill's Bay is slightly further from a rail station than the other two ferry options studied.

Table 17: Comparison sea (incl. car, bus or train) and air emissions, per passenger, Edinburgh-Orkney

Vessel	Route	Ship&Car +Pax kg CO_2	Ship&bus Per Pax kg CO_2	Ship&train Per Pax kg CO_2	Air Per Pax kg CO_2
BY SEA	via				
Hjaltland(N'bnd) (HFO)	ABZ-KOI	824	115	124	
Hjaltland(Sbnd) (HFO)	KOI-ABZ	697	98	107	
Hamnavoe (HFO)	SCR-STR	227	60	85	
Pentalina (MDO)	GBY-SMH	93	32	58	
BY AIR					
Saab 340	EDI-KOI				74

NOTE: Ship and Car is not strictly comparable with air as planes don't carry cars.
ABZ=Aberdeen; GBY=Gill's Bay: SMH=St. Margaret's Hope; KOI=Kirkwall; SCR-Scrabster; STR=Stromness; EDI=Edinburgh
HFO = heavy fuel oil; MDO = marine diesel oil

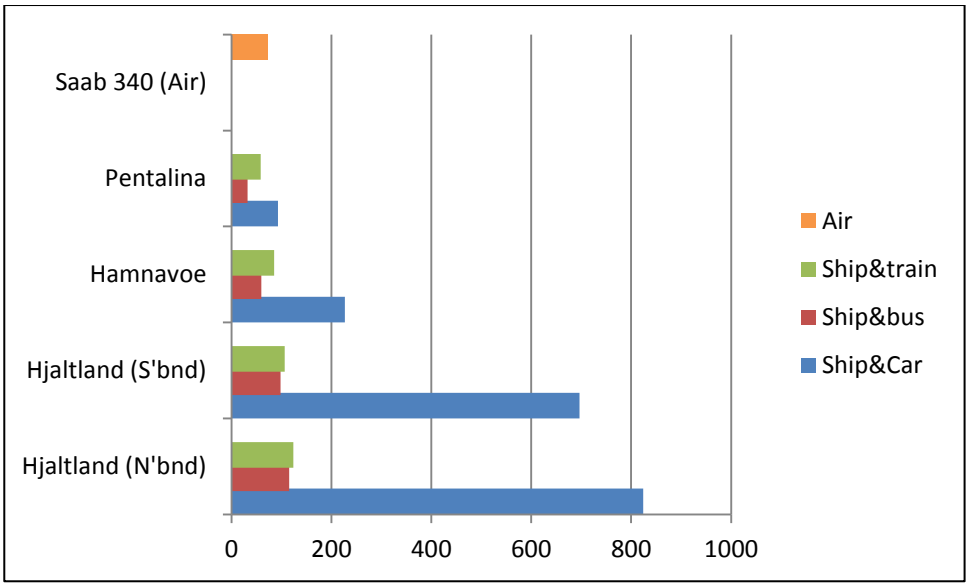


Figure 6: Summary of CO_2 (kgs) emissions per passenger, by combined transport option
Notes: All transport is between Edinburgh-Orkney, per passenger. Ship&Car CO_2 figure is inclusive of carriage of car (and passenger, based on average pax:car occupancy) on the ship. Data is based on Hjaltland and Hamnavoe burning HFO, Pentalina MDO. Air CO_2 figure is per passenger only (i.e. excludes car), so not directly comparable with ship & car.

5.2 Conclusions

Our findings suggest that Pentland Ferries' service utilising the catamaran *Pentalina* across the Pentland Firth provides for markedly lower CO_2 emissions compared to any of the longer sea crossings maintained by the

state-owned subsidised operator NorthLink Ferries. This is both in regard to the actual sea passage itself and when combined with any land transport connection.

A fundamental aspect in this analysis is that ferries *Hjaltland* and *Hamnavoe*, and to a lesser extent *Pentalina*, have higher fuel consumption and generate greater CO_2 emissions than land transport per passenger or vehicle/km. If reducing CO_2 is an objective, as indeed it represents a key plank of Scottish Government policy, then it is advisable to specify the shortest possible sea crossing as opposed to moving (and subsidizing) traffic via longer sea routes.

We note that *Pentalina* 'plugs' into cleaner shoreside electricity when berthed overnight, whereas both *Hamnavoe* and *Hjaltland*, due to their greater power requirement, use diesel generators whilst in port. This in turn further adversely impacts both of the latter ships' CO_2 emission levels, though this additional factor has not been considered in any of the calculations here.

NorthLink routes are heavily subsidized, now costing the taxpayer in excess of £40 million annually. Yet our analysis demonstrates that the best performing operator is Pentland Ferries, the latter privately owned and not subsidized. Our findings suggest that the Scottish Government therefore needs to better understand the significant environmental impacts of its own subsidized ferry services. The vast differences identified here in terms of fuel consumption and CO_2 emissions suggest that much of the subsidy allocated to NorthLink is rather needlessly wasted on fuel, although other inefficiencies have also been identified (Baird & Pedersen, 2010). Regrettably the Scottish Government seems intent on ignoring this evidence as its ongoing tender process envisages continued subsidy of the poorest performing routes highlighted here, and continued employment of the worst performing ships. Clearly the present tender process does not adequately take account of ferry CO_2 emissions, unlike ferry tenders in other countries (Baird & Wilmsmeier, 2011).

The results of this study should provide a stimulus to the ongoing campaign for improvements to the A9 road north and south of Inverness as main access route to/from Orkney, and strengthens the case for further road upgrades in Orkney between St. Margaret's Hope and Kirkwall, including action to improve access on the Churchill Barriers. In addition, Pentland Ferries has stated its preference to use the more southerly port of Burwick in Orkney (Pedersen, 2010). Sailing to/from this port would help reduce the sea crossing time from one hour to just 30 minutes, resulting in a further opportunity to help lower ship CO_2 emissions to an even greater extent.

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[1] http://www.scotland.gov.uk/Topics/Environment/climatechange/scotlands-action/climatechangeact

[2] http://www.transportscotland.gov.uk/strategy-and-research/NTS/CAT

[3] http://www.scotland.gov.uk/Publications/2006/12/04104414/0

[4] Fuel consumption related to onboard generators will be higher for ships with extensive cabin accommodation, such as *Hjaltland* (and sistership), and for ships with high live-on-board crew complements, such as *Hjaltland* (and sistership) and *Hamnavoe*.

[5] http://www.foreship.com/documents/fs-naterms.pdf

[6] mcr = maximum continuous rating is defined as the maximum output (MW) that a generating station is capable of producing continuously under normal conditions.