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Zero Emission Energy for Transport Project Report

Regional Case Study: Dumfries and Galloway

Contents

1. Introduction

1.1 Study Area

The [Dumfries and Galloway](#) Council area in Scotland covers over 6,000 square kilometres, making it the third largest local government area in Scotland. It's home to approximately 150,000 people who live at a density of 23 per square kilometre. The Dumfries and Galloway Council area shares its borders with the council areas of East Ayrshire, south Ayrshire, and South Lanarkshire in Scotland, and also the county of Cumbria in England. It is comprised of three counties: Dumfriesshire, Kirkcudbrightshire and Wigtownshire.

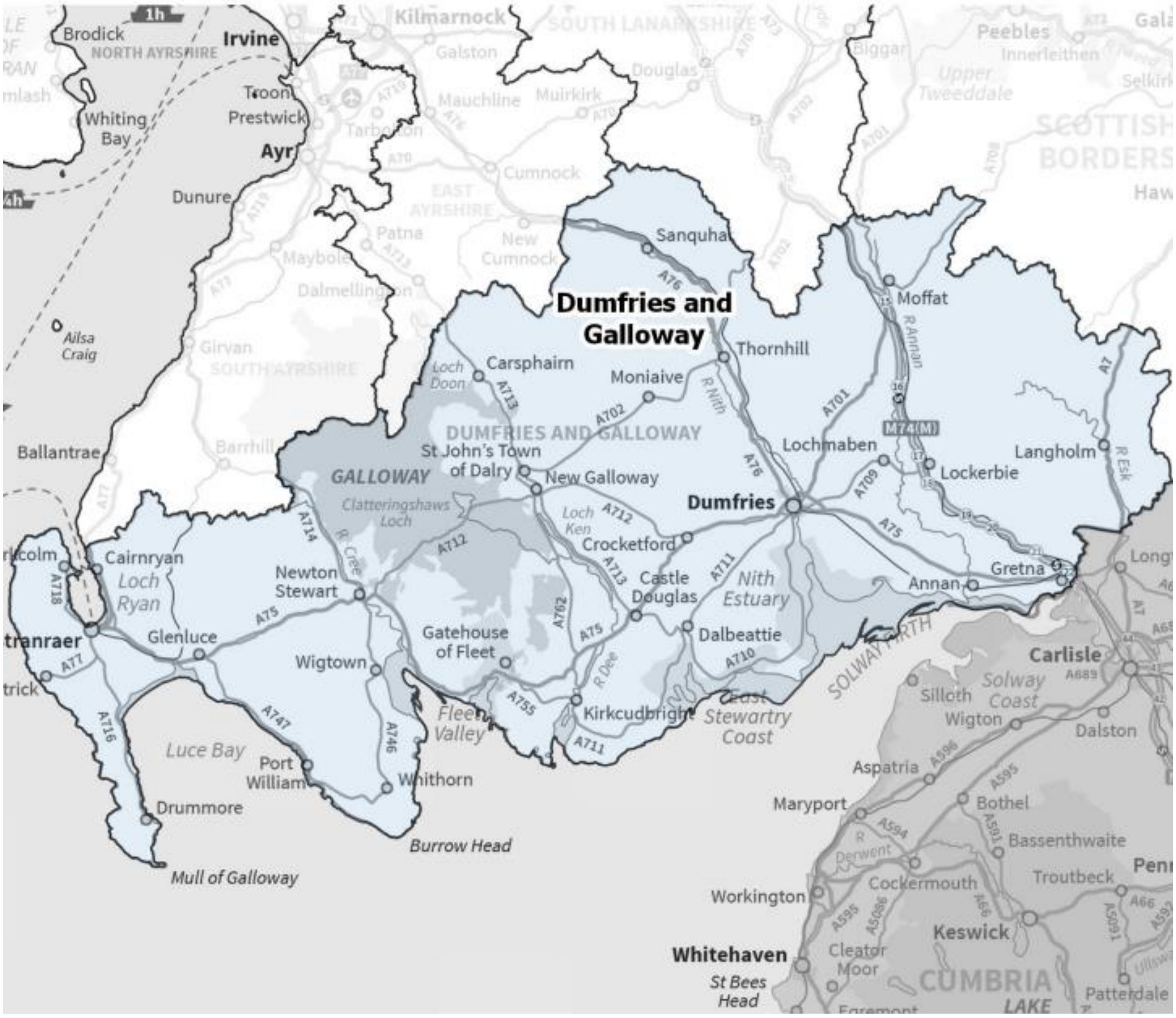


Figure 1 - Map of the Dumfries and Galloway Council area, adapted from the [Scottish Government](#) 2022.

1.2 Overarching Approach

Transport Scotland commissioned Jacobs to develop regional demand forecasts for the Dumfries and Galloway Council area for three potential Low (Scenario A), Medium (Scenario B) and High (Scenario C) hydrogen uptake scenarios across all transport modes as part of its commitment to decarbonise the transport sector. This three-scenario approach was adopted for simplicity and flexibility to compare different scenarios easily.

The details of this study for the Dumfries and Galloway Council area are outlined in the following report and estimate annual hydrogen demand for domestic or intra-Scotland transport including road, rail and maritime annually between 2022 and 2030, and for 2035, 2040 and 2045.

A three-part approach was adopted for forecasting hydrogen demand for transport consistent with the accompanying ***Zero Emission Energy for Transport: National Demand Forecasts for Electricity and Hydrogen*** as follows:

1. Transport Demand Baseline and Forecasting
2. Hydrogen Transition Scenario Development and Modelling
3. Hydrogen Demand Calculations and Analysis

While the overarching process was consistent across all transport modes (1-3 above), the individual methods for forecasting transport demand varied according to data availability, which is discussed in the following sections.

The study's results are a series of hydrogen demand forecasts for transport in each forecast year for the three scenarios. These results are then broken down into further categories; by transport mode (road, rail and maritime) and individual types of vehicles, rolling stock and vessels (as relevant).

This report is accompanied by a Microsoft Excel Results Tool (Tool) detailing the results for all three regional areas studied: the Dumfries and Galloway, Highland, as well as Fife Council areas. The Tool enables the exploration and comparison between scenarios in greater detail beyond what is included within this report.

Overall, this study has been designed with the intention to inform the market of three possible hydrogen demand scenarios for transport purposes in the Dumfries and Galloway Council area. While supply side considerations such as capacity of the existing infrastructure to produce and distribute hydrogen are critical, they have not constrained the modelling process. This is because a key objective of the study is to indicate potential maximum demand scenarios for transport and thereby stimulate investment infrastructure for supply.

2. Methodology

2.1 Transport Demand

The Dumfries and Galloway Council area is multi-modal, being serviced by most transport modes including road, rail and maritime – except for aviation. The following sections describe characteristics of the existing transport demand across the study area and the methods used to quantify transport demand for each mode within the Dumfries and Galloway Council area.

Unless specified below, the assumptions are consistent with the national technology transition scenarios the accompanying ***Zero Emission Energy for Transport: National Demand Forecasts for Electricity and Hydrogen*** report:

2.1.1 Road Transport Demand

Cars and Vans

Car and van use within the Dumfries and Galloway Council area, is distributed across the population and employment centres, rather than at specific points of interest. This is due to cars and vans being a fundamental transport mode across all sectors of the population. For this reason, it is necessary to approach and view transport demand, and the potential hydrogen demand for cars and vans as an overall function of the vehicle fleet, rather than a series of discrete geographic areas of demand.

The accompanying ***Zero Emission Energy for Transport: National Demand Forecasts for Electricity and Hydrogen*** outlines the bottom-up approach adopted to calculate hydrogen demand at a national level using transport demand projections from TMfS18.To establish the demand for the Dumfries and Galloway Council area, it was necessary to disaggregate the national demand down to the local authority level.

The disaggregation process utilised the zonal system from the TMfS18 strategic transport model. The TMfS18 model follows the standard demand model pattern of assigning origin-destination (OD) pairs to a road network to generate flows of traffic along the network. The origin totals for each zone were used to disaggregate the national demand. This process works under the assumption that most of the demand for hydrogen will be occurring at the point of origin for each journey rather than on route. The equation is as follows:

$$H_2Demand_{Zone1,Y,S} = H_2Demand_{Y,S}\frac{\sum Origin_{Zone1,Y,S}}{\sum_{Zone=All\ Zones} Origin_{Zone,Y,S}}$$

Where H_2Demand is the hydrogen demand for a specific year, Y, and for a specific scenario, S. $Origin_{Zone,Y,S}$ is the origin total for a specific zone, year and scenario.

By utilising this equation and the results of the accompanying ***Zero Emission Energy for Transport: National Demand Forecasts for Electricity and Hydrogen*** it was therefore possible to disaggregates transport demand for hydrogen a lower level to represent the Dumfries and Galloway Council area specifically.

HGVs and HDVs

The same approach to establish transport demand for cars and vans, was also used for HGVs and HDVs. However, HGV demand within the Dumfries and Galloway Council area is expected to be distributed across the major employment centres, with some concentration at freight depots. This is because of HGV demand characteristically being more heterogenous than for cars or vans. However, demand is still dispersed across many different local areas and for this reason, it is necessary to approach and view demand for HGVs as an overall function of the vehicle fleet, rather than a series of discrete geographic areas.

Buses and Coaches

Bus and coach transport in the Dumfries and Galloway Council area consists of a mixture of buses which perform timetabled public services on several routes, as well as coaches largely used for private hire or excursions across the region. Each type of service is dominated by a few large operators, but smaller firms also operate in each category on a much smaller scale.

The largest bus and coach operator in the region is *Stagecoach*, which has depots in Dumfries and Stranraer. Most vehicles that are owned by Stagecoach are buses which run local scheduled bus services, but there are also a small number of coaches at each of their depots.

Other mid-sized operators are Houstons Coaches and McCall's Coaches, based in Lockerbie. Both operators run service buses on timetabled routes around Dumfries and Galloway as well as hiring out coaches for weddings, airport transfers, and school trips amongst others. Houstons Coaches also run day tours. Several small operators with less than 10 buses and coaches also operate throughout the region, from Stranraer in the west to Langholm in the east.

In terms of methods to establish transport demand for bus and coach services in the Dumfries and Galloway region, this has been established using two complementary approaches:

- First national demand figures provided through TMfS:18 data were disaggregated for each of the six national technology transition scenarios for the Dumfries and Galloway Council area specifically. Since the TMfS:18 data only included local data for service buses, secondary sources of bus and coach data were located within the local region (such as council information) and cross-checked to establish reliability.
- Additionally, bus and coach fleet operators were contacted directly where possible, to understand and verify the details of their specific fleets.
- Importantly, the distance travelled buses and coaches in Dumfries and Galloway Council area is assumed to be constant through to 2045 aligned with TMfS:18.

This process established the TMfS:18 data only varied slightly from the locally available data. Figure 2 below shows the difference between the number of buses in the disaggregated national model for the Dumfries and Galloway Council area and the number of vehicles identified through the verification process. As shown, 164 buses and coaches were identified, of which 80 are buses and 84 are coaches.

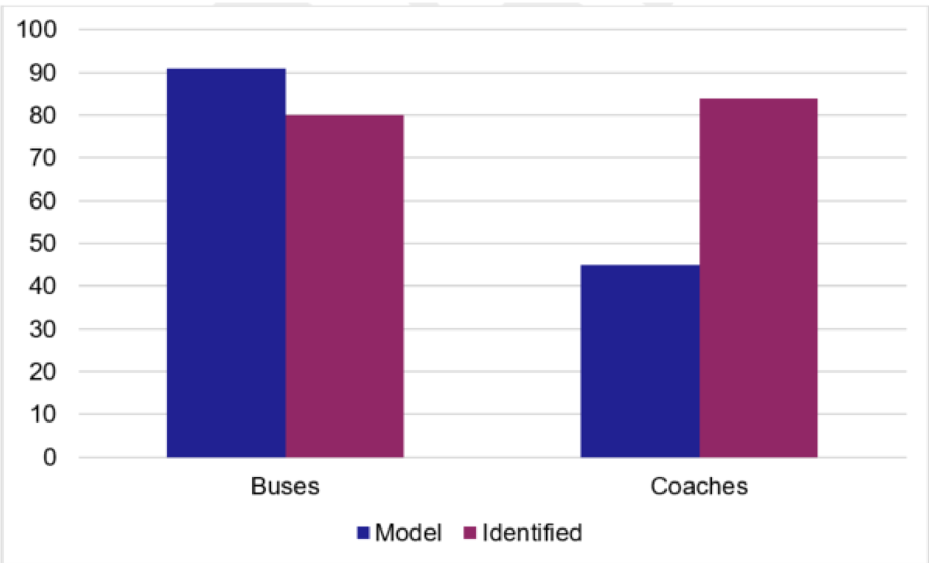


Figure 2 - Numbers of buses and coaches modelled versus identified through verification in the Dumfries and Galloway region

Since the figures are comparable, the disaggregated national model from TMfS:18 has been used to generate the hydrogen scenarios. This approach was adopted to ensure consistency across the road-based modes of transport.

2.1.2 Rail Transport Demand

There are three railway lines that are wholly or partly within the Dumfries and Galloway Council area, with only the West Coast Mainline having been electrified to date, as shown in Figure 3 below. As shown, the Dumfries and Galloway routes include:

- The West Coast Mainline between the English border at Gretna Junction to north of Beattock
- The former Glasgow and Southwestern Railway route from Gretna Junction via Gretna Green, Annan, Dumfries, Sanquhar and Kirkconnel towards Kilmarnock and Glasgow Central
- The line from Stranraer towards Barrhill, Girvan, Ayr, Kilmarnock and Glasgow Central.

The West Coast Mainline is currently electrified and it is the Scottish Government's intention to provide overhead electrification on the Glasgow and Southwestern Railway route to facilitate freight trains on this line by 2035. However, there are currently no plans to electrify the line to Stranraer, for which an alternative traction solution will be required. This could be a battery electric solution, or hydrogen.

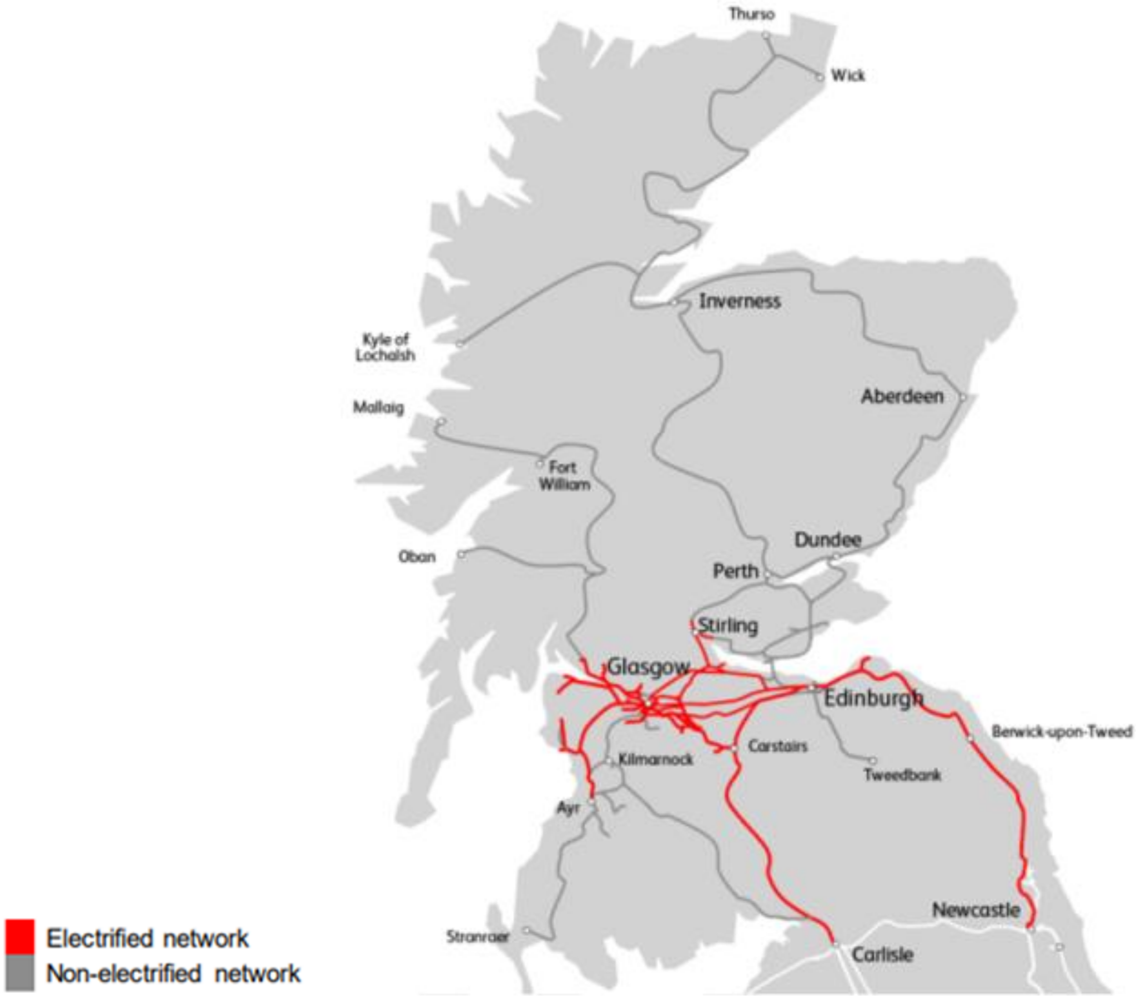


Figure 3 - Map showing railway electrification in Scotland, 2020, modified from Rail Services Decarbonisation Action Plan,, page 39

To determine the rail transport demand for rail in the Dumfries and Galloway Council area, the accompanying ***Zero Emission Energy for Transport: National Demand Forecasts for Electricity and Hydrogen*** outlines the bottom-up approach adopted, relying on route-based data provided by rail operators (including ScotRail). This report outlines that rail service demand is are expected to remain constant from 2030 in the Dumfries and Galloway Council area.

This regional study builds on this national approach, taking the existing route data and estimating the proportion (expressed as a percentage) of annual rail trip kilometres that traverses the Dumfries and Galloway Council area. A summary of the services operating on each railway line are detailed below:

West Coast Mainline

No ScotRail services operate on this route. All passenger services are provided by Avanti West Coast and operate to either Glasgow Central or Edinburgh Waverley.

The current timetable indicates seven trains per day between Carlisle and Edinburgh Waverley, all of which only call at Haymarket. There are 16 trains per day between Carlisle and Glasgow, most of which are non-stop, but some call at Lockerbie or Motherwell. All these services use electricity from the 25kV overhead.

Former Southwestern Railway Route (Glasgow – Barrhead – Kilmarnock – Carlisle – Newcastle)

The current ScotRail timetable indicates that 13 trains per day operate from Glasgow Central and terminate at Barrhill, while 25 trains per day continue to Kilmarnock. There is also one train per day from Glasgow that terminates at Dumfries, five trains per day that terminate at Carlisle and one train per day operates between Glasgow Central and Newcastle. In addition, there are eight services that only operate on the southern section of this route with six trains per day operating between Dumfries and Carlisle and two trains per day operating between Dumfries and Newcastle.

Stranraer Line

Most of the services from Glasgow Central into Ayrshire are operated by Electric Multiple Units (EMUs) and terminate at either Largs or Ayr. The current ScotRail timetable shows that each weekday, eight trains per day operate on the non-electrified network south of Ayr and terminate at Girvan. Four trains per day continue further south to serve Barrhill and Stranraer.

2.1.3 Maritime Transport Demand

Shipping

The UK Department for Transport: Maritime and Shipping provides data on tonnes of cargo handled at each port in Scotland. In total, Dumfries and Galloway Council area represents circa 9% of all tonnes handled at Scottish ports in 2019 and 30% of all domestic tonnes. Cairnryan and Loch Ryan are the two main cargo ports within the Dumfries and Galloway Council area. As these two ports are ferry terminals with ferry routes operating between Loch Ryan and Cairnryan to Northern Ireland, hydrogen demand from these two ports is analysed within the ferries section. Therefore, the hydrogen demand for Dumfries and Galloway region comes from fishing activity.

According to the 2019 Scottish Sea Fisheries Statistics, transport demand from fishing activities within the Dumfries and Galloway Council area were responsible for approximately 1% of the total fish tonnage handled at Scottish ports This fishing tonnage within the Dumfries and Galloway region has shown a downward trend between 2015 and 2018, albeit showing a slight recovery in 2019 with an annual increase of 1.6%.

In terms of methodology to establish transport demand for shipping, the same approach as for the accompanying ***Zero Emission Energy for Transport: National Demand Forecasts for Electricity and Hydrogen*** with some adjustments of assumptions to make them applicable at a regional level. For example, the national 2019 CO_2e from the maritime sector has been disaggregated down to the percentage of tonnes to represent each port in the Dumfries and Galloway Council area proportionally, using the below equation:

$$\textbf{Port A CO2e} = \textbf{Total CO2e} * \frac{\textbf{Tonnes Port A}}{\textbf{Tonnes all Scotland}}$$

In addition, the total emissions by port for the region have been split between domestic and international to understand the different categories of potential demand for hydrogen in both domestic and international shipping markets in the future.

Finally, the future growth of transport demand at each port has been forecasted. In this case, because the cargo ports are ferry terminals and these are being studied separately, this exercise has been done for the fishing ports only. The forecast of tonnage has been based on the historical tonnage growth observed during the last 5 years and the same trend has been assumed to continue.

Ferries

For the purposes of this study, it is assumed that a ferry service is only operational if there is sufficient demand for the service and, therefore, transport demand can be inferred based on the existing timetabled ferry services.

The accompanying ***Zero Emission Energy for Transport: National Demand Forecasts for Electricity and Hydrogen*** report details the methodology Jacobs used to construct a dataset including information on the 150 ferry routes currently operational in Scotland. This dataset included individual journey length, journey times and journey frequency, along with the characteristics of the primary vessel operating the route. This dataset has been relied upon for this regional study of the Dumfries and Galloway Council area.

Of the 150 ferry routes identified for the dataset, only two routes are located in the Dumfries and Galloway area. Both ports are in Cairnryan on the east shore of Loch Ryan, which lies in the most western part of the region. Unlike the other national ferry routes, both routes operating from Dumfries and Galloway provide services to large ports in Northern Ireland. The main route to Belfast departs from Loch Ryan port, is operated by Stena Line and makes six sailings a day between its two ships the Stena Superfast VII and Stena Superfast VIII. The other route from Cairnryan to Larne is operated by P&O Ferries but services are currently suspended and there is uncertainty over future timetabling. However, calculations have been made based on normal prior operation.

As there is significant overlap with shipping in this region through the multipurpose use of these ferries, the hydrogen demand has been accounted for through classing them as ferry routes and using the methodology developed here but with comparison against the dataset available for shipping.

To validate the datasets constructed in the accompanying ***Zero Emission Energy for Transport: National Demand Forecasts for Electricity and Hydrogen*** report for the local region, operators were contacted to confirm the publicly sourced information. These information requests asked for details on ferry timetables, plans for vessel replacement and the likely powertrain type of these replacements. These requests were sent to both operators in the region (listed in Table 1), but no responses were received.

The two routes identified in Table 1 below are among the largest routes in the overall study, with the Belfast route 78 km in length, and the Larne route 62 km in length. In consultation with Transport Scotland, it has been assumed that the distance travelled per annum by each of the vessels remains constant between 2019-2045.

Operator	Number of routes operated	Number of Vessels	Estimated annual distance travelled (km)
Stena Line	1	**2**	325,287
P&O Ferries	1	**1**	266,871

Table 1 - Characteristics of ferry operators in the Dumfries and Galloway area

2.2.1 Road Transition

Cars and Vans

The methodology for cars and vans hydrogen transition assumes no regional specific transition drivers, with instead, the impetus for transition occurring at a national level with the zero emission vehicle requirements pushing an overall change to both electric and hydrogen.

Due to this, the transition to hydrogen and the subsequent demand for hydrogen will be driven in large part by market forces. This will be analogous to the current situation in Electric Vehicle uptake where the general purchase of EVs is not driven by specific regional specific mechanisms of transition, but rather a more global desire to switch to hydrogen.

It should be noted that hydrogen for cars and vans is currently a very uncertain market, with the distinct possibility that the Scenario A (low hydrogen) effectively represents a zero-hydrogen scenario. This is because hydrogen uptake is currently lagging EV uptake by at least a decade, and therefore will face a more challenging market in the future – with few environmental benefits compared to existing EVs. However, for the purposes of the study, the trajectory of hydrogen vehicle uptake for cars and vans is assumed to follow TMfS:18 demand figures, leading to a peak in the total number of hydrogen vehicles purchased as a proportion of all ULEV vehicles by approximately 2035.

Due to the uncertainties around the use of hydrogen technology for cars and vans, the hydrogen uptake figures in the accompanying ***Zero Emission Energy for Transport: National Demand Forecasts for Electricity and Hydrogen*** report have been taken as the upper end of potential hydrogen transition scenarios.

- A (Low) transition to hydrogen transport: Cars and vans transition at 1/3 of the national rate of uptake.
- B (Medium) transition to hydrogen transport: Cars and vans transition at 2/3 of the national rate of uptake.
- C (High) transition to hydrogen transport: Cars and vans transition at the national rate of uptake.

Table 2 shows the predicted new vehicle purchase rates for cars based on the TMfS:18 uptake for Scenario A (Low).

Vehicle Type	2022	2025	2030	2035	2040	2045
ICE	76.0%	60.4%	0.0%	0.0%	0.0%	0.0%
BEV	16.1%	34.0%	96.8%	94.8%	95.0%	99.3%
Hydrogen	0.1%	0.1%	1.1%	1.7%	1.7%	0.2%

Table 2 - Predicted new vehicle purchase rates for cars based on the TMfS18 uptake for Scenario A (Low).

Table 3 shows the predicted new vehicle purchase rates for cars based on the TMfS:18 uptake for Scenario B (Medium).

Vehicle Type	2022	2025	2030	2035	2040	2045
ICE	76.0%	60.4%	0.0%	0.0%	0.0%	0.0%
BEV	11.9%	24.0%	70.2%	94.8%	95.0%	99.3%
Hydrogen	0.1%	0.2%	2.1%	3.4%	3.3%	0.5%

Table 3 - Predicted new vehicle purchase rates for cars based on the TMfS18 uptake for Scenario B (Medium).

Table 4 shows the predicted new vehicle purchase rates for cars based on the TMfS:18 uptake for Scenario C (High).

Vehicle Type	2022	2025	2030	2035	2040	2045
ICE	76.0%	60.4%	0.0%	0.0%	0.0%	0.0%
BEV	7.6%	14.0%	43.5%	94.8%	95.0%	99.3%
Hydrogen	0.2%	0.3%	3.2%	5.2%	5.0%	0.7%

Table 4 - Predicted new vehicle purchase rates for cars based on the TMfS18 uptake for Scenario B (Medium).

Table 5 shows the predicted new vehicle purchase rates for vans based on the TMfS18 uptake for Scenario A (Low).

Vehicle Type	2022	2025	2030	2035	2040	2045
ICE	87.6%	73.3%	0.0%	0.0%	0.0%	0.0%
BEV	3.0%	6.5%	21.8%	99.0%	99.1%	99.7%
Hydrogen	0.1%	0.0%	0.9%	1.0%	0.9%	0.3%

Table 5 - Predicted new vehicle purchase rates for vans based on the TMfS18 uptake for Scenario A (low).

Table 6 shows the predicted new vehicle purchase rates for vans based on the TMfS18 uptake for Scenario B (Medium).

Vehicle Type	2022	2025	2030	2035	2040	2045
ICE	87.6%	73.3%	0.0%	0.0%	0.0%	0.0%
BEV	6.2%	13.1%	48.6%	97.9%	98.2%	99.5%
Hydrogen	0.1%	0.1%	1.7%	2.1%	1.8%	0.5%

Table 6 - Predicted new vehicle purchase rates for vans based on the TMfS18 uptake for Scenario B (Medium).

Table 7 shows the predicted new vehicle purchase rates for vans based on the TMfS18 uptake for Scenario C (High).

Vehicle Type	2022	2025	2030	2035	2040	2045
ICE	87.6%	73.3%	0.0%	0.0%	0.0%	0.0%
BEV	9.3%	19.6%	75.4%	96.9%	97.3%	99.2%
Hydrogen	0.2%	0.1%	2.6%	3.1%	2.7%	0.8%

Table 7 - Predicted new vehicle purchase rates for vans based on the TMfS18 uptake for Scenario C (High).

Buses and Coaches

The accompanying ***Zero Emission Energy for Transport: National Demand Forecasts for Electricity and Hydrogen*** report developed six technology transition scenarios. However, for the purposes of modelling future hydrogen demand in the Dumfries and Galloway Council area only three scenarios for hydrogen technology uptake have been selected for buses and coaches (as outlined in Section 1.1). The selection of three scenarios for buses and coaches has been informed by the validation exercised conducted as described in Section 2.1.1 which identified current trends in the Dumfries and Galloway Council area (allowing more precision than the average national forecast of technology transition scenarios).

Scenario	Description	No. of buses	No. of coaches
A (Low)	Moderate take-up of electric vehicles occurs with a high price for fuel cells	3	6
B (Medium)	Moderate take-up of electric vehicles occurs with a mid-range price for fuel	9	10
C (High)	Moderate take-up of electric vehicles occurs with a low price for fuel cells	11	14

Table 8 - Purchase rates of HGV types by scenario

Based on the same modelling technique as the national model these three scenarios indicate small numbers of hydrogen vehicles in 2023. All of these results are consistent with the fact that no hydrogen vehicles are known to have been ordered so far in the Dumfries and Galloway Council area.

HGVs and HDVs

Similar to cars and vans, the hydrogen transition for HGVs assumes no regional specific transition drivers, with instead, the impetus for transition occurring at a national level with the zero emission vehicle requirements pushing an overall change to both electric and hydrogen.

However, unlike the cars and vans transition, it is possible that the transition to hydrogen will be driven by the potential inability of EVs to meet the HGV needs in either an ergonomic or economic sense. This is because EV HGVs would require exceptionally large batteries, as well as infrastructure with greater than 350kW charge points – greater by an order of magnitude than cars and vans.

The predicted uptake rates for HGVs have been specified within the report for the Climate Change Committee: *Analysis to provide costs, efficiencies, and roll-out trajectories for zero emission HGVs, buses and coaches*.

Vehicle Type	2022	2025	2030	2035	2040	2045
ICE	100%	100%	80%	9%	0%	0%
BEV	0%	0%	17%	77%	82%	82%
Hydrogen	0%	0%	3%	14%	18%	18%

Table 9 - Purchase rates of HGV types for Scenario A (Low)

Vehicle Type	2022	2025	2030	2035	2040	2045
ICE	100%	100%	80%	9%	0%	0%
BEV	0%	0%	12%	46%	62%	71%
Hydrogen	0%	0%	7%	46%	38%	29%

Table 10 - Purchase rates of HGV types for Scenario B (Medium)

Vehicle Type	2022	2025	2030	2035	2040	2045
ICE	100%	100%	80%	9%	0%	0%
BEV	0%	0%	13%	47%	57%	54%
Hydrogen	0%	0%	7%	45%	43%	46%

Table 11 - Purchase rates of HGV types for Scenario C (High)

In all scenarios, we can see the rapid drop off in the purchase rates of ICE HGVs from 2030, with the subsequent replacement by either BEV or ICE.

2.2.2 Rail Transition

The *Rail Services Decarbonisation Action Plan* *(RDAP)* sets out the Scottish Government's intention to decarbonise the rail network by 2045, as shown in Figure 5 below. The RDAP has been relied upon exclusively in this study to determine the hydrogen transition scenarios for rail in the Dumfries and Galloway Council area, which include different combinations of electrification and alternative traction solutions for the region.

To align with the RDAP, all hydrogen technology transition scenarios assume that hydrogen might be used for services between Glasgow Central and Kilmarnock to Stranraer. Approximately 21% of this route lies within Dumfries and Galloway. Additionally, the timing of rolling stock introductions and future fuel assumptions on each Dumfries and Galloway Council area route align with the scenarios already outlined in the accompanying ***Zero Emission Energy for Transport: National Demand Forecasts for Electricity and Hydrogen*** report.

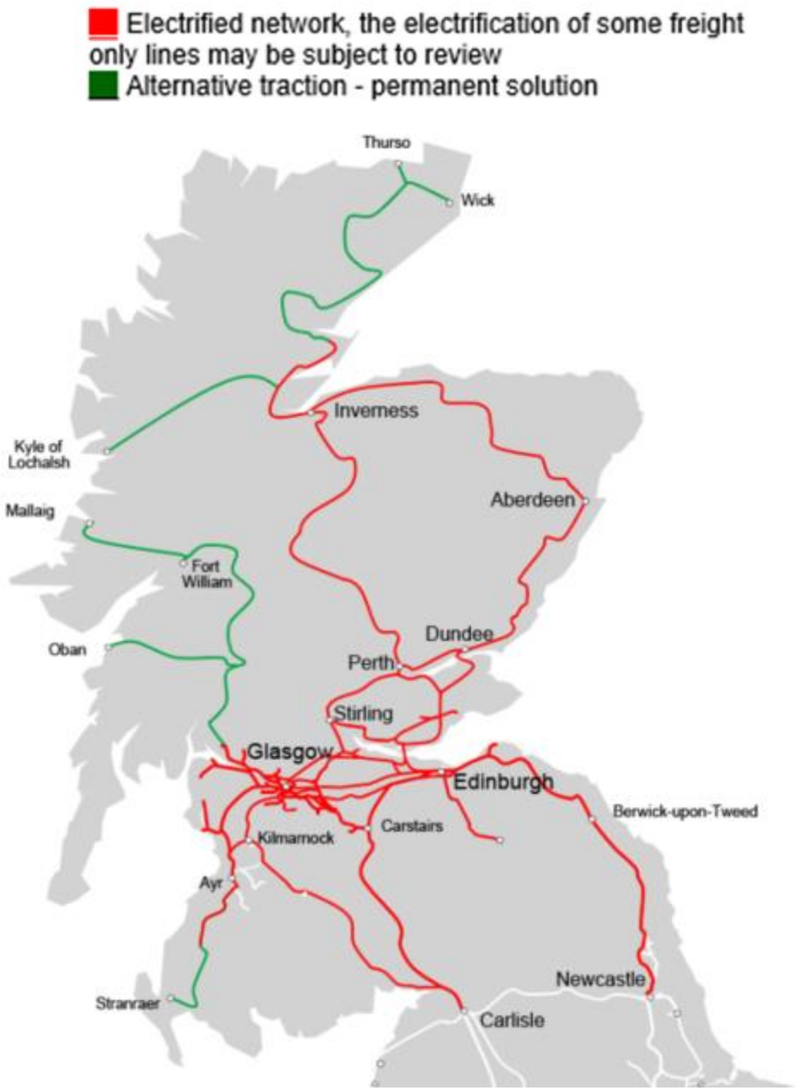


Figure 4 - Map showing decarbonised rail network in Scotland, 2045, modified *Rail Services Decarbonisation Action Plan*, page 41

There are three hydrogen technology transition scenarios A (Low), B (Medium) and C (High) for this study. Scenario A assumes that there would be no hydrogen trains operating in Dumfries and Galloway, but that hydrogen would be the traction fuel for Stranraer services under Scenarios B and C. Table 12 below outlines each of the scenarios in further detail:

Hydrogen Scenario	Assumptions
A (Low)	• No hydrogen trains introduced: battery electric used instead
B (Medium)	• Hydrogen trains introduced from Glasgow Central and Kilmarnock to Stranraer (2035)
C (High)	• Hydrogen trains introduced from Glasgow Central and Kilmarnock to Stranraer (2035)

Table 12 - Forecast transition to hydrogen for rail services.

West Coast Mainline

This route is currently electrified, and all services are electric.

Former Southwestern Railway Route

The RDAP sets out the plan to electrify this route by 2035 and therefore it is assumed all services on this route will be operated by Electric Multiple Units.

Stranraer Line

The RDAP sets out that by 2035 the line south of Ayr is unlikely to be electrified and although the line as far as Girvan should be electrified by 2045 the plan is to run alternative traction permanently between Girvan and Stranraer. This would therefore require the adoption of either Battery Electric Multiple Units (BEMUs) or hydrogen multiple units. The low hydrogen scenario assumes that BEMUs are adopted, while the medium and high technology transition scenarios assume hydrogen trains are adopted.

2.2.3 Maritime Transition

Shipping

Currently, Dumfries and Galloway Council area has not been earmarked as a major hydrogen hub. This is because the majority of offshore wind farms are currently located on the east coast of Scotland and therefore, the capacity to produce green hydrogen is considered more feasible in areas other than Dumfries and Galloway.

The hydrogen transition scenarios for the Dumfries and Galloway Council area are based on those within the accompanying ***Zero Emission Energy for Transport: National Demand Forecasts for Electricity and Hydrogen***, which were developed based on current and expected technological readiness, efficiencies and suitability of ammonia or hydrogen fuel compared to other substitute zero emission fuels year by year.

As with the national forecasts, ammonia has been considered preferable over hydrogen due to potential to retrofit existing ship engines to ammonia at a lower cost compared to hydrogen, its higher energy density compared to hydrogen (and therefore requiring less space to store and smaller fuel tanks) and the lower cost of production compared to methanol – an alternative biofuel.

Table 13 below summarises the three hydrogen transition scenarios modelled for Dumfries and Galloway Council area. Scenarios A, B and C (low, medium and high) were developed to give a range of potential hydrogen demand that would be expected for the Dumfries and Galloway region to 2045.

Scenario	Domestic (%) – 2045	International (%) – 2045
A (Low)	20%	8%
B (Medium)	40%	32%
C (High)	76%	52%

Table 13 - Hydrogen penetration rates by 2045 for the high, medium and low scenarios

Ferries

Although there are no hydrogen ferries currently in service, projects around the world are designing and testing hydrogen vessels including HYSEAS III in Scotland, MF Hydra in Norway, and Sea Change in California. Regardless, it can be assumed the technology is not currently available to many ferry operators in the Dumfries and Galloway Council area. By contrast, battery electric ferries have already become operational across the world most notably in Scandinavia where Norway has been growing its electric fleet since 2015. The world's largest electric ferry, the 143 metre-long Bastø Electric, is now commercially operational. However, there are range limitations of battery technology, due to the size and weight of batteries required. As a result, alternative fuels such as hydrogen will need to be used for longer routes.

The hydrogen scenarios developed for the Dumfries and Galloway Council area are built on the route-based dataset and methodology developed for the accompanying ***Zero Emission Energy for Transport: National Demand Forecasts for Electricity and Hydrogen*** report. Like these national forecasts, a transition profile was developed for each ferry route in the Dumfries and Galloway Council area. This profile estimated the year of vessel replacement and likely replacement fuel-type for each route.

Unlike the other routes analysed within the original dataset of 150 ferry routes, the two routes in the Dumfries and Galloway region were considered as an exception due to the size of the vessels which are 20,646 GT for the P&O European Causeway and around 30,285 GT for the Stena Superfast VII and VIII. Therefore, in a similar manner to the shipping model, ammonia has been considered preferable to hydrogen for the same reasons.

The modelled rate of uptake of hydrogen ferries is dependent on the maturity of hydrogen powertrains in the expected year of replacement.

In addition to hydrogen and ammonia powertrain maturity, the range and performance of the predominant competing technology (battery electric vessels), would also influence future technology uptake. For this reason, and considering the elements above, the replacement fuel type was dependent not only on the route length, but also projected battery energy density, estimated year of replacement, and technological readiness of hydrogen in that year. This is a development from the national scenarios, where only route length was considered when assigning replacement fuel type. Due to the uncertainty around the future maturity of hydrogen and ammonia powertrains, three possible hydrogen transition scenarios have been modelled, as described in Table 14 below specifically for this region:

Hydrogen Scenario	Lifetime (years)	Year of Ammonia Readiness	Hybrid	Hydrogen Characteristics
A (Low)	25 + 5	2030	N/A	Replacements occur up to 30 years after commissioning. Hydrogen is not viable until 2030. Replacements before 2030 will be the existing technology
B (Medium)	25 + 5	2028	N/A	Replacements occur up to 30 years after commissioning. Hydrogen not viable until 2025 and Ammonia is not viable until 2030. Replacements before 2025 will be the existing technology
C (High)	25 + 5	2028	N/A	Replacements occur up to 30 years after commissioning. Hydrogen is ready to be utilised now (no technological readiness or supply side restrictions). Ammonia is not viable until 2028.

Table 14 - Characteristics of the three modelled uptake scenarios

Key notes on the scenarios outlined above:

- All three scenarios assume a ‘medium’ battery electric range. During model development, it became apparent that varying the battery electric range by up to 50% scarcely affected the energy demand forecasts
- The location of specific hydrogen hubs has not been considered for any scenario.
- Ammonia is assumed to take longer to introduce based on the details provided in the shipping section and it being likely to take longer to be commercially viable
- In this case, due to the replacement timeframe for the Ferries on the two routes in the Dumfries and Galloway region, the high scenario is slightly more optimistic than the expectation that ammonia technology will be available by around 2030.
- Vessel replacements in this region were considered only to be ammonia due to the size of the vessels being used and therefore their associated power requirements to match the analysis and conclusions in shipping
- The replacement year of each vessel is based on its year of construction and the assumed operational lifespan of ferries. In general for Ferries, for scenarios B and C, it is assumed that ferries have a lifespan of 25 years and must be replaced in their 26th year. It is assumed that each vessel is replaced midway through the 26th year, so hydrogen demand is halved for the year of introduction (assuming six-months of operation).
- However, in this region give the age of the current vessels and the potential for this to be extended to enable replacements with hydrogen alternatives it is assumed that in Scenario A the lifespan is extended to 35 years, in Scenario B is 30 years and in Scenario C it is 28 years.
- In this analysis a 25–35 year lifespan is a conservative estimate of the actual operational lifespan of Scottish ferries. Ferries can operate for longer than 40 years. However, a 25–35 year lifespan has been assumed as this rate of replacement will be necessary to achieve the emission targets set by the Scottish Government.

Besides the methodology used to estimate the year of vessel replacement and assign an appropriate low emission replacement fuel type (as described above), the methodology is consistent with the accompanying ***Zero Emission Energy for Transport: National Demand Forecasts for Electricity and Hydrogen*** report.

3. Hydrogen Demand Forecasts

The following section describes the results of modelling of hydrogen demand forecasts for the Dumfries and Galloway Council area. The forecasts have been calculated using localised transport demand and the hydrogen transition scenarios described in the preceding sections.

Additionally, the energy demand calculations for each transport mode are consistent with the calculations and assumptions described in the accompanying ***Zero Emission Energy for Transport: National Demand Forecasts for Electricity and Hydrogen*** report.

3.1 Road Results

3.1.1 Cars and Vans

Across the results for cars and vans, there is expected to be a limited take up of hydrogen technology for cars and vans until 2035. Compared to the national results of accompanying ***Zero Emission Energy for Transport: National Demand Forecasts for Electricity and Hydrogen*** report – cars represent 9.2% of the regional hydrogen demand. While for vans, it is 1.6%, indicating that a slightly greater proportion of the hydrogen demand in the Dumfries and Galloway Council area will be driven by cars. This is compared to the 7.6% and 1.4% in the national figure. Whilst this is not substantially different, the largely rural nature of Dumfries and Galloway is likely driving the slight overemphasis of cars within this area.

Scenario A (Low)

Vehicle Type	2022	2025	2030	2035	2040	2045
Cars	0.1	0.2	0.6	2.8	5.7	7.0
Vans	0.0	0.0	0.1	0.5	0.7	0.8

Table 15 - Hydrogen demand for cars and vans for low hydrogen scenario

In Scenario A, cars will require 7.0 GWh by 2045, with vans requiring 0.8 GWh.

Scenario B (Medium)

Vehicle Type	2022	2025	2030	2035	2040	2045
Cars	0.1	0.3	1.1	5.5	11.2	13.7
Vans	0.0	0.0	0.2	0.9	1.4	1.6

Table 16 - Hydrogen demand for cars and vans for medium hydrogen scenario

In Scenario B, cars will require 13.7 GWh by 2045, with vans requiring 1.6 GWh.

Scenario C (High)

Vehicle Type	2022	2025	2030	2035	2040	2045
Cars	0.2	0.4	1.7	8.1	16.5	20.1
Vans	0.0	0.0	0.3	1.4	2.0	2.4

Table 17 - Hydrogen demand for cars and vans for high hydrogen scenario

In Scenario C, cars will require 20.1 GWh by 2045, with vans requiring 2.4 GWh.

The spatial distribution of hydrogen demand for cars and vans is shown in Section 6.

3.1.2 Buses and Coaches

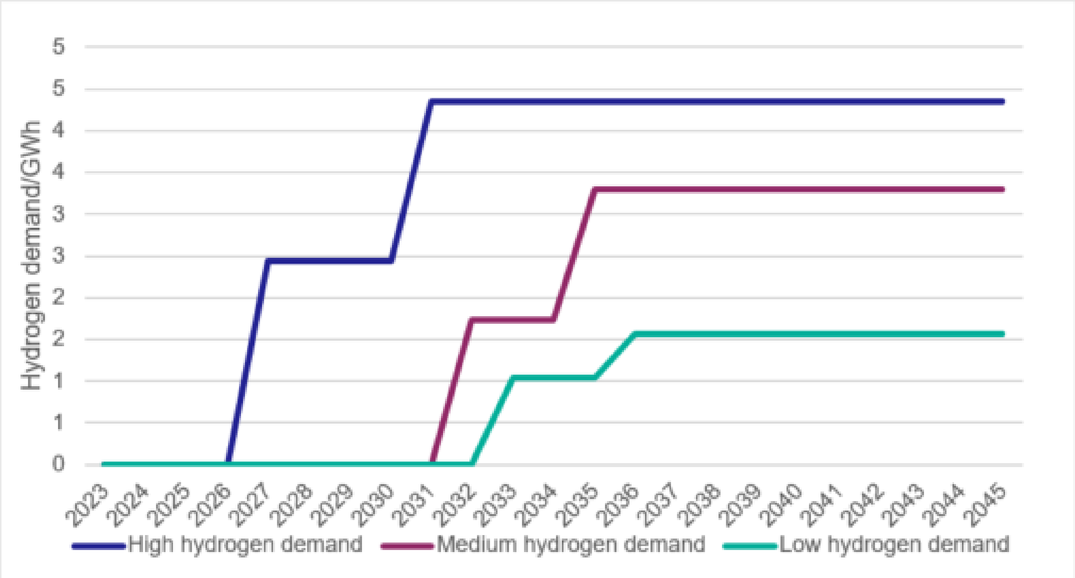


Figure 5 - Forecast hydrogen demand for buses in the Dumfries and Galloway Council area

Figure 5 above shows the Scenarios A, B and C for the demand for hydrogen over time, based on modelled approximation of growth rates, together with a series of step change increases representing small fleets of hydrogen vehicles being introduced to market. The numbers of buses and coaches making up this demand is presented in the Appendix in Section 7.

Scenario A (Low)

Moderate take-up of electric vehicles occurs with a high price for hydrogen vehicles.

The low scenario indicates 3 buses and 6 coaches at the peak. Coaches are introduced in 2033 and buses in 2036

Scenario B (Medium)

Moderate take-up of electric vehicles occurs with a mid-range price for hydrogen vehicles.

The medium scenario indicates 9 buses and 10 coaches at the peak. Coaches are introduced in 2032 and buses in 2034

Scenario C (High)

Moderate take-up of electric vehicles occurs with a lower price for hydrogen vehicles.

The high scenario indicates 11 buses and 14 coaches at the peak. The coaches are introduced in 2027. The 13 coaches are introduced in 2031.

3.1.3 HGVs and HDVs

The Dumfries and Galloway forecasts for HGVs are shown in the following tables. Unlike cars and vans, there is no take up of hydrogen at all until 2030. This is a consequence of the technology transition scenarios. However, past 2030 there is an increasingly rapid take up of hydrogen in all scenarios, and particularly in the High and Medium hydrogen scenario. Hydrogen energy demand in these two scenarios is comparable to the total energy demand for electric HGVs.

Scenario A (Low)

Assumed to follow the low uptake rates for hydrogen, as specified within the report for the Climate Change Committee: *Analysis to provide costs, efficiencies, and roll-out trajectories for zero emission HGVs, buses and coaches*.

Scenario	Vehicle Type	2022	2025	2030	2035	2040	2045
Low Hydrogen	HGV	0.0	0.0	5.0	11.6	18.7	25.0

Table 18 – Hydrogen demand for HGVs for low hydrogen scenario

In Scenario A, HGVs will require 25.0 GWh by 2045.

Scenario B (Medium)

Assumed to follow the medium uptake rates for hydrogen, as specified within the report for the Climate Change Committee: *Analysis to provide costs, efficiencies, and roll-out trajectories for zero emission HGVs, buses and coaches*.

Scenario	Vehicle Type	2022	2025	2030	2035	2040	2045
Medium Hydrogen	HGV	0.0	0.0	11.0	33.9	49.8	57.3

Table 19 – Hydrogen demand for HGVs for medium hydrogen scenario

In Scenario B, HGVs will require 57.3 GWh by 2045.

Scenario C (High)

Assumed to follow the high uptake rates for hydrogen, as specified within the report for the Climate Change Committee: *Analysis to provide costs, efficiencies, and roll-out trajectories for zero emission HGVs, buses and coaches*.

Scenario	Vehicle Type	2022	2025	2030	2035	2040	2045
High Hydrogen	HGV	0.0	0.0	11.1	33.2	50.7	64.6

Table 20 – Hydrogen demand for HGVs for high hydrogen scenario

In Scenario A, HGVs will require 64.6 GWh by 2045.

From comparison to the national forecasts accompanying ***Zero Emission Energy for Transport: National Demand Forecasts for Electricity and Hydrogen*** report, the regional forecasts for hydrogen for HGV broadly follow the national forecasts. The proportion of hydrogen for HGVs in Dumfries and Galloway is 89.5%, compared to 91% for the national totals. This indicates that, overall, Dumfries and Galloway is broadly similar in terms of its HGV hydrogen split.

The spatial distribution of hydrogen demand for HGVs is shown in Section 6.

3.2 Rail Results

Scenario A (Low)

The Low scenario assumes no hydrogen trains running in Dumfries and Galloway in the study years, so the demand is 0 GWh across all years.

Scenario B (Medium) and C (High)

The Medium and High scenarios assume hydrogen trains running on the Glasgow and Kilmarnock to Stranraer lines by 2035, with no further hydrogen trains introduced.

Scenario	2022	2025	2030	2035	2040	2045
B (Medium)	0	0	0	8	8	8
C (High)	0	0	0	8	8	8

Table 21 - Hydrogen demand for rail for medium and high hydrogen scenarios

In Scenarios B and C, services in the Dumfries and Galloway region will require 8 GWh of Hydrogen by 2035, which remains constant until 2045.

Implications for Hydrogen Usage for Rail

These estimates are based on route miles, but Network Rail's Traction Decarbonisation Network Strategy Interim Programme Business Case highlights that hydrogen powered trains have a predicted range of around 1,000 km and that it is expected trains would need to be refuelled roughly once every twenty-four hours, such as during overnight stabling.

Of the four trains per day that operate to and from Stranraer, one unit is stabled overnight at Stranraer to form the first train to Glasgow. The other units are stabled overnight at a depot in Glasgow, and it is perhaps likely that all multiple units are refuelled at a depot in Glasgow, in which case there would be no need for a hydrogen supply for rail within the Dumfries and Galloway region. However, for operational reasons, the ability to refuel multiple units at Stranraer may still be desirable. As Stranraer is at the end of the line from Glasgow Central, Stranraer is likely to be the only refuelling location in Dumfries and Galloway.

3.3 Maritime Results

3.3.1 Shipping

The Dumfries and Galloway forecasts for shipping are shown in Table 22. There is no take up of hydrogen at all until 2030. This is because technology to retrofit existing ship engines to ammonia is not expected to be commercially available until early 2030s.

Scenario (GWh)	2022	2025	2030	2035	2040	2045
Scenario A (Low)	0	0	0.1	0.5	1.0	1.5
Scenario B (Medium)	0	0	0.2	1.4	2.6	3.8
Scenario C (High)	0	0	0.4	2.4	4.5	6.7

Table 22 - Hydrogen demand for Dumfries and Galloway Council area

The hydrogen demand from Dumfries and Galloway shipping sector represents a very small proportion of the national hydrogen demand from the shipping sector. This low demand is explained because, as presented in Section **2.1.3 Maritime Transport Demand**, the main cargo ports within Dumfries region are ferry terminals and therefore, the hydrogen demand from shipping comes only from the fishing ports.

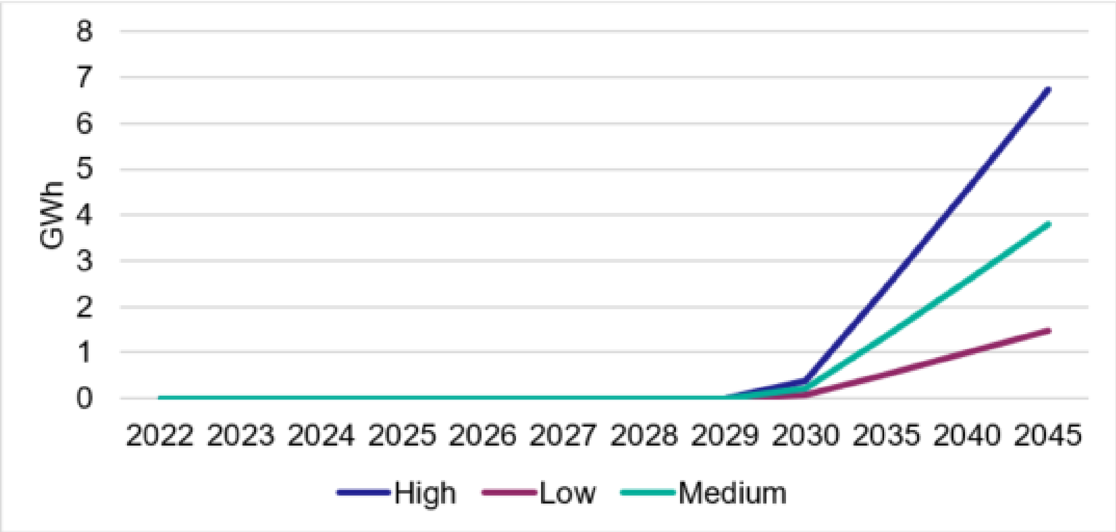


Figure 6 - Forecast hydrogen demand for the Dumfries and Galloway Council area

The hydrogen demand from ferries has been subtracted from Cairnryan and Loch Ryan ports, as these are the two only ferries ports within the region. Still, these two ports account for almost all the hydrogen demand from the Dumfries region. The hydrogen demand from the fishing ports represents only around 0.5% of the total hydrogen demand. This is in line with the proportion of emissions coming from the fishing vessels in the Dumfries area.

3.3.2 Ferries

The hydrogen demand forecasts for the Dumfries and Galloway Council area are the same for both the high and medium scenarios, and (except for the timing of the introduction of hydrogen vessels) similar for the low scenario. Figure illustrates the rate of conversion to hydrogen technology for each scenario, based on the cumulative number of vessels that have transitioned by each year.

The transition across all scenarios are relatively similar due the existing vessels having been commissioned in 2000 (European Causeway) and 2001 (Stena Superfast VII and VII) and therefore are all expected to be due for replacement towards 2030.

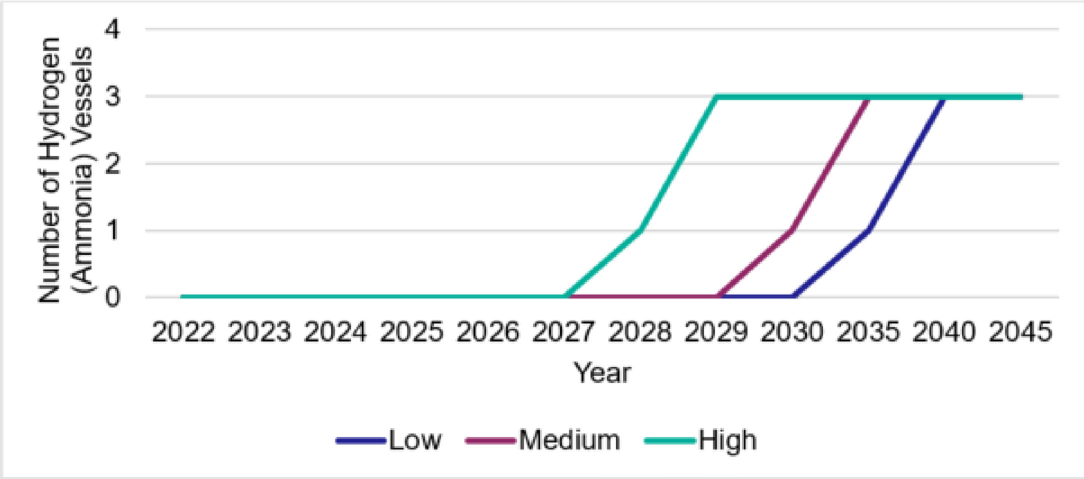


Figure 7 - Number of hydrogen vessels by year and scenario

While there are only two routes in the region, it must be noted that the longer route (Cairnryan – Belfast) operates two vessels. For simplicity, the transition of the route to hydrogen is assumed to apply to both vessels.

The replacement vessels for both routes are expected to require significant quantities of hydrogen during operation. The replacements for the Stena Superfast VII and VIII (Cairnryan – Belfast) are expected to require the greatest quantity of hydrogen, with 720 GWh of hydrogen collectively per annum between 2029-2045 in the high hydrogen scenario. The European Causeway (Cairnryan – Larne) is expected to require 433 GWh per annum between 2028-2045 (the replacement is assumed to occur a year earlier than the Stena Superfast). Both routes are not located near any of the proposed hydrogen hubs identified, but hydrogen supply is not considered as a barrier to uptake.

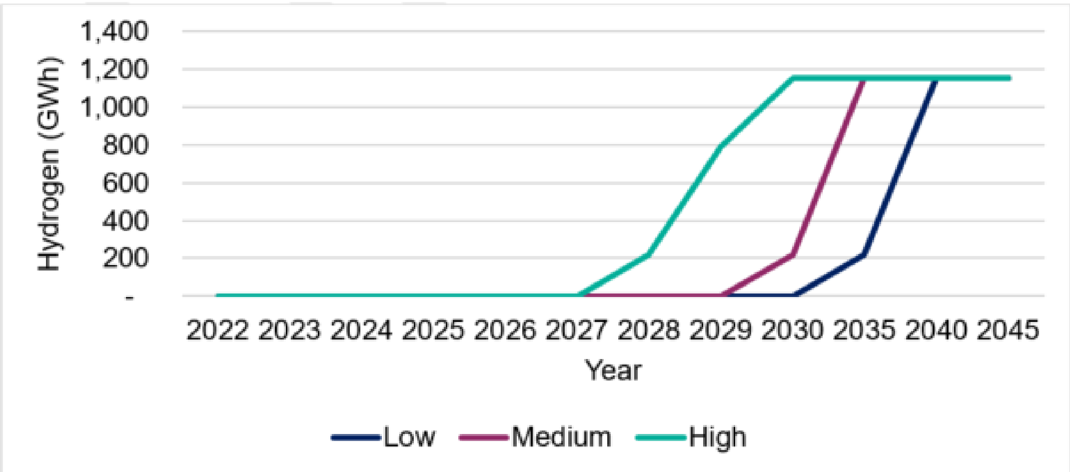


Figure 8 - Forecast hydrogen demand for the Dumfries and Galloway Council area

Figure 8 shows the estimated hydrogen demand for each scenario. Full data tables are included in the Appendix - Section 7.2.

As with all regions in the study, replacement vessels are assumed to be introduced halfway through their introductory year (e.g. July), meaning hydrogen demand during the first year of operation is only 50%. Hydrogen demand is assumed to be 100% in the second year. In addition to this, the Dumfries & Galloway routes are unique in that the hydrogen demand is assumed to be 50% of the total route demand for all years (from introduction year onward) given that both routes share refuelling outside the region with Northern Ireland.

Scenario A (Low)

In the lowest hydrogen scenario, one vessel (European Causeway) is replaced in 2035 and the other two replacements (Stena Superfast VII and VIII) occur in 2035. Hydrogen demand is therefore zero from 2022 until 2035. As the replacement vessels become operational, demand increases to approximately 1,153 GWh per annum by 2034. Hydrogen demand remains constant at 1,153 GWh through the net zero target of 2045.

Scenario B (Medium)

In the medium hydrogen scenario, one vessel (European Causeway) is replaced in 2030 and the other two vessel replacements (Stena Superfast VII and VIII) occur in 2031. Therefore, hydrogen demand increases rapidly to approximately 1,153 GWh by 2035, once both vessels are fully operational. This remains constant through the net zero target of 2045.

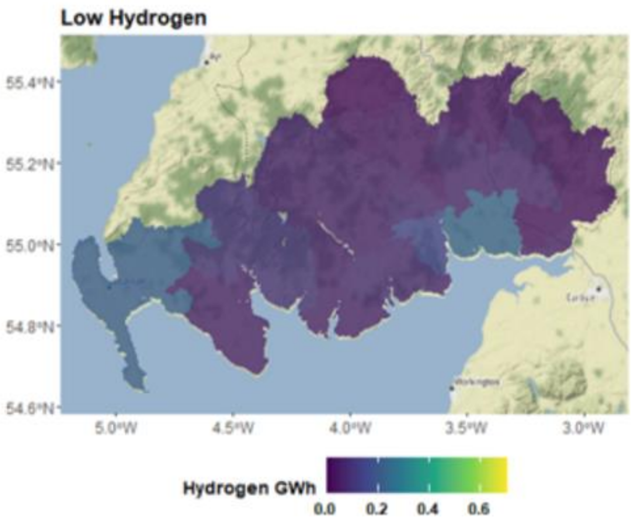
Scenario C (High)

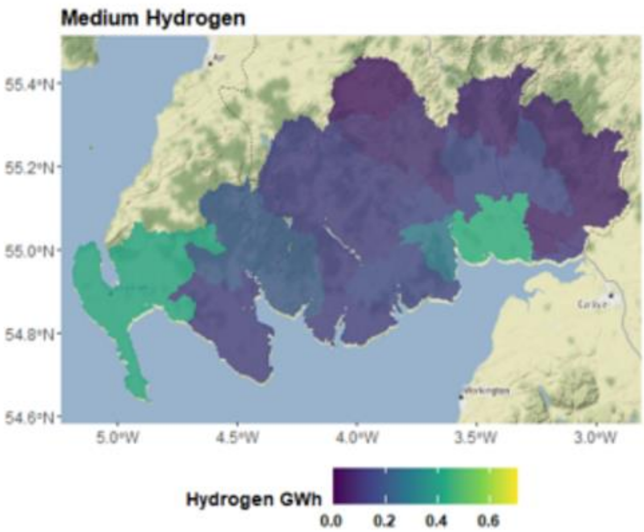
In the high hydrogen scenario, one vessel (European Causeway) is replaced in 2028 and the other two vessel replacements (Stena Superfast VII and VIII) occur in 2029. Therefore, hydrogen demand increases rapidly to approximately 1,153 GWh by 2030, once both vessels are fully operational. This remains constant through the net zero target of 2045.

6. Hydrogen Demand Mapping

6.1 Roads

Cars





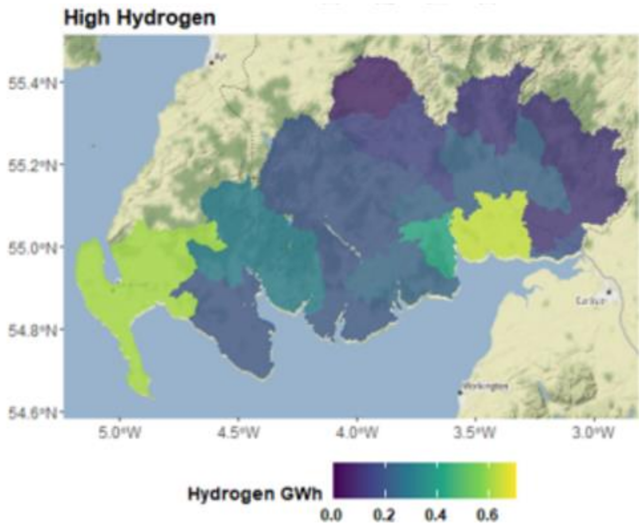
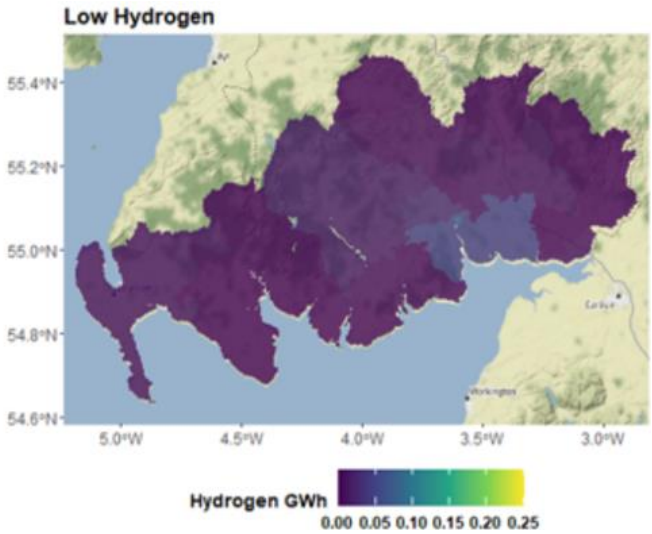
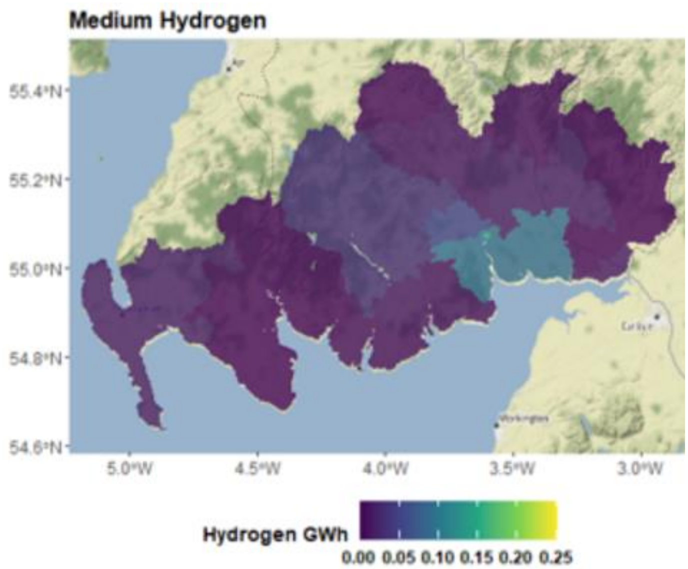


Figure 9 - Hydrogen demand for cars in the Dumfries and Galloway region for each scenario

The map shows the total hydrogen GWh demand for cars for all scenarios for 2035 within each separate area in the Dumfries and Galloway region. The results shown here are total demand, rather than density of demand, hence the relatively large values shown in the less well populated regions. There is relatively little concentration of demand, with car hydrogen demand spread across all areas.

Vans


Low Hydrogen
55.4°N
55.2°N
55.0°N
54.8°N
54.6°N
5.0°W
4.5°W
4.0°W
3.5°W
3.0°W
Hydrogen GWh
0.00 0.05 0.10 0.15 0.20 0.25


Medium Hydrogen
55.4°N
55.2°N
55.0°N
54.8°N
54.6°N
5.0°W
4.5°W
4.0°W
3.5°W
3.0°W
Hydrogen GWh
0.00 0.05 0.10 0.15 0.20 0.25

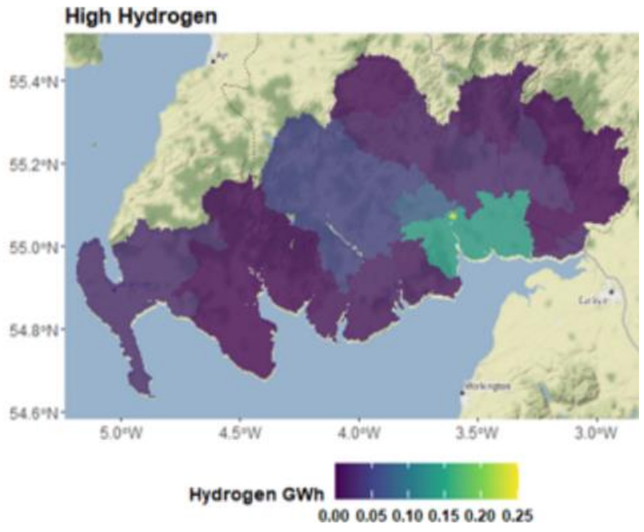
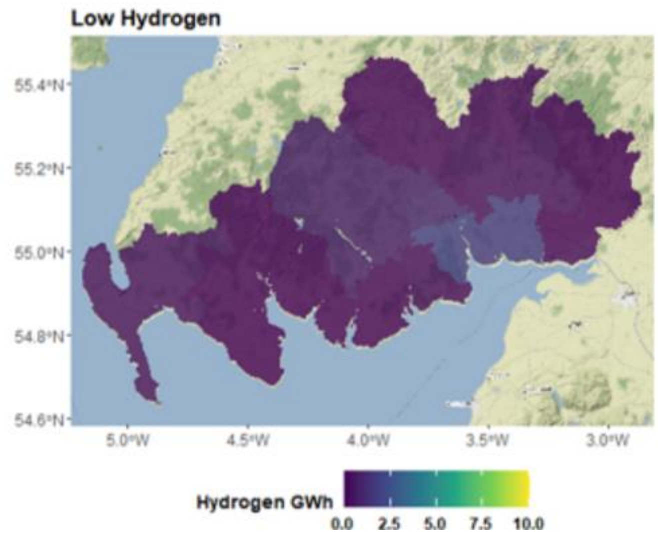


Figure 10 - Hydrogen demand for vans in the Dumfries and Galloway region for each scenario

The map shows the total hydrogen GWh demand for vans for all scenarios for 2035 within each separate area in the Dumfries and Galloway region. A major difference between car and van demand can be seen in the concentration of hydrogen demand around the Dumfries area, with less demand in the more rural zones. This indicates that demand for hydrogen refuelling for light commercial fleet is likely to be concentrated around urban areas.

HGVs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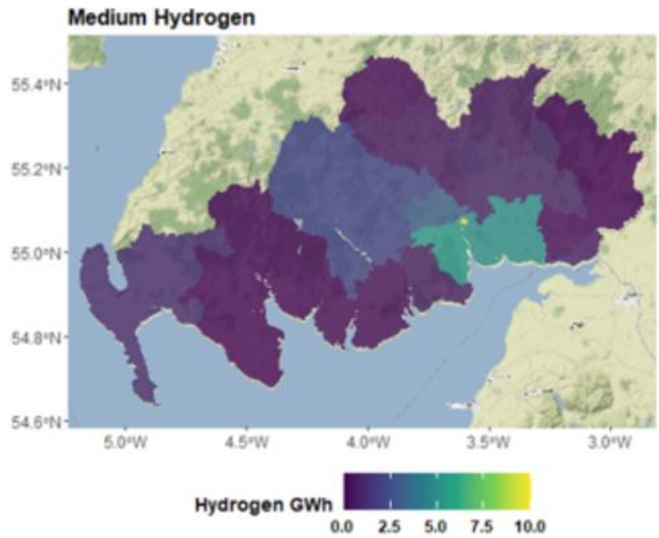
55.2°N
55.0°N
54.8°N
54.6°N
5.0°W
4.5°W
4.0°W
3.5°W
3.0°W
Hydrogen GWh
0.0
2.5
5.0
7.5
10.0


Medium Hydrogen
55.4°N
55.2°N
55.0°N
54.8°N
54.6°N
5.0°W
4.5°W
4.0°W
3.5°W
3.0°W
Hydrogen GWh
0.0
2.5
5.0
7.5
10.0

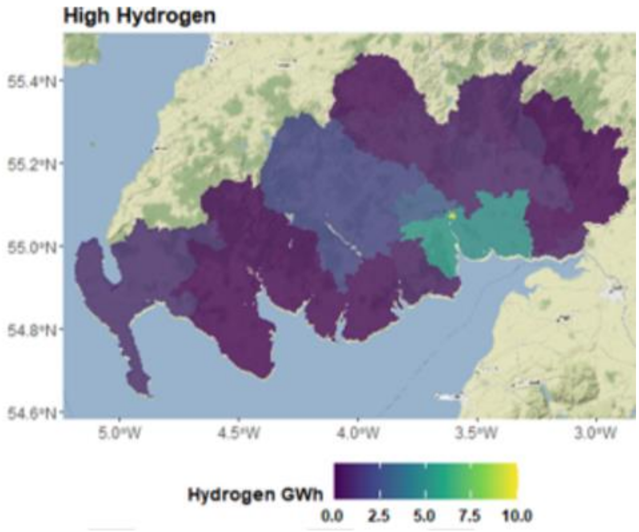


Figure 11 - Hydrogen demand for HGVs in the Dumfries and Galloway region for each scenario

The maps show the HGV hydrogen demand for the Dumfries and Galloway region. It can be seen that the total demand for hydrogen is much higher than for either cars or vans. However, the overall distribution of hydrogen demand is the same as for vans, with a particular concentration around the Dumfries area.

7.0 Appendices

7.1 Buses and Coaches

Year	High hydrogen Demand in GWh	High hydrogen fleet	Medium hydrogen Demand in GWh	Medium hydrogen fleet	Low hydrogen Demand in GWh	Low hydrogen fleet
2023	0	No H2FC vehicles	0	No H2FC vehicles	0	No H2FC vehicles
2027	2	14 coaches	0	No H2FC vehicles	0	No H2FC vehicles
2031	4	11 buses, 14 coaches	0	No H2FC vehicles	0	No H2FC vehicles
2032	4	11 buses, 14 coaches	2	10 coaches	0	No H2FC vehicles
2033	4	11 buses, 14 coaches	2	10 coaches	1	6 coaches
2035	4	11 buses, 14 coaches	3	9 buses, 10 coaches	1	6 coaches
2036	4	11 buses, 14 coaches	3	9 buses, 10 coaches	2	3 buses, 6 coaches
2045	4	11 buses, 14 coaches	3	9 buses, 10 coaches	2	3 buses, 6 coaches

Table 23 - Hydrogen demand for buses and coaches

7.2 Ferries

Year	Scenario A (Low)	Scenario B (Medium)	Scenario C (High)
2022	0	0	0
2023	0	0	0
2024	0	0	0
2025	0	0	0
2026	0	0	0
2027	0	0	0
2028	0	0	216
2029	0	0	793
2030	0	216	1,153
2035	216	1,153	1,153
2040	1,153	1,153	1,153
2045	1,153	1,153	1,153

Table 24 - Data for hydrogen demand (GWh) for each transition scenario

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