INSIGHT BRIEF

Green Shipping Corridors: Opportunity Identification

A data-based approach to evaluating potential corridors, and an initial case study of the Clydebank Declaration signatories

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The report was compiled by a team of experts from UMAS supported by the Global Maritime Forum (GMF). This work reviews shipping activity among the Clydebank declaration signatories and identifies the potential for decarbonisation via 'Green Corridors'. The views expressed are those of the authors.

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About UMAS

UMAS undertakes research using models of the shipping system, shipping big data (including satellite Automatic Identification System data), and qualitative and social science analysis of the policy and commercial structure of the shipping system. Research and consultancy is centred on understanding patterns of energy demand in shipping and how this knowledge can be applied to help shipping transition to a low-carbon future. UMAS is world-leading on two key areas; using big data to understand trends and drivers of shipping energy demand or emissions and using models to explore what-ifs for future markets and policies. For more details visit www.u-mas.co.uk.

Abbreviations

CO2	Carbon Dioxide	**IPCC**	Intergovernmental Panel on Climate Change
CO2e	Carbon Dioxide Equivalent	**Mt**	Million tonnes
GHG	Greenhouse Gas(es)	**nm**	Nautical mile
H2	Hydrogen	**Ro-Pax**	Roll-on and passenger ferry
HFO	Heavy Fuel Oil	**RoRo**	Roll-on/Roll-off cargo ferry
HFOe	Heavy Fuel Oil Equivalent	**UNFCCC**	United Nations Framework Convention on Climate Change
IMO	International Maritime Organisation	**SZEFs**	Scalable Zero Emissions Fuel(s)

1. Executive summary

Nearly 12 months on from the announcement at COP26 of the Clydebank Declaration for Green Shipping Corridors (hereafter Clydebank Declaration), a series of high-profile announcements of Green Corridor projects show that this concept is rapidly gaining traction and attention. Green Corridors can act as a key enabler of first mover investment this decade, with that investment creating hubs for new energy production and use that can scale rapidly, and attract further investment.

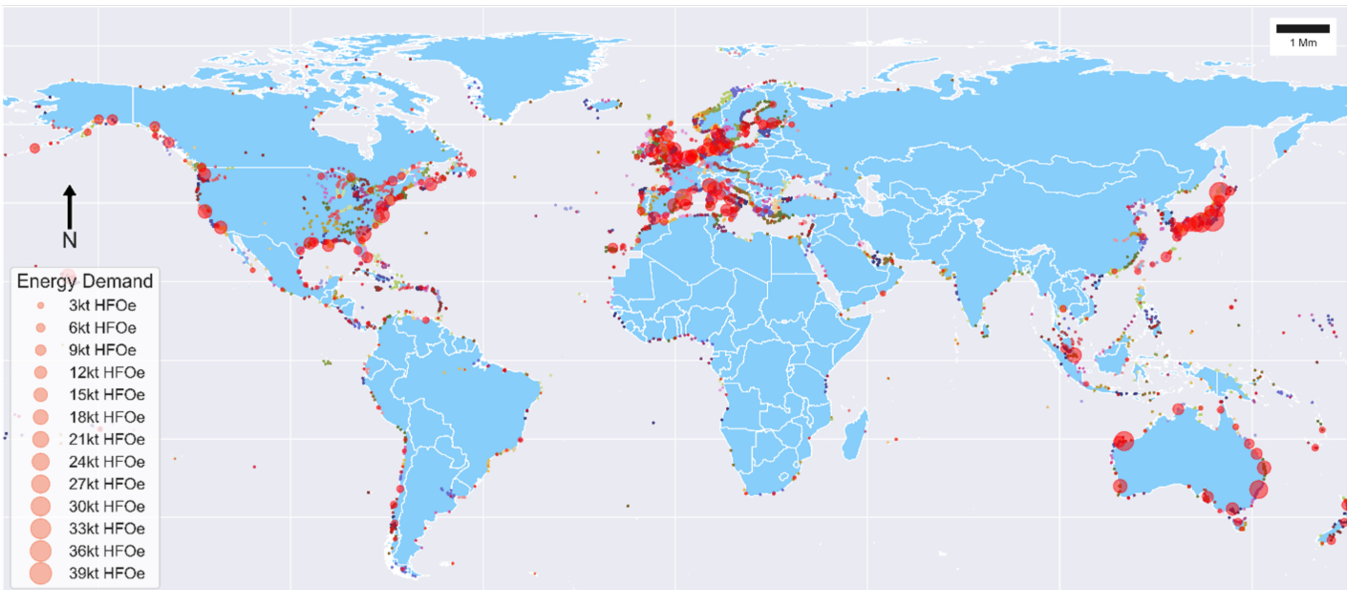
Previous analysis undertaken as part of the Getting to Zero Coalition's 'A Strategy for the Transition to Zero-Emission Shipping' (hereafter 'The Transition Strategy') estimated that ~10% of the energy/fuel used in shipping today is on ships undertaking regular and repeated voyages between ports with excellent potential for nearby low-cost hydrogen production. This demonstrates that there is large potential for Green Corridor action and investment, even before the adoption of policy at IMO which can enable the mass market transition of all ships to new Scalable Zero Emission Fuels (SZEFs).

This brief outlines how data, specifically the data produced for The Transition Strategy (made openly available here: mission-innovation.net), can help stakeholders and countries to identify the scale and geography of their Green Corridor opportunity.

The signatories to the Clydebank Declaration provide an obvious set of countries to focus on for further investigation of Green Corridors. Analysis of these countries shows that between them they have a broad range of ship types and routes with excellent early adoption potential (ferries, container ships and bulk shipping). This provides a diverse range of business models that can help green corridors align low cost and risk opportunity with maximum willingness to pay and other enablers of first movement.

In total, 16 million tonnes of current oil-derived fuel (HFOe) use is identified as ripe for substitution to SZEF, with countries such as the USA, Japan, UK, and Australia each having over 1 million tonnes of obvious first mover HFOe substitution potential. The geography of this opportunity can be seen in the map below.

Map 1: Green Corridors energy demand from Clydebank Declaration countries based on 2018 vessel activity data.



As well as identifying the scale and geography of the first mover opportunity across Clydebank Declaration countries, this briefing paper also shows how investment can be deployed progressively to help manage the risk, complexity and opportunity of Green Corridor projects.

Case studies of specific routes in a number of signatory countries reveal that the least cost and risk investment for Green Corridor can initially target bilateral domestic voyages (e.g. a ferry), built upon at a next step by vessels calling at multiple domestic ports but in a predictable and repeated pattern, and ultimately building to ships calling internationally.

Along with showing investment and corridor examples that start small and scale, the case studies also illustrate how locations can be identified that aggregate as much demand for new energy as possible, whilst concentrating on the smallest possible area of operation, thereby reducing the complexity of undertaking Corridor efforts.

The route-level data from The Transition Strategy and forthcoming tools leveraging this data, therefore, enable a prioritisation of Green Corridors that can increase the growth and scaling of demand for SZEF whilst limiting the challenges and costs of the production and distribution network that supply them.

In summary, this analysis reinforces why Green Corridors are a key and credible mechanism for starting shipping's transition to SZEF now, what scale of project might suit different locations, and how the opportunity they present can be crystallised across a large number of different countries, routes and ship types.

2. Introduction

Shipping's timely transition away from fossil fuel requires a small but significant use of its future energy sources, viz. scalable zero-emission fuels, this decade. This early use is a critical enabler of shipping's mass market transition, which needs to take place in the 2030s if the sector is to achieve a 1.5-aligned rate of decarbonisation.

This initial deployment of SZEF will:

- help mature and improve performance and safety in operations and technologies;
- optimise their supply chains;
- reduce the costs;
- start the deployment of infrastructure investment and planning;
- develop skills and training capacities; and
- enable the multi-sector collaboration and experience building that ensures processes for further investment are matured and streamlined.

Earlier GMF and UMAS work[1] provided evidence that 5% of shipping's

1 Five percent zero emission fuels by 2030 needed for Paris-aligned shipping decarbonisation

energy use needs to be substituted away from fossil fuel (or ~20 million tonnes of HFOe, equivalent to ~40 million tonnes of ammonia) by 2030. *A strategy for the Transition to Zero Emission Shipping*[2] suggested that there are several different ways to stimulate this level of SZEF use this decade. The Transition Strategy also provided evidence of the different options for where this amount of energy substitution might take place (see Section 3.1).

There is rich evidence on transitions both in and outside shipping. Drawing on this evidence, the Transition Strategy outlined three different mechanisms by which shipping's transition might unfold.

- **Plurilateral club action (Scenario 1):** A strong first mover country or group of countries initiates development of new technologies and influences other countries
- **Unilateral action (Scenario 2):** Independent action takes place in a number of countries
- **Global multilateral action (Scenario 3):** Global actions drive international spread (e.g. including a significant role driving the transition at the IMO)

Taking stock of the landscape 12 months after the publication of The Transition Strategy, two particular developments are worth highlighting:

- The IMO debate has evolved, and there is now a narrowing specification of how IMO might incentivise a shift away from fossil fuel in the global fleet, including an explicit intent to adopt GHG-pricing policy. However, there has been no acceleration of the IMO process to adopt mid-term measures, which makes the entry into force of any further IMO policies before 2026/27 unlikely, with risks that the timescale extends beyond that time. Even at the point policies enter into force, there remains no guarantee that the mid-term measure(s) would stimulate investment in scalable zero-emission fuels and vessels that can use them.
- At COP26, the UK government launched the Clydebank Declaration, seeking signatories who could commit to supporting "Green Corridor" routes. At time of writing, 24 countries had signed the Declaration.

These developments suggest that elements of each of the three types of transition are emerging. Both IMO and COP (UNFCCC) represent coordinated global action driving international spread. However, at present both provide only weak drivers – IMO policy measures for driving the fuel transition are only at a discussion stage, and the scope nor stringency of the Clydebank Declaration (24signatories stated their ambition to support Green Corridors) assure a truly global spread of zero-emission shipping. However, in many ways the Clydebank Declaration signatories represent a cohort of strong first mover countries capable of pushing to new technologies. These countries may act independently, with the level of coordination between them remaining to be seen.

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2 A strategy for the Transition to Zero Emission Shipping

The impact of actions taken by first mover countries, either independently or in partial coordination, will benefit from the availability of information that helps them target routes where zero-emission technologies might wisely be prioritized, based on data about e.g. vessel operation profiles, energy needs and potential fuel availability. This brief seeks to provide some of this information by:

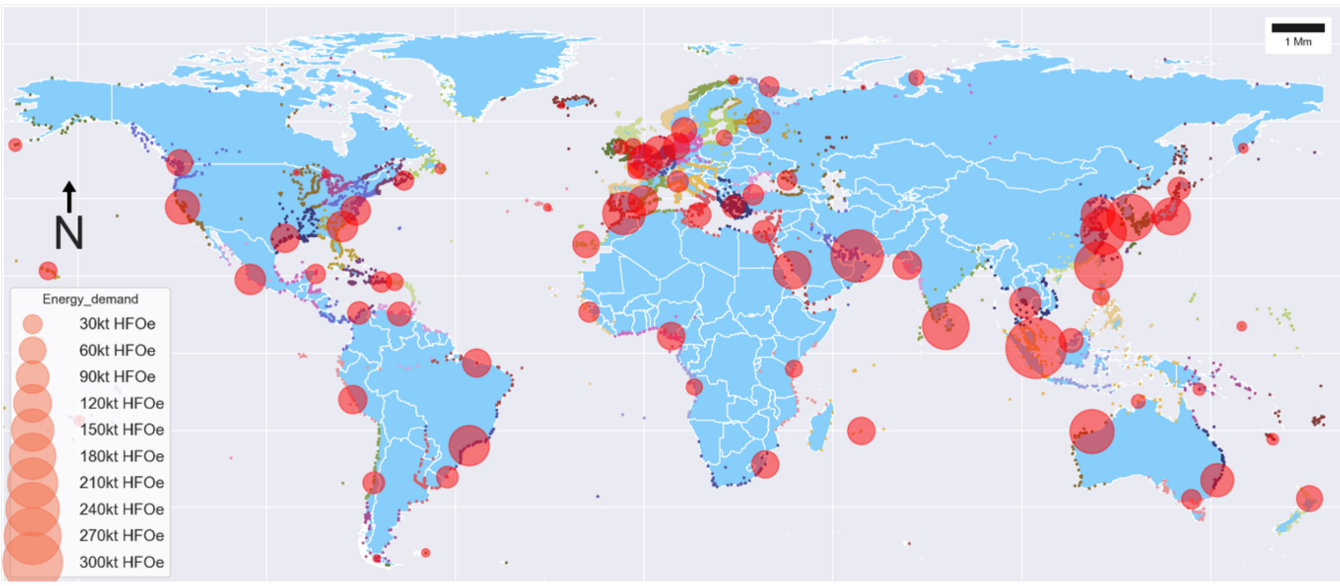
- Recapping and making more accessible the evidence behind The Transition Strategy for identifying and quantifying candidate green corridors on a country-by-country basis
- Investigating the aggregate and specific green corridors identified for signatories of the Clydebank Declaration 'strong first mover' group of countries
- Using the analysis and data to explore in greater detail some case studies of green corridor evolution in some of the Clydebank signatory countries

3. Results/Discussion

3.1 Summary of the Transition Strategy findings

One-tenth of the world's shipping fleet is a prime candidate to use SZEFs.

The Transition Strategy estimated that 10% (25.61 Mt_HFOe) of fuel consumed by the global shipping fleet is derived from regular activity within and between countries with strong H2 production potential – i.e. green corridors. Map 1 provides an overview of the geographical location of this potential, showing good potential for green corridors across all regions.



Map 2: Global decarbonisation potential of first-mover countries as presented in the Getting to Zero Coalition's 'A Strategy for the Transition to Zero-Emission Shipping' The size of the circles indicates the total energy demand of green corridor candidate vessels departing from a given cluster.

Furthermore, by categorising the fleet's activity in intra-cluster (local), bilateral (two clusters) and liner (three or more clusters), as well as into international and domestic shipping, this potential for decarbonisation can be sorted from more accessible to more challenging. The approach indicates the geographical locations where shipping activity is concentrated and infrastructure likely required, while the domestic/international classification presents the geopolitical dimension. These perspectives enable relevant stakeholders to view their jurisdiction's potential from two angles, thus helping them assess challenges, facilitate planning, and prioritise resources. Table 1 summarises the Transition Strategy's main findings.

Operational type of Strong H2 potential only	Dom/Int[3] split of vessels' operation	Average no. countries	Average no. port calls	Aggregated MDOe (Mt)	Aggregated International reduction potential (%)	Aggregated Domestic reduction potential (%)	Aggregated total reduction potential (%)	Total reduction Potential (%)
1 Intra-cluster	**Dom/Int**	2.02	9.41	0.89	0.14	0.24	0.38	**2.09**
	Dom only	1.00	5.69	3.70	0.00	1.57	1.57	
	Int only	1.74	2.25	0.32	0.14	0.00	0.14	
2 Bilateral	**Dom/Int**	1.44	4.30	0.12	0.02	0.03	0.05	**1.10**
	Dom only	1.00	6.58	1.49	0.00	0.63	0.63	
	Int only	2.05	3.46	0.98	0.42	0.00	0.42	
3 Liner	**Dom/Int**	3.71	16.50	11.80	4.16	0.86	5.02	**7.44**
	Dom only	1.00	19.99	3.50	0.00	1.49	1.49	
	Int only	3.95	7.48	2.20	0.93	0.00	0.93	
Sub total				**25.61**	**5.80**	**4.84**	**10.64**	**10.64**

Table 1: First movers potential by regularity category and domestic/international splits

3.1.2 Nearly five percent of the fleet's energy demand as the "lowest" hanging fruit, and a further six percent could be available from other accessible opportunities.

4.68% of the fleet's energy demand can be attributed to Green Corridor categories with fewer implementation challenges. First, 2.09% was identified for intra-cluster (local) activity, of which the large majority (1.6% of total) is domestic-only, 0.14% is international-only, and 0.38% a mixture. An additional 1.1% of the total Green Corridor opportunity is from bilateral activity, of which 0.63% is domestic only, 0.43% is international shipping only and only 0.05% from a mixture of both. Finally, 1.49% is consumed by vessels regularly operating among three or more clusters in a single country. This activity class is primarily located in large countries such as the US or China and island countries such as Japan or Greece.

The remaining 5.02% of first mover potential is derived from multilateral (liner) activity performed by vessels that combine domestic and international activities. These ships stop an average of 3.7 countries and about 16 different ports. The final 0.93% is consumed by ships carrying out international trading between an average of four countries and about seven ports.

3.1.3 A dataset to evaluate potential partnerships

To enable the prioritisation of engagement between countries, and streamline their search for Green Corridor opportunities, the accompanying spreadsheet: "Green Corridor Opportunities by Country Pairings Dataset" sorts this global decarbonisation potential by the country pairings between which shipping activity is performed. By

3 Domestic activity corresponds to the voyages happening between ports belonging to the same county, whereas International activity corresponds to voyages carried out between ports belonging to different countries.

elaborating on the findings of the Transition Strategy, this dataset seeks to help governments assess the countries between which there is stronger decarbonisation potential. A sample is presented in Table 2, which lists origin and destination pairings and their estimated energy demand. It also includes the number of vessels trading; their median year built, the main vessel type, and their quantity. A copy of this dataset can be found at mission-innovation.net.

Origin Country	Destination Country	Energy demand (ktonnes_HFOer/yr)	Total No of vessels	Median year of built	Main Vessel Type	No of vessels Main type
Brazil	**Brazil**	706.31	237	2011	Oil tanker	47
Brazil	**China**	608.77	107	2010	Bulk carrier	105
Brazil	**Singapore**	101.78	77	2010.5	Bulk carrier	69
Brazil	**Malaysia**	93.67	39	2012	Bulk carrier	39
Brazil	**Japan**	51.27	18	2013	Bulk carrier	17
Brazil	**USA and Puerto Rico**	44.56	27	2007	Bulk carrier	8
Brazil	**Uruguay**	29.51	52	2012.5	Oil tanker	14
Brazil	**Oman**	22.35	7	2012	Bulk carrier	7
Brazil	**Argentina**	21.63	35	2007	Container	12

Table 2: Sample of "Green Corridor Opportunities by Country Pairings Dataset"

3.2 Activity-based data as the basis for the quantitative assessment of the potential of given Green Corridors

Activity-based data allows for a multilevel review of routes' potential for decarbonisation. It can cover details from a whole fleet to the specific operational characteristics of individual vessels. Therefore, value can be extracted at different levels, depending on the use-case requirements. To illustrate this, the following section explores the decarbonisation potential of the Clydebank Declaration fleet.[4] It first analyses the location of energy demand among signatory countries, followed by a review of three example routes and how their demand profile can be used to evaluate their Green Corridor potential.

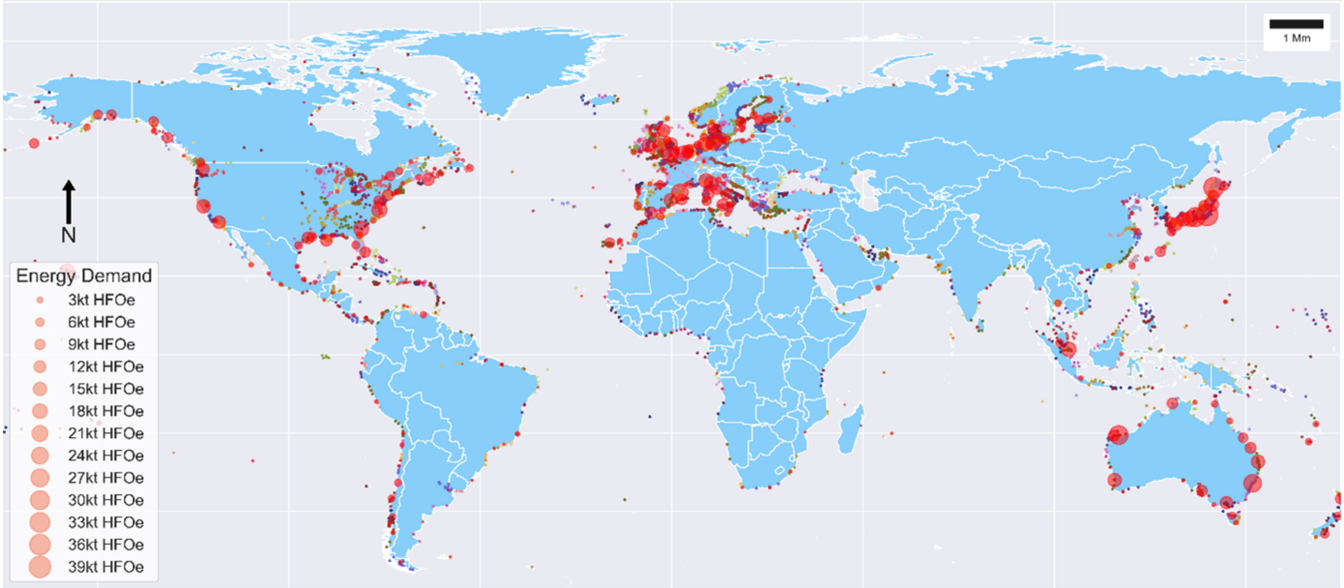
3.2.1 Where is the energy demand of the Clydebank Declaration concentrated?

The signing of a multi-government commitment such as the Clydebank Declaration provides a strong signal of political willingness around Green Corridors that should be followed by the assessment of tangible decarbonisation opportunities. This can begin with identifying the location and magnitude of energy demand clusters around which stakeholders interested in establishing of green corridors can estimate quantities of new fuels required, generate fuel demand signals, evaluate proximity synergies and other positive spill over effects.

For this, Map 3 used the methodology developed for the Transition

4 The fleet is defined by the proportion of its activity time dedicated to covering routes between specific countries. For example, this paper defines the Clydebank fleet as all vessels that spend at least 75% of their time covering routes between ports belonging to the Clydebank declaration. It includes both domestic and international activity.

Strategy to illustrate the geographic concentration of energy demand among Clydebank signatories.



Map 3: Green Corridors energy demand from Clydebank declaration countries

North America, Northern Europe, the Mediterranean, Japan, Singapore and Australia hold the most substantial potential among signatories. This makes these locations particularly low risk/high reward areas for first mover action, but also shows that they have the opportunity to scale and grow rapidly such that a first mover project can be built upon to unlock further production and use of SZEF. Europe and Japan are the regions with the densest concentration of energy demand clusters, indicating high quantities of shipping activity between nearby clusters and, therefore, the possibility for synergies in the development of fuel facilities. On the other hand, activity in the US and Australia is spread across their east and west coasts, pointing to a more "per cluster" solution of SZEF sourcing. The Mediterranean sits in the middle with strongly concentrated demand around the Spanish and Italian coasts but less concentrated demand between them. The existence of concentrated demand along the coasts of closely geographically located countries offers an opportunity for collaboration between these countries in procuring SZEF, including through the coordination of national plans (for example infrastructure development strategies) and policy.

Finally, to explore the potential on offer to given countries, Table 3 provides a ranking of signatory countries based on their first mover energy demand. Japan tops the list with an estimated energy demand on routes with good green corridor potential of around 4.8 Mt HFOe, from around 1300 vessels. This amounts to almost 1/3rd of the potential for the entire Clydebank group and, therefore, indicates the significant opportunities and leadership role held by Japan. Yet, in terms of age, Japan's fleet is the newest among signatories, with a median year of build of 2007. Compared to owners from countries like Italy (2000) or Sweden (1998), Japan's shipowners have greater productive life remaining in their fleets, typically 20-30 years. The median age for the Clydebank Declaration fleet as a whole sits at 2004, suggesting that a large proportion of the 7,745 vessels in question should be approaching renovation. This reveals a promising near-term window for the introduction of SZEF-powered vessels among Clydebank signatories and thus a ready opportunity for them to unlock first mover opportunities.

Table 3: Energy demand of the top nine Clydebank declaration signatories

Origin Country	Energy demand (ktonnes_HFOe)	Total No of vessels	Median year of built
Japan	4,840	1,309	2007
USA and Puerto Rico	2,546	636	1998
United Kingdom	1,204	656	2002
Australia	1,113	262	1999
Spain	989	352	2004
Italy	975	324	2000
Netherlands	540	637	2004
Germany	482	532	2002
Sweden	375	271	1998
Total (All Clydebank fleet)	**16,029**	**7745**	**2004**

Meanwhile, from a vessel type perspective, the Clydebank fleet's potential for green corridors is centred on ferries (RoPax: 11.0% and RoRo: 7.4%), followed by containers (7.4%) and, third, bulk Carriers (6.2%). Ferries are also the vessel types with fewer visited ports (with an average of five for RoPax and eight for RoRo), further bolstering the segment's first mover potential. Service-other[5] vessels and liquefied tankers had the lowest median voyage distance, 240 nm and 258 nm, respectively. Table 4 provides more detail on the aggregate results per vessel type. This diversity of segments showing strong potential is important because it means that within the Clydebank signatories there is the opportunity to apply first mover action in a wide variety of ship types, which can in turn unlock faster diffusion and scaling of solutions. The diversity also enables further optimisation of opportunities to niches where customer willingness to pay, stakeholder commitments might be higher and therefore barriers to early investment lower.

5 Service-other vessels include service vessels such as jack ups and other offshore service vessels.

Table 4: Clydebank declaration decarbonisation potential by vessel type

Vessel type	Number of vessels	Median voyage distance (nm)	Total HFOe (ktonne per year)	Proportion of Clydebank Fleet Fuel Consuption (% per year)	Average Number ports Visited	Average Number countries Visited
Ferry-RoPax	537	384	3560	11	5	1.2
Container	189	620	2392	7.4	14	3.9
RoRo	159	415	2009	6.2	8	2.6
Bulk carrier	501	321	1985	6.2	21	2.1
Chemical tanker	494	225	1468	4.6	29	2.4
Liquefied gas tanker	187	258	1193	3.7	22	2.3
Oil tanker	241	305	1112	3.5	22	1.6
Vehicle	77	1234	741	2.3	15	4.1
Service - other	749	242	635	2	12	1.6
General cargo	144	425	300	0.9	28	4.1

3.2.2 Route-specific analysis.

Assessing routes with a strong potential for conversion into a 'Green Corridor' is a trade-off exercise. The approach that has been taken here is to prioritise routes that aggregate as much energy demand as possible in the smallest feasible area. Doing so increases the chance of generating the maximum demand for alternative fuels while limiting the challenges and costs of the distribution network required to supply them. With that goal in mind, and using routes tracking the Clydebank Declaration base, the following section illustrates how the data can be used to build up example applications of Green Corridors.

The examples chosen showcase different ways of aggregating the energy demand of vessels active within a region, including how to expand it gradually in a phased deployment of investment that could help manage risk whilst ensuring investment is on a pathway that can rapidly scale up. The examples also explore the trade-off resulting from including more potential production and use of SZEF while concentrating the demand in the smallest area possible.

3.2.2.1 Building a Domestic Green corridor in Oita-Japan: from intracluster to multilateral potential.

Oita was identified as the head port of the northern cluster of the Kyushu Island in South Japan. Five RoRo vessels and one bulk carrier operate exclusively between ports assigned to this cluster. They account for an estimated energy demand of 21.6 kt of HFOe calling at ports within a 58 km distance from Oita (Map 4). Translating these quantities to alternative fuels will require approximately 7.0 kt_H2e[6]/yr to be distributed using on-shore infrastructure (trucking or pipelines) or sea bunkering facilities. However, this is not the only regular shipping activity linked to this port cluster.

6 Refers to the equivelent amount of Hydrogen required to cover the demand for HFOe. A conversion factor of 0.326 H2e/yr/HFOe/yr is used for the conversion. This is based on the LHV energy content of both fuels assumed as: HFO at 39 MJ/Kg and H2 at 120 MJ/kg

Map 4: Oita- Japan: Intra-cluster shipping activity

An inspection of bilateral routes highlights the Oita-Osaka route as being covered by four RoRo vessels with cumulative demand of 49.6 kt of HFOe/yr (equivalent to 16.2 kt of H2e/yr). Interestingly, the ports these vessels operate are all located within 17.4 km of Oita and Osaka, leading to a high concentration of energy demand around the Oita and Osaka ports, which are the biggest ports in their respective clusters (Map 5). The median voyage distance travelled by these vessels is 215nm which can be used as a modelling input for the travel range required for their decarbonisation.

Stakeholders would need to further investigate if this potential is split between the two different clusters or if the energy demand of these vessels could be produced and supplied in a single cluster. In

Map 5: Oita-Osaka Bilateral shipping activity

the latter case, if Oita was selected, adding the energy demand of the intra-cluster activity would increase the demand for H2e to 23.2 kt of H2e/yr (71.2 kt of HFOe/yr), strengthening the business case for a co-located plant for green H2 or ammonia production, or SZEF import terminal/dedicated infrastructure for other fuels.

An additional approach is to evaluate the potential derived from multilateral shipping activity. Thirteen vessels (five liquefied gas tankers, three Ferry RoPax, two general cargo and one bulk carrier,

Map 6: Oita-Osaka-Mizushima-Tokyo Multilateral shipping activity

vehicle and chemical tanker each) were identified as operating exclusively between the clusters of Oita, Mizushima, Osaka and Tokyo. The energy supply required to decarbonise their activity was estimated at 70.45 kt of HFOe/yr (22.9 kt of H2e/yr) with port calls within 60km of the lead ports of each cluster.

As seen in Map 6, although these vessels regularly operate through Oita, the SZEF required to decarbonise the route could also be produced and supplied in any of the other four clusters that make up the route. Adding this potential to the plans for a prospective production facility at Oita requires wider consideration, around the independent travel range suitable for the ships' design and whether the relative efficiency of allocating this potential to another cluster could be more efficient.

This can be assessed by estimating the energy required in a cluster from an "onshore" rather than a "route" perspective. Under this approach, all the energy demand required by vessels with a strong decarbonisation potential departing from ports belonging to a cluster is added together. This aggregation is done regardless of whether their activity is classified as intra-cluster, bilateral or multilateral. The result would estimate the total potential per cluster if all the departing voyages were replaced with SZEF. All other variables used for the route's analysis could still be obtained, i.e: main vessel type, year of built, and distribution distance. Red circles in Map 7 illustrate

Map 7: Aggregated onshore potential by cluster and concentration of demand

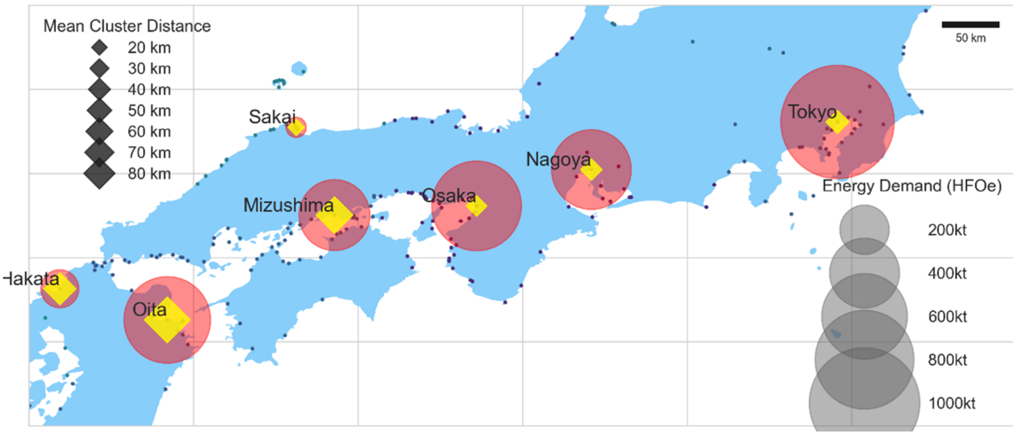


Table 5: Onshore perspective of decarbonisation potential per cluster

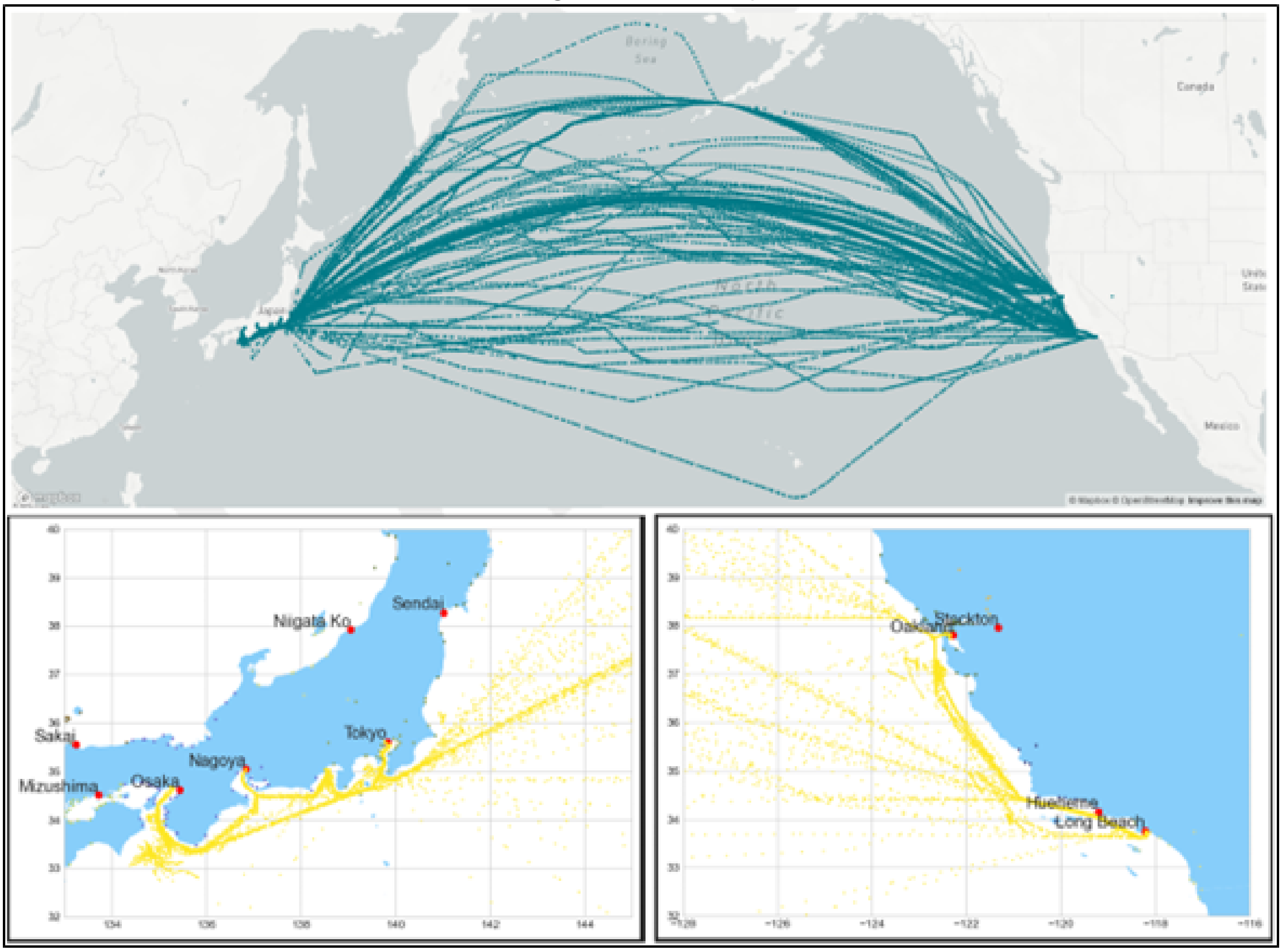
Cluster	Departures Fuel demand (kt HFOe/yr)	Departures Fuel demand (kt H2e/yr)	Cluster radius (km)	Number of stopping vessels	Mean voyage distance (nm)	Challenges/Opportunities
Tokyo	1068	347	21	918	369	*With 347 kt H2e, the Tokyo cluster is the biggest of the subset considered in terms of fuel demand. This can be seen as an initial indicator of the potential demand available for a local production plant. Other factors worth considering are a cluster radius of only 21 km, which suggests a concentrated requirement for distribution facilities. Also, with 918 vessels stopping at the Tokyo cluster, marginally less than for Osaka and Oita for almost 50% more energy, these results indicate a greater vessel size or a higher operational speed. At 360 nm for mean voyage distance, vessels departing from Tokyo are also those reaching the farthest. These findings suggest a cluster scenario of fewer bunkering operations for a greater decarbonisation gain at a location with reduced infra-structure requirements for fuel distribution.*
Osaka	669	218	17	961	266	*Second in the list of clusters, Osaka's energy demand (218 kt H2e) is similar to that of Oita. All other parameters are also close, with the exemption of the Cluster radius which stands at only 17km. This indicates that most of the cluster's activity of the identified vessels is placed within proximity of Osaka thus requiring the implementation of a smaller distribution network for a similar amount of energy demand.*
Oita	624	203	86	929	256	*The third largest cluster, Oita has similar energy demand, number of stopping vessels and mean voyage distance to those of vessels stopping at Osaka. However, it has a cluster radius five times wider which implies greater challenges in the establishment of a fuel distribution network.*

Nagoya	528	172	18	797	359	*Nagoya's characteristics are similar to those of the Tokyo cluster: A reasonable aggregated energy demand (172 kt H2e) concentrated in a small radius of 18 km for vessels covering a longer mean voyage distance, which has implications for the assessment of the bunkering requirements of suitable vessels.*
Mizushima	418	136	54	961	225	*The Mizushima cluster places 5th, yet it has a number of stopping vessels comparable to that of the top three clusters. This low energy per vessel ratio indicates the presence of smaller vessels and the likelihood of a larger number of bunkering operations for a smaller decarbonisation potential.*

the aggregated energy demand per cluster, while the yellow diamonds indicate how concentrated it is within each cluster.

Table 5 provides further details on the aggregated activity, including the number of individual vessels departing from each cluster and the average voyage distance.

In this exercise, the total potential demand from Osaka and Oita are similar at 624 kt of HFOe/yr and 669 kt of HFOe/yr. However, the results suggest that the cluster radius is smaller in Osaka. Connecting this result with the bilateral and multilateral routes findings indicates that aggregating demand at Osaka will likely result in cost savings in the development of onshore infrastructure.



Map 8: Building a trans-Pacific Green Corridor

All three routes explored and their corresponding clusters are classified as domestic Japanese shipping, thus making it an example of independent-national level action. The following section evaluates an international route and expands on the level of granularity achievable from activity data.

3.2.2.2 Building a transpacific Green Corridor: Osaka-Nagoya-Tokyo-Oakland-Long Beach

Five container vessels -with a capacity between 3k TEU and 5k TEU-shuttle between Osaka-Nagoya-Tokyo and Oakland-Long Beach. They combine a yearly fuel consumption of around 114 kt of HFOe/yr (37.1 kt of H2e/yr) and limit their stops to only the main ports in these clusters, thus significantly reducing the need for local distribution logistics.

This is an excellent example of a route stretching over a long, international distance through part of the voyage, with subsequent shorter, domestic legs at both ends. It also illustrates how, although small compared to the extent of the route, the journeys connecting places like Osaka and Nagoya are comparable in length to local shipping activity, i.e: the Oita cases studied before. In principle, the demand for these sections of the voyages could be added to the local estimates of potential. However, the vessels' sizes, large fuel consumption, and the route's international nature make this a case worth reviewing in isolation.

Accounting for a portion of the transpacific trade, the operational characteristics of these vessels provide helpful information for setting up a long-range green corridor. All vessels have a capacity of around 4500 TEU, and average yearly fuel consumption between 20 kt of HFOe and 25 kt of HFOe each. Speeds of about 12-13 knots suggest these vessels slow-steamed their voyages across the Pacific. The maximum length of voyages between ports ranged from 5000 to 6000 nm. Their port stops lasted between 20 and 30 hours in duration.

Table 6: Individual vessel characteristics of the transpacific container route between Japan and the US West coast.

Vessel ID	Ship type	Fuel Consumption (kt HFOe per year)	Fuel Consumption at sea (kt HFOe per year)	Fuel Consumption at port (kt HFOe per year)	Mean Speed at sea (knots)	Mean time spent at port (hrs)	Max Voyage distance (nm)	No. of voyages
1	Container	21.8	20.8	0.9	12	28	339	76
2	Container	22.0	21.3	0.7	12	26	367	68
3	Container	25.7	25.0	0.8	13	21	357	73
4	Container	23.2	22.5	0.7	13	23	363	70
5	Container	19.5	18.7	0.7	13	21	333	79

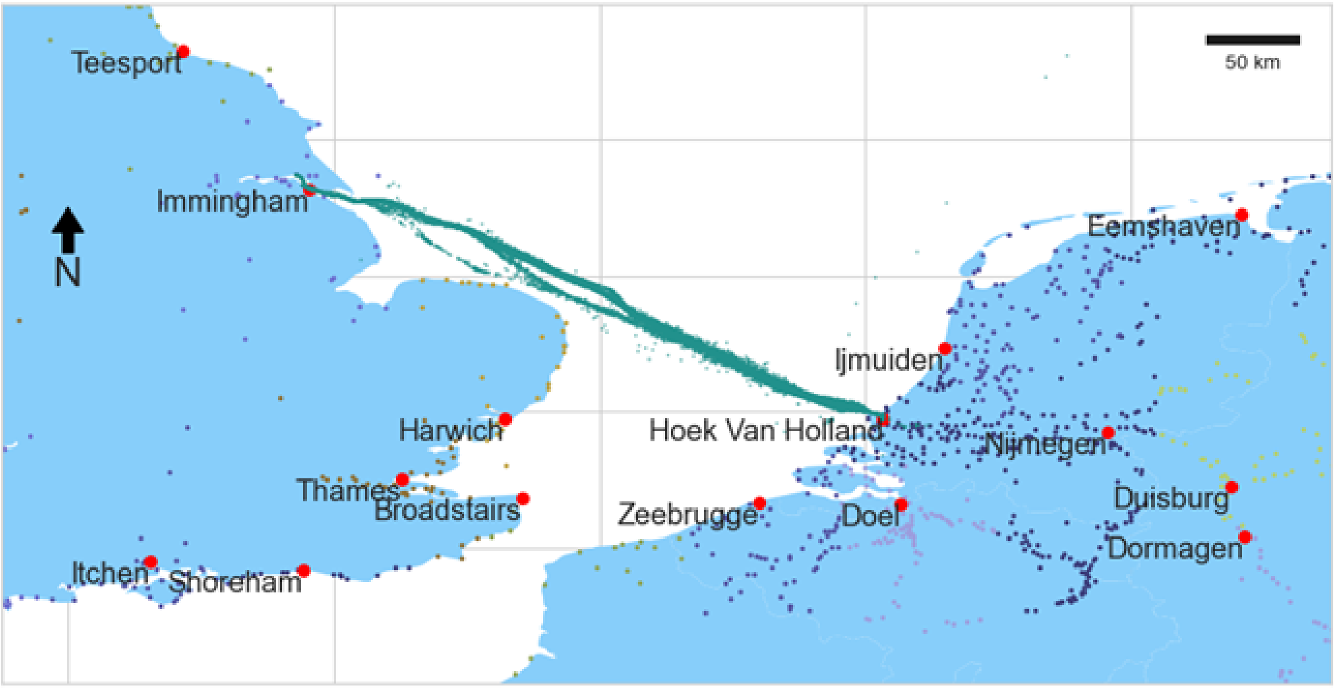
These insights can be used to adapt the design of the ships for the route and other port capabilities. Yearly fuel consumption indicates the decarbonisation potential of the route. The maximum voyage distance is helpful to define storage capacity on board and mean speed at sea to avoid over-dimensioning main engines. Time at port supports in planning logistics and provisioning facilities such as fuel bunkering or battery charging. These factors are essential to estimating the costs of decarbonising the route, so understanding them can help assess the opportunity and identify the potential to reduce costs.

Finally, the international characteristics of the route can foster collaborative initiatives. For example, suppose the renewable energy required to supply this route is more accessible in the US. In that case, Japan could still claim emissions reductions in line with their contribution toward an agreement between the two countries. This would be an example of actions taken by strong first-mover countries.

3.2.2.3 Building a bilateral Green Corridor: Immingham – Hoek Van Holland, the potential of a historical Ferry Route.

A long-established route of RoPax and RoRo Ferries, Map 9 illustrates the activity of four vessels throughout 2018. This fleet has an estimated energy demand of 42.8 kt of HFOe (13.9 kt of H2e) with the added advantage that by not calling at other ports, this route would not require a local distribution network, only bunkering facilities at either or both of the two ports they call at. Furthermore, Immingham in northeast England is home to the biggest port in the UK, while Hoek Van Holland is at the entry point to the Port of Rotterdam, the largest in Europe. Both nodes of the route are already considering adaptation to enable bunkering of SZEFs.

Map 9: Immingham to Hoek Van Holland (Hook of Holland), a historical ferry route.



A closer look to the characteristics of the vessels contributing to the route shows that three of them have a yearly fuel consumption of around 10 kt of HFOe, and a fourth with the biggest demand of about 21 kt of HFOe due to the total power of its main engine -37.8 MW compared to 21.6 MW and 15 MW for the others. All vessels have an estimated energy demand at port between 1.5 and 2.1 kt_ HFOe, a metric useful for assessing the requirements for onshore electrification.

Three vessels carry passengers (RoPax), while the smallest is a cargo focussed vessel (RoRo). All four ships have a similar mean speed at sea at 14-15 knots, with maximum voyage distances between 200 to 230 nm. At 10 and 12 hours, the RoPax vessels spend less time at port than the RoRo, which stays at port an average of 14 hours per stop. The extra time spent at port explains why this vessel performed around 40 fewer voyages than the other ferries. Regarding their age, the biggest ship is the oldest, built in 2001, while the others are newer, constructed in 2007 and 2011.

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Ship Type	Yearly Fuel Consumption (t HFOe)	Yearly Fuel Consumption at sea (t HFOe)	Yearly Fuel Consumption at port (t HFOe)	Mean speed at sea (knots)	Mean time at port (hrs)	Max voy distance (nm)	No voys	Main Engine Power (kW)	Deadweight (Tonnes)	Passengers	Year of built
RoPax	20975	19095	1879	15	10	231	357	37800	8850	1376	2001
RoRo	9117	7609	1507	14	14	216	313	15000	11407	12	2007
RoPax	11862	9795	2066	15	12	203	356	21600	9132	594	2011
RoPax	12979	10882	2096	15	12	200	348	21600	9052	594	2011

Table 7: Individual vessel characteristics of the Immingham - Hoek Van Holland route.

This level of data granularity allows stakeholders to review the opportunities of the route at an individual vessel level. For example, would it be better to set up the corridor, starting only with the biggest vessel in the route, given that it may be approaching decommissioning time due to its age? Or would it be better to start with one or both of the smaller RoPax? The technical specifications presented in table 7 suggest that these are sister vessels, so there may be a gain in the economies of scale of two vessels instead of one.

4. Future work

We aim to further develop this data and analysis to help stakeholders (governments and private companies) understand, at a broad search/sift level, potential opportunities for Green Corridors in different parts of the world.

The same capability can also be used as a source of technical and operational information, including important details for use in subsequent pre-feasibility and feasibility analysis. We are therefore exploring ways that information can be made readily and broadly available to help reduce the costs of those steps in the process, and foster collaboration and transparency.

The next step in our work is to both understand how the current results can be used by government officials and the broader ecosystem of green corridor stakeholders, and explore related uses by actors who can enable Green Corridor investments. Doing so should provide an objective summary of the method's strengths, weaknesses, and future development requirements.