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Accelerating shipping decarbonisation: A case study on UK shore power

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ABSTRACT

Shore power connects ships to land-side electricity grids, cutting fuel use in port to reduce carbon dioxide emissions and air pollution. It also enables the transition towards greater use of electric vessels. Despite these benefits, the global deployment of shore power is slow, particularly in countries such as the UK. This paper presents findings from a qualitative case study using two theoretical frameworks from the transitions literature to assess barriers to UK shore power deployment. The findings identify a need for capital funding and taxation policies, and illustrate that shipping's low status in the political hierarchy impedes implementation. Measures to strengthen interactions between shipping actors would help increase the political pressure required to implement policies supporting shore power and shipping more broadly. These changes in the governance and organisation of shipping are essential to deliver the near-term emission cuts necessary for aligning UK shipping emissions with the Paris Agreement.

1. Introduction

Shipping is overwhelmingly reliant on fossil fuels for propulsion [1] and a major contributor to climate change. Carbon dioxide (CO_2) emissions from international shipping are equivalent to those of a large industrial country such as Germany [2]. The Paris Climate Agreement has established a goal to pursue efforts to limit global temperature rises to 1.5 °C [3], and if international shipping is to make a fair contribution towards this goal, its carbon dioxide emissions need to be cut by at least a third by 2030 [4].

The literature cites myriad options for shipping decarbonisation, including shore power, demand reduction, ship efficiency improvements, wind-assist technologies and slower-speeds, as well as alternative fuels [5–8]. Ultimately, shipping will require zero-carbon fuels, however the slow turn-over of the fleet and the scale of investment needed for alternative fuel infrastructure [9] means that it is likely to be the 2030s before alternative fuels are deployed at scale. Given the need for substantial emissions reductions before 2030, other short-term measures to reduce emissions are essential [10].

Shore power[i] is one decarbonisation option that can deliver short-term cuts to CO_2 emissions. Shore power enables ships to connect to land-side electricity grids, cutting their use of fuel while berthed in ports. A review of studies of shipping mitigation measures found fleet-wide potential for 3–10% reductions in CO_2 emissions from shore power [5], a substantial reduction in a sector where mitigation is characterised by many small-gain options rather than one silver-bullet. Shore power also offers benefits to local air quality and noise

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[i] Shore power is also referred to in the literature as cold ironing, onshore power supply (OPS), shore-side electricity, shore-side power, alternative maritime power (AMP) and shore-to-ship power supply.

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pollution [11], and paves the way for wider uptake of hybrid and electric vessels [12]. Yet, in spite of these benefits, shore power deployment is limited, largely concentrated in Norway and California, with some deployment in Northern Europe and China [13]. In the United Kingdom (UK), shore-power projects are scarce, with only three large projects operational or near-completion. The barriers to shore power in general are well researched (see Section 2), but how they manifest within specific nations like the UK, why they persist and how they may be overcome is much less well understood.

This paper presents a new case study of shore power in the UK, and a novel application of transitions theories to elaborate on why socio-technical barriers to shore power persist and how they could be overcome. Forty interviews with stakeholders across the maritime sector in the UK and EU are analysed using an analytical framework that combines theories from the transition literature: the Technological Innovation Systems (TIS) framework, and the Multiple Streams Approach (MSA) (see Section 3). The paper combines insights from these theories to set out strengths and weaknesses of the UK shore power system, and barriers to improved functionality. It proposes policy solutions to overcome these barriers, and assesses the political challenges to adopting them (Section 4). Section 5 discusses these results, and the potential for a window of opportunity for stronger shipping decarbonisation policy on shipping in the UK. It outlines interventions which could both keep this window open for longer, and increase the likelihood of successful policy implementation for shore power and in the broader shipping sector.

2. Literature review: barriers to shore power, and lessons from transitions literature

Shore power enables ships to reduce fuel consumption while at berth in ports, cutting local air and noise pollution [12,14], as well as CO_2 emissions in countries where electricity supply is lower-carbon than combusting marine fuel oil [15,16]. In the UK, this would cut ships' CO_2 emissions at berth by over 70%, as ship's fuel oil emits around 700gCO_2/kWh [1], compared with under 200gCO_2/kWh for UK shore power [17]. This benefit will increase in the coming decade as the UK's electricity supply system is further decarbonised [18]. From a port perspective, emissions from ships tend to be the largest contributors to air pollution and greenhouse gas emissions, compared with port equipment or buildings. Shore power is therefore a key technology for ports to reduce their environmental impacts [19,20], helping them to meet the United Nations Sustainable Development Goals that many ports emphasise in their strategic plans [21].

Much research on shore power focusses on how the environmental benefits of shore power can be improved, for example by increasing the CO_2 benefit by using land-side micro-grids and renewable energy generation to reduce the carbon-intensity of electricity [12,22,23]. However, these benefits will not be realised if shore power deployment remains low, underscoring the necessity of understanding how barriers to the deployment of shore power can be overcome, which is the principal contribution of this paper.

2.1. Assessing barriers to shore power

Multiple barriers to shore power are well documented in the literature, through individual case studies such as of Kaohsiung Port, Taiwan [24] or comprehensive global review articles [25–27].

These barriers can be categorised in various ways, such as into economic, technical, stakeholder and institutional elements [26]. These elements vary in their relative importance. For example shore power is a mature technology and various technical issues that previously impeded deployment have been overcome, with international standards to ensure compatibility between electricity grids and ships that use different power frequencies [12]. In contrast, the literature points to serious and persistent economic problems. Shore power projects have high capital costs, particularly for ports [28]. It is difficult to recoup these costs because shore power is expensive compared with untaxed marine fuel oils [29,30]. If the external benefits from reduced CO_2 and air pollution were costed into project evaluations, investment in shore-power would provide a net positive return on investment [31,32]. However, these benefits tend not to be internalised into project appraisal, so projects struggle to be competitive, particularly from a port operator perspective.

Project complexity is also a widespread and persistent barrier. Shore power projects require investments from multiple entities: from ports and ship owners/operators, and often on land-side electricity grid infrastructure [12]. Collaboration is needed between these entities [33], but there is often a "chicken-and-egg" situation where port operators will not deploy shore power because there is no demand from ship-owners, and ship-owners/operators will not invest in ship-upgrades until they see ports where their vessels could plug-in Refs. [11,34].

There is a critical gap in the literature around why these well-documented barriers have not been overcome. Research has identified solutions – for example studies of shore power in China propose various policy or governance changes including emission control policy [35], electricity service charges [29], phasing of policy over time [36], carbon trading [37] and government subsidies [38]. Other studies have looked at optimising policy design, for example on levels of subsidy [39], combinations of subsidy and berthing priority [40], combinations of capital funding and electricity pricing [41] and relative levels of electricity and fuel oil pricing [42]. But while these give insight into how policies could be used to address barriers to shore power deployment, they do not examine the factors that obstruct or might accelerate such policies' introduction.

As pointed out by Williamsson, Costa [26], shore power's institutional, economic and stakeholder barriers are highly contextual, and these political, regulatory and cultural variations are strongest between nations. A national-level assessment of why shore power barriers have not been overcome would therefore be an addition to the shore power literature. A particular focus on the UK has merit because it is not one of the more successful countries for introducing shore power (such as Norway or the USA), but is a country where the technology's deployment is deemed to be a positive intervention [43], but has very slow deployment to date [44]. Although barriers to shore-power deployment are well known in their generic sense, they vary depending on national-scale political, cultural and regulatory conditions. Thus, an assessment of the most important specific barriers at the UK level is an important prerequisite to understanding what is preventing solutions being introduced. This study therefore assesses both UK-specific barriers and the factors preventing them from being overcome.

2.2. Transitions theories' utility for analysing shore power

The absence of research on how shore power barriers can be overcome is one that methods and concepts from the transitions literature are well-placed to address. Transition theories enable understanding of the policy and political contexts that surround system innovations, as they are adept at examining issues such as the lock-in and inertia that hinder progress towards sustainability [45]. Transition studies take an interdisciplinary approach, combining methods and ideas from economics, political studies and sociology to analyse how and why change occurs in complex systems [46,47].

Positioning shipping as a socio-technical system shows it to be comprised of a complex set of interactions between people, institutions and technologies at many scales to deliver societal needs [48,49]. Socio-technical transition analysis has been used to uncover the complex processes affecting progress towards decarbonisation in the shipping sector, in a growing shipping transitions literature. Three examples illustrate this point. First, determining the optimal conditions for new market formation in shipping is shown to be highly situation-specific [45], with heterogeneous actor motivations and fragmented governance [50,51]. Second, in the face of long-standing subsidy of polluting shipping fuels, mixes of innovation policy, market-based mechanisms and regulatory reform are needed to overcome economic barriers to new technologies [52,53]. Third, analysis of power dynamics and politics is essential for understanding the different roles played by key actors [54], and unpicking why some policies are adopted while others flounder [55, 56].

Section 2.1 highlighted the importance of unravelling national-scale political, cultural and regulatory conditions, however the gap in national-scale empirical research persists. Overall, the majority of shipping transitions analyses are at either a global scale (e.g. Refs. [48,49], multi-country studies [57] or port scale [51,54,58]. Global studies have proven the value of transitions literature in understanding, for example by exploring the transition from sail to steam (circa 1780–1900) [48,49] or the particularities of developments such as wind-propulsion [59] and slow-steaming [60]. Other global studies have focussed on governance [61], firms [50], or shipping segments [62], revealing how the interactions between established and emergent systems affect the uptake of new technologies and practices. Established systems contain multiple sources of inertia – including infrastructure, knowledge, sunk costs and vested interest – as they are designed to endure. Subsequently, emergent innovations meet resistance unless they align with established configurations [63].

At the other end of the geographical scale, studies focus on experiences of shipping transitions at sub-national and port scale to elaborate more fully on the interactions between established and emergent innovations. For example, Bjerkan and Seter [55] show that successful shore power deployment in the Port of Oslo was contingent on multiple interacting factors: cross-party political consensus, lack of controversy, a clear policy goal, integrated policies, generous funding, technological maturity and collaboration between actors. Understanding the intricacies and interactions that surround systems innovations is important to understand how blocked transitions can be accelerated.

However, between these global and local studies, analyses of specific technologies within national or sub-national contexts are relatively uncommon and concentrated on Norway [53,55,56,64,65]. There are also few transitions studies that focus on shore power, barring Bjerkan and Seter [55], who conclude that overcoming economic and regulatory barriers are pivotal for shore power deployment. In many countries the economic and regulatory measures that would affect shore power deployment are implemented primarily at a national level[ii]. This implies that a national focus for transitions analysis of shore power is a gap which can usefully be addressed.

2.3. Literature review summary

There is a gap in the literature concerning how long-standing barriers to shore power can be overcome, particularly at a national level and for countries such as the UK, where shore power deployment has been slow. Transitions theories' focus on examining the conditions for change in a technological sector means that they are well placed to address this gap. However, despite there being a vibrant body of research on shipping transitions, there are few studies that directly examine shore-power, particularly at a national scale. This leaves research questions regarding why the various barriers that impede shore power have not been overcome, and what could be done to accelerate deployment.

3. Methods

This research uses an inductive design method with three key steps: data collection via interviews and desk research, preliminary analysis to identify theories and frameworks that would help elaborate on limits to progress in shore power deployment, and more in-depth analysis of the data using the chosen theoretical frameworks.

Forty semi-structured interviews were undertaken online between May and October 2020. Interviewees included a range of actors, networks and institutions that reflect the variety of actors involved in shore power deployment in the UK (See Table 1).

[ii] Although in some countries, such as Australia and Germany, regional Government has a strong role to play in decision-making. In the UK regional bodies have lower influence.

15 interviews were conducted with ports, as they are a heterogeneous group and critical parties in shore power provision. Collaboration with two port trade associations – the UK Major Ports Group and the British Ports Association – produced a sample of ports that represented diversity in terms of their geography, predominant user, ownership structure, and attitude to shore-power. Similarly, the UK Chamber of Shipping provided introductions to ship operators representing the main UK shipping segments. Snowballing then provided additional perspectives, such as that of ports in the EU with prior experience of shore power deployment. Interviews were with senior personnel and granted on condition of anonymity – for individuals and companies - allowing interviewees to reflect candidly on their experiences. Recruitment ceased when saturation occurred, which was after approximately 35 interviews. No new topics were identified in the last five interviews.

The interviews followed an interview guide, with questions designed to gather the interviewees' perspectives on i) the merits of shore power relative to challenges facing the sector and other options to address those challenges ii) the barriers to shore power and iii) the ways that these barriers might be overcome. Interviews were recorded and transcribed verbatim with accompanying desk research used to investigate different projects, developments and policies identified by participants. Interview guides were based on a core set of questions, with slight variants for different interviewee types, and detailed follow-up questions. An abridged interview guide is shown and discussed in Appendix A.

Shipping transitions literature tends to deploy one theory or tool for analysis (see Appendix B), however Cherp et al. [66] propose that because transitions are complex, they benefit from being analysed with more than one theory or framework, allowing different approaches to uncover and illuminate different aspects affecting transitions. Informed by the themes emerging from the interview data, two such frameworks were selected: from the socio-technical perspective, the Technological Innovation Systems (TIS) theory [67, 68] and from the political perspective, the Multiple-Streams Approach (MSA) [69,70].

The TIS and MSA are complementary theories, highlighting different aspects of transitions. TIS approaches have been used in the past to diagnose the slow deployment of technologies [71], which resonates with our research questions. The TIS outlines the structure of the system surrounding a technological innovation in terms of actors and their interactions; institutions, which includes formalised rules as well as norms and customs; and infrastructures, which includes the knowledge ecologies, physical and financial structures that surround shore power. It then aims to understand how innovation systems evolve over time by focussing on system 'functions' that include knowledge development and diffusion, market formation and resource mobilisation (see Table 2). Functions are defined as processes that have an impact on the goal of the system, which is to deploy and utilise a new technology [68]. How these system functions apply specifically to shore power is set out later, for example in Table 3.

While initial coding (see Appendix C) highlighted the importance of socio-technical and political barriers, issues of power and policy making were particularly foregrounded. Political dimensions can be under-regarded in socio-technical studies (Meadowcroft, 2009), so the MSA framework was selected as an additional theoretical lens to use. MSA is widely-used in political science to understand how policy change occurs, characterising change by analysing the interactions between three "streams" that must converge for a policy to change. The 'problem stream' refers to how a problem is framed and how it gains attention over others, the 'policy

Table 1
Number of interviews by interviewee type.

Interviewee grouping	Number of interviews	Typology of interviewees
UK ports (P)	15	Geography: Northern Ireland, Scotland, England. Main cargo type: dry bulk, offshore, container, ferry, cruise. Attitudes: going ahead, actively considering, uncertain, opposed, not considered. Ownership: local authority owned, Trust port, privately owned.
European ports (E)	4	Mix of ports with successful and less successful shore power projects.
Shipping companies (S)	12	Types: cruise, container, ferry, cargo, offshore
Others (O)	9	Including 4 trade associations, 2 equipment providers, 1 electricity network company, 1 Government, 1 ship classification society

NoteP, E, S, O codes are used to identify the grouping for quotes used in section 4.

Table 2
Definition of TIS functions (based on Bergek et al. [64], and Hekkert et al., [67].

	Function	Summary Description
F1	Entrepreneurial Experimentation	Entrepreneurs combine new knowledge, technologies, markets and networks in experiments to reduce uncertainties and improve system performance
F2	Knowledge Development	Improvements in the breadth and depth of knowledge in a system; can be measured by R&D spending, patents, learning curves
F3	Knowledge Dissemination	Diffusion of knowledge within the system via networks, within and between core actor groupings
F4	Guidance of the Search	Mechanisms which steer the deployment of resources and capabilities in particular directions, via Governments or markets, by for example "hard" policy targets or "soft" processes such as iterative changes to how solutions to problems are framed
F5	Market Formation	The use of policies (such as tax breaks) and other measures to create effective spaces where new markets can thrive
F6	Resources Mobilisation	Mobilization of physical, human and financial resources for the greater diffusion and use of technologies and processes
F7	Creation of legitimacy	Regulatory and cultural processes which lead to the technology being perceived to be acceptable, e.g. regarding safety, cost, value.

stream' to how policies to overcome problems are identified and gain acceptance, and a 'politics stream' to how policymakers choose which policies to implement. Policy entrepreneurs are identified as the binding agent between these three streams, promoting solutions to problems to decision-makers at critical "windows of opportunity" when policy change occurs. Such windows tend to be brief, given the multiple competing and changing demands for policy-maker attention at any given time.

The MSA complements the TIS by investigating when and how windows of opportunity develop around a given problem that could allow for more rapid change.

The analytical framework for how MSA and TIS are combined to analyse the UK shore power system is set out in Fig. 1.

Once selected from the initial analysis, the TIS and MSA frameworks were used to analyse the interview data more deeply. The interview transcripts were returned to, using these analytical frameworks to deductively code the data to identify and elaborate on processes for change. For both TIS and MSA, analysis of the interview data was complemented by desk research and document analysis of technical and economic studies of shore-power projects, government policy documents, academic papers and industry reports.

Following the method proposed by Wieczorek and Hekkert [71] and adopted by Sawulski et al. [72], the TIS analysis involved i) identifying the structural dimensions of the UK shore power TIS, ii) analysing the effectiveness of critical TIS functions; iii) assessing the main barriers to improved system functionality, and iv) identifying solutions to increase the system's effectiveness. The MSA is then used to assess what impedes delivery of such solutions: to what extent the problems, policies and politics of shore-power are linked, who the policy entrepreneurs are, and whether there is currently a window of opportunity to accelerate or increase deployment of shore-power in the UK.

4. Results: UK shore power: system problems, goals and solutions

Sections 4.1.1 to 4.1.4 present the results of the TIS analysis, in terms of structure, functions, barriers and policy solutions. For the three structural elements of actors, institutions and infrastructures, "actors" are set out in section 4.1.1. For institutions and infrastructures, this level of detail is set out in supplementary information. Institutional structures include the "hard" rules, regulations and policies affecting shore power, and "soft" norms and customs. Infrastructures refer to the physical, financial and knowledge structures necessary for actors to deploy shore power. Similarly, section 4.1.2 on TIS functions presents a heavily abridged summary, with further detail set out in Supplementary information.

4.1. UK shore power system structure

The UK shore power structure has three components, actors, institutions and infrastructures. First, the main actors and their interactions are set out in Fig. 2.

Three core actors for a shore power project are:

(i) the port, providing the shore-side infrastructure for vessels to connect to the grid;
(ii) ship owners/operators, to ensure installation of the on-board equipment for ships to be able to connect to shore power;
(iii) the District Network Operator (DNO) responsible for electricity grid upgrades and connections from port to grid.

There are other external actors – shore power equipment providers, national and local Government policy makers and regulators. Port and shipping trade associations also play a pivotal role in the knowledge ecology of shore power, enabling knowledge dissemination within their sectors, and between their sector and regulators and other actors such as the DNOs. There are also intermediaries involved in shore power projects; consultants and other businesses with expertise in shore power project planning or energy management, and knowledge institutes such as shipping innovation networks and universities.

Unlike many energy-related systems in the UK, there is not a strong civil society presence in shipping. No national environmental non-government organisation focusses on shipping or ports, though there are local groups focussed on improving air quality near some ports.

4.1.1. Shore power system functionality

The three structural components interact to affect seven highly inter-dependent and mutually reinforcing or destabilising system functions (Table 2).

Interview analysis and desk research revealed that the strongest function is Guidance of the Search (F4) – there is an increasingly clear narrative and direction from Government and other stakeholders that decarbonisation is essential and inevitable, and that shore power has a role to play in delivering it.

Knowledge Development and Knowledge Dissemination (F2&F3) are both reasonably strong, though with notable gaps, particularly around absence or weakness in a number of critical relationships, for example between ports and DNOs, and in a lack of centralised repositories for key data or ideas, such as around business cases or electricity network upgrades.

The weakest functions are Market Formation (F5) and Resource Mobilisation (F6) – with major problems around accessing grant funding, constructing compelling business cases and the lack of policy support around fuel and electricity pricing. Interviewees repeatedly stressed two main barriers. First, the lack of capital funding support from the UK Government, contrasted with Europe. Second, shore-power, and indeed all alternative fuel technologies, have to compete with untaxed marine diesel oil. This is a problem globally but compounded in the UK by high levels of electricity taxation: countries like Germany, France, Denmark and Sweden have all lowered the electricity taxes paid by shore power projects; the UK does not do this.

On resources (F6), ports are experiencing further difficulties mobilising financial resources to deploy shore power. The lack of capital grant funding from Government is compounded by its decision to remove the subsidy for red-diesel used by ports, with interviewees stating that this will introduce costs, reducing ports' ability to fund capital projects. A final difficulty with resource mobilisation is a number of absent or weak relationships between critical actors. In particular, lack of collaboration between port and shipping operators was a widely cited problem, with interviewees often laying the responsibility for lack of action on each other. Many stressed that port and shipping entities need to collaborate more. Another interaction tension is that ports tend to have very low levels of interaction with DNOs and the National Grid, despite uncertainty about grid capacity for shore-power projects repeatedly being cited as a problem.

These market and resource barriers feed into low levels of Entrepreneurial Experimentation (F1), and problems of Creating Legitimacy (F7). Although there are established global companies offering shore power equipment and installation packages, the complexity of projects, financial barriers and lack of policy support are preventing experimentation. Ports do not yet see energy as a core business, and shore power tended not to be seen by ship operators or ports as an entrepreneurial opportunity, but rather something that might be required by them in future in response to regulatory pressure. Further analysis of shore power system functionality is presented in supplementary information.

4.1.2. Barriers to UK shore power

From the TIS analysis, the main barriers to shore power deployment are summarised in Table 3, listed against the functional and structural categories. The focus on barriers is complemented in Table 3 by the addition of "inducement mechanisms" – the Hekkert, Suurs [67] methodology focusses primarily on overcoming "blocking" mechanisms (i.e. barriers), whereas as Bergek, Jacobsson [73] point out, the encouragement and nurturing of any "inducement mechanisms" can also be useful. Solutions to address these barriers are discussed in section 5.1.

4.1.3. Policies for shore power

The work of Wieczorek and Hekkert [71] sets out goals for systemic policy instruments that either overcome system problems, or amplify inducement mechanisms, by focussing on actors and their interactions, institutions and infrastructure. Using this categorisation to reflect on the data collected, we identify eight interventions that address weaknesses or amplify strengths identified in Section 4.1.3 to improve the functioning of shore power in the UK, based on suggestions made by interviewees. These interventions are summarised in Table 4.

The introduction of a global carbon price on marine fuel oils could address the competitive disadvantage faced by cleaner fuels, but there has been little progress at the IMO to introduce such market-based mechanisms since they were first proposed in 2008. There is increasing likelihood of fragmentation of global shipping policy if progress is not forthcoming, and this could be argued to be starting to happen, with the EU Parliament voting in June 2022 to include maritime emissions in the EU Emissions Trading Scheme [74].

Without a robust global carbon price, measures such as shore-power will struggle to compete against marine fuel oils. Consequently, other targeted national economic policies (2–4), are needed to improve business-cases. Research has consistently shown (see section 2) how a variety of economic barriers slow the uptake of shore power. Our results illustrate that in the UK, particularly important constraints are a relative lack of capital funding for shore-power, combined with taxation that favours conventional marine fuel oil. A strategy to overcome these is the introduction of countermeasures, e.g. capital funding and tax exemptions delivered at a national scale through the forthcoming revision of the UK's Clean Maritime Plan. Similarly, regulatory standards can complement economic instruments by mandating provision of ship and port shore power infrastructure, as in California and recently proposed by the EU. Payments for non-compliance with such standards could be ring-fenced to provide further shore-power capital funding.

The findings here also highlight the importance of improved knowledge dissemination and exchange between the multiple actors in the UK shore power system, helping address system barriers 7–12 (Table 3). For example, stronger networking on specific issues would enable sharing of best practice, helping overcome remaining technical and economic barriers (e.g. network capacity, smart grid deployment, business model development). Knowledge dissemination would be strengthened by a central body to coordinate information sharing on shore power and UK shipping decarbonisation more generally, either through the new UK-SHORE unit, or via another Government agency, such as the Maritime and Coastguard Agency. Increasing the strength of the network of actors involved in shore-power in the UK can contribute to building the capacity and connectedness of actors lobbying for stronger policy for shipping decarbonisation generally, and shore power specifically.

As an example of knowledge dissemination, measure 6 (Table 4) on a smart-grid working group would directly address the perceived lack of expertise and capacity on energy-management. But it would also help indirectly, through strengthening knowledge infrastructures and the interactions between actors, by creating space for the development of actors' capabilities in new areas, and by helping raise energy as a higher priority issue for ports, which would help prevent energy issues being deprioritised at times when urgent events occur (such as COVID). The soft measures set out in Table 4 can therefore help to build a stronger and better connected set of actors, capitalising on the existing work of the trade associations and other entities such as Maritime UK.

4.2. Multiple streams approach (MSA): the political and policy landscape

This section uses the MSA framework to assess whether the policy or other interventions to improve the functioning of the current shore power TIS identified in Section 4.1.4 are likely to be implemented. It does this by analysing the interaction between the three "streams" used as the basis for MSA framework analyses – problem, policy and politics streams.

Table 3
Barriers to UK shore power TIS functionality.

No.	Structural area	Barrier to shore power deployment	Main functions this affects
1	Institution	Globally, marine fuel oil is untaxed	F1, F5, F6
2		High level of electricity taxation in UK	F1, F5, F6
3		Lack of guidance for ports on decarbonisation	F2, F3
4		Lack of grant funding for ports/ships for SP projects	F1, F5, F6
5		Shipping advocates have low political power compared with those in other transport modes	F4, F7
6		Lack of policy to back up broad maritime decarbonisation goals	F1, F5, F6, F7
7	Interaction	Absence of relationships between ports and DNOs	F1, F2
8		Weak and sometimes mistrustful relationships between ports and ship operators	F2, F5
9		Absence of relationships between ports and entities providing business models for energy management	F1
10		Complexity and multi-stakeholder nature of SP projects	F5, F6
11		Competitive relationships between ports preventing information sharing	F3
12	Actor	Energy not seen as a core business for ports, so some expertise and capacity is often missing	F1, F5
13		Urgent issues of Covid-19 and Brexit reducing the capacity for ports and shipping operators to focus on decarbonisation/shore power	F7
14	Physical infrastructure	Electricity assets (cables, substations etc) on port property are often old, making investments difficult, complex and costly	F1
		Inducement mechanisms	
15	Institution	Presence of a nascent overall shipping decarbonisation strategy	F4
16	Interaction	Some examples of specific ports and shipping operators increasing collaborative work	F3, F6
17	Actor	Commitment of trade associations to promote policy solutions	F4, F5, F6, F7

4.2.1. *The problem stream*

Interviewees were clear that they saw air quality and climate change as two major problems for shipping, and that there is increasing pressure locally and globally to tackle both. Historically, the global regulatory response to environmental harms from shipping has focussed on air pollution, where the IMO has successively tightened regulations on SOx and NOx from old and new vessels. More recently, climate change has risen up the global environmental agenda for shipping, with the IMO introducing a strategy for greenhouse gas emissions reduction in 2018, with the IMO's Marine Environmental Protection Committee (MEPC) stressing that increased ambition is needed in the IMO's forthcoming 2023 climate change strategy revision [75].

A similar shift in focus towards climate change occurred at regional and national scales. The EU, frustrated with lack of progress on climate change at the IMO [76], is increasingly introducing policy to reduce greenhouse gas emissions from shipping. Similarly, the UK issued the Clean Maritime Plan (CMP) for shipping decarbonisation. This has established an expectation about the trajectory and pace

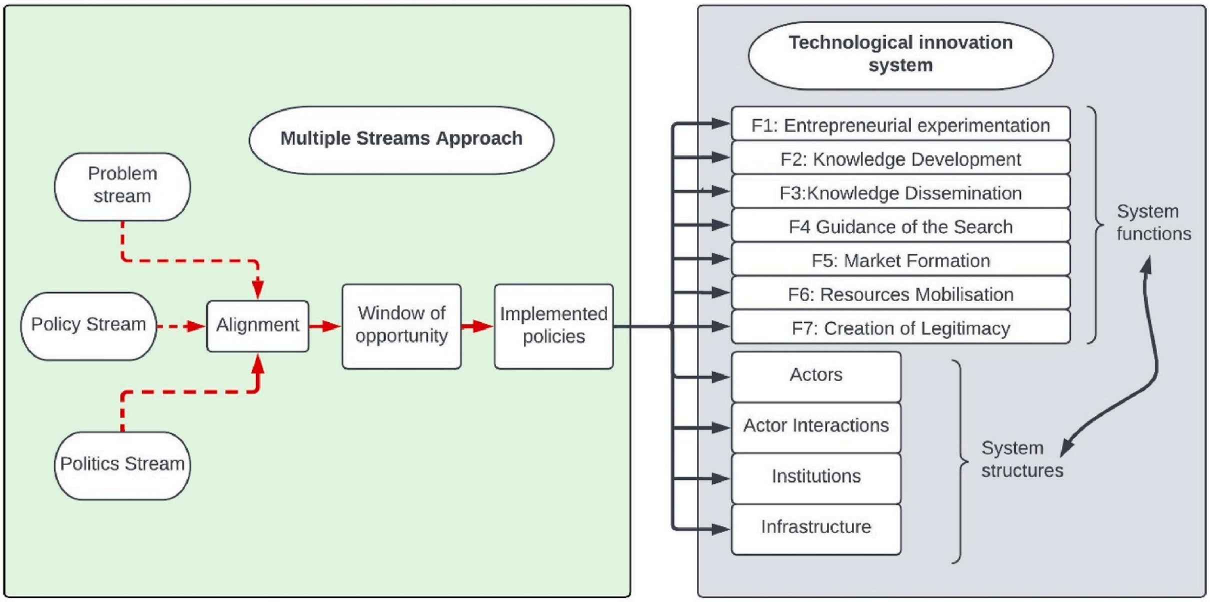

Fig. 1. A visual representation of the interaction between system properties emphasised by the Multiple-Streams Approach (MSA) and Technological Innovation System (TIS) frameworks. Interactions between MSA streams (red arrows) can lead to new policies. Implemented policies impact upon system structures and functions (black arrows); interactions between system structures affect system functions, and vice versa. (For interpretation of the references to colour in this figure legend, the reader is referred to the Web version of this article.)

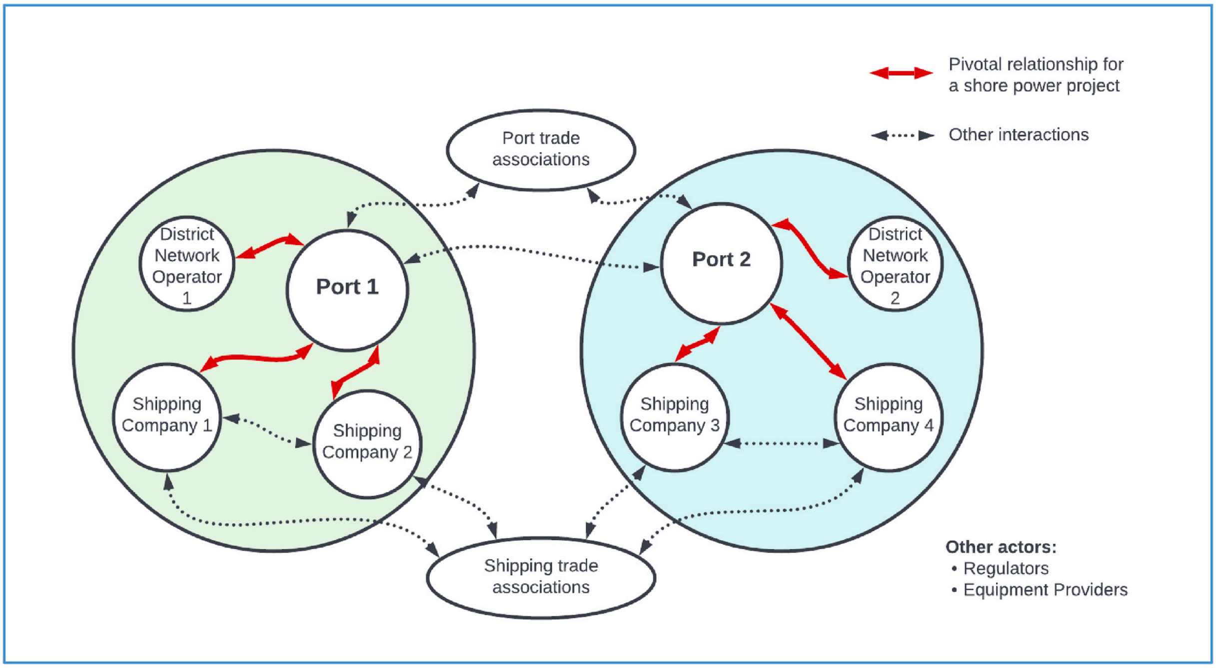

Fig. 2. Core actors and interactions in shore power projects.

of future emission reductions in the UK. Interviewees expressed a sense of inevitability around the need for action on maritime decarbonisation:

> "*The direction of travel has already been set. Through broader policy framework in things like the Clean Maritime Plan and obviously its decarb targets to 2050 and well-established carbon budgets and the CCC, so the trajectory is set. The implication for ports is that we will be under pressure on increasingly stringent emissions criteria or targets as we go forward*" [interviewee P17].

However, despite climate change being widely recognised throughout the shipping sector, respondents felt that shipping emissions were often seen as a lower-order concern within broader environmental debates. Acknowledgement of the urgency of reducing emissions is high and increasing, but a difficulty for shipping remains that its emissions are seen as a small part of a much larger global problem. In addition, it is a sector less obviously connected to people's daily lives [77], so its emissions are not high in the public or

Table 4
Interventions for accelerating shore power deployment.

	Type	Measure	Barrier (Table 2)	Detail
1	Institutional: global	Carbon pricing via the IMO	1	This might also be addressed at a regional level, for example in recent proposals by the EU Commission to include maritime emissions within the EU Emissions Trading Scheme.
2	Institutional: national	Capital funding for projects	4,14,15	Funding to the recent Clean Maritime Demonstration Competition could be expanded and made into a multi-year programme.
3	Institutional: national	Tax cuts for shore power	2, 15	Exempting shore power electricity from existing environmental taxation would help level the playing field with marine fuel oil, as other countries have done.
4	Institutional: national	Regulatory standard	6,15	Work with the port and shipping sectors on the design and implementation of a Zero-Emission berth standard or similar intervention aimed at cutting pollution in ports. This would increase demand for shore power in the shipping sector.
5	Institutional: national	Shore power information service	3,15	A one-stop-shop Government information service for ports and ship operators on technical and economic issues and business case development for shore power projects. This could be housed within the proposed new UK-SHORE office in DfT, flagged in the Transport Decarbonisation Plan.
6	Interaction	Working group for smart-grid development	5,7,17	To address network capacity issues, the trade associations, government, OFGEM, national grid and DNOs could convene a working group with the aim of developing a clear framework for enabling the development of port smart grids.
7	Interaction	Working group for data and best-practice sharing	5,8,10,11,16	The port and shipping trade associations could lead a focussed working group aiming to increase collaboration and sharing of data and best practice on shore power deployment
8	Actor	Development of business models	9,12,17	The port associations and KT networks could work with the new UK-SHORE unit to investigate business models for energy management in ports.

politicians minds, compared with those from other sources, such as cars and planes.

4.2.2. The policy stream

Various policies have been developed around the world to promote shore power, particularly to address local air pollution. One successful example is shore-power regulation in California, first deployed in 2007 and strengthened over the years [78]. Other attempts at shore power regulation have been less successful. For example, a 2014 EU directive [79] mandated shore power provision in ports, but included a clause on competitiveness which meant that in practice, lack of implementation was justifiable. Deployment has been accelerated instead through national policies: capital grant funding and reductions in electricity taxes. The 2021 EU Commission "Fit for 55" package sees proposals for strengthened regulations for shore power infrastructure for ports and ships, alongside more generic shipping policy such as inclusion of maritime emissions in the EU ETS.

In the UK, the Government's interest in shore power is likely shaped by consistent interventions in the last two years from multiple industry bodies on both the need for shore power and for policies to enable it [44,80]. Shore power is a technology option for which the Government appears to be strongly considering. In 2019, the Clean Maritime Plan had an accompanying report on maritime electrification, with shore power prominent. In 2020, a technology report for the Government included shore power as one of five priority "clusters" for maritime decarbonisation [81]. In 2021 Transport Decarbonisation Plan stated that shore power has: *"the potential to quickly reduce greenhouse gas and pollutant emissions from the ports and shipping sector, and is an option that is likely to be 'low/no regrets'"*, and committed to *"consult this year on the appropriate steps to* support *and, if needed, mandate the uptake of shore power in the UK"* [82] and in February 2022 issued a call-for-evidence on possible shore power policies [83]. However, as yet there are no specific policies to support shore power, and interviewees highlighted that the Government's strategy documents provide a weak mandate for action on shore power and other decarbonisation options:

> "*At the moment we have a vision of 2030, 2050 clean maritime industry, but in the short-term no legislation at the moment to drive change in the business"* [interviewee O5]

> *"The Clean Maritime Plan [has] quite weak, long-term objectives, no detailed road maps or plans to get there … it's not concrete or clear what they want"* [interviewee P8].

In order to be effective, interviewees describe a need for more specific interventions:

> "*The Clean Maritime Plan is more scaffolding than building. Putting the foundations down, the bricks up, let alone the electrical wiring, has been noticeably delayed, for good reason* [COVID]" [interviewee P17]

> "*We've not had anything firm from Government. To me there's a lot of uncertainty out there still*" – [interviewee P9].

4.2.3. The politics stream

At a political level, there are various pressures affecting the likelihood that shore power will be supported as a policy solution to the problems of air pollution and climate change. On air quality the signs are less positive. The Government does have an Air Quality Strategy, but although the UK legal system has found on three occasions that the Government is breaking the law on NOx levels [84], and ordered ministers to produce compliant plans to tackle air quality, the Government has still not done so. The political pressure on the Government has not yet been sufficient to persuade them to introduce a legally compliant strategy. This is mirrored in one aspect of air quality strategy – the UK Government has not followed up the Port Air Quality strategy since 2019. Although many ports have submitted draft plans, interviewees noted that there appears to be a policy hiatus:

> "*We've not heard back, it does kind of question the priority they give to this material.*" [interviewee P8]

> "*We're not getting any real pressure from regulators at the moment*" [interviewee P9]

> "*We're in the early days of developing our air quality strategy … but there's been no real driver*" [interviewee P10].

On climate change, interviewees sensed more momentum with ramped-up rhetoric and ambition from the UK Government on climate change generally, and shipping decarbonisation specifically. However, there remained considerable scepticism that this would translate into policy. It was a repeated concern that there was low civil service policy capacity on shipping within the Department for Transport compared to other transport modes:

> "*On shipping there's an astonishing lack of capacity in DfT*" [interviewee S4].

The Department was seen to be prioritising other transport modes:

> "*Traditionally it's a Cinderella mode. We've spent less than £5m on greening maritime in last 2 years, buses £250m on a single project. Clearly buses have a more core role to people's day to day life, but Maritime is a major emissions source*" [interviewee O4].

In addition, it was expressed that the Department did not have much power over the pivotal decision-making body regarding shore power - the Treasury. This is critical given the need for capital funding and tax changes to accelerate shore power deployment, which are both under the Treasury's control.

In summary, from the MSA analysis, consensus is building that shipping's air and climate impacts are a problem, in the policy stream shore power is increasingly framed by industry and policy makers as part of the solution, and in the politics stream, political pressure is increasing, but it will need to strengthen further to overcome substantial inertia to ensure policies are adopted and sustained, given the lack of priority given to shipping policy.

5. Discussion

These findings suggest a new "window of opportunity" for shore power and ports more generally may be opening. This is because climate change has risen up UK and global agendas, as has recognition of the shipping sector's contribution to this problem. But this opportunity is considered by some to be much more extensive, as shore power will likely have a wider range of end-users in future, as hybrid or fully-electric vessels become more prevalent. The work of policy entrepreneurs, particularly trade associations, has helped raise the prominence of the necessity for greater policy on UK maritime decarbonisation, and shore power in particular. There is also greater political space for policy interventions to accelerate deployment of UK shore-power, with the UK Government's creation of a nascent Clean Maritime Plan decarbonisation strategy (due for revision in 2023), and the inclusion of international shipping emissions into the legal requirements of the UK Climate Change Act 2008.

However, in shipping, political pressure to decarbonise remains diffuse, compared with other more visible or apparently easier-to-decarbonise sectors. Consequently, despite some strong advocates for shipping decarbonisation within the UK Government and in wider industry, it is also clear that at present new policies are unlikely to proceed quickly. This is considered by stakeholders to be due to a general lack of political priority given to shipping within the Department for Transport, and also by key bodies such as the UK's Treasury, who are seen as a veto-institution whose power and relative lack of interest is a formidable obstacle. This view was most recently expressed in shipping trade press reports that the February 2022 consultation into shore-power policy does not include capital funding for shore power due to Treasury reluctance [85]. This is problematic as MSA theory specifically suggests that windows of opportunity rarely remain open for long.

Overall, stronger policies for shore power can improve the weaker functions of the current UK shore power TIS, as shown in Fig. 3, which would have knock-on positive effects on other system functions. To deliver these policies requires better alignment of the three streams, and in turn, a strengthening of the politics stream in particular. There is also the possibility of a positive feedback loop, where seemingly minor interventions to improve interactions between actors can lead to greater coordination of actors in the political stream. This can lead to better aligned streams, lengthening the window of opportunity, in turn strengthening policies, positively affecting system structure and functions, and so on. Similarly, improving guidance of the search can strengthen the problem and policy streams, creating another positive feedback.

Although efforts to raise maritime decarbonisation and shore power up the UK policy agenda could be seen as a success, the hard work of securing necessary policies has only just begun. In line with the findings of Bjerkan and Seter [55], who concluded that for Oslo, shore power "*policy implementation might require even more political work than policy adoption*", it seems likely that for national UK policy for shore power to be implemented, greater political pressure will be necessary.

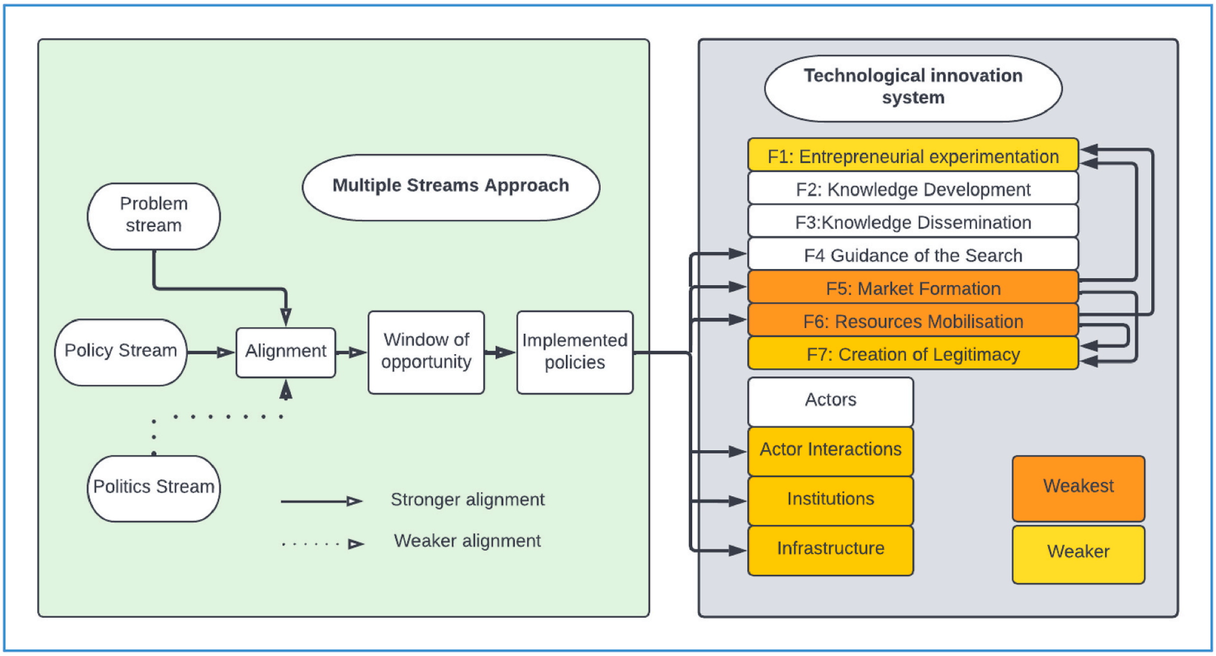

Fig. 3. Analytical framework for the UK shore power system, showing the weaker functions and structures in the Technological Innovation System (shaded yellow and orange), and how stronger alignment in the three MSA streams can lead to strengthening of system functions and structures, with further positive knock-on effects (black arrows). (For interpretation of the references to colour in this figure legend, the reader is referred to the Web version of this article.)

Here we suggest three ways in which recent developments, linked with the capacity and knowledge measures 5–8 in Table 4, may help to promote progress in all three MSA streams – problem, policy and politics.

Jones and Baumgartner [86] point out that accelerated change may occur through either reframing an issue, or through shifting the policy venues where decisions are taken: "*punctuating the equilibrium*". On reframing, the twin environmental problems of air pollution and climate change are typically treated separately. So, first a reframing of shore power as a means to tackle both problems together, formalised through greater integration of the current Clean Air Strategy (air pollution) and Clean Maritime Plan (climate change), might help strengthen arguments in the problem stream, and incentivise stronger policy to support measures like shore power that deliver on both objectives. Given the Clean Maritime Plan is due for revision in 2023, and the Clean Air Strategies for ports also require updating, there is an imminent opportunity for integration.

Second, on shifting policy venues, the trailing in the July 2021 Transport Decarbonisation Plan of a new "UK Shipping Office for Reducing Emissions – UK-SHORE", building on the perceived success of similar models in other transport sectors, for example the UK Office for Zero Emission Vehicles, might help in the policy stream through opening new venues for policy deliberation. Similarly, the recent inclusion of international shipping emissions into the UK's carbon budgets indicates that as Government now has a stronger legal requirement to cut international shipping emissions, in future there may be greater policy analysis capability in both the Committee on Climate Change and in the Department of Transport. As Carter and Jacobs [87] highlighted, in the late 2000s the institutional change of the Climate Change Act and its attendant processes around carbon budgets "wedged open" the window for climate policies in the late 2000s for longer than just the passing of the Act. It may be that including shipping in carbon budgets will wedge the window open on maritime decarbonisation, particularly if civil society pressure on Governments to act on climate change intensifies.

A third potential area for progress is via the £23 m 2021 Clean Maritime Demonstration Competition (CMDC), which may lead to a greater variety of innovators active in marine decarbonisation, better connected with each other and with a vested interest in pressing the Government in the politics stream. The CMDC, which is set to receive further funding up to around £200 m, is likely to increase collaboration between innovators across the shipping sector, and the strength and depth of business lobbies for stronger decarbonisation policies. These strengthened capabilities would help address the political problems highlighted in the MSA analysis. However, tensions between and within actor groups may well persist, given the very diverse nature of the sector. For example, a given set of shipping operators visiting a port will have very different organisational perspectives and priorities on any set of technologies. These might vary depending upon the views of their parent-organisation, on the importance of tackling climate change, whether they see competitive advantage in being a late or early mover, and whether they see shore power as conferring other benefits. Better understanding of actor-motivations in shore power would be a helpful area for future research. In this respect, the Dynamic Capabilities approach of Teece [88] and used in shipping by Stalmokaite and Hassler [50] would be useful to include in further research.

6. Conclusion

If decarbonisation is to be the next major shipping transition (Pettit et al., 2018), then shore power is well positioned to play a vital role. However, supporting policy implementation in the UK is being blocked by the lowly status of shipping in UK political hierarchy. This influential jigsaw piece within the wider shipping system faces political, economic and cultural barriers that are interacting to stymie its deployment in the UK. Interrogating these barriers has identified policy instruments and ways to support their implementation.

Shore power faces difficulties in forming markets and mobilising financial resources, particularly as it requires coordination between multiple actors to be effective. As well as having high capital costs, shore power projects have long pay-back periods and struggle to compete with relatively untaxed marine diesel oil. Provision of capital funding and reductions in taxes that shore power faces could overcome some of these economic barriers.

In terms of cultural barriers, there is mistrust between some port and ship owners, and limited interaction between electricity networks companies and port operators. There are also knowledge gaps and an absence of information sharing surrounding energy management and business cases that could valuably be addressed through cross-sector working groups and centralised information services. Both are relatively simple to implement and would improve the functioning of the shore power system.

Measures to strengthen knowledge, capacity and networking between key shipping actors would provide an additional benefit. Economic policies on shipping are currently blocked by insufficient pressure for their implementation: better coordination between shipping actors would strengthen their ability to exert political pressure to enact necessary policies for shore-power and wider shipping decarbonisation. There are opportunities to do so – the review of the Clean Maritime Plan, the extension of the Clean Maritime Demonstration Competition, and the establishment of the UK-SHORE unit.

The results from this research have implications beyond the UK. First, they have shown that part of the economic difficulty faced by UK shore power projects is caused by the global absence of carbon pricing for marine fuel oils. This absence will affect shore power project economics in all other countries also. Shore power projects globally would be made more viable if the IMO were to introduce a strong carbon price market-based measure, which it could do at its MEPC meeting in July 2023. Second, the need in the UK for additional guidance, collaboration and working groups on business models for energy management, smart grids and best practice for shore power deployment applies in other countries, and also between countries. International bodies such as the IEEE or the ESPO are candidate entities for coordinating best practice information sharing between nations, port and shipping operators on shore power deployment.

Shore power reduces air pollution, more closely aligns UK shipping greenhouse gas emissions with the Paris Climate Agreement and facilitates wider decarbonisation. Yet despite growing consensus on the imperative of shipping decarbonisation and shore power in particular, stronger policy is needed to ensure its quick and effective implementation. There exists in 2023 a rare chance to lengthen the open window of opportunity to accelerate shipping decarbonisation, but this requires urgent intervention. Increased coordination between actors, aligning knowhow, reducing electricity taxes and a provision of capital could unlock the current impasse in UK shore power deployment. This can pave the way for greater electrification of shipping fleets, integrating with energy and transport sector electrification, and in turn, elevate UK ports to become very low carbon energy hubs. Seizing rare opportunities to accelerate the energy transition is essential if our climate goals are to be met and shore power could be a critical catalyst that unlocks a much bigger prize.

Author contribution statement

Conceived and designed the experiments: Simon Bullock, Alice Larkin, Claire Hoolohan.
Performed the experiments: Simon Bullock.
Analysed and interpreted the data: Simon Bullock.
Contributed reagents, materials, analysis tools or data: Simon Bullock.
Wrote the paper: Simon Bullock, Alice Larkin, Claire Hoolohan.

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Data availability statement

The data that has been used is confidential.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Appendix A. Supplementary data

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