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DOI
10.1016/j.cstp.2022.05.003

Publication date
2022

Document Version
Final published version

Published in
Case Studies on Transport Policy

Case Studies on Transport Policy 10 (2022) 1417–1426

Contents lists available at ScienceDirect

Case Studies on Transport Policy

journal homepage: www.elsevier.com/locate/cstp

The significance of pilot projects in overcoming transition barriers: A socio-technical analysis of the Dutch shipping energy transition

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A R T I C L E I N F O

Keywords:
shipping
Energy transition
Pilot Projects

A B S T R A C T

The energy transition of Dutch shipping is a complex gradual process due to the variety in vessels, cost and lifetime of assets, uncertainty, additional costs of climate-neutral alternatives and required regulatory changes. This paper aims to create a holistic overview of both the transition barriers and enablers. A focus is placed on the significance of pilot projects.

Using the socio-technical multi-level perspective as a framework, literature on lock-in mechanisms, strategic niche management, transition pathways, and shipping specific aspects was evaluated as a starting point for determining the shipping specific barriers. Semi-structured interviews with industry experts were used to further develop the overview of the barriers and add the required enablers. Thereafter, three case studies were conducted for additional detail, context and reflection on the theory, barriers and enablers provided by experts and literature.

Pilot projects can reduce any market entry barrier for a certain vessel and operational area. These barriers can originate from interdependency, costs, uncertainty, the required assets, regulations and mindset. Pilots can significantly reduce the additional costs of climate-neutral sailing by tens of per cent, improving the market potential and creating opportunities for follow-ups, scale-ups and spin-offs. Furthermore, pilots can develop clear climate-neutral sailing practices, the new 'ways of doing', which articulates expectations and visions on a future climate-neutral cluster which makes investments less risky. It has therefore been demonstrated that subsidizing pilot projects through local governments can become a key enabler for shipping, since the global nature and complex governance structure make it difficult to initiate and accelerate the transition in other ways.

1. Introduction

In 2019 Dutch inland and sea shipping generated 3.96% of the total Dutch CO2 emissions, the shipping cluster generated 3.1% of the GDP of the Netherlands and provided 2.85% of total employment, which are approximately 285,000 people (NML, 2020)). The Dutch shipping cluster is an important part of the Dutch economy but also a significant contributor to climate change. It is crucial for the Netherlands that the cluster makes an energy transition to stop their contributions to climate change, while at the same time maintaining or even improving their economic value. Such a transition will require new energy carriers with accompanying technology, infrastructure, user practices and regulations, which is certain to impact many organizations and markets.

Authorities such as the International Maritime Organization (IMO), the EU and the Dutch government have already set out emission reduction targets (IMO, 2018; RVO, 2019; European Commission, 2019). However, these do not take away the transition barriers that actors encounter when trying to change the energy carrier they have relied on for decades. Furthermore, the requirements for a sustainable solution differ per vessel based on function, organization and operational area. An inland ferry that sails short distances on a fixed route has different requirements than a cruise ship, fishing boat or naval destroyer. This leads to different transition barriers and transition pathways. The variety in vessel types, functions, organizations and operational areas is high, the number of vessels that all fall in the same category is usually small. This makes the transition a complex multi-dimensional process, resulting in many challenges ultimately affecting the legitimacy of investments in sustainability (Bergsma et al., 2021). Creating an overview requires a transition model that takes all these elements into account.

The socio-technical transition approach focuses on the co-evolution and multi-dimensionality of a transition rather than only focusing on

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https://doi.org/10.1016/j.cstp.2022.05.003
Received 1 June 2021; Received in revised form 12 November 2021; Accepted 5 May 2022
Available online 8 May 2022

the economical, behavioural, environmental, technological or political side (Geels, 2011). It conceptualizes a sector as a regime in which regime actors maintain certain 'ways of doing' by following the 'rules of the game' (F. W. Geels, 2002). This leads to the prevailing socio-technical elements such as technology, infrastructure, markets, user practices, regulations and mindset (Kemp Et Al., 1998). These elements are well aligned with each other which means that one cannot easily change one element, e.g. a technology change also requires changes of the other socio-technical elements for all interdependent actors. Socio-technical regimes are therefore characterized by their stability, they are locked into the established 'ways of doing'. This lock-in leads to path dependence and forms a barrier that limits changes to incremental improvements at best (Geels, 2011). Reducing the emissions of the shipping cluster by over 80% is not an incremental change and will therefore require deep structural changes to all socio-technical elements. This will require transition enablers that can break through the specific transition barriers of the diverse Dutch shipping cluster.

Pilot projects with new technologies are hypothesized as an important phase between research and development and market diffusion (Geels & Raven, 2006). Performance tests that are supported by public funds could for example stimulate the adoption of wind propulsion technologies (Nelissen et al., 2016). Pilots can bring all interdependent transition elements together and facilitate a practice-based learning mode of doing, using and interacting which is valuable for innovation (Jensen et al., 2007). They can start niches with different socio-technical elements and spread the new 'ways of doing' (Geels & Raven, 2006). Most research on the potential of niche markets is qualitative in nature (Zolfagharian et al., 2019; Sengers et al., 2019). lacking a validation of the theories. Ahead of conclusive research on impact, subsidies for pilot projects are already available e.g., the Dutch Subsidies Duurzame Scheepsbouw (RVO, 2019) and the EU's Horizon Europe (European Commission, 2021), a mixed or quantitative study on the potential impact would be of value for the validation of this spending on shipping.

This paper aims to provide an in-depth understanding of the current transition barriers and required enablers based on a socio-technical transition framework. The overview of the barrier will be the basis for an in-depth understanding of the required enablers which results in the transition pathway for the Dutch shipping cluster. The focus will thereby be on assessing the value of pilot projects by investigating their resulting transition enabling potential. The methodology of this study will be introduced in section 2. The theoretical framework and relevant aspects of the shipping cluster will be discussed in section 3. This is followed by the results in sections 4 and 5, the discussion in section 6 and the conclusion in section 7.

2. Methodology

The applied methodology is based upon three phases, which are visualized in Fig. 1.

2.1. Phase I: Theoretical framework

Socio-technical transitions theory was used as a starting point and framework for collecting literature. The snowball method was used to find the literature required to fill the socio-technical transition framework with shipping specific knowledge. This method uses the references of a key paper to find more relevant literature, the references in the newly obtained literature are then again used to find literature and so on. First, a socio-technical framework was selected as a starting point, shipping literature was then collected to fill this framework. This was then used to identify the shipping landscape, lock-in mechanisms, climate-neutral niches and expected transition pathways for the energy transition of shipping.

2.2. Phase II: Semi-structured interviews

Thirteen semi-structured interviews were conducted with industry experts. The questions had an explorative nature and were based on the framework and shipping literature, to ensure that all elements that might play a role were discussed without being suggestive. The interviewees had a range of functions in decision making roles at a wide range of organizations (governmental, shipyards, shipowners, engineering firms, ports and branch organizations). Interviewees were asked to share their knowledge on transition barriers, required developments and the value of pilot projects. The interviews were analysed using Atlas-TI to categorize and label the input. A detailed and holistic description of the lock-in mechanisms, windows of opportunity and niche developments have been created by combining the input from different interviewees.

2.3. Phase III: Case studies on pilot project enablers, trajectories and finances

Three case studies were conducted on climate-neutral pilot projects to verify the answers provided by the interviewees and to obtain additional depth, detail and context. One existing pilot project and multiple planned pilot projects were analysed on their ability to tackle transition barriers and thereby provide a transition enabling effect. The trajectory from start to finish was analysed to better understand how successful pilots are managed. The costs and funding sources for the pilots were also analysed since the cost of a pilot project were hypothesized to be a barrier. This practice-based knowledge was also used to reflect on the socio-technical transition theory in the discussion.

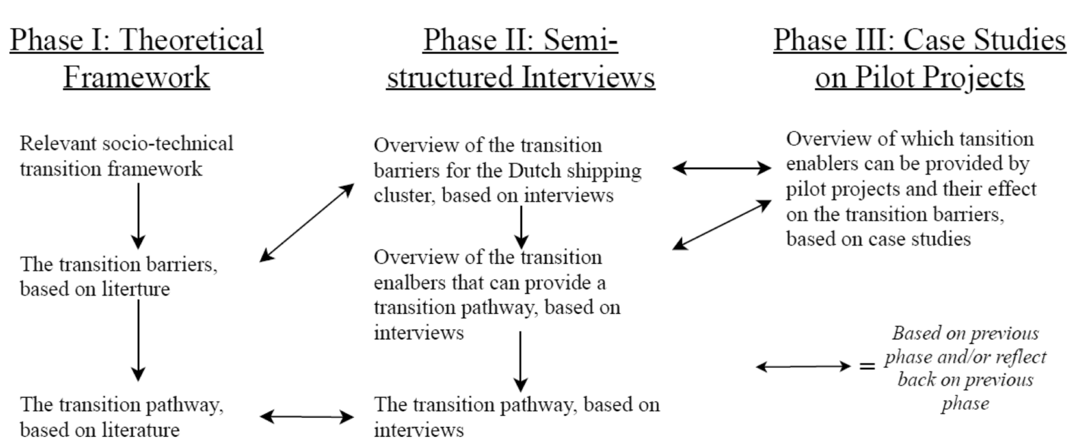

Fig. 1. Methodology based on literature, interview and case study phase.

3. Phase I: Theoretical framework, the multilevel perspective and the shipping cluster

In phase I, the energy transition of shipping was analysed by applying a socio-technical transition theory to shipping specific literature. The multi-level perspective (MLP) on socio-technical transitions is chosen to structure the theoretical framework since it provides valuable insights into sectoral transitions, as was proven by previous studies on the energy transition of shipping (Mander, 2017; Pettit, Wells, Haider, & Abouarghoub, 2018). It is based on the idea that a transition is a non-linear process that results from interactions and developments of three analytical levels: niches, socio-technical regimes and the exogenous socio-technical landscape (Geels, 2002; Kemp et al., 1998). Niches are places where radical changes to the established ways of doing can gain momentum, socio-technical regimes are formed by actors that have strongly established ways of doing in which they are locked-in; the socio-technical landscape is the exogenous structure to the regime and niche. Regime change occurs as a result of development on the three levels: "(a) niche-innovations build up internal momentum, through learning processes, price/performance improvements, and support from powerful groups, (b) changes at the landscape level create pressure on the regime and (c) destabilization of the regime creates windows of opportunity for niche innovations" (Geels & Schot, 2007). The barriers at each level identified in the literature will be discussed next.

3.1. Barriers for landscape pressure in shipping

The socio-technical shipping landscape consists of external elements such as an oil or hydrogen price, macro-economic trends, politics and policies, a spatial structure such as canals, environmental concerns or external technological developments. Changes in these elements can put pressure on the established regime and steer it in a certain direction (Geels, 2011), e.g. environmental concerns and low hydrogen prices can steer the regime towards an energy transition.

The governance framework of shipping is complex, multiple actors and agencies can be involved on both a global and local scale (Stokke, 2013). Vessels operate in countries with opposing cultures and interests, making it difficult to steer and implement policy at a national level (Karahalios, 2017). The 174 member states of the IMO that can implement regulations and policies follow a consensus-based approach; this results in slow adaptation of regulations due to a large number of unaligned actors (Karahalios, 2017). The IMO has implemented policies such as the Environmental Shipping Index and the Ship Energy Efficiency Management Plans, but these only lead to incremental improvements instead of the required regime change (Pettit et al., 2018).

3.2. Barriers for regime destabilization in shipping

The lock-in mechanism and path dependence arises from cognitive routines, shared beliefs that make actors blind for developments outside their scope, shared capabilities and competencies by shared education, deeply embedded user practices, institutional arrangements, regulations and market entry costs that create market entry barriers, legally binding contracts, sunk investments in technology, infrastructure and people, resistance from vested interest or low costs because of economies of scale (Geels, 2011; 2012). In addition to these general transition barriers, shipping-specific barriers can also be identified; this will be discussed in the following sections.

The variety in vessels, functions, operational areas and organizations in the Dutch shipping sector makes it difficult to identify certain prevailing 'ways of doing' or 'rules of the game'. It is often considered to be a cluster of sub-sectors (NML, 2020)). In the MLP this could be conceptualized as a cluster of sub-regimes, e.g. a yachting, container carriers, inland work vessels or crude carrier sub-regime. Within these sub-regimes alignment is stronger and specific regime rules, infrastructure and regulations are dominating. However, sub-regimes will still have a lot of similarities in terms of prevailing technologies, overarching regulations, policies, culture and mindset.

Many of the vessels in the shipping cluster are custom built which makes actors hesitant with implementing innovative technologies since these are associated with risks (Wijnolst & Wergeland, 2009; Faber et al., 2011; Gilbert et al., 2014;). There is a strong status quo in vessels which creates a level playing field between actors. It also creates fierce competition, which again limits the willingness to take on risks (Wijnolst & Wergeland, 2009; Psarros & Mestl, 2015). The sector has many small detached companies (Europen Commission, 2015), which means that large research and development projects are difficult. Furthermore, actors are said to feel resistance to radical change (Mander, 2017). Their mindset is traditionally inward-focused, with limited interest to show leadership for issues outside the shipping domain (Jenssen & Randøy, 2006). Other transition barriers that are mentioned in the literature are a lack of information, awareness and crew competence (Dewan et al., 2018).

3.3. Barriers for niche developments in shipping

Radical changes can only occur in niches where the lock-in mechanisms are less pronounced. These niches form 'protected spaces' for learning processes and innovative social networks that lead to converging expectations and visions on novel practices (Hoogma et al., 2005; Kemp et al., 1998).

There are many examples of market niches with special demands in shipping, e.g. submarines, exploration vessels, custom-built superyachts or work vessels for a specific task. Examples of niches where the lock-in mechanism are less pronounced are far more scarce, e.g. subsidized projects, R&D laboratories or small market niches with climate-neutral demands and the willingness to pay for them (Geels, 2012). Niches and socio-technical regimes are similar kinds of structures, communities of interacting groups, but they differ in size and stability. They are crucial for regime transitions because they provide the seeds for systemic change (Geels, 2012). Niche actors strive to develop a stable system that can outperform the established ways of doing of the regime, this requires the development and alignment of socio-technical elements by processes like standardization, formulation of best practices and attracting established actors (Geels, 2012). Strategic niche management literature creates an understanding of the dynamics behind niche management and conceptualizes pilot projects with new technologies as an important phase between research and development and market diffusion (Geels & Raven, 2006). The outcomes of multiple complementary projects can enrol more actors, stimulate the learning process and adjust expectations which in turn can supply the niche with more resources (Geels & Raven, 2006). Pilot projects provide a practice-based learning mode of doing, using and interaction which develops links between operator and designer, which is crucial for innovation (Jensen et al., 2007).

Some shipping niche innovations focus on improving the energy efficiency by, for example, changing the hull shape, ballast water reduction, hull coating, waste heat recovery, speed optimization or voyage optimization but these measures lack the potential to bring the necessary emission reduction (Bouman et al., 2017). A transition towards a climate-neutral energy carrier is required, for which batteries, hydrogen, ammonia, biodiesel and methanol are some of the more prominent options that are currently considered. The use, distribution and clean production of these energy carriers are currently very limited (Hall et al., 2018; Castro & Mestemaker, 2019). Criteria such as energy density, storage volume, the total cost of ownership, scale-up potential, safety and technology readiness level are considered (De Koningh et al., 2015; Hall et al., 2018; Castro & Mestemaker, 2019). The variety of vessels, operations, operational areas and organizations creates a variety in the criteria for a climate-neutral alternative, it can therefore be expected that multiple energy carriers will be used in the future. It does not appear that these new energy carriers can outcompete the diesel practices on price and performance, which means that a lot of value needs to be attributed to sustainability.

3.4. Shipping transition pathway

Multiple barriers for these developments were found in literature, which is summarized in Table 1. Based on these barriers and the MLP theory a transition pathway can be identified. The climate-neutral niches are not sufficiently developed to compete with the existing regime on price and performance but there is pressure from the landscape to become climate neutral, for example from the IMO 2050 goal. The regime actors have responded by modifying the direction of their development path by investing in energy efficiency but are not yet making an energy transition. These developments follow the transformation pathway which was presented in (Geels & Schot, 2007). It states that a new regime slowly grows out of the old one through gradual adjustments in regime rules and perceptions. Knowledge about new technologies will have to be imported from outside the regime, adjusted and developed in niches, e.g. by pilot projects which can thus become crucial for the transition. The adaptability of regime actors and regulations is also crucial since incentives to adopt niche innovations from within the sector are expected to be small due to inferior price and performance expectations. The energy transition of the shipping sector will thus be a goal-oriented transition that requires steering. It will not emerge by itself through market competition since climate-neutral niches can not compete with the established practices on price and performance.

This MLP analysis illustrates that there are still significant barriers at all levels that obstruct the energy transition. The transformation pathway describes that steering is required, but which concrete enablers are available for the energy transition of shipping is unclear. Furthermore, it is uncertain if the set of barriers found in literature form a holistic overview, which is itself a barrier for determining the required enablers for the entire transition process.

4. Phase II: Transition barriers and enablers according to industry experts

In phase II, interviews with Dutch shipping experts were conducted on the current transition barriers and possible transition enablers. With the knowledge from phase I as a starting point, a holistic overview has been created.

4.1. Transition barriers

The analysis of the interview transcripts provided the insight that the lock-in mechanisms actors perceive are generally the consequence of interdependency, uncertainty, commercial infeasibility, the required assets, an inward-focused risk-averse mindset and stringent regulations. The group of interdependent actors is visualized in Fig. 2. This chain can be seen as a sub-regime with aligned actors that have their own established 'ways of doing'.

Just one climate-neutral shipping service already requires a large multidisciplinary group of actors to make significant and often costly changes to their assets and 'ways of doing'. This interdependency mechanism was mentioned by all interviewees, although sometimes indirectly. The uncertainty lies in the choice for a climate-neutral alternative, which depends on the performance of technologies but also the price and availability of energy carriers. Furthermore, there are concerns about the number of customers that are willing to pay the additional costs of a climate-neutral service, which leads to commercial infeasibility, according to the interviewees. The actors that are part of the chain in Fig. 2 are in general businesses that require some level of certainty about the profitability of their service before they commit to large investments. This is strengthened by the assets they require, such as vessels and bunker infrastructure. These have a lifetime of several decades, high start-up costs, are made in low quantities and sometimes operate around the globe. This makes actors risk-averse to implementing unproven technology, which slows down innovation. Furthermore, actors in the cluster feel that the room for experimentation is limited by the fierce competition in the sector which leads to small margins. They tend to focus on surviving rather than contributing to the energy transition. They are, therefore, risk-averse and focus on their individual role in the chain. The final lock-in mechanism comes from the rules and regulations in the cluster, such as IGF codes for classification. These are based on the established ways of doing which often restricts or even prohibits climate-neutral alternatives. They also allow actors to emit greenhouse gasses without significantly paying for it, this limits the incentive and the competitiveness of climate-neutral sailing.

The barriers resulting from the MLP analysis and the corresponding barriers resulting from the interview analysis are both summarized in Table 2. This table proves that the barriers in literature can be placed under the six barriers found during the interview analysis. The interview related barriers explanation is further summarized in Table 3. This division is more suited to link to potential enablers and will be used for the rest of the paper.

4.2. Transition enablers

The landscape can stimulate the transition with three types of regulation. First, allowing climate-neutral operations. Second, supporting climate-neutral developments and third, putting pressure on the incumbent ways of doing to stimulate a transition. Allowing climate-neutral operations consists of developing regulations that enable climate-neutral operations, e.g. IGF codes for hydrogen. Pilot projects can be a driver for this development by creating a demand for these regulations. Supporting climate-neutral developments consists of subsidizing projects that have the potential of making large contributions to the transition but have high additional costs that are not covered by additional revenue. These can be pilot projects that develop climate-neutral sailing practices which result in additional costs and lower reliability. Putting pressure on the established ways of doing can be done by a carbon tax, fuel levy, emission trading system or other measures that make the polluter pay.

Regime actors might not yet be able to adopt a new energy carrier and everything that comes with it but should be able to change their mindset and development trajectory, according to some interviewees. They feel that the energy transition should be perceived as an urgent problem for both the environment and the future competitiveness of the shipping cluster. Both customers and operators should value climate-neutral sailing and be willing to endure extra costs or inconveniences during operations. This can be stimulated by pilot projects that demonstrate the feasibility of climate-neutral sailing practices.

Niches can develop a clear substantiated vision on which energy carriers and technologies are the best fit for the climate-neutral operation of a certain vessel, according to interviewees. Niche actors see batteries, hydrogen, methanol, ammonia and biodiesel all as possible

Table 1
Resulting shipping specific transition barriers found in literature.

MLP level	Barrier for required developments
Barrier for landscape pressure	Complex governance structure
Barriers for regime destabilization	Low ship production quantity
	Strong status quo in vessel design
	Many small, detached companies
	Resistance for radical change and uncertainty
	No interest in leadership
	Lack of information, awareness and crew competence
Barriers for niche developments	Price and performance of technologies
	Uncertain price and performance of technologies
	Uncertain price and availability of energy carriers

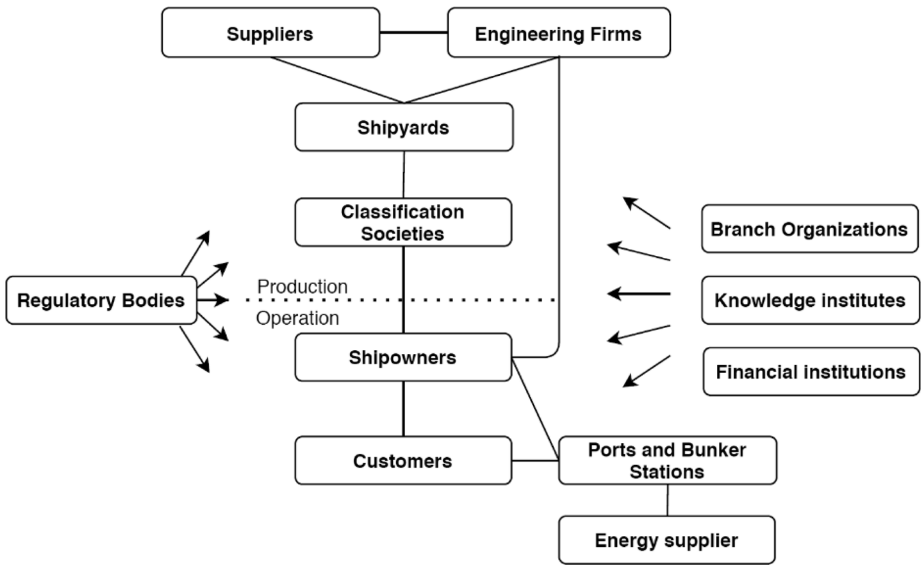

Fig. 2. The chain of interdependent actors in the shipping cluster.

Table 2
The barriers from the MLP analysis and the corresponding barriers from the interview analysis.

Barriers resulting from MLP analysis		Barriers resulting from interview analyses
Barrier for landscape pressure	Complex governance structure	Regulation
Barriers for regime destabilization	Low ship production quantity	The assets
	Strong status quo in vessel design	The assets
	Many small, detached companies	Interdependency
	Resistance for radical change and uncertainty	Mindset and uncertainty
	No interest in leadership	Mindset and uncertainty
	Lack of information, awareness and crew competence	
Barriers for niche developments	Inferior price and performance of technologies	Commercial infeasibility and uncertainty
	Uncertain price and performance of technologies	Uncertainty
	Uncertain price and availability of energy carriers	Uncertainty

Table 3
transition barriers resulting from the interview analysis.

Transition barriers result from:	Explanation
Interdependency	The value chain in the Dutch shipping cluster is long and has many interdependent actors that all must adapt, which creates inertia for the required radical change.
Commercial infeasibility	The costs and risks of a climate-neutral service are higher than what the market is willing to pay, which makes the service infeasible for a commercial party.
Uncertainty	The uncertainty in where, when and at what cost a certain vessel will make the transition to a climate-neutral sailing practice, and what this practice will be.
The assets	The vessels and infrastructure have a long lifetime, are capital intensive, are made at a low production quantity and need to have proven reliability.
Regulations	The stringent fossil fuel-based regulations and classification guidelines obstruct rather than stimulate climate-neutral sailing practices.
Mindset	Shipping actors can be risk-averse and inward-focused which makes them unwilling to contribute to the transition.

energy carriers for parts of the cluster, although opinions differ due to an ongoing discussion on their characteristics. There are many uncertainties about the production, transport, storage, availability, price, scalability and regulations of climate-neutral energy carriers, which is partly due to a lack of experience. The same goes for the new technologies that will be needed to run on these climate-neutral energy carriers, many of the technologies that are required for sector-wide climate-neutral sailing are not yet on the market or have never been proved in an operational environment. Niches environments could take the uncertainties away and align the socio-technical elements with the new energy carriers, they thereby have a crucial enabling function in the energy transition.

4.3. Hypothesized transition pathway

The transition is sketched in Fig. 3, which is based on the MLP (Geels, 2012). This figure considers the socio-technical nature of transition, the current barriers, required enablers and shipping specific characteristics. On the regime level, the cluster of shipping sub-regimes is visualized as a group of connected regimes that themselves consist of multiple aligned socio-technical elements. This cluster is locked into the established practices which prevent radical changes.

New climate-neutral sailing practices are developed on the niches level, which is visualized by the multitude of small arrows. Each arrow can be seen as independent developments, for example, caused by pilot projects or studies. The resulting developments can lead to new projects and actors which will make the niches gain momentum and move upward towards the more structured regime level. This is the result of the articulation and development of 'ways of doing' and 'rules of the game', which make them easier to adopt by regime actors. This adoption is visualized by the arrows from the old cluster to a new climate-neutral one. There are multiple niches visualized since multiple climate-neutral energy carriers are required to meet the demands of the different sub-regimes. These different niches will all have their own development trajectory which means they all have their own timeline.

Developments at the landscape level can stimulate niche development by supporting niches and putting pressure on the regime, such as changing fuel prices or making more subsidies available. This is indicated by the arrows from the landscape level to de niche and regime

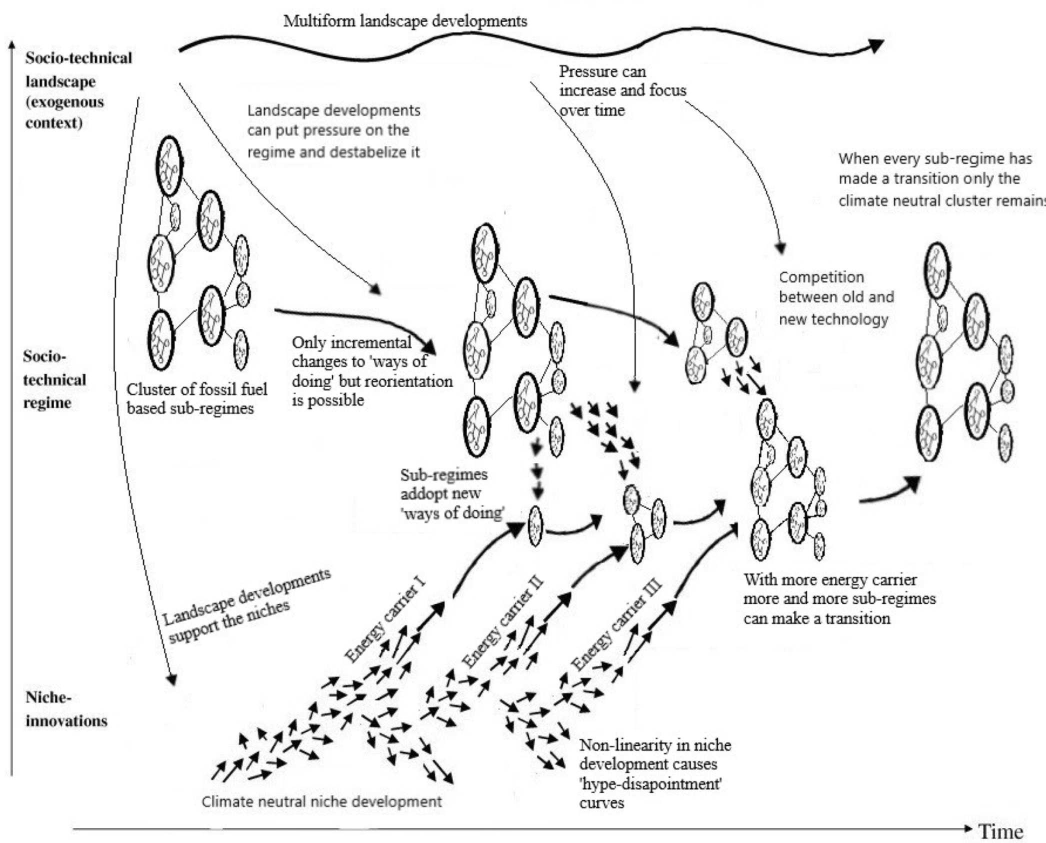

Fig. 3. Adaption of the MLP framework to describe the hypothesized shipping energy transition.

level.

The level of alignment between niches is probably limited due to large differences in technology, infrastructure and perhaps also regulations and markets and user practices. The mindset of the actors could be aligned, but it could also be unaligned due to disagreements about the choice of energy carrier. When multiple energy carriers have reached regime level it will become easier to switch, like switching between a diesel or petrol car. These regimes will keep on competing with each other which might lead to energy carrier consolidation. This depends on which energy carrier will be the cheapest in the long run for the largest part of the shipping sector.

To validate the ideas behind this shipping specific model for the energy transitions further investigations of existing small scale pilot projects has been conducted. Although, as mentioned in the introduction, major subsidies are provided as well, these projects had not yet matured enough at the time of this research to be included. The focus in the case studies was on elaborating the enabling potential in relation to each of the barriers identified (Table 3).

5. Phase III: Case studies on pilot projects

In phase III, case studies were conducted to understand the transition enabling potential of pilot projects in the energy transition of Dutch shipping. Case studies were conducted for three sets of climate-neutral pilot projects of which two are up and running and one is still in the planning phase.

All pilots are managed by a multidisciplinary group of actors with their own expertise but none of them had experience with building a vessel on alternative fuels. They relied on close cooperation and had to learn a lot along the way. The involved classification societies and local governments also had no experience with alternative fuels and had to be taken along on the learning journey. All initial pilots were small vessels that are part of a larger development plan with many follow-ups. The alternative fuels and technology make them too expensive for a commercial business case, which means that they had to find alternative sources of finance. The plans always include setting up a supply for the alternative energy carrier in the operational area. Actors all agreed that a follow-up vessel could be made easier and cheaper than the pilot vessel. The specific pilot projects are given below and summarised in Table 4.

1. A small passenger ferry which is powered by 0–85% hydrogen and 15–100% diesel

This pilot was carried out by CMB.TECH which is part of the Belgian shipowner Compagnie Maritime Belge (CMB). Other actors in this project are an engine manufacturer, a shipyard, a classification society, a hydrogen supplier, an engineering firm and local government. They started with a small ferry with a dual fuel combustion engine which can run on up to 85% hydrogen, this is supplemented with diesel. This project was followed up by a larger and more powerful crew transfer vessel and a tug that use the same technology and a hydrogen bunker station. They thereby proved and scaled up a new technology enabling shipowners to sail for 85% on hydrogen. Funding for the project was obtained within the CMB but was supported by other actors during the project since they also gained a lot of valuable knowledge. Interviews have been conducted with the project team of CMB.TECH. The first vessel was launched in 2017, crew transfer vessel and tug are expected in 2021.

2. A refit to a hybrid hydrogen-powered support and patrol vessel

A community of Shipowners, a yard, the port of Lauwersoog, an entrepreneurial development bank and local governments want to reduce the emissions and disturbance of the Wadden Sea. The community has already refitted a small sailing vessel so it can run on hydrogen

Table 4
Overview of key case study aspects.

	Main actor	Innovation	Source of Funding	Timeline
Small Passenger ferry	CMB.Tech	Dual Fuel Engine with 85% hydrogen	Joint Industry Project, no major funding sources	First ship launched 2017, 2 more in 2021
Hybrid patrol vessel	Rijksrederij	Hydrogen Fuel cell powered	Local and National government support	Re-fit started 2021, follow-ups planned
Methanol workboat	Rijksrederij	Methonal Internal Combustion	National government support	Re-fit planned for 2024, further follow-ups foreseen.

via a fuel cell and electric motor. The Dutch Ministry of Infrastructure and Water management now wants to do the same with their local support and patrol vessel the Krukel. The community plans to have many follow-up projects with other vessels in the port and also aims to set up its own hydrogen production and bunker facility. They thereby prove and scale up the hydrogen fuel cell technology for shipping. Funding for the project has been challenging since costs are significantly higher than sailing with conventional technologies, they, therefore, rely on subsidies and other governmental support. Interviews have been conducted with numerous project actors from the Lauwersoog community including the project leaders. The refitted sailing vessel was launched in 2021 and the follow-ups are expected in the coming years.

3. A refit to methanol powered workboat.

The Dutch state shipping company Rijksrederij is planning to refit one of their patrol vessels with a methanol propulsion system to obtain insights into the possibilities, challenges and costs of sailing on methanol. The Rijksrederij took part in the Green Maritime Methanol consortium to gain and share knowledge on sailing with methanol. This consortium has many shipowners, suppliers, yards, classification societies and knowledge institutes which together aim to develop sailing on methanol. The Rijksrederij aims to have many vessels sailing on methanol in the future, this first pilot can prove to the Rijksrederij as the consortium what is possible. Funding is obtained within the Dutch government, possibly supported by subsidies. Interviews have been conducted with the project management. This vessel is expected to be refitted in 2024 with numerous follow-ups before 2030.

5.1. The transition enabling effects of pilot projects

A practice-based mode of innovation is considered to be crucial by both interviewees and literature (Jensen et al., 2007), as it aligns with the innovation process of low quantity products. Experienced based and proven know-how is valued more than theoretical know-why when one is building a small series of vessels with high-reliability demands. Interviewees from the production part of the cluster emphasized the need for pilot projects, stating that there is only so much you can do from behind a desk. Pilot project leaders state that they can clarify which energy carrier and technology will be affordable, reliable and sustainable and improve these dimensions. Their impact will be the most significant for the pilot vessel type and operational area but is likely to have a knock-on effect on larger parts of the cluster.

Case studies proved that pilot projects can also stimulate regulatory change since they will create a demand for regulations and policy that allows climate-neutral operations and supports the development. A pilot will encounter all the existing regulatory barriers and thereby expose which changes are necessary. All pilot projects that were studied required close involvement of classification societies and local authorities and developed their knowledge. The design of the pilot vessel can therefore serve as a baseline on which new regulations can be built. Furthermore, pilots can open a window of opportunity for regulations that put pressure on the established ways of doing, by proving that there is a feasible and sustainable alternative.

Case studies proved that pilot projects impact both the mindset and market and user practices when they demonstrate a climate-neutral alternative that is operationally feasible. They can build trust in the new technologies and inspire others to start making contributions to the energy transition. The finished pilot created interest from many different parties of whom a couple ordered vessels with a scaled-up version of the proven propulsion system. The knowledge development and spreading of this knowledge can thus enable follow-up projects or spin-offs and make scale-ups manageable.

It was found that pilot vessels are significantly more expensive than their diesel counterparts. For example, the CAPEX of the fuel cells and energy storage for a hydrogen vessel can at the moment be three times as expensive as equivalent diesel propulsion. The OPEX of hydrogen compared to diesel can also be three times as expensive. As the commercial gains from investing in pilots are in general still far away, the pilots require the support of subsidies. Research also showed that the CAPEX can be reduced by more than 20% with a single pilot. OPEX reduction strongly depends on the required energy carrier demand. A bunker station or even local production of e.g. hydrogen can be established when the demand is high and stable enough. This can eventually lead to cost reductions that make the climate-neutral energy carrier competitive with diesel on OPEX, but this requires large investments which again require a high level of certainty for a stable and substantial demand.

The case study proved that a pilot project can create an incentive for all interdependent actors in the shipping cluster to cooperate and co-develop climate-neutral sailing. Their initial demand for climate-neutral technology may loosen the interdependency barrier, reduce uncertainties and reduce some of the commercial infeasibility for follow-up projects. It will create an opportunity for learning processes based on doing, using and interacting which can lead to a practice-based innovation cycle of evaluating, redesigning and testing. The pilots were analysed on their ability to overcome the barriers listed in Table 3, which included a financial analysis to assess the commercial infeasibility. The results are in Table 5.

5.2. The trajectory of a climate-neutral shipping pilot project

This study identified multiple transition barriers which also form a challenge for pilot projects. The typical trajectory of a pilot project is visualized in Fig. 4 which resulted from the case studies. It illustrates that a pilot has to be carried out by a group of interdependent actors that

Table 5
The transition enabling potential of pilot projects, based on their ability to remove or reduce the current transition barriers.

Barrier	Transition enabling potential of pilot projects
interdependency barrier	Remove interdependency barrier, by creating a network of actors that are aligned with a climate-neutral energy carrier
commercial infeasibility barrier	Reduce commercial infeasibility barrier, by acquiring knowledge and experience (with engineering and classification) and increasing production of components
uncertainty barrier	Remove uncertainty barrier, by acquiring knowledge and experience and demonstrating solutions
the assets barrier	Reduce the assets barrier, by lowering start-up costs for follow-ups, scale-ups and spin-offs
regulatory barrier	Remove regulatory barriers, by creating a demand for regulatory changes and possibly serving as a design baseline
mindset barrier	Remove mindset barrier, by demonstrating feasible climate-neutral shipping practices

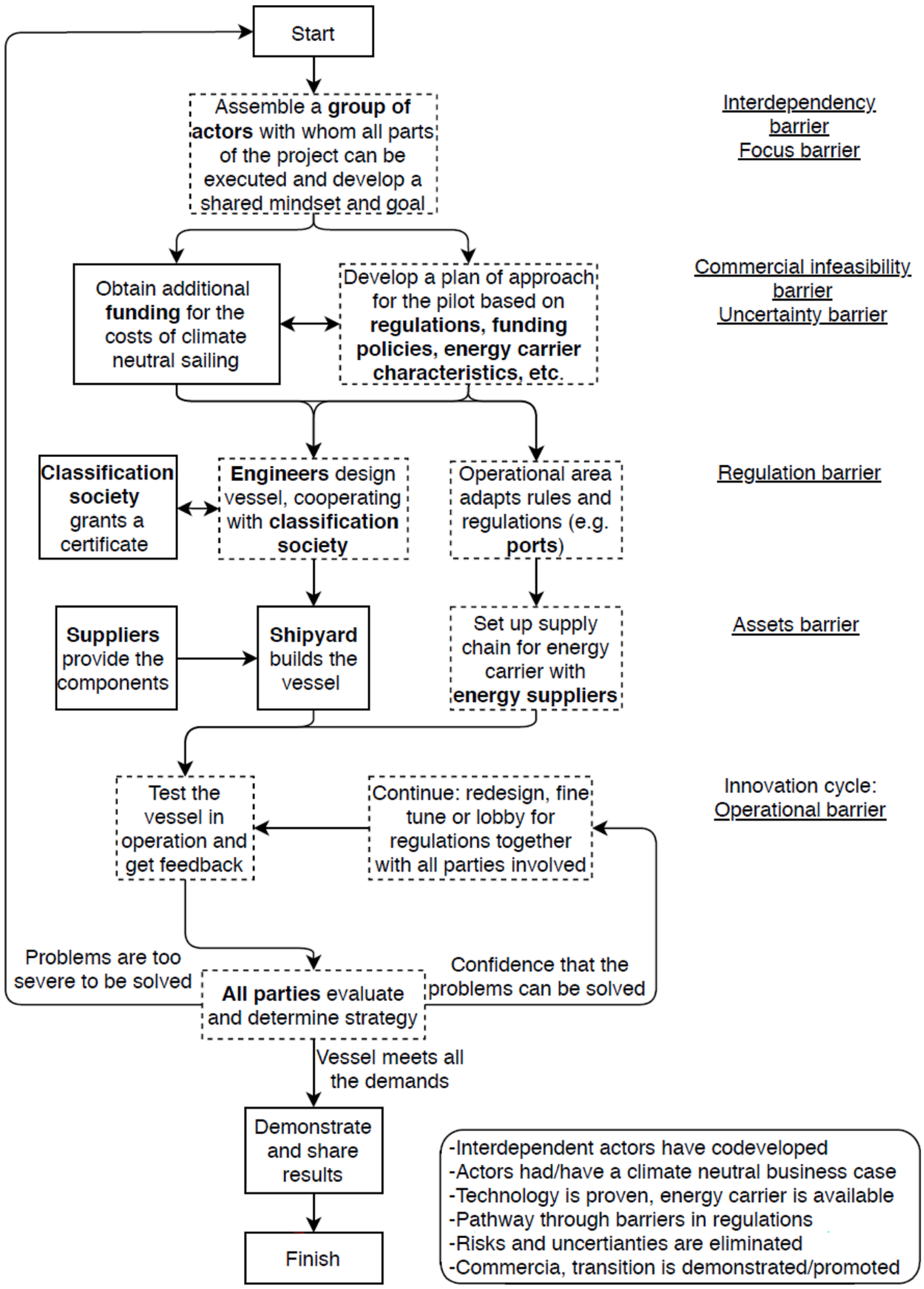

Fig. 4. The trajectory of a pilot project. The different barriers are identified on the right. The box line is dashed when the element does not have to be repeated during a follow-up project.

have secured additional funding. Close cooperation will be required between these actors since the trajectory can be challenging and requires multiple experiences. Subsidized research consortia with all relevant stakeholders, therefore, appears to be best suited for carrying out pilots. This trajectory also illustrates what the transition enabling effect of pilots can be by tackling all these challenges and demonstrating the result. The box line is dashed when the element does not have to be repeated during a follow-up project to further illustrate the transition enabling effect. This development trajectory of a pilot project can be seen as a close-up of one of the arrows at the niche level in Fig. 3, follow-up projects will then be follow-up arrows. Pilot projects can thereby bring a practice to the regime level, but this does require the right group and support from the landscape and regime.

5.3. *Limitations of pilot projects*

A transition cannot take place until an affordable, reliable and sustainable alternative has been proven together with a pathway around the lock-in mechanisms. The interviewees from phase II agree that both further developments of climate-neutral sailing as regulatory changes are needed before the cluster can make a transition. According to phase I, the development of climate-neutral sailing requires niches, the windows of opportunity for radical change. These do however require support to fund the additional costs that commercial parties are unable to cover. These pilot projects can take away market entry barriers such as interdependency or uncertainty but cannot reduce the costs to a level in which a cluster-wide transition is possible. Regulatory measures will be needed to remove this transition barrier, e.g. a fuel levy, carbon tax or emission trading system.

6. Discussion

The MLP conceptualizes a transition as the evolution from one socio-technical regime to another, which is driven by developments in niches and pressure from the landscape. This study tried to apply the theory to the energy transition of shipping in phase I but found some difficulties with this concept in phases II and III. The main issue is that the shipping sector has not a single regime with prevailing socio-technical elements due to its large variety in vessel functions, organizations and operational areas. This study, therefore, conceptualized the sector as a cluster of shipping sub-regimes, but in fact, it might rather be a cluster of niches. The market for one vessel type, with one marketable function, owned by one organization type in a certain operational area is in general very small. This might explain that the companies in shipping are in general much smaller than in the aviation, automotive or rail sector. A company that operates in container transport, ferry's, wet bulk, offshore work and cruise ships in both inland, short sea and deep-sea transport would need to be aligned with many kinds of operational practices. This can also explain why vessels are only built-in small series and why standardization of different design elements remains difficult, which is strengthened by the long lifetime of vessels. The innovation budget of organizations is thereby also limited since the possible market-based legitimacy for the innovation is always relatively small compared to the other beforementioned sectors.

Another mismatch between theory and practice is that the shipping regime has a very weak governing structure, while the MLP argues that without pressure from the landscape climate-neutral practices might never out-compete the established 'ways of doing' (Geels, 2012). Given the current commercial infeasibility of many climate-neutral shipping practices, it is likely that they will not suddenly start to out-compete the established practices, but the governing structure is not likely to radically change this any time soon. There are examples of radical changes to the landscape resulting from IMO regulations, e.g., the International Convention for the Prevention of Pollution from Ships in response to a spate of tanker accidents (IMO, 2021). However, this measure was far less consequential than the ones that are required now and safety likely leads to less division than future climate change. The emission reductions for SOx and NOx can also be seen as radical changes, but these took over a decade and are again far less consequential than carbon limitations that lead to an energy transition. Research into stimulating radical IMO regulations could present valuable insights for changing the shipping landscape but for now, other ways need to be identified to influence the competition between climate-neutral shipping and the established shipping practices.

The question is, how can all these different vessels that operate in different circumstances make a transition without radical changes to the global shipping landscape? The optimal strategy is likely to vary per niche since the transition barriers and feasible enablers differ. For many niches, a full transition cannot be expected in the near future. The focus should therefore be on the niches for which a transition is possible and the support that can be created by local landscape actors, for example by legislation or subsidies. Climate-neutral 'ways of doing' can be established in these niches, and perhaps then be exported to another niche. Pilot projects can play a crucial role in developing and spreading climate-neutral shipping practices and will be the result of support from the local landscape. The energy transition will then be driven by practice-based developments by supported pilots, followed by further developments in a suitable niche that is supported by a local landscape and then diffusion of the climate-neutral shipping practices to other niches.

7. Conclusion

This study developed a detailed description of the transition barrier that actors in the Dutch shipping cluster encounter. Such a holistic overview of the problem can be the first step towards a solution, it provides insights that can substantiate the strategy of both actors in the field as policymakers on the side-line. The required developments for the three analytical levels are a direct consequence of the barriers and further assist actors and policymakers in determining their strategy. The focus on pilot projects gives an insight into their importance for niche development and gives substance to what these projects can yield. It was remarkable to hear that the experts from the production side see this as a crucial tool for developing climate-neutral sailing while outsiders were not aware of the developments it can bring to the shipping industry.

The shipping cluster is characterized by a wide variety of vessels, operations and organizations which makes the already multidimensional energy transition increasingly complex. It is widely believed that there will be multiple energy carriers in the future with their accompanying technology, infrastructure, regulations and user practices. They will also have their independent development trajectories and timelines towards being fully developed. This difference in timelines in combination with differences in vessels, functions, operational areas and organizations creates a difference in transition feasibility which will result in a gradual transition. Some parts of the cluster will be able to make the transition years before the others. This gradual process can be sped up by shortening the development trajectory of climate-neutral sailing, implementing regulations to change the additional costs and changing the mindset in the cluster. Emission targets should therefore be set per sub-regime rather than focusing on the cluster. Pilot projects will be a crucial part of developing climate-neutral operations, which will depend on actors that are willing to take on the challenge.

The number of actors that were interviewed was limited but the resemblance in the answers of experts from the same field instilled confidence in the validity of their answers. Furthermore, experts from all fields presented in Fig. 3 took part in the study with the exception of a representative for an energy company and classification society. Case studies were used to verify if the possible yield of pilot projects, the results proved that the theory was accurate.

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.

Acknowledgments

We would like to acknowledge the Rijksrederij for supporting this research. Without their input, availability, insights and data this work would not have been possible.

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