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Environmental Innovation and Societal Transitions 46 (2023) 100687

Contents lists available at ScienceDirect

Environmental Innovation and Societal Transitions

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

Complexity challenges for transition policy: lessons from coastal shipping in Norway

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ARTICLE INFO

Keywords:
Sustainability transition
Transformative innovation policy
Policy mix
Complexity
Alternative fuels
Hard-to-abate sectors

ABSTRACT

This policy briefing discusses decarbonization policies of "hard-to-abate" sectors, emphasizing the implications of these sectors' complexity. Specifically, we discuss two sources of complexity: (a) heterogeneity in the form of variation across and within technologies and user segments and (b) interdependencies between technologies (within and between their value chains) and between user segments and adopter groups. Based on research on coastal shipping in Norway, a global frontrunner in decarbonization of this sector, we suggest three guiding principles for developing policy mixes for decarbonizing hard-to-abate sectors: (1) employ technology-specific policies but aim at broad sectoral or general policies when suitable, (2) consider value chain interdependency and user segment heterogeneity when prioritizing technologies and user segments, and (3) translate (rather than transfer) successful policies to other settings (e.g. user segments).

1. Introduction

Decarbonization is accelerating in sectors such as electricity, personal transport, and housing, largely induced by policy. However, sustainability transitions need to advance also in other sectors, including those considered *"hard-to-abate"*, such as energy-intensive process industries (e.g. steel, cement and chemicals) and heavy duty transport (e.g. shipping and aviation).

In this policy briefing, we connect to recent writings on the need for new policy approaches to achieve sustainability transitions (e.g. Fagerberg, 2018; Rogge and Reichardt, 2016; Schot and Steinmueller, 2018; Weber and Rohracher, 2012). We argue that *complexity* presents particular challenges and uncertainties for design of policy mixes for advancing sustainability transitions in hard-to-abate sectors. More specifically, we discuss two sources of complexity: *heterogeneity* and *interdependency* in technologies, value chains and users.

While some degree of heterogeneity and interdependency characterizes most sectors, we argue that hard-to-abate sectors differ from the early decarbonization sectors in ways that further increase complexity. First, they are generally even more scale-, energy- and capital-intensive. They tend to have longer investment cycles and higher entry barriers, resulting in long-lasting relationships and interdependencies between stable sets of value chain actors. Second, in contrast to solar cells or electric cars, which benefit from standardization and mass production, technological configurations in hard-to-abate sectors are often tailored to specific applications. This results in substantial heterogeneity as well as technology and value chain interdependencies, where user-producer relations are of greater importance (Binz et al., 2017). Moreover, high design complexity and need for customization generate both interdependency

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https://doi.org/10.1016/j.eist.2022.100687
Received 11 April 2022; Received in revised form 2 December 2022; Accepted 14 December 2022
Available online 20 December 2022

and heterogeneity, resulting in slower learning rates and limited economies of scale (Malhotra and Schmidt, 2020). Because of the longevity of, for instance, ships or process industry plants, adaptation also becomes highly contingent on previous technology choices. Finally, core actors in especially process industries and deep-sea shipping tend to be relatively distant from end customers, resulting in little awareness and "visibility" of emissions and, thus, little demand for change. Without pressure from end consumers, there are also weaker incentives for policymakers to introduce more stringent climate regulations.

Given these characteristics, hard-to-abate sectors represent critical cases to illustrate the implications of heterogeneity and interdependency for policymaking more generally – a topic that we believe needs further consideration in the transitions literature. We contribute to this discussion by using examples and insights from a research project on a sustainability transition in Norwegian *coastal shipping* (GREENFLEET, 2017-2021).

Maritime transport represents about 3% of total GHG emissions, but this is expected to increase due to growing global trade unless low- and zero-carbon (LoZeC) technologies are developed and diffused (Bouman et al., 2017; IMO, 2020; Pettit et al., 2018). Consequently, the International Maritime Organisation (IMO) has pledged to reduce total emissions by 50% by 2050 and to phase out fossil fuels completely by 2100. Norway can be considered a frontrunner in maritime decarbonization, with a target of 50% emission reductions from coastal shipping by 2030 compared with 2005 (NFD, 2020). Decarbonization is also considered a market opportunity for Norway's sophisticated maritime sector (Bugge et al., 2021). Especially since around 2014-2015, various LoZeC technologies (batteries, biofuels, hydrogen) have been introduced (Bach et al., 2020; Bergek et al., 2021). Different types of national policy instruments (e.g. market pull, technology push, networking, and cluster support) have facilitated the introduction of LoZeC technologies in domestic shipping, while global regulations have also played a role (Steen et al., 2019; Tvedten and Bauer, 2022). Despite these developments, transitioning coastal shipping is proving difficult due to the characteristics of both the sector and LoZeC technologies.

This case therefore offers an opportunity to reflect on the policy challenges of decarbonizing hard-to-abate sectors. While some conditions are context-specific, we suggest that heterogeneity and interdependency are characteristics that this sector shares with, for example, heavy industry. We, thus, distil three (non-exhaustive) guiding principles for policy mix design to support decarbonization of hard-to-abate sectors in general.

2. Challenges for designing policy mixes in complex sectors

The shipping sector illustrates the challenges of transition policy in a sector characterized by significant *heterogeneity* in the technologies developed for decarbonization (see Table 1) and the needs of the user segments implementing these (see Table 2). Here heterogeneity refers to variation across as well as within technologies and user segments.

On the technology side, transitions in shipping require various LoZeC technologies that differ in maturity, availability, and applicability (see Table 1). Technological heterogeneity emanates not merely from early-phase experimentation with different solutions, which over time can be expected to result in a few dominant solutions, but rather from application-specific requirements that are likely to prevail over time. Significant variation is also found at the sub-technology level. To exemplify, hydrogen can be used in gaseous or liquefied forms, each of which requires different supply chain infrastructures (i.e. production, transfer and storage facilities)

Table 1
The status of low- and zero carbon innovations in shipping.

	Biodiesel (FAME & HVO)	Liquefied biogas (LBG), biomethane	Battery-electric	Green hydrogen (H2)	Liquefied natural gas (LNG)	Ammonia (green)	Methanol (green)
Reduction of carbon emissions	Moderate	High	High	High	Low	High	High
Technological maturity	High	High	Moderate	Low	High	Low	Low
Availability (infrastructure, production, bunkering / charging)	Low	Low	Moderate	Low	High	Low	Low
Upscaling potential of value chain	Low	Low	High	High	Moderate	High	High
Applicability in existing vessels	High	Low (high in LNG vessels)	Low	Low	Low	Low	Low
Applicability in shipping segments	All	All	Short routes	Medium length routes	All	All	All

Table 2
Key characteristics of selected Norwegian shipping segments affecting the adoption of LoZeC technologies.

Segment	Vessel size	Routes	Customer demand for LoZeC technologies
International cargo	Very large	Very long Often unfixed	Emerging in container shipping, limited in e.g. bulk transport
Domestic cargo	Large	Medium-long Often fixed	Emerging
Domestic passenger	Small to large	Very short/medium-long Fixed	High (in public procurement)
Aquaculture	Small to medium	Short/medium-long Some fixed	Limited
Ocean fishing	Medium to large	Medium-long/long Some fixed	Limited
Coastal fishing	Small	Short/medium-long Some fixed	Limited
Offshore	Medium to large	Medium-long/long Some fixed	High (Equinor)

(Mäkitie et al., 2022; Steen et al., 2019).

On the user side, there is considerable heterogeneity between user groups and segments (e.g. freight, passenger, fishing, offshore supply), which implies that the susceptibility to implement alternative technologies differs between users (Bergek et al., 2021). Institutional and task environments (e.g. market size and end consumer preferences, technical demands for operations, and infrastructure requirements) differ substantially across segments. In addition, previous investments by ship-owners significantly condition the possibility for new technology uptake, given the long pay-back time for ships. Moreover, not all ships can be retrofitted with all LoZeC technologies due to, for example, weight and space limitations. Incentives and resources allowing users to invest in LoZeC technologies can also differ substantially within segments (Mäkitie et al., 2022).

For policy mix design, there is thus a need to consider specific innovation system weaknesses as well as user segment variety and actor characteristics (cf. Bach et al., 2020; Bergek et al., 2021; Mäkitie et al., 2022; Steen et al., 2019). This might, however, result in a large number of complex, unique mixes of technology push and pull instruments, with the risk of redundancies, incoherencies, and inconsistencies within and across instrument mixes – something the policy mix literature tends to advice against (cf. e.g. Rogge and Reichardt, 2016). Avoiding these risks would require substantial policymaking capabilities and constant attention to policy coordination.

The introduction of LoZeC technologies in shipping also points to *interdependencies* between technologies, within and between value chains, and between user segments, which affect innovation.

In terms of interdependencies between technologies, innovation in one technology may be influenced by other emerging or established technologies. Battery-electric and hydrogen technologies have strong potential synergies (Bach et al., 2020), and biofuels benefit from being well-aligned with existing sectoral configurations designed for fossil fuels (e.g. infrastructure, propulsion systems, legislation) (Bach et al., 2021). At the same time, LoZeC technologies also compete for resources and investments (Steen et al., 2019) and can lock each other out of the market, as witnessed for biofuels in some segments (Bach et al., 2020; Bach et al., 2021). As complex capital goods, ships also have large and varied energy requirements for different operations (e.g. propulsion, heating/cooling, sanitation), creating sub-technology interdependencies that also influence user choices.

The broader adoption of LoZeC technologies is naturally interdependent with the production and distribution chains of these technologies. For example, battery-electric vessels are dependent on onshore power connectors and grid capacity (Mäkitie et al., 2022). Such interdependencies are particularly critical for technologies whose value chains are practically non-existent, such as zero-emission hydrogen. The simultaneous or preceding development of adequate supply networks is thus necessary for successful deployment. However, long investment cycles and large capital investments both downstream (in shipping) and upstream (in energy production/distribution/storage) may create "waiting games" between sectors.

Interaction between user segments can also impact innovation, for example in terms of spillovers, cost reduction, shared infrastructure, and uncertainty reduction through experiences with early applications. In Norway, the ferry segment has been the key niche market for battery-electric vessels, paving the way for their application in other segments (Bergek et al., 2021; Bugge et al., 2021; Sjøtun, 2019). Moreover, maritime battery development has benefited from widespread use of batteries in onshore transport, while the limited availability of biogas creates competition between different shipping segments as well as between land- and sea-based companies (Mäkitie et al., 2022). However, there are limits to positive spillovers across segments because of differentiated energy needs and opportunities (due to, e.g., space for onboard energy storage) of users.

Policymakers should, thus, be attentive to interdependencies between technologies, value chains, and user segments already in the early phase of innovation. This to some extent contrasts earlier work on multi-sectoral dynamics in transitions, which suggests that such issues mainly arise in acceleration phases (Markard, 2018). Considering interdependencies when developing policy is needed in order to avoid "waiting games" that constrain developments from the very beginning or, conversely, to enable the co-development of several technologies or segments through spillovers (Mäkitie et al., 2022). Such uncertainty reduction through policy is particularly important in hard-to-abate sectors, where scale-, energy- and capital-intensities increase the perceived risks of actors when investing in new technologies with immature value chains.

3. Policy recommendations

As shown above, policy for sustainability transitions in hard-to-abate sectors, such as shipping, has to balance the need for technology- and segment-specific policies and the general requirements on effective policy mixes in terms of consistency and coherence, while simultaneously addressing potential positive and negative externalities between technologies and segments.[1] We suggest three (non-exhaustive) principles to address this complexity:

First, the same policy instruments should be used for as many technologies as possible. This could mean replacing technology- or segment-specific policies with sectoral (or even general) policies when possible (possibly with smaller adjustments to specific technologies or segments) (Bach et al., 2021; Bergek et al., 2021). For example, a carbon fee would improve the competitiveness of all LoZeC technologies across segments. As such, interdependencies may offer "two-for-one" opportunities, where the same policies can benefit several technologies or segments by leveraging the capabilities of one user segment for innovation in other segments (Bergek et al., 2021) or catering to the common infrastructure needs of heterogeneous user segments (Mäkitie et al., 2022).

Second, value chain interdependencies and user segment heterogeneity should be central when prioritizing which technologies and segments to stimulate and support. Technology-specific policies needed to support radical innovation should thus be designed with consideration for the availability of both supply- and demand-side actors and their capacity to respond to the implemented policies (Bugge et al., 2021; Sæther et al., 2021).

Third, due to heterogeneity and interdependency, a policy instrument that has proved successful for one specific technology/segment might not have the same effect on other technologies/segments. This calls for careful translation of successful policies. A case in point is public procurement, which has been central to create traction for battery-electric and hydrogen technologies in the ferry segment by including stringent environmental targets for companies tendering to operate publicly governed ferry routes (Bergek et al., 2021). This idea of wielding the power of purchasing and ownership could be translated to, e.g., the freight segment by premiering low emissions goods transport, and to aquaculture and offshore segments by including stricter environmental requirements in government-awarded licenses (Bach et al., 2021).

4. Conclusion

The literature on policy for sustainability transitions has highlighted the importance of considering internal coherence and consistency of policy mixes (cf. Rogge and Reichardt, 2016) as well as the specific settings in which they are to be implemented (Mavrot et al., 2019). In this policy briefing, we link up to this discussion by arguing that policymakers aiming at inducing transitions of hard-to-abate sectors need to consider sector complexity in terms of heterogeneity and interdependencies in technologies, value chains, and users. We identify opportunities and challenges associated with this complexity and suggest that policymakers should 1) employ technology-specific policies but aim at broad sectoral or general policies when suitable, 2) consider value chain interdependency and user segment heterogeneity when prioritizing between technologies and segments, and 3) translate (rather than transfer) successful policies to other settings. These suggestions can, potentially, reduce the need for policy coordination and provide guidance on how to address directionality in policy mixes targeting highly complex sectors (cf. Magro and Wilson, 2019).

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. All of the sources of funding for the work described in this publication are acknowledged below.

Data availability

The paper builds on previously published research. Data availability is stated in those publications (see references in text).

Acknowledgements

This work was funded by the Research Council of Norway [grant numbers 268166 and 296205]. The funder has not had any

[1] Whether policymakers should employ technology-/sector-specific policies or use "technology-neutral" policies has long been discussed. Environmental economists tend to argue that general policies are preferrable, referring mainly to cost efficiency and the risk of crowding out potentially better technologies (cf., e.g., Jaffe et al., 2005). Others argue that "technology neutrality is often an elusive objective that neither can nor should be prioritized as the main guiding principle" for policy (Azar and Sandén, 2011, p. 135). Empirical evidence suggest that while general policies can promote incremental improvements of already commercially available technologies, technology-specific policies are required to stimulate more radical innovations (Bergek and Berggren, 2014; Sandén and Azar, 2005). Moreover, recent literature highlights that the feasibility of transition pathways depends on technology- and sector-specific conditions (Turnheim and Nykvist, 2019). Our position is therefore that technology-/sector-specific policies are necessary in the context of sustainability transitions but should be designed carefully to avoid the potential problems mentioned above.

involvement in study design; collection, analysis and interpretation of data; writing; or the decision to submit the article for publication.

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