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Multi-dimensional forces and niche dynamics in the socio-technical transitions: Future alternative fuels in the shipping industry.

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ABSTRACT:

World's population is increasing, resulting in significant issues such as climate change and global warming. These issues damage the world's environment, which is evident from the increase in the earth's temperature in the last few decades. Pollution is one of the primary reasons for these issues, and emissions significantly contribute to pollution. System change is needed because system innovations can improve environmental performance to address these significant issues. This study used the multi-level perspective (MLP) as a framework to study these system transitions in the context of the shipping industry because it contributes 3% to the world's emissions. There are three levels in the MLP model: macro, meso, and niches. Niches are the layer for innovations and new technologies, and meso level is the current regime, and the macro level is the external environment known as the socio-technical landscape. Multi-dimensional forces are acting as drivers for innovation and new technologies, and, similarly, these forces pressure regimes. Furthermore, different niche dynamics are also studied. PESTEL analysis and Delphi study is used for data collection. It was found out that environmental and political forces with the mediation of society and economy result in regulations. These regulations are driving technological development. Moreover, future alternative fuels for the shipping industry for the next 10 and 30 years are also discussed in the study.

KEYWORDS: Socio-technical transition, multi-level perspective, niches, regime, multi-dimensional forces, shipping industry, alternative fuels.

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Abbreviations

IMO	International Maritime Organization.
E.U	European Union.
MLP	Multi-level perspective.
SOx	Sulphur oxide.
NOx	Nitrogen oxide.
CO^2	Carbon dioxide

1 Introduction

Since the world's population is increasing, the problems have increased. One of the significant issues to be concerned about is sustainability, including climate change, ecological loss, ecosystem problems, energy, resource shortage, and many more (Geels, 2011; Köhler et al., 2019; Koistinen, 2019). Sustainability challenges have emerged because of existing stable systems, which are obstacles to system change (Geels, 2011; Koistinen, 2019). Because of human activities, significant problems in the world disturb the ecosystem balance. For instance, the impact of harmful gasses on the environment, and due to this impact, the earth's temperature is rising (Royal Society, 2020). A quick response is needed in society to solve the challenges by incorporating sectors like transportation, energy, agriculture, and water. Rapid action must be taken to reduce the effect of greenhouse gasses to resolve the issue of climate change. The culminating trend of the rise in earth's temperature (Royal Society, 2020) needs to be stopped, and actions on a global level are required. Different science disciplines have emerged to look into these crucial issues of global systems, such as sustainable science and sustainable development, bringing together natural and social sciences. Such developments in study and research will provide profound insights and understanding from different sustainability perspectives (Geels, 2020; Koistinen, 2019).

Transitions to more sustainable systems will affect the ecosystems in positive ways. First, such transitions (zero carbon emission) will change the energy systems and the critical sectors necessary for human activities and life, such as the agricultural sector, transportation, and city systems. Second, to cater to problems in society such as energy security and others, innovations in industries such as health care, agriculture, and food will be needed. Most importantly, these transitions will foster growth; for example, the green initiative of the European Union will work towards the solution of environmental problems, and it will also provide investment and employment opportunities. The world can use its technological capabilities to increase energy production in sustainable ways, which will offer a new trajectory to the world markets (locally and internationally). Innovations must be nurtured to reach that stage (Geels, 2020).

In human evolution, adapting to change and transition from one system to another is constant and, at the same time, a challenge. To work towards a solution for essential issues (for example, climate change), transitions towards sustainability are very critical. Through these solutions, knowledge and society are interlinked toward sustainable pathways. Sustainable transitions are a scientific response to cater to these pressing environmental issues. Transitions cannot happen rapidly; they can take decades to occur. It is a slow and gradual process toward a change, and during the change, the societal structures are also transformed (Campos et al., 2016).

Environmental challenges such as climate change or reducing resources (for example, food, and energy) result from unsustainable utilization and production in society. These are problems that cannot be solved through only technological development or technological change. For instance, electricity is produced more because of advanced technology, but its effects are also harmful, and the production is hampering the resources available. Moreover, these problems can be solved by entirely changing the systems in society and technology. In other words, socio-technical systems change, and these shifts are known as sustainable transitions. Several characteristics of sustainable transitions are different in the sustainability domain and broader social science (Köhler et al., 2019).
The first characteristic is multi-dimensionality, which explains that there is more than one element involved in socio-technical systems: technology, business models and markets, culture, society, political system, policies, consumer behavior, distribution channels, and many more. The second characteristic is co-evolution, according to which transitions entail changes in all the dimensions and elements of the socio-technical systems; therefore, the process is co-evolutionary. It is a non-linear process, which means multiple and interdependent changes and developments. Third, multi-actors because society includes various actors and groups from political, scientific, industrial, household and research backgrounds, and every group has its resources, ideology, values, and interest. A single actor cannot address the transition issue because of its complexity, so multiple actors and groups are involved in the transition process. Fourth, stability and change act like two sides of the coin. On the one hand, there are many aims, for example, green technology (battery-powered vehicles, alternative fuels for the transportation sector).

On the other hand, as discussed earlier, lock-in mechanisms strive for stability. System change happens because of multi-dimensional interactions and the two forces of stability and change. The transitions study considers different theories to understand the concept of stability and change. In addition, as the fifth characteristic, sustainable transitions are a long-term process; for example, if we look at the green initiatives, first, they will appear at the micro-level, and then the system will be changed, which takes time. Second, the lock-in mechanisms try to act against the change because of their stability, and unlocking takes time. Sixth, it is open-ended and uncertain, meaning that there are multiple innovations and drives for changes, and the outcome is unknown because of the reason one will be applied in the future. Secondly, there are three processes involved in the transitions (innovation, political, society, and culture), and there is a degree of uncertainty involved in these processes. Seventh, there is always some level of disagreement between the social groups regarding the initiative pathways of system change towards sustainability. Transitions will result in changes in economics and business models for influential industry players (for example, automotive, energy, and many more). These strong and influential market players always try to save their interest, influencing transition speed. Last, it has normative directionality because the aim of sustainable transition is for the public good, and because of this factor, private actors are less inclined towards the purpose. Due to this reason, public policies play an essential role in driving the initiative, in the form of taxes, subsidies, regulations, and policies aiming at innovations. This situation explains transition expectations in such statements as normative statements (Köhler et al., 2019).

When looking at these characteristics, transitions are multi-dimensional, and different levels and actors are involved in system change. Moreover, it does not focus on only one dimension, such as economics or industry; however, it considers all the social groups of the society and considers all the dimensions. These are not short-term but include system aspects, and there are many innovations, including different new technologies, policies, and social behaviors. Socio-technical transitions are the gradual change from one socio-technical system to another socio-technical system. However, the issue of the lock-in mechanism is of vital importance to consider because existing systems are stable because of these mechanisms, which makes it extremely difficult to transform from one pattern to another. For example, countries having big industrial economies, such as China and India, are still running on fossil fuel-based systems because of the lock-in mechanism (Chang et al., 2017; Köhler et al., 2019).

Due to the importance of sustainable transitions, several approaches include multi-level perspective, strategic niche management, technological system approach, and transition management (Chang et al., 2017; Köhler et al., 2019). These approaches are the frameworks for transitions, which are multi-dimensional and complex. Moreover, these approaches consider a systematic perspective to study the complexity involved in transitions along with critical phenomena, for example, path dependency, emergence, and non-linear dynamics. These approaches and frameworks are from innovation studies because transition research originates from innovation studies. The most prominent approach used for studying transition is the multi-level perspective. (Köhler et al., 2019). The multi-level perspective is an analytical framework that investigates socio-technical transitions. This approach considers institutional theory, evolutionary economics, and social and technical aspects of innovations. Moreover, according to this theory, innovation results from a dynamic process at three system levels. These levels are regimes, niches, and socio landscape. Regimes are the meso-level of the model, which is stable and works on the existing set of rules resulting in path dependence and gradual change. Niches are the locus of innovations; it is the micro-level of the model where the innovation takes place in protected places. The socio-technical landscape puts pressure on the other two levels, which results in new technology or innovations. Interaction between niche and regime levels is multi-dimensional (for example, technologies, markets, culture, etc.), and actors involved at both the levels create groups to fight for their interests and navigate transitions. According to MLP, transitions happen in systems, and tensions in regime and change are the gravity point for the model (Geels & Schot, 2017; Köhler et al., 2019).

There are other approaches as well. However, they have drawbacks; for example, technological innovation system is a framework based on the interaction of actors of the system for innovation. The role of actors in innovation is an issue because the support of actors as intermediaries can be different (Kanda et al., 2019). Another framework includes transition management, which considers policies and governance responsible for innovations. Kanda et al. (2019) argue that technological innovation systems consider and focus on the meso and micro levels. Let's look at the other transition frameworks. They are either not multi-dimensional or consider some level, and different levels are not focused, which means an element(s) is missing in other transition frameworks. Instead, the MLP framework is a complete model including all the three levels of society and technology; micro, meso, and macro; also. It is a multi-dimensional framework that considers all aspects of technology and society while looking at transitions. Pressures at the landscape level because of socio-technical change (for example, climate change) result in niche innovation and destabilization of regimes, resulting in a window of opportunity for innovation to come forwards on a broader level. Köhler et al. (2019) provide different views of micro and meso-level interaction and the outcomes (innovations on a more general level).

Looking at the MLP model, it can be understood that niches are driven by different forces, resulting in innovations. All the three levels in the MLP are interrelated, and there are particular dynamics in each level, along with tensions. Early scholars have focused on niches and innovations, but niche dynamics and tensions at the regime level are less studied (Köhler et al., 2019). This gap provides a research opportunity, which will be explored in this study. Furthermore, niches can have different dynamics, resulting in an emerging standard in the industry. These different dynamics are also explored in the study.

1.1 Research Objectives and Questions

Early scholars have studied niche innovations, but less attention has been given to regime tensions, resistance, and niche dynamics (Köhler et al., 2019; Laribi & Guy, 2020;

Yliskylä-Peuralahti, 2017). This thesis aims to study the impact of different forces on the niche and regime levels of the MLP model in the shipping industry, with a particular emphasis on the emergence of alternative fuels and associated technologies. Moreover, the thesis also looks at the future of niches and their barriers. The study uses the MLP framework in the context of decarbonization of the shipping industry to explore the socio-technical transition concerning future alternative fuels. The above main aim is divided into the following objectives:

- The identification of forces(drivers) responsible for niche momentum concerning alternative fuels,
- The identification of forces acting as regime tension (destabilization of the current system),
- Look into different dimensions of the niches and their dynamics.

In this context, the research question of the thesis is as follows:

- How do multiple dimensional forces impact niche momentum and act as sources of regime tensions in the socio-technical transition concerning alternative fuels in the shipping industry?
- How do these forces impact the emergence of a dominant standard during niche development?

The shipping industry is responsible for almost 70% to 80% of the world's trade volume and value, making it the most significant contributor to the trade sector. It plays an essential role in the economic condition of the world. It is such a key factor for global trade that it operated to supply goods, medical supplies, and essential goods even during the pandemic when the world was closed. Among all other modes of transportation, road or rail, sea transportation is the most efficient way because the carbon footprint and emission through sea transportation are the lowest. However, 3% of total global carbon emission comes from the shipping industry. However, as the world population grows and the increase in production, energy, and transportation also grow. It is expected that by 2050, carbon emissions will grow from 50% to 250% (and as per IMO, out of the predicted carbon emissions, 15% will be directly from the shipping sector (Serra & Fancello, 2020)), which will result in worsening the effects of climate change on the environment of earth. To cater to this problem, organizations worldwide, such as the United Nations (U.N.) and International Maritime Organization (IMO), have made targets to reduce carbon emissions. The goal is to reduce carbon emissions by at least 50% (compared to emissions in 2008) by 2050. Moreover, the European Union (E.U.) is also working towards decarbonization with the help of the Green Deal agenda. In this agenda, the transition toward climate neutrality and reduction in greenhouse gas emissions are prioritized, including all the sectors responsible for carbon emission, including the shipping industry (Nisiforou et al., 2022; Serra & Fancello, 2020).

International Maritime Organization (IMO) is an organization that oversees emissions regulations of the shipping industry and is leading the process of its decarbonization. IMO has developed a roadmap for the shipping industry for its decarbonization; this roadmap is challenging. According to this roadmap (in which 2008 is the base year) and the devised strategy by IMO, the target to reduce shipping green-house gas emissions is 50% by the year 2050. Moreover, the target for reduction in average carbon intensity is up to 40% (minimum) by 2030 and 70% by 2050. IMO's strategy is the starting contribution toward reducing carbon emissions to cater to the serious issue of climate change (Serra & Fancello, 2020).

Systems such as energy, transportation, agriculture, and food are causing grand challenges to the environment (for example, climate change and energy problems), and solving these grand challenges; a socio-technical transition perspective is used. There are similar characteristics related to these systems, such as economic implications. There are multiple actors involved in these systems. These systems have multiple political, cultural, social, economic, and technological dimensions. Moreover, the transformation in these systems is not rapid; however, they are more of a longitudinal nature. One example is the German electricity transition, in which there were many actors involved and many factors such as culture, society, and policies, which put pressure resulting in innovations. These innovations disturbed regimes under socio-technical landscape developments and shocks (Geels, 2020). The shipping industry is also transitioning from heavy fuel oil (HFO) to other fuels to reduce carbon emissions (Nisiforou et al., 2022).

Similarly, Yliskylä-Peuralahti, (2017) studied the MLP model to understand the transition in the shipping industry about the innovations in niches. Also, barriers are discussed in the study. She argues that there are multiple actors involved in the transformation of the shipping industry, which is also explained in the MLP model. There are drivers defined from the landscape level, such as reducing greenhouse gas emissions and technical knowledge development. Also, the main barriers are explained in the study, such as economic recession, technological uncertainties, low demand for the emission-free industry by ship owners, less regulation pressure, and vested interest of regime actors.

1.2 Structure of the thesis

There are a total of five chapters in this thesis. The first chapter introduces the topic along with its background, and then in the later section of the chapter, the research objectives and questions are explained. In the second chapter, socio-technical transitions are presented, along with the analytical framework of a multi-level perspective. In the last section of the second chapter, different forces are discussed concerning how they can be driving forces for the niches and, at the same time, act as regime tensions. Furthermore, niche dynamics such as competition and coopetition are also discussed in the chapter. In this chapter, essential terms and concepts of the framework are explained.
The third chapter describes the methodology used for the thesis and the data collection. Both quantitative and qualitative data are used in the thesis. Interviews were conducted to collect qualitative data, and a particular method known as the Delphi method used quantitative data. The chapter also includes data from workshops with experts.

Chapter four presents the results after data collection. In this chapter, the data collected will be looked into detail, and the results will be explained in this chapter. The study's findings are presented in this chapter, which will describe the collected data. In chapter 5, the discussion and conclusion will be explained in detail. This chapter is analytical because it discusses the data collected and its connection with the analytical framework, looking into findings from the data collected. Moreover, this chapter will also provide the conclusion, limitations, and direction for future research.

2 Literature Review

2.1 Climate change as a trigger toward socio-technical transitions

A theory about the climate and the impacts caused on it was presented by Swedish Nobel prize winner Arrhenius (1896). It was criticized until the 1950s when analytical methods were used to find the impact of human activities on the environment. Since then, much research has been done on the issue of global warming and anthropogenic emissions of greenhouse emissions. It was by the 1980s when organizations such as World Meteorological Organization (WMO) and United Nations Environment Program (UNEP) started to look into the role of carbon dioxide and other emissions in climate change (Höök & Tang, 2013). One of the significant threats to our environment nowadays is climate change, and the threat is further expanded to a socio-economic perspective. Natural processes and 'anthropogenic activities' are the reasons for the fluctuations in the climate in the long term. Because of these activities, a rise in the temperature can be noted in the past decades (Golam & Sarwar, 2006).

The ozone layer is depleting because of these human activities, resulting in greenhouse effects reinforcement (Corbett, 2003). The greenhouse gasses act as an obstacle for the heat to bounce back to the sun, and hence a rise in the earth's temperature can be seen. In the last century, the temperature increase has been 0.5oC, and over the previous three decades, the temperature has risen to 0.4oC. The earth's temperature will continue to grow at a higher rate (Golam & Sarwar, 2006).

In a report issued by The National Academy of Sciences (Royal Society, 2020), the sun is the primary energy source for the earth, and the heat from the sun is reflected. However, the required amount of heat stays in the earth's atmosphere. Climate change occurs when there is a disbalance between the required amount of heat and the available amount of heat in the atmosphere. Greenhouse gasses such as carbon dioxide, methane, and nitrous oxide play a significant role in keeping the temperature high as they absorb the heat from the sun and then emit that heat. Greenhouse gasses are also emitted because of human activities, disturbing the temperature and climate. However, carbon dioxide is the most significant contributor to climate change. The industrial revolution is the biggest reason for the increment in greenhouse gasses.

In the same report, the sources of human-emitted greenhouses are also explained, which include Carbon dioxide (CO2), methane (CH4), nitrous oxide (N2O), and halocarbons. Fossil fuels are the main reason for increasing CO2, and other human sources are cement manufacturing, deforestation, and other changes in the use of the land. It is the most significant contributor to greenhouse gasses. Methane is also increasing the greenhouse gasses because of the rise in levels of livestock and activities related to it and livestock. Nitrous oxide is also a contributing factor in the greenhouse gasses because of activities related to agriculture, for example, the use of fertilizers. Lastly, halocarbons or chlorofluorocarbons (CFCs), and all the chemicals in refrigerators, also play an important role in greenhouse gasses. CFCs are also damaging the ozone layer. However, its production has been banned in many cases, but the alternatives used in place of CFCs are also increasing greenhouse gasses (Royal Society, 2020).

The industrial revolution happened for many reasons, but energy can be called a point of gravitation for the industrial revolution. Energy is the reason for most human activity because it covers all the sectors of humankind. Because of its importance, it plays an essential role in economic development and well-being. With the increase in world population, the need for energy also increases to fulfill its requirements, and to do so, energy is one of the major environmental pollutants. The biosphere, which has worked as an environment stabilizer, is also destroyed when polluting the earth. Because of the damage caused to it, now the environment is unstable (Akaev & Davydova, 2021). Energy systems are changing as technology advances, and because of the rapid change, socio-technical lenses are used. Many global problems are related to it, and currently, the most important one is climate change. The range of energy systems usage starts from the micro-level, such as the individual household, to the macro level, such as global political economies, which means energy is essential for everything. Decreasing the carbon emission level while using energy is the most crucial factor to consider, and also it is the greatest challenge of our time. Looking at all the aspects of climate change, although many governments are not responding correctly through policies, a significant shift in energy industries can be seen. Wind and solar energy usage is an example of such energy shifts, and because of these shifts, energy economies are shifting (Sovacool et al., 2020). With the evolution of societies, several problems came to the surface, and these deeply rooted problems, are related to the production and consumption of the society. Over the last decades, issues such as automobile catalysts for reducing tailpipe emissions have been catered to through innovation. Environmental performance can also be improved through system innovation. These transitions require changes on the system level, for example, from one energy or transport system to another. When a systematic change occurs with the help of technology alongside consumer patterns and other aspects, such a phenomenon is also called 'socio-technical transition' (Elzen et al., 2004; Geels, 2011). Socio-technical transition functions in different societal areas such as 'transport, energy, housing, agriculture and food, communication and health care'. Because of their particular kind of nature, transition studies are studied differently from other studies. There are specific characteristics of transition. First, it is a process that involves the system's change, including both technical and social perspectives. Transition comprises the consumer side and the comprehensive form of incorporation of technology embedded in the society. Second, it is a process that includes multiple actors and social groups from the society, starting from researchers and ranging to social movements and social interest groups. Third, transitions refer to the range of change rather than the speed of change; the shifts are called radical shifts. Fourth, it takes more than 20 to 30 years for a transition to happen, which is a long-term process. Lastly, it is a process that considers the macroscopic view and includes the aggregate organizational perspective, including all the relevant actors (Geels & Schot, 2017). It is essential to understand that society's structures, cultures, and practices are analyzed collectively. Structures are the 'formal, physical, legal and economic' aspects that allow or stop practices. Cultures are the cognitive, broad, and ideological aspects responsible for logic-making. Practices are the 'routines, habits, and procedures by which the social actors keep the society system functioning. These three aspects are changed fundamentally for transitions (Darnhofer, 2014).

In the socio-technical transitions, there are two approaches—first, historical studies are completed in socio-technical transitions. Pioneers and entrepreneurs who developed the technologies are responsible for these transitions, which were done for commercial purposes. There were no beforehand objectives, rules, policies, or planning involved, and these transitions changed the functioning of society. Such transition includes transitions from sailboats to steamships. In the second approach, transitions revolve around societal changes, which are focused on 'transition to sustainability', which relates to the behavior of human beings, and such kind of transition is directed in the right direction. The future outcome of these transitions is unknown because they are in the process and not completed (Darnhofer, 2014).

There are specific characteristics of transition towards sustainability that distinguish it from all historical transitions. First, such kinds of transitions are goal-oriented. They aim for a goal to achieve. The purpose is to work on an environmental problem; as discussed earlier, historic transitions had no aim, and they happened to explore opportunities (Darnhofer, 2014; Geels, 2011). Because sustainability is a collective goal, private actors have limited outcomes from it, resulting in the problem of free riders and prisoner's dilemmas.

On the other hand, public authorities and civil societies are more critical for these transitions as the goal is a similar collective good. Sustainability is a topic with many meanings and interpretations. Therefore, there can be disagreements regarding the direction of such transitions (Geels, 2011). Secondly, sustainable transitions do not mean that results in the shape of solutions will not be the most beneficial ones; compared to the current technologies, they can be costlier, and the performance will vary. The economic system will also require changes in taxes, subsidies, and frameworks to make sustainable transitions happen. Because of these critical economic change requirements, such as policy change, will be resistance to sustainable transitions (Geels, 2011).

Sectors such as transportation, energy and agriculture, and food are the sectors where sustainable transitions are needed the most. Large firms represent these sectors, for example, car manufacturing companies. These large firms have 'complementary assets', and by using these assets, they can experience large-scale testing in their specialized factories. Once they develop it, their distribution channels can help distribute them along with the different technologies. Such features provide a strong position for the large firms and make them the pioneers in developing and bringing innovations. However, in many cases, these large firms cannot be the pioneers who bring innovative sustainable transitions. Still, they act as a helping hand through their complementary assets to increase the pace of these transitions. However, the firms defending the current system and regimes need to alter their strategy (Geels, 2011).

When looking at all the characteristics of transitions, it can easily be understood that multiple actors are involved in this process. There are interactions on the technological, political, economic, and cultural levels and opinions (Geels, 2011; Geels & Schot, 2017). Sustainability transitions are multi-dimensional, and also there are different dynamics of structural changes. These structures have several lock-in mechanisms such as 'economies of scale, such investments in machines, infrastructure, and competencies'. Existing systems are stable because of different factors, including power, shared beliefs, and politics. Moreover, on the user side, user lifestyles and selection criteria are the factors that act as a lock-in mechanism because of the adjustment in the current systems. These lock-in mechanisms make it difficult to transition from one system to another (Geels, 2011). The technological innovation approach for technological change includes the social aspect of the society and culture, which is looking into the innovation systems considering a multi-dimensional view (Hekkert et al., 2007). However, this approach does not consider structural change and the difficulties that innovations come across in an existing system. The Multi-level Perspective is an approach that considers both the multi-dimensionality and the structural changes along with their challenges. Moreover, the MLP approach does not only look into a technology-push substitution in the patterns of transitions; it also recognizes other patterns of technology where the regime is disturbed once the technology is substituted. Geels (2011) mentioned different approaches, such as 'long-wave theory on techno-economic paradigm', which also considers structural changes and multi-dimensionality. However, it is more towards the economies, and MLP is focused more on the energy, transportation and agriculture, and food systems. Although both the approaches are close to each other, TEP only considers economic systems and aggregate processes. MLP considers the systems which are more comprehensively covering the transitions in several groups (energy, transportation, agriculture, and food) strategies regarding these groups, resources, beliefs, and interactions between the actors involved (Geels, 2011).

2.2 MLP model as a framework for mapping socio-technical transitions

In socio-technical transitions, systems are shifted from one to another. Geels (2012) presented several different approaches for transitions. Still, a socio-technical transition is an approach that is wider than all other approaches, and this characteristic makes it different from other approaches. The Neo-classical approach towards transitions considers the economic view as environmental issues, which occur because of harmful market failures. This approach is dominated by policy debates, as these problematic market failures are corrected with the government's help and through changes in, for example, taxes. However, private actors do the actual work because higher prices are better for them, and they try to find an optimal solution for such problems. Another approach is the psychological aspect, which depends on society's behavior and attitude. This approach assumes that the change in attitude is behavior change, leading to recommending policies, such as education campaigns. The third approach which is presented is through the lens of ecologists. In their view, environmental problems occur because of 'modernism, capitalism, and anthropocentrism', and they find the solution through a change in culture resulting in new ideologies and greener values. Another approach is from the view of engineering and industrial ecologists, and according to the environmental problems that occur because of the polluting manufacturing and production methods, these can be corrected by the use of clean technology, production with less waste and pollution, and trying to reduce the materials which produce pollution. The last approach is by political scientists, in which targets and goals are set, and regulations are implemented. Policies are made executed with the help of the bureaucracy and sanctions. Each of the above approaches considers limited dimensions (Geels, 2012a). However, the socio-technical transition is an approach that considers the multi-dimensionality, interaction between actors, and also the co-evaluation between the industries (Geels, 2011, 2012a; Geels & Schot, 2017).

Several approaches for sustainable socio-technical transitions include strategic niche management, technological system approach, transition management, and the multi-level perspective (Chang et al., 2017; Köhler et al., 2019). Technological innovation system uses the system and evolutionary theory. It considers technologies, actors, and institutions involved in the socio-technical systems, aiming to develop innovative technologies. Actors are guided through the rules set by institutions. According to this approach, only systems are insufficient for innovation, so there are seven functions involved, and their fulfillment results in innovative technologies. These functions are knowledge development and diffusion, entrepreneurial experimentation, influence on direct search, market formation, legitimization, resource mobilization, and development of positive externalities. This framework is based on the interaction of actors in the system for innovation, and the role of actors towards innovation is an issue because the support of actors as intermediaries can be different (Kanda et al., 2019).

Strategic management is also a framework for looking into transitions and emerging new technologies and innovations. It includes evolutionary economics and sociology of economics. It is the process where protected spaces are created for innovations and new technologies. In those protected spaces, experiments are carried out for innovations, and socio-technical systems are required to bring transformation (Loorbach & van Raak, 2006). According to this framework, mostly new actors (not always) are responsible for innovations who strive for these innovations. These innovations at the niches are developed through learning, social networks, and vision and expectations, and through these processes, innovation paths are defined (Köhler et al., 2019).

Transition management also provides a framework for transitions, considering policies and governance (Loorbach & van Raak, 2006). Moreover, as per the framework, innovations can result in four steps of policy; strategic activities (provides a vision for transition pathway), tactical activities (planning and more concrete route building of these pathways, along with investment assurances), and operational activities are the experiments through which new technologies are developed. The learning process is carried out through experiments, and reflexive activities are controlling activities that are carried out, for example, for vision adjustments (Köhler et al., 2019).

Due to the complexities, and essential issues such as transportation, energy, agriculture, and food, these should be studied from a multi-dimensional perspective. The analytical framework must look at several approaches to their interactions. Multiple-level perspective (MLP) is an approach that provides a framework to look into the socio-technical transitions. MLP is an approach that includes the insights from evolutionary economics (technological trajectories, regimes, niches, speciation, path dependence, routines), sociology of technology (innovations are socially constructed through interactions between engineers, firms, consumers, policymakers), structuration theory, and neo-institutional theory (shred beliefs and constrained actors, norms and regulations, the duality of structure which is that structures are both context and outcomes of actions 'rules of the game' that structure actions) (Geels, 2011, 2012a). MLP as an analytical framework includes multiple disciplines and focuses on technology and society together, meaning that the new technology and the space where it is applied (environment) are created together in the same process (Yliskylä-Peuralahti, 2017).

There are three levels in the MLP which looks into transitions. These analytical levels interplay with development within them, making the process of transitions a non-linear process. These levels are; niches, socio-technical regimes, and external socio-landscape. Niches are the spaces and places where the innovation takes place, socio-technical regimes are the places where there are already established practices and related rules and regulations, and because of these rules and regulations, these regimes are stable. The socio-technical landscape is the external environment (Geels, 2002, 2011, 2012a). Every level is stable within its settings. There is a hierarchy seen in the levels of the MLP model because regimes come under the landscape, and the niches exist inside the regime, or it can also exist outside the regime (Geels, 2012a) (Figure 1). Higher-level means stability, and a lower level are less stable. Stability in the levels is defined by the number of actors and the alignment within the elements (Geels, 2011).

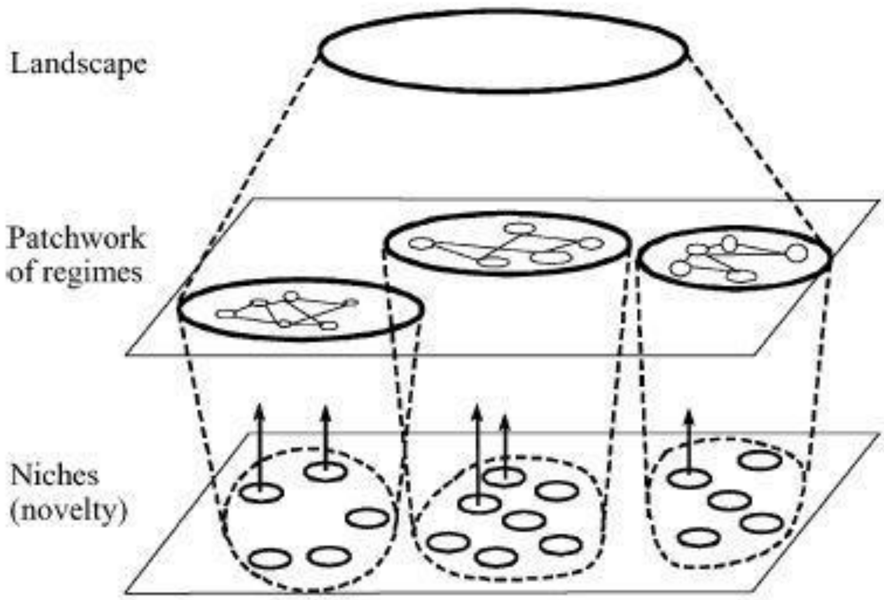

Figure 1. Different levels of MLP and their hierarchy (Geels, 2011)

Relation between the three layers can be easily understood by looking at the figure and multi-level perspective. Regimes are more stable as they are responsible for the stability of the current technological developments and "the occurrence of trajectories". The landscape level is the macro level in the model, and at this level, there are external factors, and the pace of change at this level is slow, which acts as a guide for trajectories. Niches are the micro-level, where radical innovation starts and is further developed. All these levels are nested, and the landscape includes the regimes, and within regimes, there are niches. Innovations emerge at the niche level, in the background of the regimes, along with the landscape and the specific issues, rules, and capabilities (Geels, 2002). The change of activities at the micro-level and the stability at the meso level (regime) can be understood with the help of MLP (Geels, 2012a). According to (Geels, 2002, p. 1259), "The different levels are not ontological descriptions of reality, but analytical and heuristic concepts to understand the complex dynamics of socio-technical change".

In studying society and technology, all three levels are different and represent a configuration in society and technology. Furthermore, the logic of these three levels is that they have many different varieties of coordination and different structures for the activities in 'local practices'. Stability and size are both different in all three levels. At the micro-level (niches), a small social network exists which is unstable and uncertain, and this level includes the entrepreneurs and innovators who are taking chances to innovate something. The rules are not adequately defined at the niche level, and the course of action is different because of a lack of structural uncertainty. Because of these factors, the actors involved at this level strive to maintain this level.

On the other hand, Regimes are more stable as more actors are involved, meaning more extensive social networks, the structure is more defined, rules and regulations are clear and more in place, and markets are more stable and structured. Socio-technical landscapes are the macro level in which the background structures are broader, guiding the course of action. Moreover, the nature of alignment between these three levels is evolutionary. At the micro-level (niches), radical innovations start, but one of them will be selected. Once selected, its wider diffusion depends on the alignment of the remaining two levels; regime level and landscape level (Geels & Schot, 2017).

MLP framework has been used in different socio-technical transitions. Criticism has also arisen for the use of MLP in the transitions. For example, one criticism is that it only considers the technological aspect and ignores the involvement of politics and agency (Rivas Hermann, 2012). Responding to the criticism concerning agency, Geels (2011) suggests that agency is present in the MLP because it is developed based on evolutionary economics and constructivism. Hence, the agency is in MLP except for three types of not developed agencies: rational choice, power struggles, and cultural discursive activities.

2.2.1 Socio-technical landscape – the macro level

The macro-level of the MLP model is the level that is unreachable and is above the two other levels; meso and micro (Hölsgens et al., 2018). This level represents an environment that is not in control and affects the actors of the meso and micro levels of the model (Darnhofer, 2014; Geels, 2004; Geels & Schot, 2017; Hölsgens et al., 2018; Yliskylä-Peuralahti, 2017). It includes all the relevant macro-level factors (Hölsgens et al., 2018). These factors are divided into three dimensions such as (Geels, n.d.; Geels & Schot, 2017)

- Non-changing or very slow changing factors (e.g., climate)
- Changes that happen over a very long period (e.g., German industrialization)
- Quickly changing factors that act as shocks (e.g., wars)

These are the factors that the macro-level of the MLP model comprises, which result in the landscape as they create an external environment. This external environment cannot be affected by actors in the short term. However, macro-level changes in society such as cultural changes, globalization, and many others occur due to human influence. However, on the micro (niche) and meso (regime) level, the actors cannot change the landscape or, in other words, changes cannot be brought willfully at this level by the other two levels (Darnhofer, 2014; Geels, 2004; Geels & Schot, 2017).

Furthermore, the socio-technical landscape can pressurize the regime because of unexpected side-effects that accumulate over time and result in problem creation, and also these problems increase with time (Darnhofer, 2014). The pressure from the landscape will change the practices, which results in the creation of a window of opportunity for micro-level (niches) to bring in new technology, and this becomes more obvious if the existing system at the regime level is unable to cater to the arising problem (Darnhofer, 2014; Hölsgens et al., 2018).

2.2.2 Socio-technical regimes – the meso level

Existing systems are stable in many ways, making transitions a complex process; this is called the lock-in mechanism in a socio-technical regime. The direction of regimes is led towards particular innovation trajectories because these regimes are coordinated and guided through research and development activities. Furthermore, this concept is broadened from 'cognitive routines to the sociological category of rules'. Technological regimes are the rules present in complex engineering activities, including; processes, production, skills, product features, and many more, rooted in the organizations and infrastructures (Geels & Schot, 2017).

Rules are considered a concept interchangeable with the idea of organization. There are three types of rules; cognitive, normative, and regulative. Cognitive rules relate to sense-making or meaning of something, such as belief systems, technical language (jargon), categorization, and principles for guidance. Normative rules are the rules which are towards norms, duties, and responsibilities, such as a code of conduct or system of authority. Lastly, regulative rules are those kinds of rules considered the constraining factor for behavior and interactions, such as government rules and regulations are there for structuring economic processes (Geels, 2004; Geels & Schot, 2017).

Although technological regimes are more related to the network of engineers, however, in socio-technical systems and engineering networks, social groups are also included, such as researchers, consumers, policymakers, and special-interest groups. Rules are connected within regimes and also between different regimes. Once they are there, they coordinate with each other, make dependencies, and create their network. Such coordination and linkages among groups and regimes are known as social-technical regimes (Geels, 2004; Geels & Schot, 2017; Hölsgens et al., 2018). According to Hölsgens et al. (2018, p. 2), "the focus remains on technological change, but many relevant social groups are involved. Therefore, one could also imagine a regime in which not technologies and engineering practices are central but other constructs" (Figure 2). These discoveries are connected with product specifications connected to formal regulations (Geels & Schot, 2017).

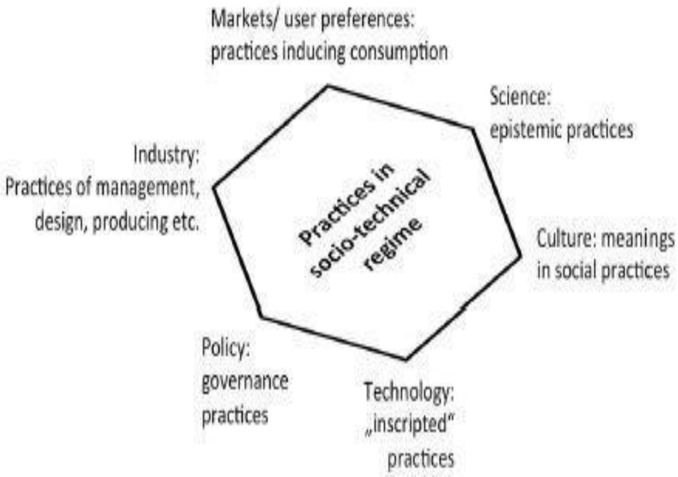

Figure 2. Socio-technical system elements from a practice point of view (Hölsgens et al., 2018)

Regime level is stable (Geels & Schot, 2017; Hölsgens et al., 2018; Klitkou et al., 2015). The alignment of different aspects of the systems, such as structure and system dimensions, are all aligned together, making this level stable and influencing technological change as an opposing force. Some mechanisms impact the socio-technical transitions; these are called lock-in mechanisms (Geels & Schot, 2017; Klitkou et al., 2015). Klitkou et al. (2015) drive different lock-in mechanisms that are prerequisites for transitions. These lock-in mechanisms include; learning effects, (dis) economies of scale, network externalities, and public regulations. Public regulations can be at the national level or continent level, and these can be in the shape of institutional learning effects, collective actions, or differentiation of power.

Furthermore, in the same study, it has been observed that sometimes these lock-in mechanisms can act as negative and positive roles in the socio-technical transitions. Also, these lock-in mechanisms can act as a directional force for creating a new technological direction for mature technological trajectories. For example, renewable energy technology can pave the way for e-mobility or hydrogen utilization. Most importantly, new technological pathways are influenced at this level because of the inclusion of multiple stakeholders who interact in the social and economic context. The context is highly impacted by the regime level of the MLP model (Klitkou et al., 2015).

Furthermore, the trajectories created at the regime level are not only for technology but can also happen for policies, industries, science, culture, and markets. Social groups create these different trajectories with specific plans, standards, and preferences, issues to cater to, and these social groups have their structured policy cycles, which results in trajectories. To ensure the organizational running of socio-technical systems, many groups interact with each other and create networks that depend on similar dependencies. These social groups overlap in some way keeping their identity and independence. This circumstance results in the many trajectories in which systems of society and technology co-evolve (Figure 3) (Geels, 2004; Geels & Schot, 2017).

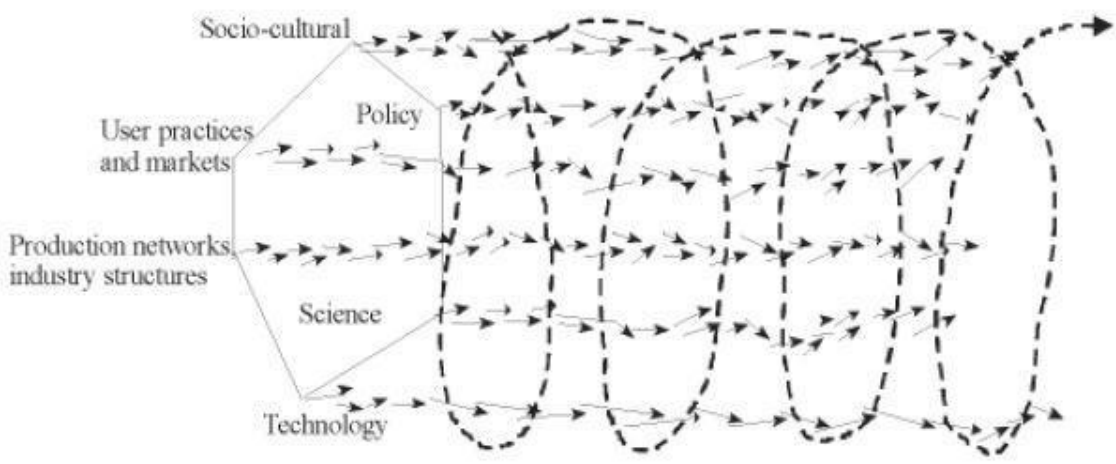

Figure 3. Different trajectories in regimes as a result of co-evolution (adopted from Geels, 2004; Geels & Schot, 2017)

Another relevant concept is the idea of a 'window of opportunity', created when there are tensions and the desynchronization in the systems, which provides different trajectories. Windows of opportunities are the point when the regimes' stability is disturbed, and innovations at the niche level come into play (Geels & Schot, 2017; Hölsgens et al., 2018). According to transition theory, innovations that change the existing regimes usually happen outside of regimes. Other than being part of the existing systems, regime actors are strong. They have the motive not to change the existing systems as they have benefits in the current systems in terms of political or financial reasons. So, a window of opportunity provides the possibility for transitions to take place. For many scholars, the niche level has been given more attention because transitions start from this level; innovations need to be developed and supported without adequately looking at the other two levels (niche and landscape). Because of this approach, regimes are only conceived as barriers that need to be overcome. This unbalanced approach is against the MLP model itself, which is why multi-level alignment is considered in the model. The other two levels are to be considered to understand the destabilization of regimes (Hölsgens et al., 2018).

2.2.3 Niches – the micro level

Micro-level MLP models are the niches where the innovations take place. These are small spaces for experiments where new technologies emerge (Darnhofer, 2014; Geels, 2002, 2012b; Yliskylä-Peuralahti, 2017). These protected spaces for innovations function as "incubation rooms", and these protected spaces are required for the innovations because the radical novel technologies are "hopeful monstrosities" (Geels, 2002, p.161), which is why there is a lot of uncertainty and issues in experimentation process (Yliskylä-Peuralahti, 2017). Innovations result in the emergence of new knowledge, new products, new groups and networks, and rules. The novelties which emerge at the niche level are not stable, and their performance is low at the start, which makes this level an incubation room, and these incubation rooms are the protecting shield against the market (Geels & Schot, 2017; Marcon Nora & Alberton, 2021). These protected spaces are essential for the emergence of new technologies because they encourage changes that can result in a socio-technical change (Marcon Nora & Alberton, 2021). The niche level acts as an internal stimulus and provides momentum and starting point for transitions (El Bilali, 2019).

Small market segments are essential for innovations; there is a facility for reproduction because of resource availability. It is to be considered that these small niches are not available for innovations, so it is crucial to have these new markets, technologies, and consumer liking alongside the stable markets, technologies, and user preferences. Entrepreneurs are the ones who can make such new markets through their commitments to the cause for some time. Moreover, there is always a factor of unpredictability regarding the end product because it depends on the actor who will come forward along with the commitment (Geels & Schot, 2017).

The protected spaces can be provided in many ways, and one way for such space is by providing subsidies for projects in which demonstration of new technologies can be done. Moreover, they can also be places with specialist user requirements due to which new technologies are supported by the users (Darnhofer, 2014). Innovations at the niche level are radical because they are on a different track than the current system on which the market depends. Moreover, they are also different from the dimensional perspective of existing society, business environment and model, and infrastructure. This is why the survival of these innovations is difficult in current stable markets (Geels, 2020.).

Technological niches are the first step towards a change. Along with technological development at the niche level, implementation of technology by users is affected by other factors such as a change in society and other mature and competing technologies. Changes in user requirements, current policies, and infrastructures are required by technological change. New technology is developed at the micro-level of the MLP, and this level also provides financial support for the development of new technology. Moreover, it also helps network create for the development of the latest technology and gives a pathway for the learning process and adjustment of institutions, their management, and organization. These are essential factors for developing and distributing innovations (Hoogma et al., 2005).

According to (Darnhofer, 2014; Geels, 2002, 2004, 2012b; Hoogma et al., 2005), three processes happen at the niche level, and these are defined below.

- Learning processes

  There are problems associated with developing new technologies because much uncertainty is involved. A learning process occurs in developing new technologies, an important goal. There are different dimensions of this process, including learning about the technology issues and their countermeasures, organizational issues, business environment, markets, user side aspects (e.g., demand), the requirement for the technology (e.g., infrastructure), and policy change, and societal meaning.
- Network creation

  Another process is network creation, which involves new actors and old ones, and these actors will create a network. There are different interests of involved actors because some will take part for defensive reasons, but others will show initiative. Moreover, actors are always required as they increase the resources for innovations.
- Creation of expectation

  The result of new technology developments is unknown at the niche levels, so there is resistance at this level. To overcome such opposition, the involved actors make promises and increase the expectations of the new technology. Factors such as sharedness, credibility, specificity, and solutions to a problem of society make the promises and expectations stronger. This process also helps attract more actors and get funding for technology development.

There are experiment projects on the micro-level of the MLP model, and through these experiments, the stakeholders of the niche level learn about the innovations in real-life circumstances. New technological development is more paced at this level if the expectations are shared and specific. The learning process can result in a durable design, and the size of the network is increased (Geels, 2012b).

There can be two types of relationship between niches and regimes; competitive and symbolic. Innovations at the niche level will be a symbolic relationship between the two levels when they act as an addition to the current technologies. The relationship can play its role in the diffusion of innovations or new technology. Innovations can become more robust and grow if the actors protect them at the niche level, and over time, they can pick such strength that they challenge or replace the current systems (regimes). However, if the relationship is symbolic, these innovations will align with the current systems. Challenging the existing regimes without destabilization can also happen in the case of symbolic relationships. In this case, the innovation as an add-on becomes mainstream. However, as per the MLP model, such happening is complex and can be very long in terms of time compared to the window of opportunity (Hölsgens et al., 2018).

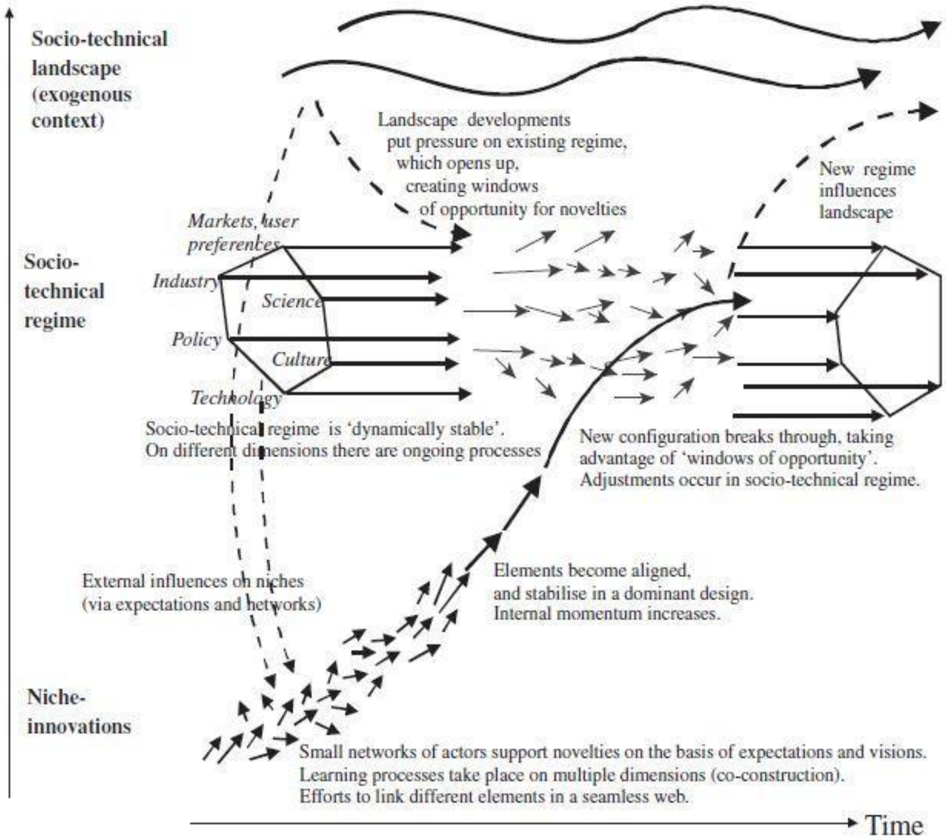

Figure 4. Multi-level perspective on socio-technical transitions (Geels, 2012b)

The multi-level perspective on the socio-technical transitions framework can be seen in Figure 4. Transitions particulars can be different in different domains and regions, but the general assumptions of the framework are as follows.

- New technologies and innovations occur at the micro-level, resulting in internal momentum.
- The changes act as a pressurizing force on both the regime level and the current systems at the landscape level.
- When the existing system cannot cater to a problem at the regime level, then regimes face a destabilized situation, resulting in a window of opportunity for innovation at the niche level. Innovations and new technology after creation at the niche level spread and create disturbance in the whole system or parts of the system.

- Transitions happen by aligning processes among and between the three layers (micro, meso, and macro) of the MLP model.

2.3 Niche momentum and regime tensions in socio-technical transitions.

According to Geels et al. (2017), transitions are long-term processes that can take more than decades, and these long processes have four phases. The first phase starts from the micro-level, the MLP model's niche level. At this level, innovations and new technologies emerge, and, as discussed earlier, the network of actors is not stable at this level, and the outcome of the experiment is uncertain. It can also fail (Yliskylä-Peuralahti, 2017). The second phase is the entrance of the innovations and innovative technologies that emerged at the niche level into small markets. These markets are known to be the stabilizing phase for innovations because they provide resources for further development (Darnhofer, 2014; Hoogma et al., 2005). At this phase, the innovations create trajectories along with a dominant design from which the expectations are high, and the rules start to stabilize.

The third phase is where the innovations and technologies are widely spread into the existing regimes, and competition starts here. This competition also destabilizes the regimes and creates tensions because of constant/persistent problems (e.g., climate change, air quality, or other reasons). These tensions can be pressure from the landscape. Moreover, destabilization can combine both persistent issues and pressure from the landscape. According to Geels et al. (2017, p. 466), "Struggles between niche innovations and existing regimes typically play out on multiple dimensions, including economic competition between old and new technologies; business struggles between new entrants and incumbents; political struggles over adjustments in regulations, standards, subsidies, and taxes; and discursive struggles over problem framings and social acceptance."

There are drivers for niches due to which momentum can be seen in the third phase; also, there are reasons for tensions due to which the regime level is destabilized (Geels et al., 2017). All of them are given below in Table 1.

Table 1. Drivers for niche momentum and regime tensions (adapted from Geels et al., 2017)

Drivers	**Niche drivers**	**Regime tensions**
Techno-economic	Price and performance improvement because of R&D, learning process, economies of scale, complementary technologies, network externalities, and network building.	Technical failures, infrastructure issues, and negative externalities (e.g., zero-emission)
Social	Social awareness and pressure, social groups support, finance, and political backing.	Disagreements of social groups, the defection of key social groups from the regime.
Political	Support for policy changes towards niche development such as subsidies and supportive regulations.	Eroding the political influence of incumbent industries, declining political support, removal of supportive regulations, and the introduction of disruptive policies
Cultural	Positive disclosures and visions attractions, cultural drives and motivation, and increased socio-political legitimacy.	Negative cultural discourses undermine the legitimacy of existing regimes (e.g., climate change, diesel cars, and air quality).

The last phase includes substituting the new technologies and innovations in the existing regimes. Such substitution also includes changes in the infrastructures, rules, regulations, business environment, users' lifestyles, and opinions about normality. All of this results in the creation of new regimes which are institutionalized and gradually accepted (Geels et al., 2017).

2.3.1 Regime tensions

For system changes or alternative technologies, the idea of regime tensions is fundamental to consider. There are different internal dynamics for other regimes, and they cause fluctuations and differences, for example, political cycles, business environment, models, technology trajectory, cultural choice, and shifts and industries. There are varied reasons for tensions in regimes. Pressure from the landscape to cater to essential issues such as climate change, for example, is pressurizing the transportation and energy industries for cleaner ways of operations and technological changes. Also, ideological culture changes can create such tensions on a broader level.

Moreover, long persistent technological issues can also create tensions in the regimes for new or altered technologies. For example, in the case of carbon-free fuels, because the existing fuels have a lot of carbon emission and to cater new technologies in alternative fuels of efficient designs and engines of ships needs to develop. Third, negative externalities are also a reason for regime tension. One system's operation can affect other systems, such as safety concerns. They need to be identified by external actors because internal actors of regimes will try to cover the issue. Examples of negative externalities include pressure on Greenpeace's mission by social groups. Fourth, users can also pressure the regime, resulting in regime tensions because the existing technologies cannot meet the requirements. These tensions can be because of cultural changes, economic impacts, including price fluctuations and rules, and policy changes in the shape of taxes (Geels, 2004).

Moreover, business strategies, which are sustainable transitions, may typically include the goal of adopting renewable materials, hybridization, or alternative fuel, which can also create tension in regimes (Pelli & Lähtinen, 2020). For instance, in the case of the shipping industry, the goal is for emission-free fuel, which puts pressure on existing companies to find alternative solutions to cater to this problem. Furthermore, business models play an essential role in system transitions. Recently, there has been much emphasis on non-technical processes, such as low carbon systems, improved sustainability, and a circular economy (Pelli & Lähtinen, 2020). Indeed, keeping in mind all the theories (Geels, 2011, 2012a) and dimensions involved in the MLP model, different drivers are responsible for destabilizing existing regimes and creating tensions. Turnheim and Geels (2013) analyze the British coal industry, and the results explain the destabilization of regimes and tensions in the regimes. Competitive and financial resource problem creates tension in the regimes, and the reason for such tensions are the market shifts, competition, supply issues, innovations, and new technologies. During these times, organizations that are already working in the existing regimes will try to stabilize in different ways; for example, changing the strategy and compatibility with current technology is the goal of organizations.

Moreover, regime tensions can also result from shifts in cultural beliefs and values, and during this, the actors involved abandon industry-specific institutions regarding the beliefs and values. Pressure can come from the economic and socio-political environments, which entails policy change, public opinion, or movements from social groups towards a goal, such as climate change. Another reason for regime tensions is the issues related to performance in terms of financial or regulations from the external environment. Moreover, as the pressure keeps increasing, the commitment of regime actors to stabilize the regime will decrease with time. However, due to the lock-in mechanism, regime actors will still try to defend current regimes (Turnheim & Geels, 2013).

Economic factors in an environment incorporate the actors included in the economic transactions, and in industry, organizations compete based on price and performance. Moreover, another aspect is the socio-political environment that the regime faces, and the pressure on regimes from this perspective can be in the forms of actors involved in policymaking, social groups, and movements. In regimes, organizations try to find the fit for the society they work and be according to rules. Pressure can come from the institution creating policies, regulations, and public values and expectations (Turnheim & Geels, 2013).

Many forces are responsible for destabilizing regimes, making them multi-dimensional (Raven et al., 2016, Turnheim & Geels, 2013). The pressure from an economic perspective is derived from the technological competition and demand side, which relates to the user's choices. Pressures from the socio-political environment are because of shifts or changes in society's values and beliefs and changes in the policy by the local or international institutions. All these pressures at one point are directed in one direction. Authors name such incidents' perfect storm', because in the case study discussed in the research, all the forces acting in one direction, and these pressures cause the destabilization of the British coal industry (Turnheim & Geels, 2013). Furthermore, regime tensions result from issues arising in functionality, inability to adopt the changes in the environment (technological, social, rules, and regulations), and misalignment of the actors of regimes (Valta et al., 2022).

Moreover, transitions that cater to more significant environmental problems such as climate change or zero-emission targets will take longer. Such transitions will entail changes in dimensions such as political, cultural, economic, and technological. Existing regimes will be opposing such transitions because such transitions include changing the core capabilities and interests of the regime actors. It is also argued that policymakers can impact more if the pressure for creating strict policies is from the public. If policy creation is not backed by public demand, policies are not enough for transitions (Penna & Geels, 2012).

In short, from the discussion above, it can be understood that regimes are destabilized from multiple dimensions, and pressures from such multiple dimensions can create tensions. Tensions in regimes result in an opening window of opportunity for new technology or innovation, which happens at the niche level of the MLP model. In the context of our research, we can now say that the existing fuel used in the shipping industry is facing pressure from many dimensions, for example, economic and socio-political. These pressures are destabilizing the regime, and a window of opportunity is opened for new technologies. In the next section, we will discuss the drivers of these innovations.

2.3.2 Diver for Niche momentum

Many scholars have used the MLP framework for the low-carbon transitions in different fields (Geels, 2012b, 2012a; Geels et al., 2017; Hölsgens et al., 2018; Hoogma et al., 2005; Klitkou et al., 2015; Yliskylä-Peuralahti, 2017). Innovations at niches go in more than one direction, for example, technological, cultural, behavioral, policy, and infrastructural. There is an aspect of uncertainty associated with niches but more actors' involvement in niches results in higher momentum (Geels, 2012b). As we saw that there are multiple dimensions for regime tensions. Similarly, the drivers for niche momentum are multi-dimensional, including technology, culture, user side, policies, and political influence (Raven et al., 2016).

Policy creation is an essential factor in working toward the goal of climate change that can strengthen the transition because they provide rules and regulations, and technologies are developed following these rules and regulations. Policies can impact socio-technical transitions, which drives the change and plays its role in destabilizing the regimes and breaking the lock-in mechanisms. It can help reduce the uncertainties for investors working towards the goal (for example, climate change) through innovations by applying a technological selection environment and creating expectations. Policies can help provide spaces for experiments at the niche level on new technologies by allocating budgets. The author argued that the policies should be stable and should not be changed rapidly. The policy can facilitate system transformation and a smooth process because it can protect the experiments for innovations through different projects and provide space for experiments on the technology. Policy creation can be better if more actors are involved, which means that government organizations and society can participate. For example, the theme of Green resources in the Dutch energy transitions, and the goal is to include 30% green resources for energy. The path which is taken is Biomass production in the Netherlands.

Moreover, knowledge can also be shared through policy implementation, and resources can also be shared, for example, government-funded experiment facilities (government funding for different projects towards decarbonization) (Li, 2020). Subsidizing is also a way to develop niche innovations. The Wuxi government shaped the market to use solar products by providing subsidies (Zhang et al., 2021). For instance, Yliskylä-Peuralahti (2017) studied the maritime industry for renewable energy in the shape of bio-fuels using the MLP model. According to the study, policymakers can act as a driver. They need to come forward to play a significant role in creating niches where sustainable fuel production can happen, which can be done through financial incentives and other ways. Policies can create problems for the existing regimes, so current regimes create obstacles for new technologies. These obstacles include low demand from the users as a sustainable fuel is costly, and the regulations are not strong enough to implement sustainable fuels.

Additionally, there are issues such as more knowledge required to operate innovations and new technologies, higher cost of operations, and costly maintenance. All of these are the tensions at the regime level when the niche drivers push the system towards innovation and new technologies to cater to the issue of climate change. New technologies are costly, but their technology is advanced, and their performance is much better. Moreover, new technologies are environmentally friendly, such as biogas in ships, which has reduced emissions.

Social networks and groups are also a driving force for niche innovations, which act as societal pressure. Actors involved in the development of new technologies can create a network. The actors in the network can include policymakers, organizations that are working to develop new technology, researchers, and all other relevant actors. These networks are profound as they have a common goal. In these networks, the resources are shared within their organizations and between the organizations of other actors involved.

Moreover, commitment toward a common goal is mobilized in these groups, making it easy to share the resources. Interaction is an essential aspect of these groups because the group is kept aligned (Tomenendal et., 2018). Catering to climate change is the main goal for many social groups, and we can see the activities of the Norwegian government by looking at their steps toward renewable energy sources. Many groups are involved in Norway in cater the issue of climate change.

Other three key factors play a role in driving the innovations and bringing new technologies, including environmental, economic, and technological. Energy security is fundamental because petroleum reserves are reducing at a high rate globally, and new technologies are created in niches. The energy pressure acts as a technological driver for bringing new technologies in the shape of renewable and green energy systems and battery-powered electric vehicles. Carbon emissions are destroying our environment, creating the issue of climate change. The role of transportation is significant in this sector as it pollutes the air and affects health. Heavy diesel fuel is one of the main contributors to carbon emissions. New and different technology can reduce traditional fuels in the shipping industry, improve the environment, and reduce air pollution. These aspects are pressures from the landscape level on the niches, and policies are created to accommodate them. Different governments have invested 13 to 16 billion dollars in policies and programs. A market is designed for battery-powered vehicles to ensure that the new technology vehicles can gain popularity. There are three main characteristics of such policies: research and development of new technologies, creation of the infrastructure, and purchasing incentives in the shape of taxes and rebates. These create pressure at the landscape level and result in drivers for the niches (Berkeley et al., 2017).

Change in culture and visions entails transitions (Darnhofer, 2014; Hölsgens et al., 2018). Culture change has been observed within the last few decades, and during this change, new values have emerged and become dominant. Once these new values are prevalent, these values put social and political pressures on change. The change starts with the technology and economic aspects of the existing systems, which entail changes to achieve sustainability, such as climate change. Socio-technical transitions incorporate both technology and social elements, and culture plays a vital role in the social aspect.

It means a change in culture entails technology and social change (Tibbs, 2011). Changes in culture and user practices are backed by social groups and movements, which oppose the existing systems and drive toward new technologies (sustainable transitions, e.g., transportation system). It can be seen in the case of land transportation. The niches and cultures have deviated from the normality, and the automobile industry is challenged, for example, urban planning or car-sharing schemes (Geels, 2012b). Cultural change plays an essential role in the socio-technical transitions because it requires technological and social changes to be included in the change, and the change is towards a common goal and vision of the society.

2.3.3 Niche dynamics

The interaction between three levels results in transitions in the MLP model. There is a particular relationship between these three levels, making them a nested hierarchy. Moreover, there is an interplay between the three levels in different levels. Transitions can also happen with the first step of innovation as an internal momentum by niches. Socio-technical landscape puts pressure on the stable regimes, resulting in the destabilization and creating a window of opportunity for the innovation in the niches to take over the existing system, technologies, and regimes (Geels, 2012; Geels et al., 2017; Laribi & Guy, 2020).

(Laribi & Guy, 2020; Raven, 2007; Papachristos et al., 2013), The micro-level of the MLP model is not considered static because of its interaction with internal and external environments. These factors can be stakeholders, market shares, new technology requirements, etc. When a transition takes place, then niches are internal developments. Niches emerge in a system because of growing needs and requirements of improvements in technology, for example, in the emergence of digital computers. There are alternative niche emergence and development forms (e.g., competition, hybridization, accumulation). For instance, Ollivier et al. (2018) look into the perspective of socio-technical transitions using the MLP framework. Accordingly, regimes can be influenced by niches through technological competition. However, there was no niche competition in the transition process, and different kinds of niches (new technologies) existed simultaneously. The coexisting niches interact with regimes both separately or together. These different niches can influence and affect regimes in different ways, for example, industry practices in terms of manufacturing, processing, research, etc.

Occasionally, this competition can turn into a struggle reminiscent of different standard wars in the history of technological progress, where setting the industry standards is key for achieving architectural dominance (Rabetino & Kohtamäki, 2018). Niche competition can be seen in the war between HD-DVD and Blu-rays. Both were competing for emergence as the industry standard. There are different stakeholders involved in making a technology emergent in a regime. In this case, different players supported Blu-rays, such as the device they run, content provider support, and many others. Other alternatives, for example, internet downloads, were also emerging in the market. Niche competition can lead to different technological options and price sensitivity and rely on support from stakeholders, alliance building (network effects), and supporting technology (for example, HD television sets for HD-DVD) (Den Uijl & de Vries, 2013). There are different standard wars in the market, which results in the emergence of a market standard, for example, the battle between CDs and the music standards of the time, and these battles take time to settle (many years) (Stango, 2004).

Alternatively, niche accumulation is a pattern in the MLP model in which new innovations and technologies are applied in the niche markets through a sequence of different application domains. Niche accumulation develops internal momentum and takes time to emerge as new technology. This approach involves a strategy in which new technologies are distinct from current ones in stable regimes, including markets, technologies, a network of actors, and institutions. The goal of niche accumulation is to provide safety and stop early rejections with the help of carrying out radically different projects and experiments in niche markets. The protected spaces for the new technologies are where new technologies are refined and experimented with while they grow and develop. New technologies can combine and move from one niche market to another, resulting in a better fit between the markets and new technologies. Because of this fit between new technologies and the market, internal momentum also increases, resulting in a new socio-technical regime (Geels, 2011; Laribi & Guy, 2020; Raven, 2007).

In the process of niche accumulation, the market share of the new technologies and innovations increases with their development. There are elements created to back these new technologies, such as policies, regulations, infrastructures, etc. After further development of the latest technologies, and once the usage rate of these technologies is increased; then, the environment created for the protection of these new technologies is removed. Niches are essential to study because the transition process often starts at this level by bringing new technologies to the market (Laribi & Guy, 2020). Figure 5 below represents the concept of niche accumulation.

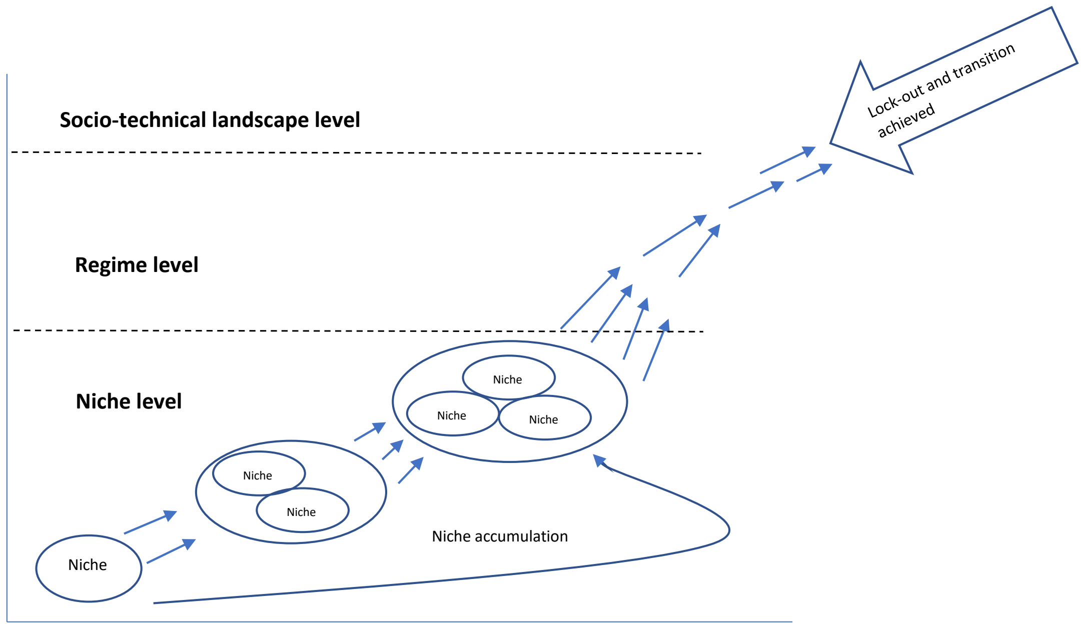

Figure 5. Niche accumulation (Laribi & Guy, 2020)

Hybridization is a pattern in the transition process in which old technology used in the regime is hooked with the new technology developed at the niche level, resulting in a hybrid technological design. The new technology is initially considered an add-on element, but the main goal is to go to mainstream markets and overtake current technologies. The whole process results in a hybrid configuration (Geels, 2011; Raven, 2007). One example of such a transition is the movement from sailing ships to steamships. Steam engines were used as an add-on element in sailing vessels. These engines were used when the wind was low and sailing functions could not be performed. In the 1840s and 1850s, ships utilized steam engines and wind, and in terms of operation, the contribution was the same, resulting in hybridization.

Moreover, in the same example, steam engines replaced sailing ships after a long hybridization period. New technologies can eventually take over the old technologies in the hybridization process. Once the new technology dominates old technologies, then the old technology can only exist in some niche markets; for example, in the case of the sailing ships to steamships, old technology is used as an auxiliary technology in a niche market such as luxury cruises. One other possible way is that the old technology will ultimately be eradicated from the market, but such transitions take a lot of time (more than decades) (Raven, 2007).

3. Methodology

3.1 Research design

Research design is fundamental in an academic study because obtaining results is systematic, thorough, and careful through a proper research design. On the other hand, the researcher must be unbiased during the whole process, and also there should be no influence of the researcher on the study and its results. The research strategy adopted in this thesis is mixing quantitative and qualitative data collection techniques. Moreover, the methods are exploratory case study and Delphi study. This thesis aims to study the driving forces for niches and regime tensions toward socio-technical transition for the shipping industry. Moreover, this thesis will also explore the niche dynamics which play a role in developing a new standard in the shipping industry. It looks into the different multi-dimensional forces, the competition, and coopetition at the niches (alternative fuels). Furthermore, explanatory research is applied where more than one outcome is expected (Hafeez, 2021), as in the case of niches (new technologies, multi-dimensional forces, etc.).

For the qualitative data collection method, semi-structured interviews involving field experts were conducted. The Delphi method is used by Skinner et al. (2015), explained later in this chapter, for the quantitative data collection method. Interviews are used for quantitative data collection because they are a highly effective way to collect data that includes broader information. Interviews are conducted with respondents who can see the question from multiple perspectives to cater to the problem of bias. Moreover, data collection through these interviews is regarding a current phenomenon of the world, resulting in more accurate findings (Eisenhardt & Graebner, 2007). The research process is shown below in Figure 6.

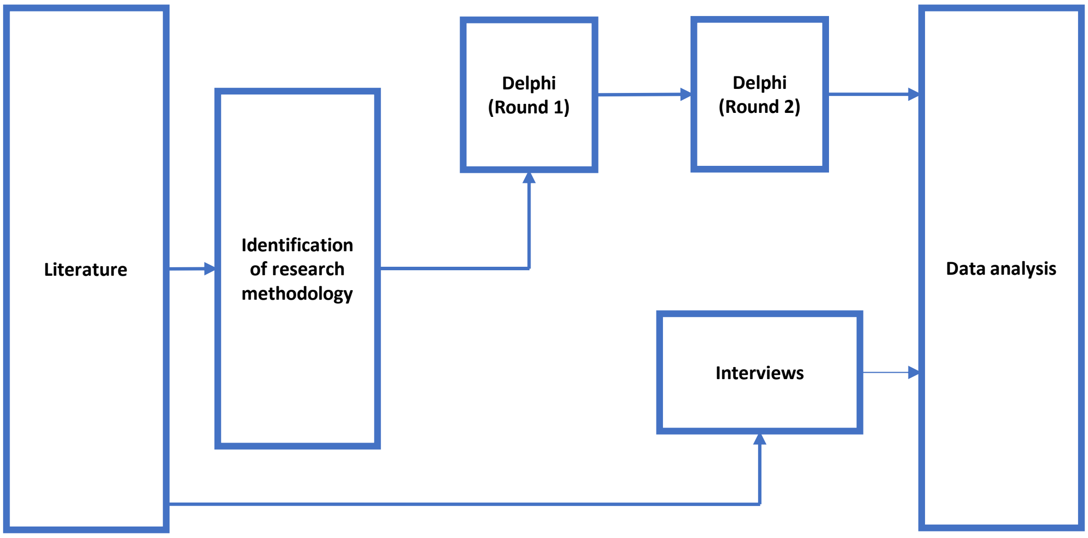

Figure 6. Research process

3.2 Research Methods

The mixed method is used for this thesis, and the mixed method benefits both qualitative research methods and quantitative research methods. Delphi method has been used as a quantitative method of data collection, and for the qualitative method, semi-structured interviews are used. The Delphi method was used for this thesis because it provides expert opinions regarding future forecasting. Moreover, it helps in creating a consensus among the field experts.

The Delphi method has been in use since the 1950s and became famous for its usefulness in future technological forecasting. Its unique characteristics characterize it, such as it includes top field experts who can foresee the future of the technology; second, it consists of a panel of experts who are between 10 to 30 in normal circumstances. Third, anonymity is a characteristic that results in more objective answers and results. Fourth, there are several rounds in this method, and they can be two minimum and ten maximum to reach a consensus. Last, there are iterative rounds, and feedback is taken from the experts in each round, and the experts are required to justify their answers, which become sources of information for the next round (Skinner et al., 2015).

Other methods are also available for future technological forecasting, such as action research, which includes practical solutions and incorporating the organizational actors as per their competencies. Another method is action design research used to design ensemble technological devices. Another widely used method alternative to the Delphi method is the standard survey. The difference between the two is that the survey depends on the sample size for validity and statistically essential effects on the population. However, the Delphi method is a method that removes these dependencies because of expert involvement. Through Delphi methods, the results are more insightful because of the expertise of the respondents (Skinner et al., 2015). The process of developing the questionnaire is given in Figure 7 below.

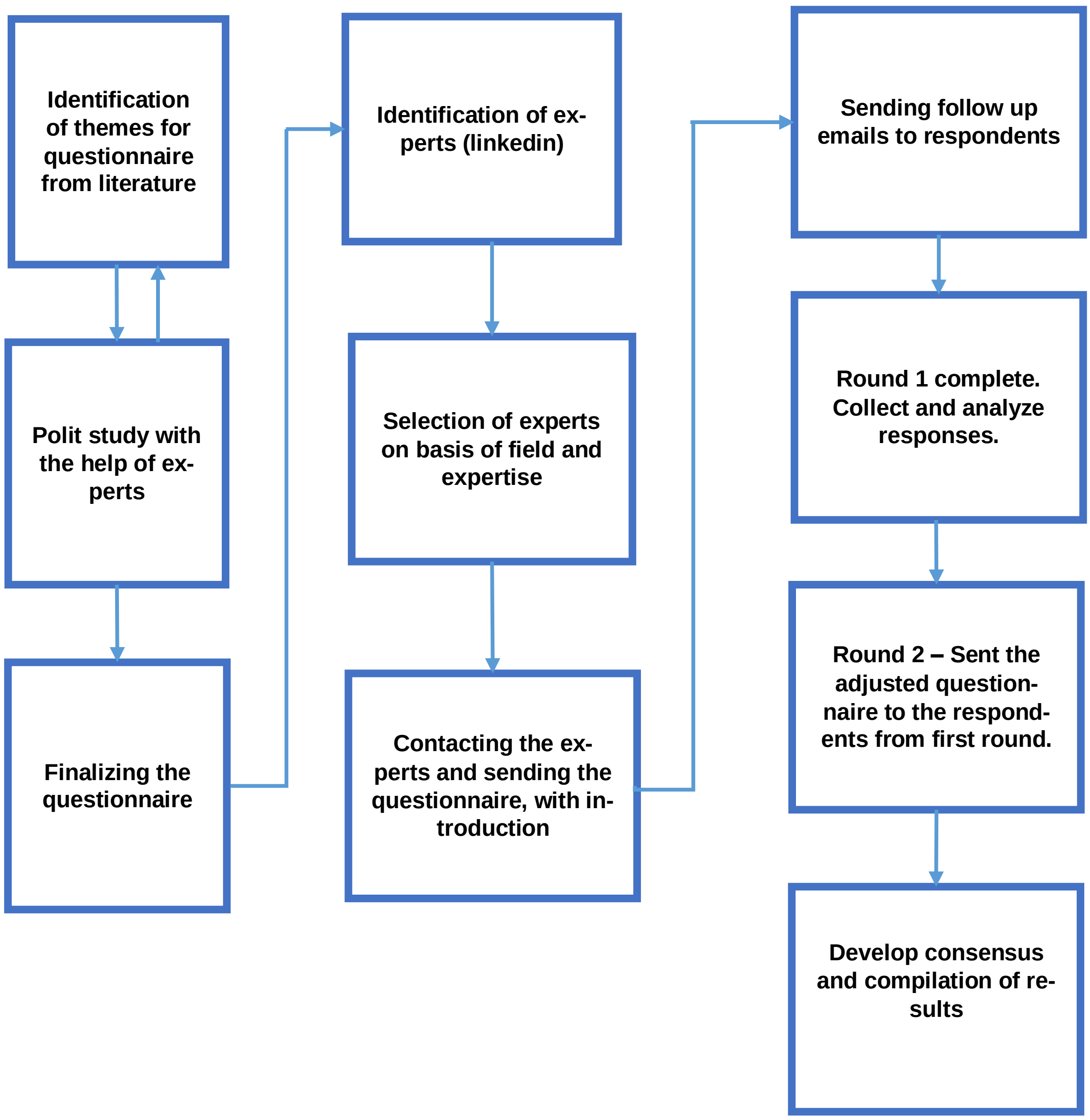

Figure 7. Delphi questionnaire development process.

For the Delphi method, a questionnaire was developed from the literature. Next, after adjustments due to the expert remarks during a pilot, the questionnaire was finalized. Field experts were selected, and they responded to the first round. After the first round, some adjustments were made (e.g., adding options for questions), and then the adjusted questionnaire was again requested to be filled by first-round respondents. For quantitative data, interviews were conducted in a semi-structured format. Questions were developed from the literature review after reviewing the drivers for niche momentum and regime tensions.

3.3 Research context

The shipping sector comprises 80% of total international trade and plays a vital role in the world's economy. The share of the industry is high in international trade. The percentage of greenhouse gas emissions is also high, reaching 3% of the total greenhouse gas emissions (Mallouppas & Yfantis, 2021; Serra & Fancello, 2020). System changes will be required in the shipping industry because of the regulation and strict targets by organizations such as IMO and E.U. There are efforts done to the decarbonization of the shipping industry. To reach the target of 1.5 ºC of temperature rise, the shipping industry, a global collaborator of 3% in greenhouse gas emissions, needs to be emission-free (Mallouppas & Yfantis, 2021). The shipping industry is a significant contributor to carbon emissions in the environment. This sector needs to transition to new low-carbon shipping industry and transportation system to reach the targets set by IMO for the shipping industry to reduce carbon emissions and play its part in catering to climate change (Yliskylä-Peuralahti, 2017).

According to (Mallouppas & Yfantis, 2021), there are two measures to decarbonize the shipping industry: operational and technical measures. Technical measures include ship size etc., and operational measures include the slow speed of ships, waste heat recovery, etc. The use of alternative fuels is also now considered a technical measure toward the decarbonization of the shipping industry. There are different ways through which are given below

- Hull designs
- Economy of scale
- Energy and propulsion
- Sailing speed
- Alternative fuels and energy sources
- Rerouting and scheduling

This thesis focuses on using alternative fuels for the decarbonization of the shipping industry. Fuel used by the shipping industry is less refined, which results in a high amount of greenhouse gasses. Heavy fuel oil is mainly used as a primary fuel in the shipping industry, along with other fuels such as marine gas oil and marine diesel oil, but primarily heavy fuel oil, which emits much sulfur. The use of alternative fuels is a way to reduce emissions. Table 2 provides an estimate of emission reduction, from which it can be seen that alternative fuels are an effective way of emission reduction in the shipping industry.

Table 2. A Percentage of possible emission reduction through alternative fuels (Mallouppas & Yfantis, 2021)

Alternative fuel	**Average possible emission reduction (CO_2)**
Biofuels	25-100%
Liquefied Natural Gas (LNG)	0-20%
Hydrogen	0-100%
Ammonia	0-100%
Fuel Cells	2-20%
Electricity	0-100%
Wind	1-32%
Solar	0-12%
Nuclear	0-100%

All of the alternative fuels are under development, and these are possible pathways for a reduction in emissions in the shipping sector. Moreover, using alternative fuels and required technology means system change for the industry (Mallouppas & Yfantis, 2021). Previously, there have been socio-technical transitions in different sectors such as water management, energy, etc. Through MLP, the socio-technical transitions in transportation can be studied (Geels, 2012a, 2012b; Rivas Hermann, 2012; Yliskylä-Peuralahti, 2017). The shipping industry has undergone considerable socio-technical developments, especially after the oil crisis in the 1970s. The oil crisis in the '70s is majorly responsible for the focus and development of alternative fuels for fossil fuels (Rivas Hermann, 2012). Moreover, studies have been done on low-carbon transportation but mainly on land. MLP best suits the scenario because it has been used for the previous transitions where multiple actors were involved in the transition process, and the three levels were interrelated.

Furthermore, MLP can be a helpful model for understanding the barriers and enablers of a process of change in society. Such a process occurs throughout some time regarding industry or part of the industry. Also, this model enables us to understand the paradigm of change on a more general level. More importantly, it helps us understand the struggle of politics and power present in a transition process. These barriers and enablers that impact the transition process can be multi-dimensions, such as environmental, socio-technical, socio-economic, socio-political, and institutional (Yliskylä-Peuralahti, 2017).

3.4 Data Collection and analysis

3.4.1 Interviews

Both qualitative and quantitative data are collected for this thesis. The mixed method of data collection is used to study complex phenomena because of the complexities and multi-dimensionality involved. Moreover, when data comes from multiple sources, the results are more credible. These credible results will strengthen the conclusion and suggestions, for example, for researchers, managers, or users of the study. When mixed, both these methods can help develop the results with the other method.

Moreover, mixed methods used in a research study help understand the topic being researched in-depth, and it also widens the range of the study. Therefore, a mixed research method provides the best way to address research questions. Through this method, weaknesses of qualitative and quantitative methods are also compensated, along with combining the strengths of both (Dawadi et al., 2021). The mixed-method is used in this research as this method will cover the multi-dimensions of the study topic. Also, it will consider the complexities involved in socio-technical transitions. Moreover, the complex issue will be understood more deeply through this data collection method.

There are three different types of interviews through which quantitative data can be collected; structured, semi-structured, and unstructured. Structured interviews are those with strict rules of no possibility of deviating from the listed questions. In structured interviews, the possibility of asking follow-up questions is zero. It can be helpful in such areas of research where little information is needed and in-depth information is not needed. On the other hand, semi-structured is the type of interview in which the interviewer sets fundamental questions, and then from those set questions, follow-up questions are asked, which is based on the interviewee's answer. This type of interview helps create a deep understanding of the topic while keeping in mind the set of questions, which results in keeping track and focus on the interview and stopping deviating from it. Last, unstructured interviews are the type of interviews with no strict rules. There are open-ended questions, and this interview starts with a fundamental question, and the interview is then constructed based on the fundamental question. However, the issue with this interview type is that interviews can deviate from the main topic; these interviews are time-consuming and can confuse the participants (Gill et al., 2008). Semi-structured interviews are used for the data collection of this thesis. Although scholars have studied niches, regime tensions are not focused so much in the past, creating the need to understand the topic deeply. So, semi-structured interviews will help deep understand the forces of niche momentum and regime tension.

All the participants are from different organizations in Finland. Their names cannot be used due to confidentiality, but altogether they are six in number. Furthermore, they are field experts and have worked for more than five years in their organizations. Participants were selected from companies in the shipping industry and different sectors such as battery manufacturers, shipping engine manufacturers, etc. All the participants were from different backgrounds, which provided a better understanding of the multi-dimensionality of the forces in the MLP framework.

PESTEL analysis was used for the interviews to represent the multi-dimensional forces for the MLP model in this thesis. It is an analysis tool that helps analyze the external environment impacting the industry or business environment. This method provides information about the relevant factors to a business, industry, or industry sector. PESTEL analysis includes political, economic, social, technological, environmental, and legal aspects. It is an essential tool for analyzing the environment and defining the future pathways regarding the developments (Matovic, 2020.). All of these factors included in the PESTEL analysis are macro-environment factors. The industry environment can be defined as the relevant external physical and social factors that are important while decision-making or defining future pathways. Moreover, these factors are sometimes the reason for value creation (for example, innovation or new technology or service) (Chao et al., 2007). This aspect makes it a critical analysis tool for this thesis, which discusses the multi-dimensional forces for niche momentum and regime tensions.

The interviews were conducted via Zoom software on video. These interviews were recorded with the permission of the interviewees. Once all the interviews were conducted, they were transcribed through MS Office. After the transcription, the interviews were divided into PESTEL elements; for example, discussions on political drivers and tensions were separated from the rest of the data and gathered under the political heading. The data was sorted by putting the text of each element under its related heading. Once data for each element was separated, then an important chunk of data was copied to the MS Excel sheet. The columns of the excel sheet were divided as per the company name, and PESTEL element data was copied into the rows. After this process, similarities were found in each of the columns, resulting in important drivers, regime tension, and niche dynamics. The patterns were then used for the discussions of the thesis.

3.4.2 Delphi method

For quantitative data, the Delphi method has been used to develop a consensus through the opinion of the field experts. The consensus is formed through several rounds of questions (Hasson et al., 2000). A pilot testing was done after creating the first draft of the questionnaire from the literature review, and through iterative rounds of adjustments, the questionnaire was finalized. Finding the right experts is of particular importance. The researcher has used the platform LinkedIn, where field experts searched through different search criteria, such as company name or professional background. Moreover, different companies and consultants were also searched, such as DNV and shipping associations of different countries, and through the internet database, contact details were taken. A selected field expert provides other experts' details in a few cases, also included in the survey. There was a list of 110 created. After creating the list, participants were sorted out who exactly matched the research interest and questionnaire, for example, relating to the shipping industry and working towards decarbonization of the shipping industry. The respondents were selected worldwide because I thought a wide geographical spread would better understand the topic under study. After sorting out, 84 participants were left. Webropol 3.0 was used to create the questionnaire and distribute it electronically via email. An introductory email was also written so that the participants could know the idea behind the questionnaire. In the first round, 39 respondents filled out the questionnaire. After adjustments, the questionnaire was sent to the same participants. There were several follow-up emails sent in both rounds. In the second round, 27 respondents filled out the questionnaire. A minimum of two rounds is required for consensus development (Skinner et al., 2015), and in two rounds for the Delphi of this study, the consensus was achieved. Furthermore, according to Karakikes and Nathanail (2020), among 41 Delphi studies in different fields, 17% were completed in two rounds, 71% were conducted in three rounds, 10% in four, and 2% in five. However, looking into the use of Delphi methods for the transportation sector, most of the studies consisted of two rounds, which means that two rounds are sufficient for completing a Delphi study. The survey was sent to more than 90 respondents; in the first round, 39 respondents responded; in the second round, 27 respondents replied. In the results section, the researcher will discuss the second-round results of the Delphi study because consensus is developed after the second round. The first section of the questionnaire was general, regarding the work sector, working experience, and region of working of the respondents.

The reason for this section was to develop solid and generalized results. Figure 8 below shows the result concerning these questions.

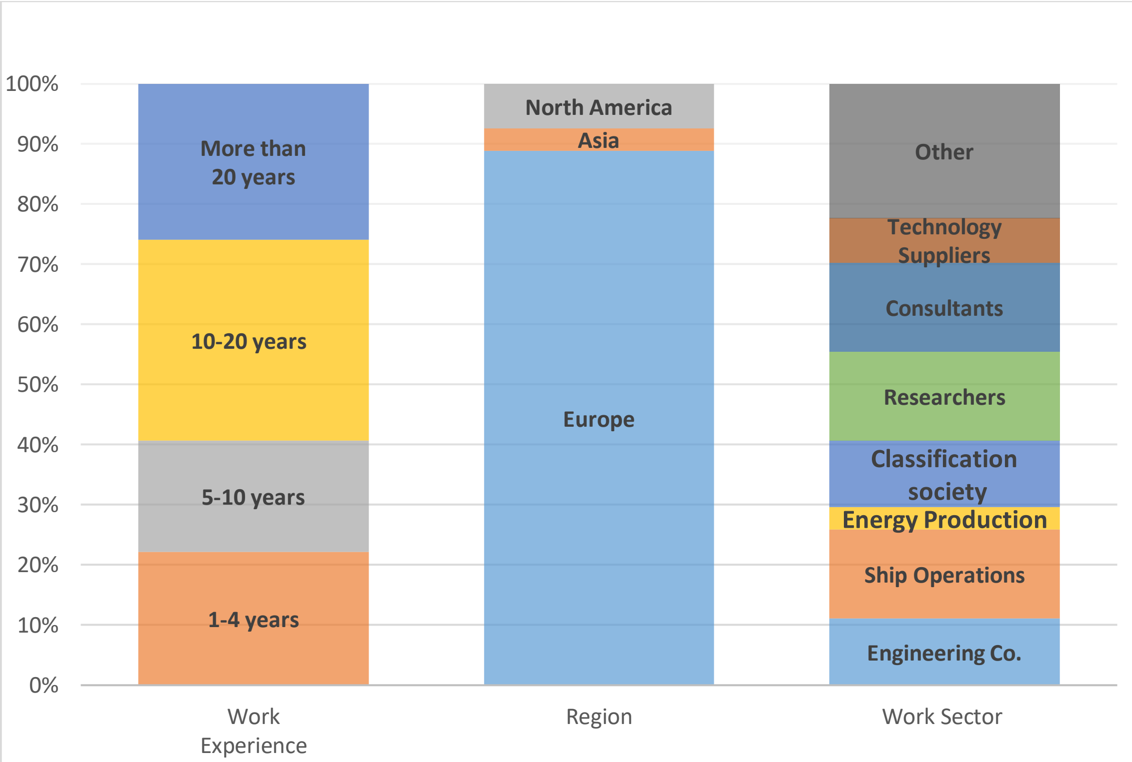

Figure 8. Demographics of the respondents to the Delphi.

The respondents are diverse in all aspects, as seen in the figure above. Six respondents had an experience of up to 4 years, 5 of the respondents were working in the industry for more than five years but less than ten years, 9 are the ones who had an experience of more than ten years and less than 20 years. The remaining seven had an experience of more than 20 years. Furthermore, the survey is geographically spread. Most of the respondents are from different countries in Europe (24), one of the respondents is from Asia, and two respondents are from North America. This result shows that input is from the places where there are many docking stations (Europe, Asia, and North America), and this input is vital to this survey. Last, experts were chosen from different work sectors because these sectors play the role of stakeholders in the shipping industry and technological developments and are related to the industry. Various working industries can be seen in the figures, and among others, there are respondents from non-for-profit organizations and the finance sector.

Moreover, after the first round, general questions, for example, the work experience, region, etc., were excluded from the questionnaire. New open-ended questions were added for the respondents, in which they could explain the reason for changing their answers. However, most respondents did not change their answers in the second round. For answering the questions, a Likert scale was used in the questionnaire of our Delphi study. The scale consisted of five options consisting of highly disagree, disagree, neutral, agree, and highly agree. For some questions, the scale consisted of very low feasibility, low feasibility, neutral, high feasibility, and very high feasibility options.
After the completion of each round, data was obtained from the Webropol software by exporting the results in excel sheets. Excel sheets contained the data by having separate sheets for each question. Statistical data analysis tools were used, and averages and standard deviation were calculated for each question of both rounds. After calculating averages and standard deviation, data from both rounds were compared, and a consensus was achieved. Higher the average and lower the standard deviation were more favorable for consensus creation. Graphs were generated using the results after the consensus was developed. The results and graphs are shown and discussed in chapter 5.

3.4.3 Workshops

Data was also collected through workshop activities in November 2021 and May 2022. Thirty-five experts participated in the first workshop and twenty-eight in the second one. (including the organizing team members). The online tool Mentimeter was used to collect the data in both events. The participants were experts from the shipping industry and engine manufacturing companies. All persons were experts in their fields and aimed at decarbonizing the shipping industry.

In both workshops, the participants got a list of the questions through an online link distributed among them to the Mentimeter. The first workshop included the question regarding the drivers for the niche momentum. They answered the questions by entering their answer into the software. They also ranked drivers. A similar approach was followed in the second workshop, in which the participants were asked about the possible blending of the fuels for the shipping industry. Also, a discussion was held regarding the energy transition of the shipping industry.

After they answered the questions in each workshop, there was a discussion held in which they provided helpful information for the study. After the poll, the responses were commented on and discussed with the audience. Notes were made during the workshop, and after compiling notes from both the workshops, an excel sheet was drafted, in which the notes were shifted. These responses generated notes that support the analysis and conclusions of the data.

3.5 Reliability and validity

Reliability and validity are the quality check of the data collection methods. It is an essential factor to consider as it is the foundation of the research because data are collected through them. Reliability means that the results will be the same if the method is applied on different occasions but in constant conditions. Moreover, validity explains that the used method can measure what is intended. It means that the questions must generate answers which can adequately address the research questions. This thesis's reliability level is increased so that the field-related people (who know about the topic) are considered while conducting the interviews. The questions for the interview were crafted after studying literature from several sources and pioneers of the MLP model to increase the validity. For explanatory studies, internal validity measures are applied, and this thesis uses the pattern matching technique for internal validity. In this technique, the patterns from the literature are matched with the results from the interviews. Then, the research questions are answered (Yin, 2018).

The interviews were conducted with different industry experts and at different times. Once the data was collected, then as discussed in chapter 3 (section 3.4.1), the data was sorted out in an excel sheet. There were constant patterns found in the excel sheet, and the quotations in the excel sheet were aimed in the same direction (for example, niche drivers), which explains that the research questions were adequately answered in the interviews. For example, these experts discussed political will, and it was mentioned by more than half of the respondents, which means that the method used is reliable and the validity is also checked. Moreover, the questions were carefully developed for the interviews after an extensive literature study, which was later matched with the answers from the interviews.

The data from the interview shows the pattern, and hence the validity is increased.
The Delphi method is based on the basic assumption that more numbers of respondents will result in the right decision because there are many people involved in the study. The arguments provided in the study make decisions stronger, resulting in the method's validity. Moreover, there were arguments also offered in the survey by the participants. As the participants are the top experts in the field, they have more knowledge, which validates the content in the Delphi questionnaire. Furthermore, because of several rounds in the Delphi method, the respondents' validity is checked each time, resulting in increased validity. However, if the response rate is high, then the validity of the questionnaire is strong, and a low response rate shows that the validity is low (Hasson et al., 2000). The validity of this Delphi study is high. First, the pilot questionnaire was sent to experts to check that the questions were valid. The second criterion that makes this Delphi study reliable and increases validity is the response rate. Almost 50% of participants responded in the first round, and more than 70% of responses were received in the second round.

4 Results

4.1 Regime Tensions

There are different forces creating tensions in the current regime of the shipping industry: legal, technological, economic, cultural, social, political, and environmental). These forces are acting as multi-dimensional forces toward the socio-technical transition of the shipping industry and putting pressure on the current regime of the shipping industry towards an emission-free shipping industry. Moreover, all of these forces are interconnected and play their part in destabilizing the existing industry regime.

Current technologies and systems are under pressure because of the trends focused on legislation, driving technological development toward cleaner technologies. Regulations are driving the technologies, creating a problem for the current technologies (combustion engine and heavy diesel fuel), and these regulations are advancing with time. It was found out that organizations such as IMO and E.U regulate the engine manufacturers and users of the ships to convert to emission-free technologies. This circumstance results in a technological shift because regulations will make the operation of certain technologies challenging. The workshop also discussed that regulations would result in problems for the technologies in use (for example, fossil fuels) and help technological development.

> *"We're not at the end of the line, so it's going to become better, and that's the purpose of the regulations. To actually get everyone in line and do the right thing" – Director for Sales and Product Management.*

> *"In my view, it's easier to see where I should put my eggs? Where should I Focus when I build or upgrade my fleet or order new bills. What is important? What will it be? How is it influencing my business"- Director, Sustainable Fuels & Decarbonization.*

> *"We are now at the middle of the Euro 6 regulation in full preparation for the Euro 7 Regulation, and I think the latest review on emissions for the shipping industry was during the*

Sulphur CAP implementation. It was that 2019 I think. Until then, it was possible to run the ships with the heavy fuel oil. " – Technical Manager.

"I know these regulations coming from the EU side, these new ones and then there are these EEDI, and see carbon intensity index we are working with them our team, that calculates the EEDI numbers, and we have been studying these carbon intensity index, but we monitor the fuel consumption, and we simulate the energy efficiency"' _ D. Sci. (Tech.) RDI Programs.

"Shared responsibility of you know reducing emissions the IMO targets. 20 thirty 2050 there are very ambitious and, but they're also forcing that through the carbon intensity indicator, for example, EEXI, it's another good example on that ever-tightening EEDI regulations" – Senior Customer Success Manager.

"'I think everyone is also waiting for how the regulations will change. So, what is the opinion in the future? So, can we burn anything or is all the technologies which burn something are not okay" – D. Sci. (Tech.) RDI Programs.

Technologies are changing and moving towards greener solutions, and energy transition is happening in the shipping industry. Better and environmentally friendly solutions are under the development process so that fossil fuels can be replaced with a technology that is less pollutant. Furthermore, pressure from the end-user can also be observed in the discussions with the interviewees, resulting in the shift of technology from fossil fuels. Again, other industries are also putting pressure on the shipping industry to move toward emission-free technologies.

"I see a trend towards expanding the clean-up effort, so to speak, going passenger cars electrifying then hybridizing or going with the different fuels in the heavy-duty industry and off-road and also expanding to the shipping industry. But this is already happening. Perhaps maybe more visibility. It's an industry that in a way is well known."- R&D Fellow.
"Many of the companies who outsource transportation, logistics or forest tree cutting or whatever, demand from the suppliers that you need to have the latest technology, sometimes even the higher technology What the regulation requires. Municipalities are very special in this, so that some municipalities may say that yeah, we want to buy grass cutting from your company, but your vehicle needs to be electrically operated, even though that's

not a regulatory obligation. So, this is probably one of the big megatrends"- Director Sales and Marketing.

The current system (fossil fuel) will also face some problems, such as high tax rates for using fossil fuels or the machines and engines using fossil fuels. Moreover, suppose the user changes the technology. In that case, they can get some subsidies; this acts as economic pressure on the current technologies that are not emission-free or emit high pollutants. In this reign, policymakers are putting pressure from the economic perspective with the help of different measures so that the manufacturers and users should not act as an obstacle in the energy transition of the shipping industry. It can be seen in the following example.

"Economy of the government, of course. Can they control the directions or even stop some of these fuels used or some other trends, by using such high taxation or get having this tax free electric cars now" – R&D Fellow

"The fossil fuel Could hit some additional taxes That drives really the users to giving up their own old machines and not just keeping their old machines alive for ages because they are better and easier to operate, and et cetera" - Director Sales and Marketing.

There is a shift seen in the cultural values and beliefs of the public, which is also acting as a problem for the current technological systems of the shipping industry (fossil fuels, combustion engines, etc.). They are not liked by the customer anymore, and they are moving towards greener solutions that are environmentally friendly, resulting in creating problems for the current technologies. Similarly, social drives are also putting pressure on manufacturers in the shipping industry. Regulations and policies are related to society, and they need to be regulated, which can create awareness in the right direction. Social pressures are related to the policies reflected in the legislation, so social pressures are building up in the society through different social groups and social trends by using social media.

"People have already learned to hate diesel and the piston engine. If you go there to the city center and ask that should we get rid of piston engines or combustion engines? Most

likely people say that yes, let's go to something which doesn't pollute" – Director Global Product Management.

"So, I think for the EV market, it's When you look at Norway. The end consumer has already decided – electrification... I think Audi said 2025 is the last or the last or 2026ish in that range. They will not develop any new internal combustion engines from that day on. But by then, I mean BMW and Volkswagen; they're both out of the internal combustion engine within the next Four or five years, so it's. It's maybe one or two. Uh, product lifecycle changes, and they will be out of internal combustion engines" - Director for Sales and Product Management.

"So, I think social media it's something that, in my view, should be a little bit more regulated when it comes to influencing social matters; it's good, don't get me wrong. Look at the Floyd case in the US and Black Lives Matter and equality. And I mean, they are social Cases; it's areas that benefit from this kind of engagement, but in the shipping industry, I find it right now kind of hard to connect one with the other, except if we think about yes, the emissions that come out of the shipping. Industry and how to improve them? Yes, I think this is something that could become very trendy. And, by extension, influence politicians who could put more pressure on the legislators. It's a chain of events"' – R&D Fellow.

Politics is also influencing the energy transition in the shipping industry because of social pressure on politicians, which destabilizes the shipping industry's current regime. As per the interviews, one way of doing it is through stopping the investment in the current technologies in the existing systems, which will drive the companies to develop environmentally friendly solutions and technologies.

"The pressure from the society and it is building up. Politicians are making decisions to reduce the climate deterioration and have stopped investing in fossil fuels and so on." – Director- Sustainable fuels and decarbonization.

There are agendas worldwide, green agendas, and these agendas are there from an environmental point of view, putting pressure on the companies and organizations toward sustainable solutions. It can be observed in the explanation given by the interviewees; they discussed different agendas driving the transition toward zero carbon emissions.

"Climate is one of them. The wilder the climate becomes, the more at risk this industry is, in particular, who transports goods from around the world through the ocean. If you are in a hurricane season that never ends, chances are the risk to your cargo is higher. So, addressing climate change is affecting the shipping sector towards different solutions"' – R&D Fellow.

4.2 Niche momentum and dynamics

There are multi-dimensional forces responsible for driving the socio-technical transition in society. Similar is the case for the shipping industry. These multi-dimensional forces are interrelated, creating momentum toward new technologies and bringing a new system to the shipping industry. Interviewees were asked about these forces, and they responded in the following way

According to the respondents, it is the leading force behind technological innovation and the development of new technologies concerning the legal drivers. The shipping industry is run by legislation, and the technology used in the ships must be according to them. Moreover, the future direction of the technology used in the shipping industry will be directed by the regulations imposed by different organizations (IMO, EU, etc.). It is also found that companies are looking forward to the legislation and developing their technologies to comply with them.

"Our business is 100% driven by legislation. The development of our products is 100% tight with what the government agencies require of OEMs to cut emissions as a consequence of the whole emission regulation program that started in the early 70s."- R&D Fellow.
"I'm expecting to see. Some sort of CO2 reduction? Uh, limits for the future, so we will step into a new era; instead of, uh, limiting Poisonous emissions, we start to limit CO2, which is not traditionally being treated as a poison. So it drives into new technology for sure... the regulation will Show the direction where to go"- Director Global Product Management.
"I would like to see more regulations based on technologies so that we would think about what is available, how we can develop these technologies. And how we can achieve these."- D. Sci. (Tech.) RDI Programs.

The workshops also found out that actions from bodies such as IMO and EU result in different principles such as Poseidon principles and taxes. Taxes were the most discussed legal driver because the socio-technical transition is happening in the shipping industry. Moreover, as explained in the interviews, similarly in the workshop discussion, regulations are driving the technological developments in the industry, which makes it one of the most impactful drivers towards the transition.

Regarding the technological drivers for transition in the shipping industry, the interviewees responded to the question in the following way.

> *"I think we need to get to the point very soon that we also ask ourselves which technologies are actually worth using in a particular application? And that's why it's so important to have a lot of solutions available so that you can actually have a large variety to pick from the preferable solution or the preferable technology in any individual application… I think, generally, my expectation is we are going to see a lot of new players, a lot of new ideas"- – Director for Sales and Product Management*

> *"There's a process you go through to make something that can look very risky and very unsafe at the beginning, turn it into something standard and safe and perfectly good to use and any new technology that that deals with the reduction of emissions and relies on things that might look risky today will be definitely in a very different level in the future, as long as we spend the time and the money in research and development; we will eventually get there" – Technical Manager.*

> *"We are developing a prototype at the first stage of our business. This is the work we have in front and now we have ahead. Yes, and around that, we need, of course, to attract funding to support our prototyping activities" – R&D, fundraising, and development.*
> *"I can see that there's already like coming solutions, you know, creating those platforms for like technology platforms to enable this, you know overall better, early efficient or better-operated industry"- Senior Customer Success Manager.*

> *"So, we are actually there now running reference tests and surprisingly good results, up to close to 50% of power reached on that engine. We take it then step by step to develop technologies that would better suit Hydrogen; it looks promising... Of course, we see technological development as we have the need and we'll do to reduce the carbon*

footprint, but the technology is maybe not fully available, and the fuels are not available so that it will lead to this development of energy-saving devices or actual implementation of them." – Director, Sustainable Fuels & Decarbonization.

"Public programs, so it's fully okay, of course, the 10 million EU-funded projects. And yes, we are lucky to have companies to coordinate for the whole program" – Director, Sustainable Fuels & Decarbonization.

Different technologies are being tried in the market, and there is a lot of learning happening in the market, and new technologies are developed. According to the data collected, there are different technological solutions required for different applications. Once they are developed, the most efficient can be selected from the options. Furthermore, some of the technologies will not look suitable now. Still, with the technological development, they can be tested and improved and result in more efficiency than others for the transition purpose. These will happen with technological development, and research is required for the cause, which requires funding, for which the companies are striving. Moreover, technological development is also a driver for funding to develop and test new technologies. Furthermore, it can also be observed that the technological driver is the emission-free shipping industry, and engine manufacturers are developing new technologies for this aim. The respondents also mentioned other drivers, such as electrification, carbon-free fuels, and data sharing.

There are different ways to enable the energy transition, and low carbon emission in transportation can be achieved. According to the experts, there are other important ways. According to the experts, supply chain optimization, marine power plant, voyage optimization, slow steaming, and other measures may also be effective (Figure 9). Furthermore, alternative fuel seems to be the most effective and quick way toward zero carbon emission.

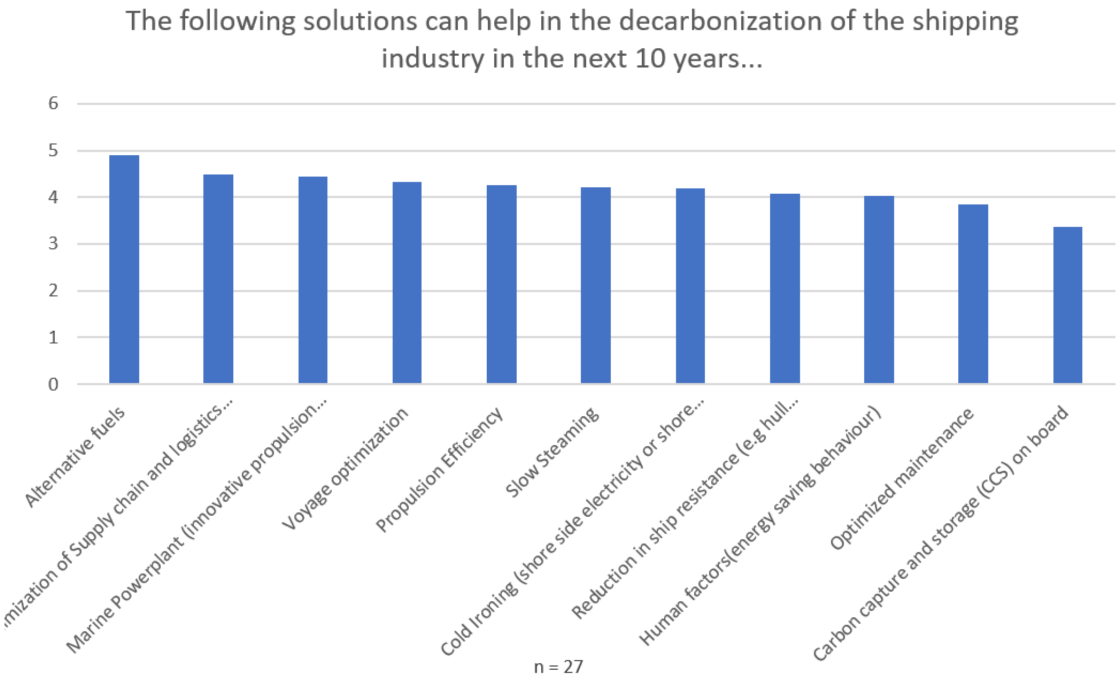

Figure 9. Solutions for decarbonization.

Generally speaking, LNG and biofuels seem to be the dominant options until 2030, and synthetic fuels may dominate after. Still, there are differences between segments (short sea shipping, deep sea, cruise vessels, short sea cargo). Based on the Delphi study, Figure 10 shows the emergence and use of alternative fuels for the shipping industry for the niche market of short sea shipping. In the ten years, the most feasible fuel is LNG with an average of 3.8, and biogas (average 3.7) and biodiesel (average 3.7) are the feasible fuels after LNG. Furthermore, other fuels follow the lead of the top three most feasible fuels (LNG, biogas, and biodiesel). Battery, wind energy, and synthetic diesel were the addition by the experts.

In the 30 years, Methanol seems to be the most feasible alternative fuel for the short sea shipping niche, with the highest average of 4.1. Hydrogen is the second most feasible fuel (average of 3.8) and the third-highest in the Ammonia, with an average of 3.5. There were two new options added in the first round: battery and wind energy, and the battery is the most feasible option among the two new, with an average of 4.1. However, only 21 respondents submitted their responses for the new opportunities, so the averages of already mentioned fuels were the highest.

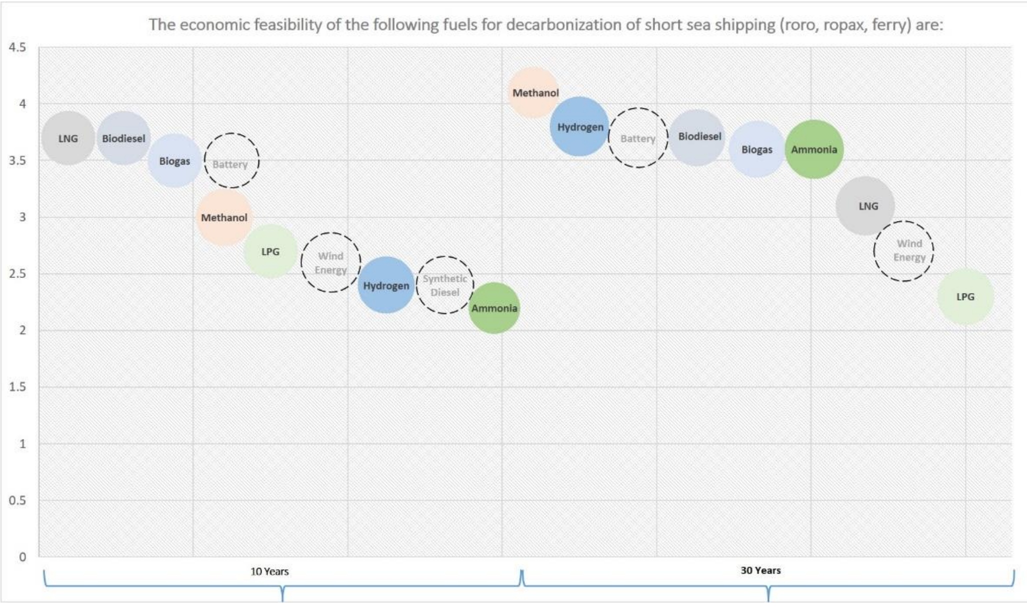

Figure 10. Alternative fuels for short-sea shipping

Concerning deep-sea shipping, Figure 11 below represents the answers for ten years and 30 years. LNG has had the highest average for ten years, making it the most feasible alternative fuel in the shipping industry, followed by biodiesel (average 3.8) and biogas (average 3.4). Furthermore, Methanol also has the same average (3.4). The rest of the fuels are followed by these top average fuels: LPG (average 2.9), Ammonia (average 2.7), and Hydrogen (average 2.0). The experts also made new additions, including wind energy, synthetic diesel, and battery. According to the experts, wind energy is the most feasible, comprising 3.0.

Similarly, for 30 years, the most feasible fuel is Ammonia and Methanol having an average of 4.0 (average 4). These alternative fuels are followed by biogas (average 3.7), biodiesel (average 3.6), LNG (average 3.2), Hydrogen (average 3.0), and LPG (average 2.3). The respondents also add new options through the open question; these include wind energy and nuclear energy. Among the two, wind energy is considered more feasible, with 3.3.

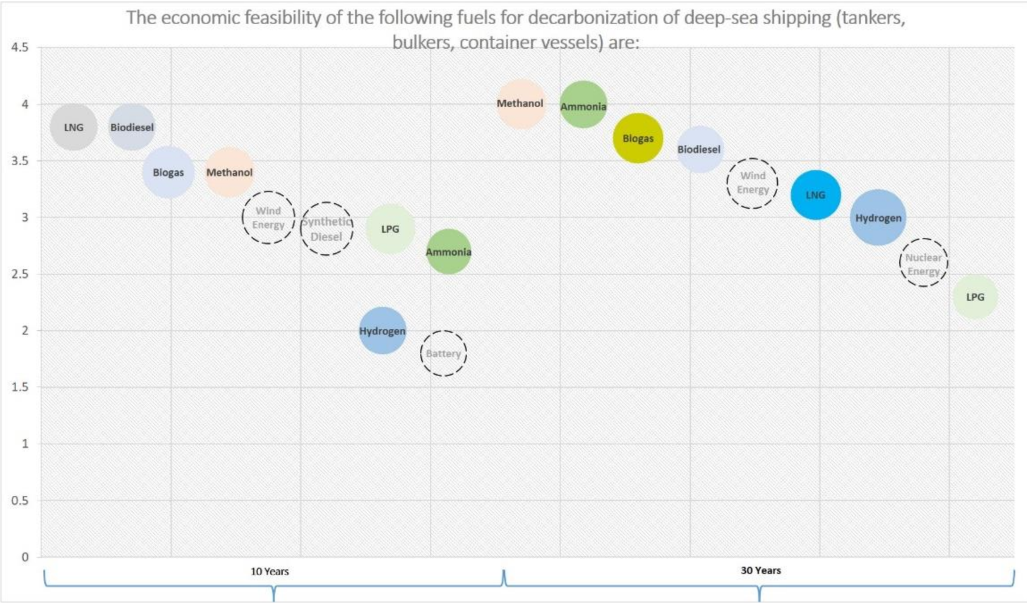

Figure 11. Alternative fuels for deep-sea shipping

Concerning cruise vessels, the results can be seen in Figure 4. According to the experts, the most feasible fuel for cruise vessels in the following years is LNG (average 4.1). Other feasible fuels include biogas (average 3.9), Methanol (average 3.1), LPG (average 2.6), Hydrogen (average 2.1), and Ammonia (1.7). New options given by the respondents are synthetic diesel, battery, and wind energy. The most feasible among these new additions is synthetic diesel comprising an average of 2.7). For 30 years, the most feasible fuel is Methanol having an average of 4.1, followed by other fuels: biogas (average 3.7), bio-diesel (average 3.7), Hydrogen (average 3.4), Ammonia (average 3.2), LNG (average 3.1) and LPG (average 2.0). Similarly, a new option was added: wind energy has an average of 2.5. The results are given in Figure 12 below.

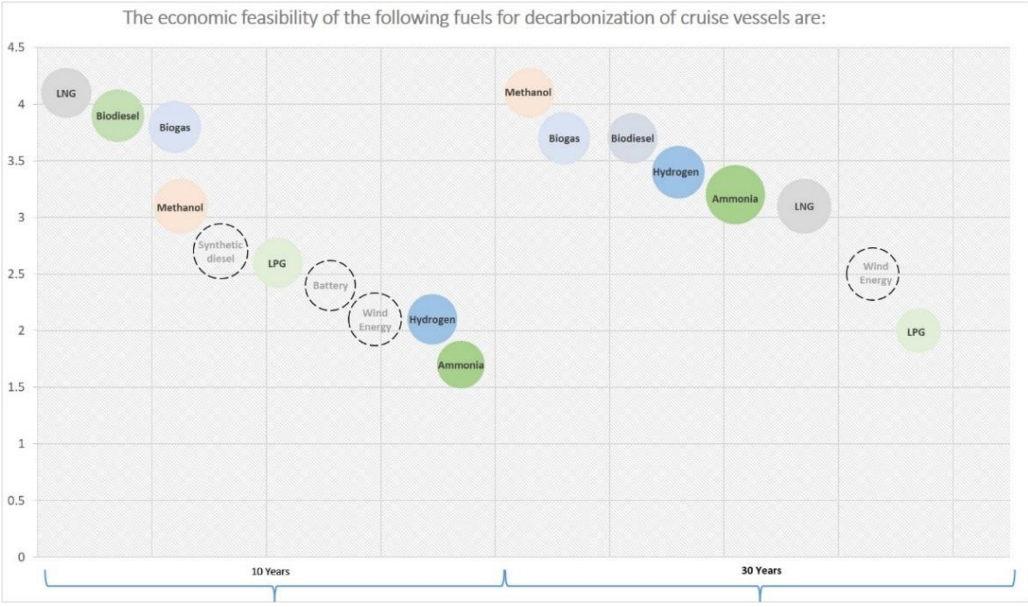

Figure 12. Alternative fuels for cruise vessels

The last market is short sea cargo. For the next ten years, biodiesel has been the most feasible fuel with an average of 4.0, followed by LNG (average of 3.8). Other fuels as per their feasibility are biogas (average 3.6), Methanol (average 3.4), LPG (average 2.9), Ammonia (average 2.7), and Hydrogen (average 2.4). Only wind energy is given as a new option having an average of 2.6. Methanol has the highest average of 4.0, making it the most feasible fuel for the next 30 years, followed by Ammonia (3.8). Hydrogen (average 3.8), biodiesel (average 3.7), biogas (average 3.5), LNG (average 3.0), and LPG (average 2.2) were also ranked as per their feasibility. New options were also included by the respondents: wind and nuclear energy. Wind energy is the most feasible among the new options having an average of 2.7. The results can be seen in Figure 13.

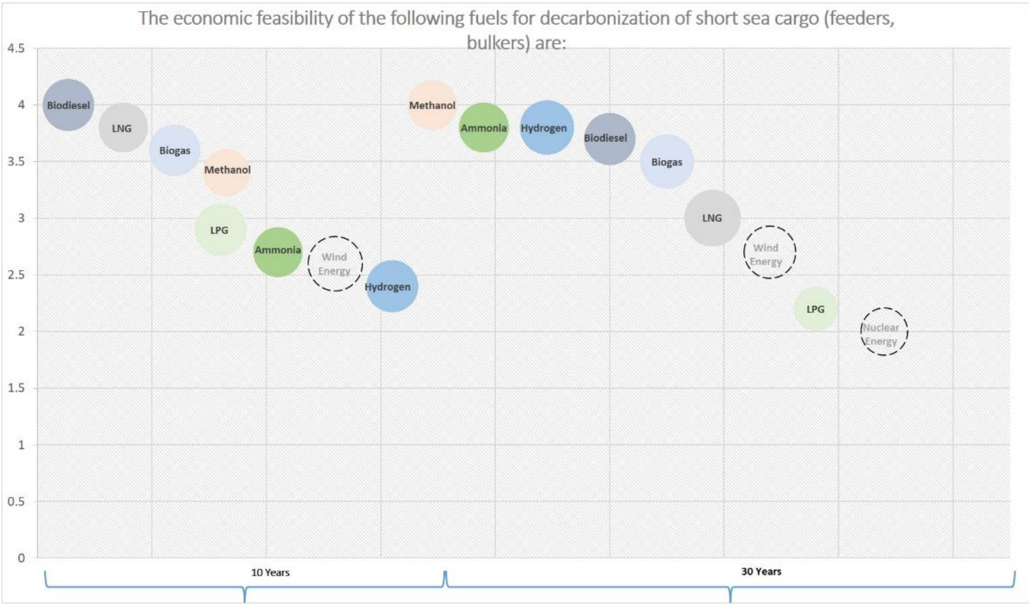

Figure 13. Alternative fuels for short-sea cargo

In short, the leading alternative fuels will not be the same for all segments, and the transition timing depends on the demand, fuel availability, and infrastructure development. Although it seems challenging to conjecture, even for main stakeholders in the industry, workshop discussions point to fossil fuels declining in importance but remaining present for a few decades to come, supported by scrubbers, carbon capture, and SCR technologies. Blending (drop-in) seems to be the option that will begin to dominate in three to five years as a transitional solution, standing for a couple of decades. Finally, the next decade could see the strong emergence of green fuels as a more definitive solution (hydrogen, ammonia, and methanol). In this context, according to the experts, LNG (fossil and bio), biodiesel, and biogas (perhaps also methanol) are on the horizon until 2030. When thinking beyond 2030, methanol and ammonia seem relevant in deep-sea shipping and short sea cargo (biogas and biodiesel being one step behind in both cases and hydrogen for the latter). Instead, methanol and, to a lower extent, biogas/biodiesel may dominate cruise vessels (with hydrogen and ammonia one and two steps behind, respectively). Methanol and hydrogen, to a lower extent, are the most potential ones in short sea shipping (although, in this case, it seems to be a bit more open since ammonia, biodiesel, and biogas (even batteries) are high in the valorization too). Of course, these results do not consider blending possibilities, which seems to be a good transition option until one fuel becomes the standard, probably way after 2030.

The last questions in the survey explore barriers and uncertainties toward alternative fuels. According to the experts in the panel, the main challenges are technology readiness, low energy density, safety issues, and bunkering capabilities. They also emphasized the heavy investments and low financial performance, the requirement for new business models, and the regulatory uncertainty. On the other hand, there were many options regarding possible uncertainties (Figure 14). The most significant uncertainty per the experts is whether alternative fuels will be used for short or long-distance shipping. A similar type of alternative fuel can be used in all ships (long or short distance). Another issue is the use of alternative fuels by other industries. It can also produce a spillover effect and result in economies of scale. The future supply of the alternative fuel, meaning the availability, is also a barrier. Other obstacles and uncertainties include the LNG and LPG usage that will be only used for short terms. Adjustments will be needed to the ships once the fuel for the engines is changed. Another uncertainty concerns the regulations that can limit the options of alternative fuels. Also, there is a barrier to reducing local emissions (or greenhouse emissions). From the investment point of view, technological change can be a barrier to the zero-carbon emissions goal set by the IMO.

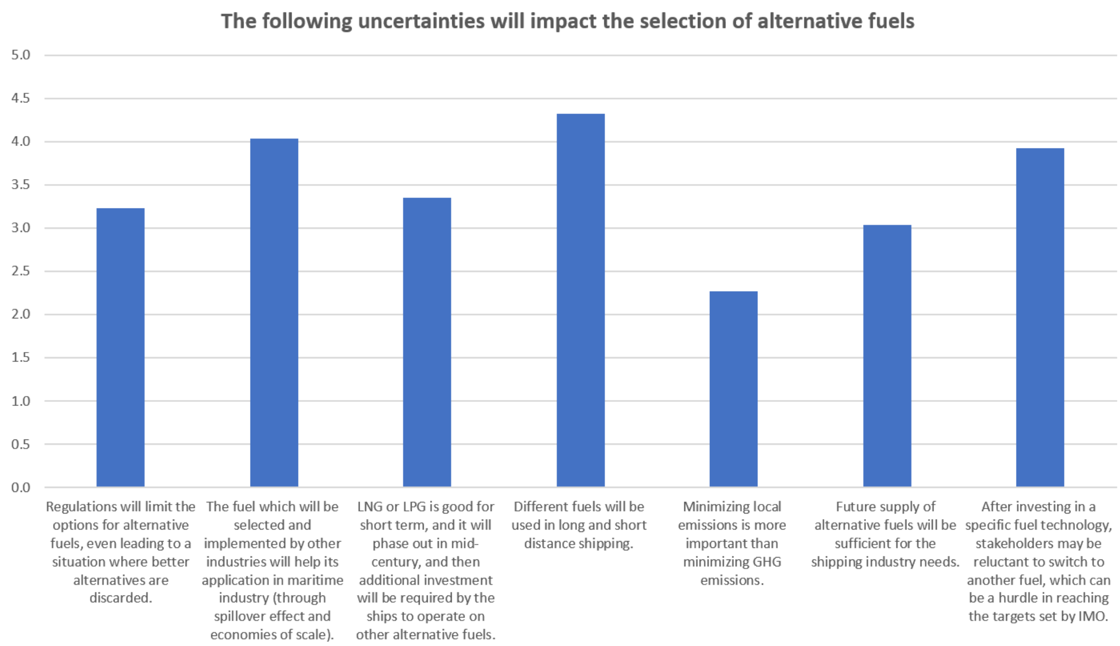

Figure 14. Uncertainties regarding alternative fuels

Concerning the drivers of niche momentum and their dynamics, following the PESTEL model. Thus, the respondents explain to the economic drivers as follows. To gain loans at low-interest rates, companies are working towards a sustainable solution in the shipping sector, which shows that economics plays a driving role in the energy transition of the shipping industry. Moreover, through the workshop discussion, it was found that the effect of taxation will be there on the shipping price and end consumer, and sustainable finance was also discussed. Through the initiative of sustainable finance, interest rates for the users and manufacturers of ships will be lower, aiming at the decarbonization of the shipping industry. In the interviews, the driver was answered in the following way.

> *"Some are, of course, smaller customers that need the help and guidance, and some are more big customers that know themselves and need more dialogue to understand. But what would be a feasible fuel or feasible technology for them? So, they are very closely monitored, these financing mechanisms" – Director, Sustainable Fuels & Decarbonization. "It's all often the economics. What is the best for the economics that what will be and also it needs to be, Trusted technology, which will be the winning technology" –Technical Manager.*

> *"Banks and financial institutions port authorities also require certain, you know, efficiency for cargo owners, from their clients from their ships and the partners they do business with. A lot of companies are also following the ESG environmental, social, and governance, you know, KPIs, and there they just have to meet certain targets. So, it is not only reducing greenhouse gases; it's not only about reducing fuel costs but also getting, let's say, cheaper financing, cheaper loans, getting cheaper or lower part costs and so forth" - Senior Customer Success Manager.*

Cultural perspectives are also changing in public. Vision and values are changing for the users and the market, acting as drivers for shifting the shipping industry to cleaner technologies. It can be seen through the following example

> *"There are many ways that people try to affect. In China, It's more like in my mind it's coming that see that the environment is suffering and they are more and more I would say*

that especially the younger generation that they see a lot of value to try to Save the environment"' – Director Sales and Marketing

"In Finland, for example, and people, we have access to all the information that of course, what you are selecting, but we are supporting your ideas and is it coming more and more green ideas." – R&D Fellow.

"I think there is a very clear change in the past, let's say five years, on how the ship owners, the charterers, and the industry in general approach these topics. Let's say, previously, the fuel savings, and especially like reducing emissions in using a decree in house gases, was seen more like a PR stunt, but more like providing value for the image and PR value for the company. But I think that is now history because of the general public" – Senior Customer Success Manager.

Concerning the social drivers for the energy transition towards a carbon-free shipping industry, the respondents mainly focus on the social pressure arising in the world and driving the industry towards energy transition.

"One big financer said that they already start to see the pressure from the society and it is building up" - Director, Sustainable Fuels & Decarbonization.

"The social aspect comes into the picture when we have the end-user, yes. Oh well. I don't know if you know the big picture, which evolves around the agricultural market or business. There's a lot of pressure on agriculture producers, yes, but they should be more sustainable. They should do their agriculture in different ways. They should not open the ground, just leave it, use fewer chemicals and things like that and also try to reduce the amount of emissions they produce by using their machinery by lightening their farms and warming their farms. And for the animals or things like that, there's a lot of pressure on that, and that pressure Is socially touchable already"' - R&D, fundraising, and development.

Regulations and policies are related to society, and they need to be regulated, which can create awareness in the right direction. Social pressures are related to the policies reflected in the legislation, so social pressures are building up. Interviewees also showed interest in this aspect; for example, they explained.

“I think the expectation of every end consumer and citizen becoming the expert in energy storage, sustainability and recyclability and those kinds of issues I, think that is, that is too much to ask for the everyday citizen. And that is exactly why it needs to be regulated. Because that's a burden on the end consumer …. there is something that is already being done in the battery regulation to make sure that if you are interested as an end consumer so that you can get the information where my battery is coming from, is it a better or worse battery? Is it just a sustainable battery yes or no?” – Director for Sales and Product Management.

“So, I think social media it's something that, in my view, should be a little bit more regulated when it comes to influencing social matters; it's good, don't get me wrong. Look at the Floyd case in the US and Black Lives Matter and equality. And I mean, they are social Cases; it's areas that benefit from this kind of engagement, but in the shipping industry, I find it right now kind of hard to connect one with the other, except if we think about yes, the emissions that come out of the shipping. Industry and how to improve them? Yes, I think this is something that could become very trendy. And, by extension, influence politicians who could put more pressure on the legislators. It's a chain of events. ” – R&D Fellow.

Social and cultural aspects were also discussed at the workshop. According to the discussion, society has pressured for transition in the shipping industry. Along with the social pressure, other drivers were also mentioned, such as a healthy environment, human health, and the brand image of the companies. Moreover, taxes are also considered a societal driver for socio-technical transitions. Concerning the political drivers, most respondents answered elaboratively about the political drivers responsible for the niche momentum of the transition happening in the shipping industry.

“There's a lot of political will involved. Electric vehicles have been out for how long. There has always been a talk about the transition to electricity, and it took just enough political will to really make it happen... If there's enough political will to make it happen, and chances are it will.”- R&D fellow.
“It's well-intended, and as far as I see, I think we're moving in the right direction; it's not perfect from the 1st draft for sure. But I think that's actually the task for the political regulators, for the legislation too to create the rules around the market.” – Sales and Production Director.

"And governments they have the driving force because they are increasing the price of fossil fuels and taxation and they are lower taxes for electric cars and maybe also industrial, or machinery's they can support in many ways and so they are forcing to certain direction even if not at the moment Very quick quickly The best way to cut emissions or economy, but this taxation, and governments are pushing in that direction" – R&D Fellow

It can be seen that political will is an essential driver for the niche momentum. It is also helping the rules and regulations to be facilitated by political will towards the decarbonization of shipping. The electric vehicle transition can help to understand it. Moreover, other participants also added to the political drivers.

"A rapid or faster Development for emission alternatives on this industry if political will and OEM participants proactively looking for cleaning act. The responsibility of cleaning up the act and many OEM participants are very proactive in looking for solutions. They have their development divisions Looking for improvements, and if that gets combined with enough political helping hand. I think we can see a rapid or faster Development for emission alternatives on this industr"'- Technical manager.

"The pressure from the society and it is building up. Politicians are making decisions to reduce the climate deterioration and have stopped investing in fossil fuels and so on." – Director- Sustainable fuels and decarbonization.

It can be seen that political influence can impact the energy transition in the shipping industry, and niches are looking into better technological developments. Funding for new technologies provided by the politicians is among other drivers that we identified through the data. Interview participants also explained the current scenarios and their willingness toward the great cause of decarbonization. A lot of improvement is still required, but efforts are being made in this reign. There is not much effort put into making the right decision, and it is resulting in a massive barrier to the development of the new technology and socio-technical transitions.

Organizations and businesses sometimes oppose political decisions, as we can observe from the discussions with the interviewees. These decisions can sometimes create a problem for companies and make it difficult for them to shift and adjust according to the political decisions. However, this is a complex issue, and more insight is needed to carry it forward regarding the energy transition agenda successfully.

> *"When it's fully political decisions, then, of course, the time is an issue that it will drag on and on and on, and somebody puts in vehicles, and we will not approve this. And then it's just. It's delayed"' - Director, Sustainable Fuels & Decarbonization.*

> *"The cars that are zero emissions and these things. These are things that get you to vote... The connection with reality can be, in some instances, quite questionable. So, for me, political decisions need to also be in a way have some oversight that we don't by legislation, then force a solution that will create a problem somewhere else, or fix a problem by creating another that you don't see now, but it's going to hit you Like a Pamplona bull ten years now on the road." - Funding advisor, Research services.*

Environmental drivers toward energy transitions were also discussed in the interviews. The responses were extensive, for example.

> *"Emission clean-up is a big agenda, and it's percolating other industries, it's Media wise, and attention wise is still very much focusing on on-road and the transport sector, but to me, the shipping industry is just another type of transport. It's just not on wheels. The transport does just like a long truck haul. And I see a trend towards expanding the clean-up effort, so to speak. Going passenger cars electrifying then hybridizing or going with the different fuels in the heavy-duty industry and off-road and expanding to the shipping industry. But this is already happening. Perhaps maybe more visibility. It's an industry that, in a way. Is well known" - Technical Manager*

> *"Traditionally, we've been limiting NOX and particulate emissions. But now, clearly, the whole greenhouse gases are kicking in. So, I'm expecting to see some sort of CO2 reduction limits for the future so that we will step into a new era; instead of limiting Poisonous emissions, we start to limit CO2, which is not traditionally being treated as a poison. So, it drives into new technology for sure." – Director Global Product Management*

There are green agendas all over we can see, according to the interviewees, and these environmental agendas are also driving the politicians towards trying for a cleaner environment. It was also found that emissions considered for polluting the environment have broadened its scope (for example, including different emissions, which were previously not included). The shipping industry can see the transition because of the environmental driver, among other sectors. Environment as a driver towards decarbonization of the shipping industry was also discussed at the workshop discussion. The same points were raised in the workshop, for example, green agendas and agendas aimed toward a cleaner environment.

Technologies are the new development in the niches of the shipping industry, which can use the alternative fuels in the combination or single fuels can also be used. While discussing different technologies, the respondents also clarified that there could be a combination of one of the alternative fuels (blending), as there is no single solution for the decarbonization of the shipping industry. It was also found that current technologies (propulsion systems) can still be used with other alternative options to reduce the emission in the shipping sector, and the industry will move forward toward the socio-technical transition. Furthermore, it can be observed that the current engine will be used in the ships for a long period of time because, without it, the technology will not advance. Internal combustion engines will be used in ships. There will be adjustments in these engines, which can run on the traditional fuel and alternative fuel, such as Ammonia or LNG. Current emissions can be reduced with the help of blending fuels. The use of batteries can also be seen in this context, as batteries can be used for the electrical system of the ships. This will impact the socio-technical transition of the shipping industry gradually. Moreover, these fuels are also used in other industries, for example, racing cars. The internal combustion engine will develop with time. Once it is developed completely, alternative fuels can be used as a replacement fuel for fossil fuels, resulting in a socio-technical transition.

> *"You have the blend scene or blending of fuels hydrogen, Natural gas or diesel biodiesel, etc. And then slowly move over to higher contents of this new fuel and reduce the fossil fuel amount in the blend Step by step. We already run this summer 40% ammonia in 60% diesel." – Director, Sustainable Fuels & Decarbonization.*

'Blends of fuels are also a possibility. One way to reduce the carbon footprint is by adding something that can work with your combustion process without generating any emissions, like blending Hydrogen and CNG. That's a way I believe that, in the end, it will be a mix. I don't think it would be one thing that Will do it for everything' – Technical Manager.

"I would raise the hybridization at some point or some form. In our machines as well, so keeping the diesel engine piston engine. And then hybridize some parts of the existing machine, like pumps, and recuperate energy with the turbo-charger. Installing hybrid mode systems." – Director Global Product Management

"Toyota is designing, and we're building already engines with fuel cells, but also with internal combustion." – Director , Sustainable Fuels & Decarbonization

"'Electrification is coming, but the internal combustion engine is also evolving. There will be Improvements, hybridization, and other fuels E-fuels D- fuels, hydrogen" - R&D Fellow, Technical Manager.

5 Discussion and conclusions

This chapter includes a discussion based on data collected and presents the general conclusions of the thesis. Future research directions are also suggested based on collected data and experts' opinions. The primary research questions of the study are: 'How do multiple dimensional forces impact niche momentum and act as sources of regime tensions in the socio-technical transition concerning alternative fuels in the shipping industry?' And 'How do these forces impact the emergence of a dominant standard during niche development?'

The study was done in the context of decarbonization of the shipping industry under the MLP framework to observe the socio-technical transition. The shipping industry is going through a transition phase from the use of fossil fuels polluting the environment and creating a basis for climate change to zero-emission solutions. There are different options available for zero-carbon emission. Still, alternative fuels are one of the most efficient ways to achieve the goals. The energy transition can be completed in the shipping industry through the application of new technologies which can adopt alternative fuels in different market segments. There are various market segments: deep sea shipping, cargo vessels, short sea shipping, and short sea cargo, and based on their nature (for example, long-distance or short distance), different technologies(niches) are suitable for them. The basic idea was to look into the forces behind the niche momentum towards the fuel transition of the shipping industry and to study the forces that create regime tensions for the existing technology (e.g., fossil fuel and combustion engines). For the study, the development of different technologies to adopt alternative fuels is considered technological niches. Four different vessels are regarded as the market segments, and they are also considered market segments. Niche dimensions are considered in different alternative fuels in niche markets. In this context, different niche dimensions were also evaluated in the study. Furthermore, an effort was made to discuss the alternative fuel options for the shipping industry, along with the uncertainties related to the shipping industry's transition.

5.1 Discussion

According to the MLP model, niches are where new technologies and innovations are developed and tested. There are multi-dimensional forces that are driving the niche momentum. In this study, those multi-dimensional are examined. According to the data collected, there are problems in the existing system, creating tensions in the regime and shifting the technological use in the shipping industry, aiming to save the environment from the effect of climate change and global warming. Figure 15 shows the multi-dimensional forces acting on the socio-technical transition of the shipping industry.

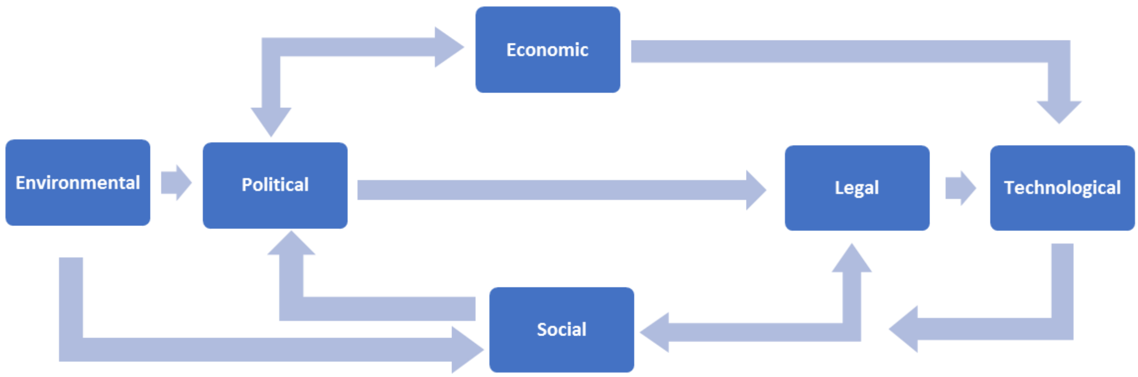

Figure 15. Multi-dimensional forces toward a socio-technical transition of the shipping industry

It was noticed that the environment is the primary driver that stimulates the industry to protect the planet from the catastrophic impacts of climate change. The earth's temperature is rising, and there are agendas from organizations such as the E.U to address this issue, directing the shift towards sustainable technologies. Both the user and manufacturer sides feel the pressure from these institutions and their agendas. Moreover, due to environmental drivers, the focus on emission types has also increased, meaning that even minute details are considered essential, resulting in the change of the previous image. Global waste and recycling are also an issue that needs to be considered. Looking at this issue from the perspective of the environment is essential because they are also polluting the environment. Furthermore, health concerns are increasing; for example, China has a high amount of pollution, destroying their environment, and health concerns are growing. Green agendas are critical to cater to all these issues. They are playing their role in the socio-technical transition of the shipping industry, as it is a significant contributor to harmful emissions. These agendas put pressure on the policymakers, and due to this pressure, the policymakers will be more focused on creating these policies to make the socio-technical transition happen (Penna & Geels, 2012).

Environmental concerns put pressure on politicians' agendas to act accordingly to address critical environmental issues such as climate change, global warming, emission reduction, etc. These pressures result in political moves aiming toward the decarbonization of the shipping industry because it is a significant contributor to the world's emissions. Thus, the political will is the first factor (and one of the most crucial) that plays its role in driving the socio-technical transition of the industry. Because of political will, no legislation may emerge, and, consequently, we can see the evolution from traditional vehicles to electric vehicles. Previously, in the context of politics, such ideas were considered PR stunts, but now they are taken more seriously.

Environmental aspects may also create social movements, and, eventually, the society puts pressure on the politicians and legislators to move legislation in some wished direction. Because politicians also want to gain or retain citizens' confidence, they follow such trends. Politicians have direct links with rules and regulations, such as regularizing specific technology or providing subsidies for adopting new technology. Taxes are one way to control the emissions; by imposing these taxes, both the user and manufacturer are directed towards the goal. Developed countries such as China, Norway, etc., are setting an example through their leadership. For example, there are organizations, IMO, acting as a helping hand in this context. Moreover, there are grants by governments also helping because, through these grants, new technologies and innovations can be developed. Companies are working towards greener solutions because of the political will and inclination toward socio-technical transitions. Furthermore, politicians are feeling pressure from society to work toward the energy transition, resulting in the shift of the current regime (Penna & Geels, 2012, Yliskylä-Peuralahti). However, these political instances are complex because some countries or big companies will try to oppose them through political moves or lobbying because of the economic impact on them. Politicians need to make the decisions quickly, and focus should be given to the whole value chain, not just the result.

Political will is also an important driver toward the socio-technical transition of the shipping industry. Because of political will, we can see the transition of traditional vehicles to electric vehicles. Previously, in the context of politics, such ideas were considered PR stunts, but now they are taken more seriously. Society puts pressure on the politicians to move in this direction. Because politicians also want to gain the people's confidence to be elected again, they follow such trends. It is also found that politicians are directly linked with rules are regulations, for example, regularizing particular technology or providing subsidies for adopting new technology. It is the primary driver of developing the latest technology because regulations drive the technologies that will be created and ultimately developed. For example, if LNG is implemented as an alternative fuel, the percentage of different harmful emissions will be regulated.

Social drivers play the role of mediators in the transition of the industry. Because of the social demands, environmental agendas and politicians are driven towards the goal of decarbonization of the shipping industry. Society has pressure because of shifts in values and culture. Society is inclined toward better technological solutions; it is evident from the example of the adoption of electric vehicles in Norway or social trends on social media for decarbonization. Moreover, society is shifting because of the health issues created by the emission from the shipping industry as it plays a massive role in the emissions. According to the data collected, the traditional combustion engine is not liked by the public. To cater to the tension in the regime, many car manufacturing companies are also shifting their businesses and moving to environmentally friendly solutions (electric vehicles). Abandoning the combustion engine or new efforts for emission-free technologies are creating tensions in current regimes, and societal and cultural change pressurizes for greener solutions. Because of all these factors, taxes can be seen as a result. Society is now focused on the impact of industries creating pollution and related issues. Big companies are now putting their effort to cater these issues, and others are following their lead. From the societal perspective, taxes can make society work towards the decarbonization of the industry, as seen in leading countries such as Norway, which are acting as a leader in driving the transition toward a clean environment. Electric cars have fewer taxes than cars with traditional combustion engines, which is paving a pathway for the decarbonization of the industry (Turnheim and Geels, 2013). Of course, the relationship may be reversed in specific markets, with regulations forcing citizens to change behavior towards acceptance of new regulations. Moreover, new technologies and associated business models could eventually change society's behavior and push citizens to demand new legislation (e.g., Uber and Airbnb).

Along with the social driver as a mediator, the economic perspective is also considered in some categories. The current regime of fossil fuels is under pressure because of economics developing in the industry. Shipping fleets using fossil fuels will come under taxes because of their emission percentage. Also, stakeholders such as financial institutions will provide loans at lower interest rates to the shipowners who are using their ships with the technology that is lower in emissions. It is found in the study that all these are the economic pressure from the economic perspective. It can align with the British coal industry, where similar economic aspects were responsible for the regime tension (Turnheim and Geels, 2013). Moreover, the fuel and energy prices will impact the shipping industry's transition. Technological development, rules and regulations, and political stability are connected with the economic driver, a mediator in the transition process. Taxation will result in higher prices for the end-user, and companies are making efforts in the technology sector toward more environmentally friendly solutions, which will gradually reduce the cost. Similarly, loans from financial institutions will be given to the stakeholders at lower interest rates if they are working towards the decarbonization of the shipping industry.

The drivers and regime tensions mentioned above result in the form of legislation on the shipping industry. Legislations are driving the technological developments in the niches towards greener solutions, for example, less emission from ships. Due to the legal driver, the transition from traditional combustion engines towards cleaner technologies is seen because legislation limits the percentage of emission (Sox, NOx, etc.) from the combustion of fuels. These regulations are put forward by institutions such as the IMO and EU through different targets for 2030 and 2050. Regulation helps reduce the use of certain technologies, for example, environmentally friendly, and can pave the way for the development of new technologies. Moreover, engine manufacturers, ship owners, and all the stakeholders involved in the industry strategize their operation, investment, and technological use because complying with the legislation will be the fundamental aspect of running their businesses. Tax is also a form of legislation because it can stop the use of a particular technology or ship, through which the target set by IMO and EU will be achieved. It was found that legislation needs to be stricter if these goals and the socio-technical transition are completed. However, legislation can also create problems for the economic side of the industry, for example, in the shape of increased fuel prices. Moreover, these legislations need to be technologically neutral. It means that the legislations have to consider technological development, and if technological development is not considered, legislation is put in place. The stakeholders will be able to cope with the legislation, and the industry will stop functioning, so the legislation can be strict but realistic.

According to the MLP model, in socio-technical transitions, innovations and new technologies are developed at the niche level of the model. There is a lot of earning happening in the shipping industry to make the socio-technical transition happen. It can be seen that different fuels are tested, for example, the use of hydrogen by an engine manufacturer. Moreover, there is a failure in technologies; for example, hydrogen cannot be used currently as an alternative fuel because of the issues such as storage and the high rate of inflation. This is being applied in other industries, such as racing cars, but it still requires development and testing for the shipping sector. These technological drivers are also collecting funding for the niche level in the MLP, where new technologies can be developed. Aiming toward the emission-free shipping industry is a strong technological driver, resulting in further technological development. Furthermore, the use of batteries in the car engines is also tested in the ships, resulting in the electrification of various market segments. There is external pressure for technological developments, for example, by the green agenda by institutions such as the EU. Due to this pressure, technological solutions are experimented with for the shipping industry (Geels, 2004, Pelli & Lähtinen, 2020). Energy optimization is also a technological driver through which energy transition can be seen.

Many technological and non-technological solutions are available to decarbonize the shipping industry and make the socio-technical transition happen. The use of alternative fuel seems to be the most efficient way of attaining the goal. Other solutions can also have an impact, for example, reduction in the speed of ships, which will result in less use of the diesel, and emissions will be less. But these solutions can have different adverse effects, for example, the long time required to reach the destinations. Looking at the results from the Delphi study, interviews, and discussion at the workshop, through the use of alternative fuel, the target which is set to be achieved by the regulators and policymakers could be one of the fastest and most efficient ways. There is a lot of research on alternative fuels in different kinds of ships. Many vessels use LNG as an alternative fuel, and the emissions are much less than those from diesel. However, there is a problem with the Methane slip, which needs to be catered to. According to Safety4Sea (January 2022), 251 ships are using LNG as their fuel, and 403 are in construction. Indeed, 2021 was when the number had increased the most compared to previous years. Moreover, using LNG as an alternative fuel, emissions such as SOx and particulate matter are eliminated, and NOx is reduced by up to 80% (DNV, 2022). Due to these results, alternative fuels are among the fastest and most efficient ways of transitioning in the shipping industry. This fact shows that there is a lot of focus on developing technologies that can use alternative fuels to reduce the emissions from the shipping industry.

Furthermore, it can also be seen that four market segments are considered in the study: Short sea shipping, Deep-sea shipping, Cruise Vessels, and Shortsea cargo. LNG seems to be the most appropriate fuel to decarbonize the shipping industry for most market segments and a shorter period, i.e., 19 years. It is justified by the explanation and discussion with the interviewees that the availability of fuel will be a problem in the future because other sectors are also using LNG. So, it means that LNG is a short-term solution. Moreover, it is also currently used by many vessels as an alternative fuel. Currently, the shipping industry is using this fuel along with the available technology for the transition towards greener solutions, and also it is reducing emissions. In the MLP model, these are the new technological advancement at the niche level, and the experiments are done on these technologies to break the lock-in of the existing regime of engines using fossil fuels (Geels, 2004).

The reason for dividing the period into two categories (10 years and 30 years) is that IMO sets targets for 2030 and 2050. In 2050, the target is to have an emission-free shipping industry. Many technological development projects are tested by different engine manufacturers, which can use other alternative fuels to reach the target. There are three most essential fuels which can help in the long run of 20 years: Methanol, Ammonia, and Hydrogen, which can be used in vessels for emission reduction. According to the data collected, projects are currently in progress to test these alternative fuels in the vessels. As observed, legislation needs to be technologically neutral, and as per this study, legislation can also have a negative impact. Because legislation will be strict, it can reduce the chances for those technological developments which can be more efficient than the current ones, so technological neutrality is critical to consider. Among other uncertainties, if a fuel is used in other industries, it can be helpful for the shipping industry, for example, the use of Hydrogen in racing cars. It can be seen that the results from the Delphi study and interviews are matching regarding most of the issues. Technologies are currently being developed, and there are uncertainties associated with them in these developments. These technological developments and their uncertainties also impact investment decisions because investors always want to be on the safer side. Still, if the technology is changed in the future, there will be a big issue for them. Local emissions and greenhouse gases both are important to consider when aiming at the targets set by

IMO. Technological developments in progress always carry uncertainties that can create issues for the stakeholder. The niche level of the MLP model provides the flexibility to test these technologies. Asses these technologies, and once they are fully developed, they will take over the existing regimes.

There can be different patterns at the niche level of the MLP model. According to the data collected, the only pattern at the niche level of the MLP seen in the shipping industry is using the current combustion engine with technological developments. These developments can make the necessary adjustments to the existing combustion engine and use the alternative fuel. These fuels can be used as single fuels, blended with fossil fuels (depending on their characteristics, e.g., liquid or gas), or even with other technologies such as electrification. It was also noticed that electrification could be used for running different systems of the ships, while for the main engine, heavy diesel fuel can be used. All these are possible combinations that can be used in the shipping industry. With future technological development, they can emerge as a dominant standard. They can replace the existing regime of the shipping industry, hence resulting in the socio-technical transition in the industry. Moreover, as per the hybridization strategy explained by Geels (2011) and Raven (2007), once the technology is developed completely, the combustion engines can be replaced by engines that can only use alternative fuels or electrification. Different technologies are developed and tested in niches, such as high emission (NOx, SOx PM, etc.) from the combustion engine. It was also found out that there is social pressure on the companies, and companies are feeling the pressure to develop new technologies, for example, alternative fuels for the shipping industry. Moreover, other stakeholders are also putting pressure on the companies (Geels, 2004).

Culture plays an essential role in changing the ideology of a society, and currently culture shift can be seen towards the decarbonization of the shipping industry, and its role is essential role in this perspective. During the study, it is observed that the general public's behavior is changing, and they are more inclined toward an emission-free environment. An increase in electric vehicles is an example of this behavioral change. Combustion engines are not preferred nowadays, and according to the experts included in the study, culture toward cleaner ways of transportation is preferred by society. Developed countries are progressing towards the goal of this societal change, for example, China and Norway, and the young generation is aiming at seriously saving the environment.

According to the data collected and interpreted, changes in the behavior and visons of the people result in social movements. There are different social movements, for example, the European Green Deal or social trends in the society towards greener ways of doing business. Through discussions with the experts in the interviews, it is evident that social pressure in society is driving the energy transition, and companies are developing new, greener technologies. End-users of the goods and products are more aware of the product's origin, and they are playing their part by putting pressure to make their products greener. Most organizations try to find environmentally friendly technology because of social pressure. For example, in the case of battery production, the raw material used in the battery will be environmentally friendly. The battery could be charged many times and used for a more extended period than the traditional battery. One of the reasons for this technological development is societal pressure.

5.2 Conclusion

Problems of the world are increasing day by day with the population increase. One of the most significant issues the world faces is climate change. The earth's temperature is rising, and an increase of 0.5°C has been seen in the earth’s temperature, and according to scientists, it will keep increasing. There is an energy crisis currently happening in the world. One of the biggest reasons for these drastic changes is pollution, which incorporates emissions from many sectors, including manufacturing, transportation, etc. Climate change impacts the earth’s environment and all the activities happening on the planet. The threat to the climate also incorporates a socio-economic perspective. Emissions from different human activities include Carbon dioxide (CO^2), methane (CH_4), nitrous oxide (N_2O), and halocarbons, and fossil fuel is the main contributor to these emissions.

The shipping sector comprises 80% of the world's transportation, and it is the most preferred mode of transportation because of the economic benefits. Emissions from the shipping sector account for almost 3% of greenhouse gas emissions. There is an energy transition happening in road transportation, for example, battery-operated vehicles. This transition is not only limited to road transportation; the shipping sector is also going through such a transition phase. Technological shifts always entail socio-technical and socio-economic change. The Multiple-Level perspective is used as a framework to look into these changes. There are three levels in the framework: socio-technical landscape (macro-level), socio-technical regimes (meso level), and niches (micro-level). The landscape is the external environment in the model, regimes are the existing systems, and niches are the places where technological developments are happening. Once these technological developments mature, they break the lock-ins at the regime level, and new technologies become the standard by replacing the existing systems and technologies. This study is about the socio-technical change happening in the shipping industry.

Multi-dimensional forces are acting in the MLP, which are interrelated. These multi-dimensional forces work as driving forces for the niches to innovate and develop new technologies. Simultaneously, these forces also pressure the regime level, resulting in regime tensions. These forces include: political, environmental, technological, economic, social, and legal. Both qualitative and quantitative data are collected to look into these forces driving the socio-technical transition toward zero-emission in the shipping industry. According to the study, a shift in the political view can be seen toward a cleaner environment. Politicians feel the pressure, and some countries are leading by example, such as Norway, in terms of electric vehicles. There is a lot of political will involved in the decarbonization of the shipping industry. Environmental agendas are putting pressure on the politicians to work toward this aim. Moreover, the political will and environmental agendas are pressed more because of the social, cultural, and economic perspectives. The culture and values of society are changing. As they are shifting towards more sustainable and greener solutions, politicians are feeling the pressure, and environmental agendas by organizations such as the EU, are more surfaced and focused.

Due to these pressures and helping hand from the societal and economic perspective, there are rules and regulations implemented by institutions such as International Maritime Organization (IMO) and European Union (EU). Furthermore, there are targets also set by IMO for 2030 and 2050, and by 2050, the target is to make the shipping industry emission-free. These legislations act as a driver for technological development. Currently, there are regulations implemented on the percentage of different emissions from the shipping industry, and there are taxes also imposed, which can drive the socio-technical change. Technological developments are happening to do business and keep the industry running according to the regulation, which is at the niche level of the MLP model. There are different funded projects aiming at the decarbonization of the shipping industry and working towards the targets set by IMO.

All these forces act as driving forces for technological developments, and simultaneously, they also result in regime tensions. Due to these forces, current technologies are under pressure (fossil fuels and internal combustion engines). New technologies are developed so that alternative fuels can be used. There are two milestones: 2030 and 2050. Alternative fuels are one of the fastest and most efficient ways of reaching the targets. LNG is the prominent fuel to be used till 2030, and in the more extended period, Methane, Ammonia, and Hydrogen are the alternative fuels that can be used in the shipping industry. The use of these fuels can reduce emissions. Certain uncertainties are also associated with technological developments; for example, regulations can impact the use of a specific fuel, and later on, it can be the efficient one. Others include using alternative fuels in other industries, creating availability problems, and resulting in economies of scale.

5.2.1 Conceptual contributions

The main contribution of this study focuses on the exploration of niche dynamics. The niche level of the MLP has specific dimensions: competition, hybridization, and accumulation. The shipping industry is currently using the pattern of hybridization, in which existing technologies (combustion engines) are adjusted and can use both alternative fuels and heavy diesel fuel. This pattern can be the first step towards the emergence of a new standard, as we have seen in the case of sail ships, in which the combustion engines were only used where there was no wind. Still, later on, the combustion engine, which was the niche technological development, took over the old technology (sail ships) and became the industry's new standard.

Similarly, in the future, once the technology is developed and mature with the advancement the technology, only alternative fuels can be the standard for the shipping industry, and fossil fuels will not be used anymore. Resulting in the change of the existing regime, and a socio-technical transition of the shipping industry can be achieved. This will take some time (a few decades), but the goal can be achieved since many projects are trying to develop technologies that can use alternative fuels. This will impact the whole industry; for example, ship owners will be under a lot of pressure because they will have to reinvest. There can also be resistance because of the stakeholders trying to safeguard their interests, but these can be overcome through the application of regulations. Transition in the shipping industry will be done smoothly, and in the course of this smooth transition, all the stakeholders can anticipate the expected changes and strategize accordingly.

5.2.2 Limitations and future research

There are certain limitations of the study. For example, longitudinal research is needed to see the technological developments and look at the industry's transition. In addition, the interviews were conducted only among experts in Finland, resulting in limited insights from the perspective of the global shipping industry (although many stakeholders in the Finnish ecosystem are important international players). Furthermore, there was no representative from the regulation side included, which acted as a limiting factor for the study because any representation from the regulation side would have given more deep insight.

There is a need to look into socio-technical transition more deeply concerning future research. There are three niche dynamics mentioned in the study, and only one pattern could be found, i.e., hybridization. There is a need to study niche dimensions more in-depth. For example, there is a possibility that in the future, there will be competition in internal combustion; once the technology is more mature, which can use alternative fuels. This will result in competition between the current technology and the new technology. So, niche competition can also impact the shipping industry's transition, which needs to be studied further. Similarly, two technologies can be combined, resulting in a regime change in the shipping industry; this pattern (niche accumulation) also needs to be studied because this will impact the stakeholders involved (for example, engine manufacturers).

Furthermore, there are big and stable companies operating in the shipping industry. They might try to save their interest, creating barriers in the transition process. The effect of the regime's strong players, acting as a barrier to socio-technical change, can be due to, for example, the economic factors involved. There is a need to study these barriers and their impact on the stakeholders, technology, and transition.

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Appendices

Appendix 1. Invitation for the interviews

Hello,

I am contacting you on behalf of the University of Vaasa, and as an expert, I would like to seek an hour for an interview session based on your experience in the shipping industry. (Organization name) is working towards decarbonization of the shipping industry, and your insightful opinion will help me understand the topic in-depth.

I am working on a master's thesis under Professor. Rodrigo Rabetino Sabugo, University of Vaasa. The aim of the thesis is to study different forces which are driving the transition in the shipping industry. Furthermore, different patterns in the technology development will also be discussed.

As an expert, your opinion is of high value to the aim of the project. If there is anything, you would like to ask, kindly contact me at hammad.u.syed@uwasa.fi.

Br,

____

Syed Hammad Ul Haq

Project Researcher, Clean Propulsion Technologies.

Vaasan yliopisto UNIVERSITY OF VAASA Clean Propulsion Technologies

University of Vaasa.

Email: hammad.u.syed@uwasa.fi

Appendix 2. List of interview questions

1- How politics is acting as a driver in the transition of the shipping industry toward decarbonization?
2- How economics is acting as a driver in the transition of the shipping industry toward decarbonization?
3- How society is acting as a driver in the transition of the shipping industry toward decarbonization?
4- How technology is acting as a driver in the transition of the shipping industry toward decarbonization?
5- How legislation is acting as a driver in the transition of the shipping industry toward decarbonization?
6- How environment is acting as a driver in the transition of the shipping industry toward decarbonization?

Appendix 3. Delphi Questionnaire (Round 1)

Hello,

The aim of this Delphi study is to look at different solutions for decarbonization of the shipping industry, projection of alternative fuels along with their application circumstances, and also find the role of fuels in decarbonization in the maritime industry. The survey results will form the basis for the selection of a fuel that will reduce carbon emissions and find a solution for the EU's and IMO's 2030/2050 targets. Your participation in the survey and your individual responses will be strictly confidential to the research team and will not be divulged to any outside party, including other survey participants.
If you have any questions, please contact me at hammad.u.syed@uwasa.fi
For terms and conditions regarding confidentiality of data, please click on the following link.

- Professional Title: ______________________________

- Work Experience from fuel and/or ship power-related areas

  - Less than 1 year
  - Between 1 - 4 years
  - Between 5-10 years
  - Between 10- 20 years
  - More than 20 years
- Region
  - Europe
  - Asia
  - North America
  - South America
  - Africa
  - Oceania

The following solutions can help in decarbonization of shipping industry in next 10 years					
In my opinion, I …	Highly Disagree	Disagree	Neut-ral	Agree	Highly Ag-ree
Reduction in ship resistance (e.g Hull hydrodynamics)					
Propulsion Efficiency					
Marine Powerplant (innova-tive propulsion plants, waste heat recovery, auxiliary ma-chinery)					
Supply chain and logistics (trading network designs, economies of scale, emerging trading routes)					
Slow Steaming					
Cold Ironing (shore side elec-tricity or shore to ship power)					
Voyage optimization					
Optimized maintenance					
Human factors (energy saving behavior)					
Alternative fuels					
Carbon capture and storage (CCS) on board					

The economic and environmental feasibility of the following fuels for decarbonization of Short sea shipping (feeders, bulkers) in the next 10 years are					
In my opinion, I …	Very low feasibility	Low feasibility	Neutral	High Feasibility	Very High feasibility
a. LNG					
b. LPG					
c. Bio Gas					
d. Bio Diesel					
e. Methanol (Bio, green and blue)					
f. Ammonia (Green and blue)					
g. Hydrogen (Green and blue)					
h. Other (please mention)					

The economic and environmental feasibility of the following fuels for decarbonization of Short sea (roro, ropax, ferry) in the next 30 years are					
In my opinion, I …	Strongly disagree	Disagree	Neutral	Agree	Strongly Agree
a. LNG					
b. LPG					
c. Bio Gas					
d. Bio Diesel					
e. Methanol (Bio, green and blue)					
f. Ammonia (Green and blue)					
g. Hydrogen (Green and blue)					
h. Other (please mention)					

The economic and environmental feasibility of the following fuels for decarbonization of Deep sea (Tankers, bulkers, container vessels) in the next 30 years are					
In my opinion, I …	Strongly disagree	Disagree	Neutral	Agree	Strongly Agree
a. LNG					
b. LPG					
c. Bio Gas					
d. Bio Diesel					
e. Methanol (Bio, green and blue)					
f. Ammonia (Green and blue)					
g. Hydrogen (Green and blue)					
h. Other (please mention)					

The economic and environmental feasibility of the following fuels for decarbonization of Cruise Vessels in the next 30 years are					
In my opinion, I …	Strongly disagree	Disagree	Neutral	Agree	Strongly Agree
a. LNG					
b. LPG					
c. Bio Gas					
d. Bio Diesel					
e. Methanol (Bio, green and blue)					
f. Ammonia (Green and blue)					
g. Hydrogen (Green and blue)					
h. Other (please mention)					

The economic and environmental feasibility of the following fuels for decarbonization of Short sea cargo (feeders, bulkers) in the next 30 years are					
In my opinion, I …	Strongly disagree	Disagree	Neutral	Agree	Strongly Ag-ree
a. LNG					
b. LPG					
c. Bio Gas					
d. Bio Diesel					
e. Methanol (Bio, green and blue)					
f. Ammonia (Green and blue)					
g. Hydrogen (Green and blue)					
h. Other (please mention)					

The following uncertainties will impact the selection of alternative fuels					
In my opinion, I..	Fully disagree	Disagree	Neut-ral	Agree	Fully ag-ree
a. Regulations will limit the options for alterna-tive fuels.					
b. The fuel which will be selected and imple-mented by other industries will help its ap-plication in maritime industry (through spill-over effect and economies of scale).					
c. LNG or LPG is good for short term, and it will phase out in mid-century, and then addi-tional investment will be required by the ships to operate on other alternative fuels.					
d. Different fuels will be used in long and short distance shipping.					
e. Minimizing local emissions is more im-portant than minimizing GHG emissions.					
f. Future supply of alternative fuels will be suf-ficient for the shipping industry needs.					
g. After investing in a specific fuel technology, stakeholders may be reluctant to switch to another fuel.					

Thank you

Appendix 2. Delphi Questionnaire (Round 2)

Hello,

Thank you so much for the response during the first round of this survey. As explained earlier, the Delphi study's mechanism is that it has iterative rounds to find a consensus. Now we are at the second round of the survey.
We invite you to rethink and answer the questions. If you want to change your answers, you can select an appropriate answer from the options, and if not, then kindly repeat your answer. Your previous answers are also given in the survey.

If you have any questions, please contact me at hammad.u.syed@uwasa.fi

For terms and conditions regarding the confidentiality of the data, please click on the following Privacy note.

The following solutions can help in decarbonization of shipping industry in next 10 years					
In my opinion, I …	Highly Disagree	Disagree	Neutral	Agree	Highly Agree
Reduction in ship resistance (e.g Hull hydrodynamics)					
Propulsion Efficiency					
Marine Powerplant (innovative propulsion plants, waste heat recovery, auxiliary machinery)					
Supply chain and logistics (trading network designs,					

economies of scale, emerging trading routes)					
Slow Steaming					
Cold Ironing (shore-side electricity or shore to ship power)					
Voyage optimization					
Optimized maintenance					
Human factors (energy saving behavior)					
Alternative fuels					
Carbon capture and storage (CCS) on board					

If you have changed any of your answers, please state the reason below

____

The economic and environmental feasibility of the following fuels for decarbonization of Short sea shipping (feeders, bulkers) in the next 10 years are					
In my opinion, I …	Very low feasibility	Low feasibility	Neutral	High Feasibility	Very High feasibility
i. LNG					
j. LPG					
k. Bio Gas					
l. Bio Diesel					
m. Methanol (Bio, green and blue)					
n. Ammonia (Green and blue)					
o. Hydrogen (Green and blue)					

p. Other (please mention)	

If you have changed any of your answer, please state the reason below

____

The economic and environmental feasibility of the following fuels for decarbonization of Short sea (roro, ropax, ferry) in the next 30 years are					
In my opinion, I …	Strongly disagree	Disagree	Neutral	Agree	Strongly Ag-ree
i. LNG					
j. LPG					
k. Bio Gas					
l. Bio Diesel					
m. Methanol (Bio, green and blue)					
n. Ammonia (Green and blue)					
o. Hydrogen (Green and blue)					
p. Other (please mention)					

If you have changed any of your answer, please state the reason below

____

The economic and environmental feasibility of the following fuels for decarbonization of Deep sea (Tankers, bulkers, container vessels) in the next 30 years are					
In my opinion, I …	Strongly disagree	Disagree	Neutral	Agree	Strongly Agree
i. LNG					
j. LPG					
k. Bio Gas					
l. Bio Diesel					
m. Methanol (Bio, green and blue)					
n. Ammonia (Green and blue)					
o. Hydrogen (Green and blue)					
p. Other (please mention)					

If you have changed any of your answer, please state the reason below

____

The economic and environmental feasibility of the following fuels for decarbonization of Cruise Vessels in the next 30 years are					
In my opinion, I …	Strongly disagree	Disagree	Neutral	Agree	Strongly Agree
i. LNG					
j. LPG					
k. Bio Gas					
l. Bio Diesel					
m. Methanol (Bio, green and blue)					
n. Ammonia (Green and blue)					

o. Hydrogen (Green and blue)					
p. Other (please mention)					

If you have changed any of your answer, please state the reason below

____

The economic and environmental feasibility of the following fuels for decarbonization of Short sea cargo (feeders, bulkers) in the next 30 years are					
In my opinion, I …	Strongly disagree	Disagree	Neutral	Agree	Strongly Ag-ree
i. LNG					
j. LPG					
k. Bio Gas					
l. Bio Diesel					
m. Methanol (Bio, green and blue)					
n. Ammonia (Green and blue)					
o. Hydrogen (Green and blue)					
p. Other (please mention)					

If you have changed any of your answer, please state the reason below

____

The following uncertainties will impact the selection of alternative fuels					
In my opinion, I..	Fully disagree	Disagree	Neut-ral	Agree	Fully ag-ree
h. Regulations will limit the options for alterna-tive fuels.					
i. The fuel which will be selected and imple-mented by other industries will help its ap-plication in maritime industry (through spill-over effect and economies of scale).					
j. LNG or LPG is good for short term, and it will phase out in mid-century, and then addi-tional investment will be required by the ships to operate on other alternative fuels.					
k. Different fuels will be used in long and short distance shipping.					
l. Minimizing local emissions is more im-portant than minimizing GHG emissions.					
m. Future supply of alternative fuels will be suf-ficient for the shipping industry needs.					
n. After investing in a specific fuel technology, stakeholders may be reluctant to switch to another fuel.					

If you have changed any of your answers, please state the reason below

____

Thank you