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Reduction of GHG emissions from ships: evaluation of inter-company R&D cooperation models in the case of Hapag-Lloyd

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Abstract

Decarbonization provides a crucial challenge for the maritime industry, resulting in growing concerns about how to achieve the initial IMO strategy on reduction of GHG-emissions from ships. In this context, R&D cooperation has become an important domain for industrial practice, constituting a preeminent strategic framework and vital factor for actively shaping the industry's development towards a sustainable future. Leading global liner-shipping companies emphasize the importance of R&D to surmount disruptive challenges. However, based on the variety of R&D cooperation models, it remains to be investigated how such collaborations should be configured. This paper seeks to address practical collaboration concepts by defining holistic requirements from a corporate perspective, which are subsequently matched with a portfolio of external stakeholders and cooperation configurations. For this process, a mixed-methods research design has been adopted, sourcing the required information from expert interviews with the primary stakeholder groups and culminating in the construction of two multi-criteria decision-making models to draw dynamic inferences. On this basis, econometric analysis suggests knowledge-based R&D cooperation models, and early-stage involvement of academic institutions and classification societies. This provides the framework for actively engaging in a variety of further technological test-phases in the future, to evaluate imminent GHG-reduction alternatives and perpetuate sustainable value creation. The research results empirically support theoretical literature on environmentally related R&D cooperation and contribute to the understanding of strategic partnerships. This adds economic robustness to a widely discussed topic.

Keywords: Decarbonization, Research cooperation, R&d, Sustainability, Liner shipping

Introduction

International liner shipping is referred to as the most energy-efficient and cost-effective mode of cargo transport (IMO 2018, p. 1). While seaborne trade accounts for 90% of international transport, growth in the container shipping sector is expected to closely follow the underlying GDP development, resulting in a demand increase for seaborne trade of 60% by 2050 (IMO 2018, p. 1). This is in line with the estimated 150% fleet tonnage increase in container shipping to mid-century (DNV GL 2017, pp. 8–10). The world fleet consumes about 250 million tons of marine fuel, reflecting 3% of the world's carbon dioxide emissions (SMW 2019, p. 4; DNV GL 2017, p. 8). The IMO set forward to "peak GHG emissions from shipping as soon as possible and to reduce the total amount of GHG emissions by at least 50% by 2050, compared to 2008" (IMO 2018, p. 6). GHG-reduction can be defined as one of the key challenges in shipping, resulting in substantial environmental changes, subsequently affecting all industry participants (DNV GL 2017, p. 55; Wärtsilä n.d.-a). Shipping companies have to actively embrace the challenges and inter alia cooperate on the reduction of GHG emissions from ships.

"It's time to deliver something concrete. Research & Development (R&D) will be crucial, as the targets agreed in the IMO strategy will not be met using fossil fuels." (Kitak Lim, IMO Secretary-General) (SMW 2019, p. 4). The Economist Intelligence Unit estimates the cost of inaction towards GHG-reduction at USD 43 trillion, reflecting the total value of manageable assets at risk before the end of the century (Maersk 2018, p. 15). The long-term nature of this GHG-reduction challenge provides an uncertainty factor and a wait-and-see approach would be problematic for tackling the imminent technological and regulatory disruption (SMW 2019, pp. 4–6). In order to achieve GHG-reduction, R&D cooperation can be defined as the "cornerstone in decarbonizing the shipping industry" and all stakeholders involved have to collaborate on incentives and jointly develop innovative solutions (Brünggen 2019; Grötsch 2019; Rayner 2019; Clayton 2019; Maersk 2019, pp. 13–14; DNV GL 2017, p. 69; United Nations 2015, p. 3; Joules n.d.-a, p. 3). The requirement for R&D cooperation is congruent with the prerequisite knowledge generation towards the prevalent uptake of a propulsion and fuel solution variability (Mohrdieck 2019; Nagel 2019; IMO 2019, p. 5). Therefore, R&D cooperation models have to be specifically considered to ameliorate the innovation potential and preparatory work of the whole industry towards decarbonization. To a similar extent, the topic of environmentally-related R&D cooperation is a growing area of research and the rationale of this study emanates from the fact that "companies are increasingly expected to join with other organizations – both public and private – to address social and environmental problems" (Beck et al. 2017, p. 4; Albani and Henderson 2014, pp. 1–3; De Marchi 2011, p. 7). It remains to be investigated, how such cooperation models must be configured in the shipping industry (Mohrdieck 2019). The focus of this study culminates in the following research question, which is supplemented by three individual research aims:

Research question

"Which R&D cooperation models are most suitable for liner shipping companies, in order to effectively address the initial IMO strategy on reduction of GHG emissions from ships?"

Research aims

1. "Determine which cooperation requirements have to be defined internally."
2. "Determine which cooperation partners have to be considered in this context."
3. "Determine which cooperation elements are crucial for this purpose."

Literature review

Sustainability in shipping

Literature and research on GHG-reduction alternatives in shipping reflect that towards 2050 oil-based fuels will constitute 47% of energy for shipping, with a respective proliferation of gas-based fuels to 32% (DNV GL 2017, pp. 3,10). The remaining 21% are to be provided by carbon-neutral energy sources, such as biofuel and electricity (DNV GL 2017, p. 10). In order to achieve this fossil-fuel transition, environmental innovation is required, which De Marchi refers to as the development of "new or modified processes, techniques, practices, systems and products to avoid or reduce environmental harms" (De Marchi 2011, p. 2). In a study by De Marchi, it is further defined that environmental innovation is primarily triggered by regulations and externalities, resulting in an increased importance of R&D cooperation with external partners (De Marchi 2011, p. 1). Moreover, most empirical analyses have assumed an uptake of a broad spectrum of decarbonization alternatives with no "one size fits all" solution evolving over time (IMO 2018, p. 4; DNV GL 2017, p. 29; Joules n.d.-a, p. 3).

According to the IMO, short-term and medium-term objectives primarily refer to a wide-ranging knowledge building process, the implementation of operational efficiencies and the development of rules and regulations (IMO 2019, pp. 3, 5–6; IMO 2018, pp. 7–9). Therefore, the implementation of break-through CO_2 reduction solutions is found in the IMO long-term perspective (Erdmann 2019; IMO 2019, p. 2; IMO 2018, p. 9). In parallel, the growing importance of market-based measures is increasingly covered in literature as the IMO Environmental Committee indicated that "technical and operational measures would not be sufficient to satisfactorily reduce the amount of GHG emissions from international shipping in view of the growth projections of world trade" (Erdmann 2019; Kristiansen 2019; IMO n.d.). Respectively, a market sentiment jointly recommends the implementation of a "fuel levy" in order to source an R&D fund for commercially viable decarbonization solutions in technological-engineering and energy-based focused fields of study (Kristiansen 2019; IMO n.d.). Apart from such measures, the course of action to achieve the IMO GHG reduction target can be generally subdivided into the three categories of technological-engineering measures, energy-based measures and operational measures (Erdmann 2019; von Berlepsch 2019; Hapag-Lloyd 2019f, p. 59; Hapag-Lloyd 2016).

Technological-engineering measures

DNV GL estimates the fuel consumption per vessel to decline by 18% due to hull and machinery energy efficiency measures (DNV GL 2017, p. 53, 55). Such measures include the limitation of a vessel's shaft power, the installation of waste-heat recovery systems or retrofits to optimize primary energy converters (Adamopoulos 2019a; Joules n.d.-a, p. 8). In addition, researchers consider fuel cells, while the solution horizon towards 2050 is likely to be even further extended and differences in the way how ships are bunkered and how multi-fuel compatible engines can be designed have to be evaluated on a holistic scale (Becker 2019; Brünggen 2019; Nagel 2019; Smith 2019; Hapag-Lloyd 2019d, p.1; MAN Energy Solutions n.d.-b; Ship Technology Global n.d.).

Energy-based measures

IMO reinforces the need for liquid fuels for long-range shipping, with energy-density per ton being the primary criterion in technological research for evaluating, whether a fuel alternative should be specifically considered towards 2050 (Dörner 2019; Timmerberg 2019; IMO 2019, p. 5). To outline the respective energy-based CO_2 reduction alternatives, the IMO further differentiates between fossil-free fuels (synthetic energy carriers produced from non-fossil renewable energy sources), zero-carbon fuels ("energy carrier that does not release any CO_2 when being used in internal combustion engines") and low carbon fuels (IMO 2019, p. 2). Literature and research on fossil-free fuels emphasize the uptake of liquid fuels generated out of renewable energies and CO_2 (Expert Conference of the Association of German Engineers 2019; IMO 2019, p. 2; Deutscher Bundestag 2018, pp. 4–6). These fuel alternatives are titled "PtX" (Power-to-Anything), including both PtL (Power-to-Liquid) and PtG (Power-to-Gas). Shell further refers to the high energy density and convenient storability of PtX fuels and states the potential to use existing infrastructure (Expert Conference of the Association of German Engineers 2019; Warnecke 2019, p. 21). Adding to these studies, recent research projects considering fossil-free fuels refer furthermore to challenges in the energy extraction and fuel transport. This underlines the requirement for a life-cycle assessment of the whole well-to-propeller value chain (Erdmann 2019; Smith 2019; Timmerberg 2019; International Maritime Organization 2019, p. 2; Joules n.d.-b, p. 10; Ship Technology Global n.d.). In contrast to above outlined fossil-free alternatives, a different point of view is taken by researchers evaluating the direct onboard use of electricity, which, based on DNV GL, will cover 1/30 of global energy demand for shipping towards 2050, next to further marginal measures (Timmerberg 2019; IMO 2019, p. 2; DNV GL 2017, p. 53; Joules n.d.-a, p. 9). Nevertheless, on an international liner scale, most analyses assume the applicability of electricity only as a hybrid or auxiliary propulsion (Timmerberg 2019; Joules n.d.-a, pp. 9, 12, 20; Joules n.d.-b, p. 26). Additionally, LNG is considered as an energy-based alternative on an interim level, as it will account for 32% of total energy use in shipping by 2050 (Adamopoulos 2019b; DNV GL 2017, p. 53; Technological and Environmental Forum LNG 2019). Reflecting solely the vessels' combustion phase, LNG can reduce GHG emissions by 28% for two-stroke engines, which is argued to be insufficient for the depicted IMO decarbonization goals (Adamopoulos 2019b). However, recent studies insinuate to not empirically illuminate the role of potential CO_2 reductions in the production chain of LNG (Grötsch 2019; Timmerberg 2019).

Operational measures

Following these studies, further empirical efforts have been carried out concerning operational GHG-reduction measures as precursor to the outlined decarbonization objectives (Adamopoulos 2019a). In this context, studies by DNV GL estimate such measures to reduce fuel consumption per ton-mile by 35–40% until 2050 (DNV GL 2017, p. 10). In line with this, DNV GL makes the hypothesis of vessel speed declining by 5% towards 2050, resulting in bunker consumption reductions of 10% (Becker 2019; Guntermann 2019; Smith 2019; DNV GL 2017, p. 53). In addition, research conducted by Fraunhofer Institute proposes environmental data analysis i.a. for weather routing as further operational setscrew (Fraunhofer n.d. (b)).

Taking all outlined GHG-reduction solutions into account, shipping companies need to evaluate how to combine and implement the depicted alternatives. In this regard, it is reflected in econometric research studies that environmentally innovative firms collaborate on technology development with external partners more frequently than other innovative companies (De Marchi 2011, p. 1). The underlying principles for such inter-company cooperation models have been broadly analysed in economic literature and key findings are outlined in the following paragraphs.

Inter-company cooperation

Kermani et al. define inter-company cooperation as a "collaboration of different parts of a cooperative process in order to meet a common purpose or seize an opportunity in the market" (Kermani et al. n.d., p. 1). Fett & Spiering propose that these "parts of a cooperative process" can be further subdivided into a horizontal or vertical scale (Fett and Spiering 2015, p. 24). Badillo and Morena define horizontal partnerships as "cooperation agreements with competitors or enterprises of the same sector", while referring to vertical cooperation models as "cooperation agreements with suppliers … or with customers or clients" (Badillo and Moreno 2016, p. 5). Bouncken et al. disentangle further the analysis by considering coopetition as an "inter-organizational relationship that combines cooperation and competition" (Bouncken et al. 2015, p. 1). Moreover, recent literature explores the configuration of lateral or institutional cooperation agreements with "consultants, commercial labs, private R&D institutes, universities, other higher education institutions, the government, public research institutes or technology centers" (Badillo and Moreno 2016, p. 5).

Following above outlined structural cooperation setups, supplementing empirical efforts have been conducted to evaluate the resource requirements for various collaboration models (Fett and Spiering 2015, p. 2). Recent studies find empirical evidence on the importance of technological and knowledge capacities of the potential partner company and identify headcount requirements as a primary driver in the formation of a cooperation model (Fett and Spiering 2015, pp. 2–3, 16). In this regard, literature refers to "input-relative motives" to search for collaboration partners, and Fett and Spiering underline the substantial relevance of mutual value addition to pursue a joint market entry (Franco and Gussoni n.d., p. 10; Fett and Spiering 2015, p. 3, 15). Fett and Spiering further outline the reduction of the underlying financial exposure and the respective risk mitigation as critically relevant considerations before entering a cooperative partnership (Fett and Spiering 2015, p. 2, 14). A different view is taken by studies focusing on the areas of tension within a cooperation model. Such areas of tension include i.a. the corporate culture, underlying rationale, trust and confidentiality of the cooperation partners (Fett and Spiering 2015, pp. 3–5, 14, 17; Moss Kanter 2010).

In order to depict the characteristics of R&D cooperation, a staggered approach was adopted, dividing the comprehensive body of economic and social science consecutively into the subjects of R&D, R&D cooperation and environmental R&D cooperation.

Research & Development

The majority of studies define R&D analogous to Hall as "activities undertaken by firms and other entities … in order to create new or improved products and processes … increase the stock of knowledge … and use this knowledge to devise new applications" (Appendix A) (Hall 2006, pp. 1–2; Cambridge Dictionary n.d. (b)). R&D as such does not directly provide a "homogeneous activity" but can be subdivided into its components "Research" and "Development" (Hottenrott and Lopes-Bento 2014, p. 39). Hall, based on work by Nelson, classifies R&D into three primary stages of activity, reflecting the basic research phase, the applied research phase and the development phase, covering both, the acquisitive manner of knowledge generation and the testing and conceptualization of new products and processes (Hall 2006, pp. 1–3). Supplementing studies evaluate R&D with regard to the underlying market cycle, referring to Hud & Hussinger, who state the pro-cyclicality of R&D with a higher required ROR for credit-constrained firms. A slightly different view is taken by Añón-Higón et al., outlining the comparatively low opportunity costs in times of economic downturn (Beck et al. 2017, pp. 4, 17).

R&D cooperation

An increasing amount of studies on R&D cooperation underline the aspects of inter- and intra-sectoral knowledge spillovers and ex-post sharing of research results, depicting a company's opportunity to "use knowledge created by another firm with no cost or with less cost than the value of the knowledge" (Beck et al. 2017, p. 18 / Katz and Ordover 1990, pp. 3, 10, 22). In this context, a societal rate of return is indicated by Comin et al. and Beck et al. compiled of the "spillover effect of knowledge creation" added to the private R&D ROR, resulting in societal returns of 20–60%, as assumed by most empirical analyses (Beck et al. 2017, pp. 7, 12, 23, 29; Border 2002, p. 3; Katz and Ordover 1990, p. 1) (Fig. 1). In contrast, several supplementing studies have been published on the underlying uncertainty about R&D outcomes, defining it as primary risk factor. Literature i.a. brings forward the potential "lack of appropriability" of R&D outcomes, asymmetric information exchange, antitrust constraints, or intellectual property requirements (Hall 2006, p. 4; Katz and Ordover 1990, pp. 2, 33) (Fig. 1).

An additional theoretical approach to examine the characteristics of R&D cooperation is grounded in the innovation economics literature (Badillo and Moreno 2016, p. 1). Referring to Perkmann & Walsh, research partnerships can be defined as "formal collaborative arrangements among organizations with the objective to cooperate on research and development activities" (Beck et al. 2017, p. 70; Perkmann and Walsh 2007, p. 268). In line with De Marchi, such "formal collaborative arrangements" might result in substitutional effects between a company's internal R&D activities and external R&D partnerships (De Marchi 2011, pp. 1, 3). Beck et al. however also raise the awareness that R&D cooperation across sectors might be rather heterogeneous and differs along aspects, such as the cooperation partner size and age, the commercial potential of R&D

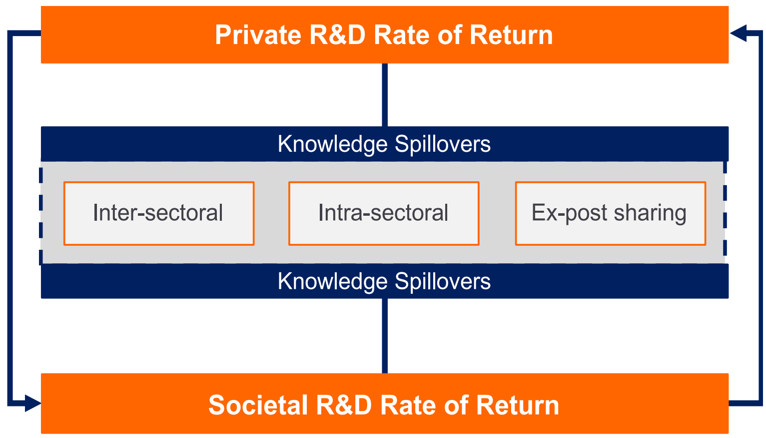

Fig. 1 Knowledge Transfer Channels and R&D Rate of Return (Own Illustration)

projects and the duration of a cooperative partnership (Beck et al. 2017, pp. 15, 16, 35). In this regard, recent studies further differentiate between leading and laggard industries, where the latter ordinarily generates more benefits from R&D cooperation models (Beck et al. 2017, p. 16).

With reference to the incentives and underlying reasons for public and private entities to contribute to R&D partnerships, empirical analyses highlight that "the stock of knowledge created by doing R&D makes one more productive in acquiring additional knowledge" (Hall 2006, p. 4). The relevance of this "absorptive capacity" is reinforced in a systematic study carried out by De Marchi, specifically stating the resulting ability to "identify, assimilate and exploit the knowledge coming from external sources". This becomes even more essential with increasing market uncertainty and technological turbulence (Beck et al. 2017, p. 46; De Marchi 2011, p. 3).

Further principal motivations to cooperate on R&D include the incorporation of external knowledge, risk mitigation or the sharing of complementary capabilities and resources (Beck et al. 2017, pp. 4; 15; Badillo and Moreno 2016, p. 3). In line with this, R&D cooperation models can also be beneficial in raising financial subsidies or creating intellectual property (Beck et al. 2017, p. 23). Although primarily focused in this study, specialized R&D cooperation configurations, including partnerships with governmental organizations or less flexible equity-based R&D Joint Ventures have been investigated as well (Marinucci 2012, p. 9; De Marchi 2011, p. 3; Katz and Ordover 1990, pp. 20, 38).

Environmental R&D Cooperation

In the field of R&D cooperation, a specific differentiation between environmentally related and non-environmental R&D has to be considered, with this study focusing on the former (De Marchi 2011, p. 3). De Marchi reinforces the need for R&D cooperation in the context of environmental innovations, due to the underlying "credence and complex character" (De Marchi 2011, pp. 1–2). Literature asserts the requirement for restrictive policy intervention leading to a "regulatory push and pull effect", which becomes even more important concerning "radical changes of technological systems towards the greening of industries" (De Marchi 2011, pp. 1, 2; Katz and Ordover 1990, p. 1). De Marchi reaches the conclusion that continuous information exchanges within a broad stakeholder scope and an in-depth capability development are highly important to attain environmental targets (De Marchi 2011, pp. 1–3, 5).

Methodological research approach

Methodological framework

The exploratory and descriptive purpose of this study has to be flexibly constructed in order to address the long-term nature of the subject and corresponding regulatory uncertainty, which nevertheless does not lead to an „absence of the direction to the enquiry "(Saunders et al. 2016, p. 164; Saunders et al. 2009, p. 140). It was decided that an abductive research design is most suitable for the purpose of this investigation to make reasonable inferences and develop logical theories, based on a limited number of observations (Dudovskiy n.d.). In line with this, a mixed-methods research was conducted, based on which cooperation criteria were subsequently categorized and quantitatively weighted. The weights were assigned based on the relative importance of the criteria from a corporate perspective and derived from the conducted interviews with internal and external stakeholders. This culminates in the construction of two multi-criteria decision-making models in order to assemble the most advisable cooperation partners and collaboration configurations in the context of GHG-reduction (Appendix B).

Qualitative data collection

Seventeen expert interviews were conducted, including 12 external and 5 internal top management and department-specific opinions in order to cover a large scope of sources for the developed criteria model and achieve data saturation (Schoonenboom and Johnson 2017; Saunders et al. 2016, p. 274; Saunders et al. 2009, p. 235; Greener 2008, pp. 48–49). In accordance with the research question, this provides the contextual understanding required to draw conclusions about potential cooperation configurations (Greener 2008, p. 80). The interviews were conducted in a semi-structured format and selected via a non-probability purposive sampling technique (Saunders et al. 2009, pp. 320, 322–323, 328; Greener 2008, p. 34). The sample was drawn from a broad set of parties involved in and affected by upcoming GHG-related regulations in shipping (Saunders et al. 2016, p. 274). For the purpose of the interviews, experts are defined as a person or group that has "acquired knowledge and skills through study and practice … in a particular field or subject to the extent that his or her opinion may be helpful in fact finding, problem solving or understanding of a situation" (Business Dictionary n.d.). Through the development of structured discussion guides for each interview, consistency was ensured and a direct allocation of the respective responses into the research findings was possible, allowing for supplementary situation-dependent and probing questions (Barrett and Twycross 2018, p. 1; Saunders et al. 2009, pp. 329, 332, 337–338; Greener 2008, pp. 87, 90).

Regarding the literature-based research, multiple-source secondary interpretivist data complemented the gathered primary research and broadened the scope of this study (Easterby-Smith et al. 2015, pp. 378–379; Saunders et al. 2009, pp. 77, 258, 262). This includes peer-reviewed qualitative information published in working papers, research articles and academic literature (Easterby-Smith et al. 2015, p. 66). In case gray literature was used, the sources were evaluated based on their credibility and face validity to sufficiently answer the research question (Easterby-Smith et al. 2015, pp. 378–379; Saunders et al. 2009, pp. 258, 269–272; Greener 2008, p. 37).

Quantitative data analysis

With reference to the quantitative approach, two primary data analysis streams are applied. Based on Kumar et al., two Multi Criteria Decision Making Models were developed, which can be defined as "a branch of operational research dealing with finding optimal results in complex scenarios including various indicators, conflicting objectives and criteria" (Kumar et al. 2017, p. 1). These criteria models follow the concept of a Pough Matrix and provide criteria- and scoring-based decision support between competing concepts (Cf. Pugh 1981). Respectively, Hapag-Lloyd's 91 cooperation requirements (as outlined in 5.1) are matched with both, the identified 42 potential cooperation partners and the individually classified 69 cooperation elements in order to derive the most suitable cooperation configuration from today's perspective, while ensuring decision-making flexibility towards 2050. For this purpose, categories and subcategories were derived to address a corporation's primary areas of concern. For an international shipping organization, these areas of concern include the question for the underlying corporate need for R&D cooperation and whether this need is valuably catered by the respective cooperation model (cf. "Value-addition requirements"). Furthermore, the categories include "Regulatory requirements" to assess whether regulatory considerations are speaking against a certain cooperation configuration. "Administrative requirements" and "Financial requirements" are added, to receive first insights on whether a cooperation model holds simplified due diligence considerations. Overall, this categorization allowed to structure the inquiry and assess the cooperation requirements comparatively. These were subsequently weighted on a 0–1 scale and multiplied with respectively assigned 10,101 scores for each cooperation partner and element, following the weighted sum model developed by Fishburn in 1967 ($A_i^{WSM} = \sum_{j=1}^{n} w_j \times \sum_{k=1}^{n} w_k \times x_{ik}$) (Fishburn 1967, pp. 435–453; Kumar et al. 2017, p. 3). Weighing these requirements on a 0–1 scale has been done using the Simple Multi-attribute Ranking Technique (Godwin 2019, p. 7). This implies that the criteria were initially ranked in terms of their importance from least to most important within their respective category. On this basis, the weights between 0 and 1 have been subsequently assigned in pairwise comparison between one criterion and the criterion with the next higher importance. Looking for example at the category of financial requirements, the two requirements considered are the reduction of financial exposure and the development of financial models to transfer R&D related expenses to customers. In this context, the reduction of financial exposure received the weight 0.75, while the development of financial models respectively received a weight of 0.25 in order to sum up to 1. Such a comparative scaling allowed to consider the relative importance of each requirement in order to quantify the qualitative information derived from the conducted expert interviews and literature research. Regarding the assigned scores, all scores were selected from a balanced 0–10 (0: "No Match" / 10: "Absolute Maximum Match") scale with a definite centre, providing sufficient room for differentiation and data diversity (Hareendran et al. 2012, p. 3). The results are re-evaluated through a binary grid of 12 minimum and 3 exclusion requirements before the final ranking. These minimum and exclusion requirements, including i.a. limited organisational adjustments, antitrust or compliance aspects or the underlying aim of risk minimisation, allow a pre-separation of unfavourable cooperation models. A binary approach has been applied in order to specifically exclude considerations that either do not fit the most fundamental requirements for a cooperation model or have to be discarded as they are in conflict with other considerations. Under real world circumstances, this might streamline an otherwise time-intensive due diligence process and provide a better perspective of the potential stakeholders to cooperate with on R&D.

Strategic evaluation of suitable R&D cooperation models

The above outlined setup of a Pugh Matrix to provide criteria- and scoring-based decision support for selecting the most suitable R&D cooperation partners and assessing how such a cooperation should be configured is subject to potential limitations. As this study assesses the case of Hapag-Lloyd, the defined and subsequently categorized 91 cooperation requirements reflect R&D cooperation aspects from the perspective of an international liner shipping company. This allows to address the study's objective to provide guidance which R&D cooperation models are most suitable for liner shipping companies, in order to effectively address the initial IMO GHG strategy. It has to be noted that this evaluation process however should not substitute a full-fledged end-to-end DD process, which might take months in real world settings. Furthermore, while these categories and requirements reflect the considerations of an international organization, additional requirements and respective weighting might be applicable if the concept is transferred to different corporations.

Internal and external cooperation requirements

The criteria catalogue constituted for the evaluation of potential cooperation partners and configurations includes requirements that can be divided into the two segments of Soft Factors and Hard Factors. These segments are respectively subdivided into the Soft Factor categories of Administration, Regulatory Environment, Value-adding Factors and Financial Consideration, while the Hard Factors are aligned with the categories Technological-engineering Factors, Operational Factors and Energy-based Factors, as outlined in 2.1 (Dörner 2019). Supplementing this classification and complementing the setup of this model, the identified cooperation requirements are further organized according to their measurability. The individual requirements were categorized based on their connection to internal or external influencing factors and pre- or post-cooperation aspects (Menges 1972, p. 132; Franco and Gussoni n.d., p. 10). Regarding the pre- and post-cooperation influence, requirements important for the setup of a cooperation model were identified as "Input", while requirements influencing the outcome of a cooperation model were defined as "Output". This is in line with the selected criteria duration, meaning that requirements have to be considered either only once during a cooperation or multiple times. If this selection cannot be allocated to specific points in time during a cooperation, such requirements have been classidied as underlying "Attitude". Furthermore, certain requirements were identified as "trigger-requirements", if a corporation pursuing this cooperation evaluation cannot actively influence the respective requirement (e.g. regulatory constraints are set in stone and a cooperation model has to be set up accordingly). This results in the illustrated requirements catalogue, which reflects a sufficient heterogeneity in line with scientific implications from the literature review. Table 1 shows a selection of cooperation requirements which were specifically underlined by the interviewees and the literature research.

Table 1 Selection of Cooperation Requirements (Abr)

ID	Administrative Requirements	Weight	Trigger	Internal | External Influence	Pre- | Post-cooperation Influence	Criteria Duration
1	Underlying supplier-buyer relationship	0,07	N	External	Input	Onetime
2	Confidentiality & secured intellectual property	0,02	N	Internal	Output	Onetime
3	MEPC 2023 Roadmap wait-and-see approach	0,18	Y	External	Input	Onetime
4	Extend of headcount involved	0,03	N	Internal	Input	Reoccurring
ID	**Regulatory Requirements**	**Weight**	**Trigger**	**Internal | External Influence**	**Pre- | Post-cooperation Influence**	**Criteria Duration**
1	Regualtory constraints	0,5	Y	External	Input	Onetime
2	R&D fund	0,2	Y	External	Input	Onetime
ID	**Value-addition Requirements**	**Weight**	**Trigger**	**Internal | External Influence**	**Pre- | Post-cooperation Influence**	**Criteria Duration**
1	Access to external R&D resources & infrastructure	0,03	N	External	Input	Onetime
2	High underlying learning curve & inter-sectoral knowledge gain	0,01	N	Internal	Output	Attitude
3	Development of holistic dynamic scenarios	0,006	N	Internal	Output	Reoccurring
4	High underlying roll-out potential	0,09	Y	Internal	Output	Onetime
5	High CO2 reduction potential	0,09	Y	Internal	Output	Onetime
6	Mitigation of "supplier trade off"	0,001	N	External	Output	Onetime
ID	**Financial Requirements**	**Weight**	**Trigger**	**Internal | External Influence**	**Pre- | Post-cooperation Influence**	**Criteria Duration**
1	Reduction of underlying financial exposure	0,75	Y	Internal	Output	Reoccurring
2	Development of financial models to transfer R&D related expenses to customers	0,25	N	Internal	Output	Onetime

Source: Own Illustration

Administrative requirements

From an administrative perspective, the interviews highlighted the importance of an underlying supplier-buyer relationship, influencing the cooperation partner selection and making it easier to flexibly allocate specific resources or tasks and jointly evaluate future projects (Brünggen 2019; Jahn 2019; Nagel 2019; Rayner 2019; Sames 2019). The majority of interviewees indicated that these scale aspects are in line with the involved headcount and respectively allocated expert knowledge, which is consistent with previous results (Jahn 2019; Kettelhodt 2019; Timmerberg 2019; Fett and Spiering 2015, p. 9). Certainly, a pure supplier-buyer relationship does not constitute a cooperation model itself. However, pre-existing relationships on a vertical level can support the initial setup of joint R&D endeavors and mutual value creation. Correlating with the depicted data input, this paper identified the aspects of intellectual property and confidentiality as further administrative criteria (Dörner 2019; Hartung 2019; Jahn 2019; Hapag-Lloyd 2019f, p. 76; Fett and Spiering 2015, p. 5; Klingebiel and Joseph 2015; Katz and Ordover 1990, p. 2). The underlying market environment can be considered as an individual requirement (Brünggen 2019; Rayner 2019; SMW 2019, p. 1, 6; Joules n.d.-b, p. 26). This culminates in a "wait-and-see" trigger criterion, based on the fact that the IMO requirements will not "take effect before 2023" (Kristiansen 2019; DNV GL 2017, p. 69).

Regulatory requirements

De Marchi and Rennings describe a regulatory push and pull effect, stating that on the one hand, regulations push economically constrained companies towards R&D cooperation. On the other hand, regulations are also demanded (pulled) by companies to mitigate a potential competitive disadvantage (De Marchi 2011, p. 1). In general, this push and pull effect, however, might be limited to R&D related efforts, while similar pursuits in day-to-day operations result in the risk of collusions and cartels. R&D-related subsidies provide a further crucial regulatory trigger requirement (Erdmann 2019; Guntermann 2019; Grötsch 2019; Hartung 2019; Nagel 2019; Sames 2019; von Berlepsch 2019; Kristiansen 2019; Maersk 2019, pp. 13–14). This could be e.g. related to a R&D fund managed by the IMO. (Guntermann 2019) However, administrative burden and comparable shortcomings must be considered (Hartung 2019; von Berlepsch 2019; Katz and Ordover 1990, p. 4) (Fig. 2).

Value-adding requirements

Two primary requirement-clusters for cooperation models can be defined according to the R&D value chain (Hall 2006, pp. 1–3; Fraunhofer n.d. (d)). Regarding knowledge-based criteria, the expert interviews revealed the high importance of such requirements for early-stage R&D cooperation models (Brünggen 2019; Jahn 2019; Kettelhodt 2019; Rayner 2019; Katz and Ordover 1990, p. 4). Referring to Hartung, it is critical to ensure a high learning curve in R&D cooperation models (Hartung 2019). To a similar extent, this requires sophisticated knowledge management and life-cycle performance assessment (Grötsch 2019; Joules n.d.-a, p. 6; Joules n.d.-b, pp. 2, 40). Research analyses indicate a requirement for broad scenario analyses and stress tests, covering e.g. regulatory or financial impacts or the fleet's carbon and retrofit flexibility (Becker 2019; Brünggen 2019; Grötsch 2019; Kettelhodt 2019; Sames 2019; von Berlepsch 2019; Nagel 2019; DNV GL 2017, p. 77; Joules n.d.-a, p. 2) (Fig. 2).

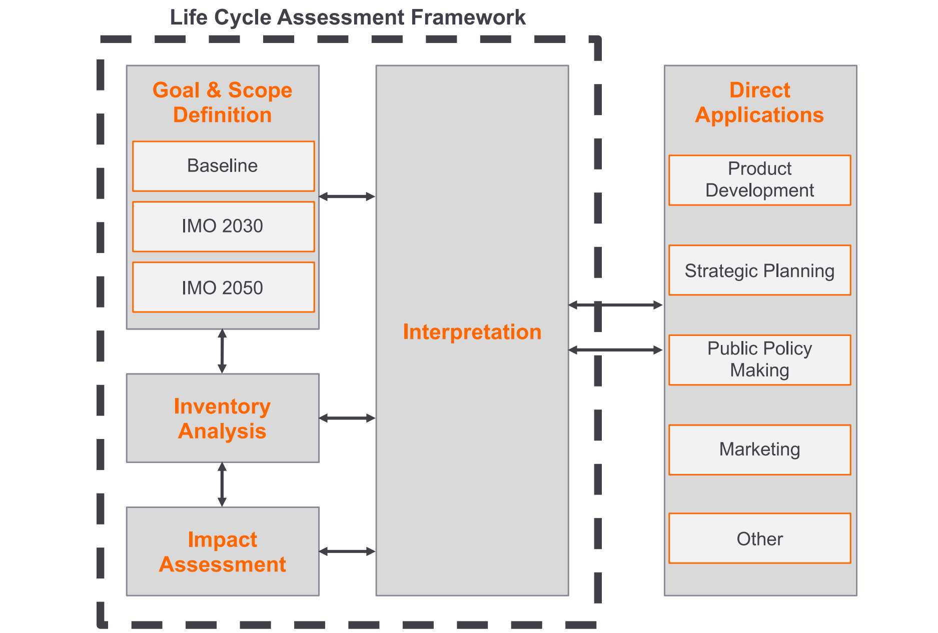

Fig. 2 Standardized Life Cycle Assessment Framework (Based on Joules n.d.-b, 40)

Grötsch and Jahn outline the aspect of differentiating advantages, referring to the competitive knowledge a company internally transfers out of a cooperative R&D project (Grötsch 2019; Jahn 2019). Based on the fact that shipping companies oftentimes have no internal R&D setup, access to complementary knowledge is crucial and correlates with previous research, indicating a substitutional effect between external R&D cooperation and internal R&D effort (Erdmann 2019; Jahn 2019; Kettelhodt 2019; Hapag-Lloyd 2019b, p.1; Badillo and Moreno 2016, p. 3; De Marchi 2011, p. 1). Underlying supplier trade-offs have to be carefully considered, since e.g. the oil industry claims to be a valuable cooperation partner for developing GHG-reduction alternatives, while the sale of conventional fuel still constitutes a major revenue driver (Smith 2019). Another finding underlines constant evaluation of the competitors' initiatives, potentially resulting in an economic FOMO (Fear of missing out) and serving as a trigger requirement (Erdmann 2019; Hartung 2019; Kettelhodt 2019; OECD and ITF n.d. (a), p. 37). The actual CO_2 reduction and break-through potential of the respective R&D cooperation model have to be taken into account, since marginal decarbonization benefits could result in an unfavorable input-output imbalance (Becker 2019; Dörner 2019; von Berlepsch 2019).

Financial requirements

Throughout the interviews, strong evidence was found for requirements reflecting the underlying financial exposure of this decarbonization challenge, in addition to the strategic qualitative criteria. Due to the long-term nature of this decarbonization challenge and related financial uncertainty, it has to be evaluated, how such economic and financial indicators can be integrated into the overall evaluation (Erdmann 2019; Hartung 2019; Kettelhodt 2019; Nagel 2019). Price reductions, reflecting e.g. the spread between the fuel alternative to be tested and current fuel purchasing prices provide an essential trigger requirement on the one hand (Dörner 2019; von Berlepsch 2019). On the other hand, R&D efforts also require financial commitments from the customer side (Becker 2019; Brünggen 2019; Dörner 2019; Guntermann 2019; Hartung 2019; Kettelhodt 2019; Rayner 2019; von Berlepsch 2019).

Future requirements

Continuing with the evidence found for cooperation requirements that cannot be evaluated from today's perspective but pose a specific criterion towards 2050, the interviews e.g. highlight the technical compatibility, classification accordance, and insurance aspects (Becker 2019; Brünggen 2019; Dörner 2019; Guntermann 2019; Nagel 2019; von Berlepsch 2019).

Minimum and exclusion requirements

This study provides additional evidence for minimum and exclusion criteria that must be included in the criteria model for reevaluation purposes. To begin with the minimum requirements, the majority of interviewees underlined the agility and flexibility of a R&D cooperation model as essential prerequisite, which supplements the depicted solution variety aspect and the various knowledge-based criteria (Becker 2019; Brünggen 2019; Grötsch 2019; Guntermann 2019; Jahn 2019; Kettelhodt 2019; Smith 2019). Substantiating previous literature, this study has also found that an aligned objective horizon and synergy potential is required for mitigating cooperative tensions and compensating the lack of an internal R&D setup (Erdmann 2019; Hartung 2019; Menne 2019; Clayton 2019; Fett and Spiering 2015, pp. 3–4; Hapag-Lloyd 2017, p. 90; Albani and Henderson 2014, p. 1). This has to be in line with Hapag-Lloyd's Strategy 2023 and should influence it's corporate core only to a limited extent (Brünggen 2019; Dörner 2019; Hartung 2019; Jahn 2019; Rayner 2019; von Berlepsch 2019; Fett and Spiering 2015, p. 17; De Piante 1999, p. 8). Antitrust and competition law has to be considered, specifically in the context of horizontal overlaps (Erdmann 2019; Guntermann 2019; Hartung 2019; Jahn 2019; Mohrdieck 2019; Smith 2019; Hellenic Shipping News 2018; Kullas and Koch 2010, p. 2).

Comprehensive stakeholder and cooperation partner overview

In addition, a comprehensive overview and selection of potential cooperation partners has to be constituted. These external stakeholders are classified into segments of technical, fuel-related, academic, and political partners, while also considering competing shipping companies and customers. To evaluate the defined 42 potential cooperation partners, a further categorization took place according to their direct or indirect relation to shipping companies, their operative involvement, and their scope (Appendix C) (Grötsch 2019). The stakeholders are divided into public and private institutions and perceptional conditions of first movers, fast followers and late followers. This categorization took place, considering the stakeholders' prevailing R&D cooperation experience and involvement in past projects (Dörner 2019; Erdmann 2019; Grötsch 2019; Hartung 2019; Jahn 2019; Klingebiel and Joseph 2015). Correlating the outcome with previous studies, potential cooperation partners are subdivided into a horizontal, vertical and lateral scale (Brünggen 2019; Rayner 2019; Badillo and Moreno 2016, p. 5; Fett and Spiering 2015, p. 24). In this context, horizontal cooperation models take place with similar companies on the same step of the value-creation chain. Correspondingly, vertical cooperation models involve companies from preceding or subsequent steps in the value-creation chain, while the lateral scale also includes companies outside of a corporations industry or value-creation focus. This paper evaluates cooperation potential of 42 individually identified external stakeholders, based on 3822 assigned scores and 630 minimum and exclusion assessments (Table 2). Further quantitative analyses indicate an approximate normal distribution of the allocated values. This study reveals that from today's perspective and based on the outlined requirements, applied and theoretical research organizations, classification societies and universities have to be considered as primary cooperation partners for shipping companies in the current development stage of GHG-reduction. These top 4 cooperation partners jointly provide experience from previous projects, while also being commonly considered as first movers with an early involvement potential (Hartung 2019; Jahn 2019). Hapag-Lloyd may gain access to external R&D resources with a high probability for competitive and differentiating advantages. A multiple linear regression analysis further provides evidence for a positive correlation between the scores assigned for the applied and theoretical research organizations. This concurs with a similarly administered multiple linear regression, considering both research organization types and classification societies, which do not significantly correlate. This validates the ranking and supports a multilateral cooperation model (Table 2).

With reference to practically oriented collaborations with research organizations, Jahn specifically outlines the high flexibility and agile configuration of such a cooperation, supporting the required risk minimization and uncertainty reduction (Jahn 2019). These aspects are broadly in line with the lateral university collaborations, as Nagel and Dörner e.g. underline the expected variety of alternatives, requirement for internal knowledge impulses and advanced development stage as primary drivers for such cooperation (Dörner 2019; Nagel 2019). Universities can provide rigorous thinking while taking real-world constraints into account, which is highly important in this exploratory stage and provides shipping companies with an overview of the "wider energy puzzle" and current scientific environment (Becker 2019; Brünggen 2019; Menne 2019; Smith 2019; Timmerberg 2019) This correlates with preceding literature. (De Marchi 2011, pp. 1, 5; Joules n.d.-a, p. 3; Franco and Gussoni n.d., p. 11).

Regulatory partners and port authorities have to be considered for infrastructure aspects (Brünggen 2019; Jahn 2019; Rayner 2019; Sames 2019; SMW 2019, pp. 5, 6; World Shipping Council n.d.). This substantiates analyses by De Marchi, highlighting the inclusion of governmental organizations into the process of environmentally related R&D cooperation (De Marchi 2011, 3). Customers appear to be specifically important for eco-innovation R&D cooperation projects, also on a B2B-level (Brünggen 2019; Nagel 2019; Rayner 2019; Sames 2019; Smith 2019; Timmerberg 2019). The regression analyses reveal that all customer groups are significantly positively correlated. From a vertical perspective, on the supplier side, OEMs and Oil Majors score relatively high and have to be considered for the transfer from knowledge-based to technology-based R&D and test-phases (Becker 2019; Brünggen 2019; Dörner 2019; Grötsch 2019; Guntermann 2019; Hartung 2019; Nagel 2019; Maersk 2019, p. 13; Shell Marine 2019, pp. 1–2; Shell Marine 2018, pp. 1–2; Burgard et al. 2018, pp. 1, 5; Joules n.d.-b, p. 10; Ship Technology Global n.d.). A cooperation package approach and underlying

Table 2 Cooperation partner ranking

Ranking	Cooperation partner	Score
1	Applied Research Organisations	7.1321
2	Theoretical Research Organisations	7.0946
3	Classification Societies	7.0213
4	Universities	6.9911
5	IMO (Intergovernmental Regulatory Bodies)	6.6685
6	GAM (GNP & GBP)	6.6519
7	Spot (FCL)	6.6408
8	Machinery OEMs (incl. M&R)	6.6196
9	Oil Majors (Contract)	6.5800
10	German Shipowners Association (Lobbying Associations)	6.5704
11	ECSA (incl. Environment & Safety Working Group)	6.5614
12	ICS	6.5360
13	WSC	6.5344
14	Oil Majors (Spot)	6.4390
15	Spot (LCL)	5.9850
16	International Liner (Alliance Partner)	5.9082
17	International Liner (Non-Alliance)	5.8682
18	Laboratories (Fuel & Chemical)	5.5282
19	Bunker Suppliers (Non-producing)	5.2924
20	Consultants	5.2543
21	Quant. Economists	5.0608
22	Bunker Traders	5.0576
23	BIMCO	4.9781
24	Software & Data Analysis Providers	4.8484
25	Naval Architects	4.8209
26	Marine Engineering Offices	4.8075
27	Ship Yards	4.7953
28	Simulators & Commercial Labs	4.6943
29	Ports & Port Authorities	4.6033
30	EU Commission	4.5740
31	German Government	4.5665
32	Bunker Surveyors	4.5555
33	Charterers	4.3183
34	Hydrodynamics Institutes	4.3074
35	Infrastructure Providers	3.7753
36	Consumers (Indirect Customers)	3.2444
37	Knowledge Intensive Business Services (KIBS)	3.1999
38	Startups, Accelerators & Technology SMEs	0.0000
38	Electrolysers (eg. Shell, Yara, Siemens)	0.0000
38	Ammonia Producers (eg. Yara)	0.0000
38	Regional Liner	0.0000
38	Regional Niche Carrier	0.0000

Source: Own Illustration

supplier-buyer relationship could be important (Becker 2019; Brünggen 2019; Hartung 2019; von Berlepsch 2019; Wärtsilä 2018, p. 1; De Marchi 2011, pp. 3, 5; ABB n.d.; MAN Energy Solutions n.d.-a; Wärtsilä n.d.-b).

Validation analysis

For further validation and evaluation purposes, the average assigned scores have been compared with the weighted end scores. This analysis reveals that the individually assigned scores are generally not leveraged through a high requirements weighting. This implies that the weighted end scores are in most cases not significantly higher than the average assigned scores, which in turn would indicate that although the stakeholders assign a relatively low score, a certain requirement might receive a high importance solely based on its defined weight. This reduces the potential risk of fluctuations towards 2050 and the developed scoring risk assessment indicates that the majority of stakeholders is located in an appropriate range, without specific outliers.

Fragmentation and classification of cooperation elements

After outlining contemporary cooperation requirements and matching these with a portfolio of potential cooperation partners, the next step requires to include the 69 primary cooperation elements derived from the theory of R&D collaboration into the perspective. These cooperation elements are clustered into 24 segments, allowing a modular development of the most suitable cooperation configuration. The required flexibility to configure a huge variety of potential cooperation models in the context of decarbonization in shipping is provided, which is supported by Fett and Spiering and consistently corroborated throughout the interviews (Hartung 2019; Kettelhodt 2019; Fett and Spiering 2015, pp. 3, 7). Subsequently, 6279 individually assigned scores, which are approximately normal distributed and 1035 minimum and exclusion assessments resulted in a ranking of the most suitable cooperation elements (Table 3).

For the purpose of generating a wide perspective across the complete time scale of a cooperation model, starting with the formation and concluding with the dissolution, the following set of analyses is based on a cooperation elements digest (Appendix D, E). In this regard, the analyses highlight that shipping companies should focus on short- to medium-term R&D cooperation models with a respectively efficient formation phase and in-depth strategic coordination (Jahn 2019; Grötsch 2019; von Berlepsch 2019; Fett and Spiering 2015, pp. 4, 8; Kermani et al. n.d., p. 1).

This study specifically excludes the foundation of a separate legal entity in the current advanced research stage and substantiating previous research studies the cooperation direction has to be considered, with vertical and lateral cooperation models being important (Grötsch 2019; Jahn 2019; Mohrdieck 2019; Fett and Spiering 2015, p. 23). Referring to the final scores, the most remarkable result is related to the segment of the cooperation outcome and respective range of R&D involvement (Table 3).

This should focus on knowledge-based R&D cooperation models, supporting shipping companies in broadening their horizon towards 2030 and 2050, while competitively positioning the company in the underlying environment through a level of solution certainty and unilateral knowledge spillovers (Brünggen 2019; Dörner 2019; Hartung 2019; Jahn 2019; Rayner 2019). Such intangible knowledge focus is in line with the MEPC roadmap

Table 3 Cooperation elements ranking

Ranking	Cooperation partner	Score
1	Internal Knowledge Impulses	8.8270
2	Knowledge Integration	8.7318
3	Short Formation Phase (<0,5 years)	8.1463
4	Vision (Outcome)	8.1331
5	Vertical Cooperation Direction	7.9983
6	International Scope	7.9006
7	Centralized Cooperation (Mgmt. Level)	7.8064
8	Low Investment Requirement	7.7890
9	Knowledge-based R&D (Intangible)	7.7325
10	Work-shops	7.6886
11	Short-term Cooperation (<2 years)	7.6219
12	Privately Funded	7.5924
13	Topic Exploration	7.4165
14	Bilateral Scope	7.1881
15	Limited Internal Cooperation Influence	7.1705
16	Lateral	7.1336
17	Inflexible Cooperation (not open)	7.1119
18	Underlying Long-term Supplier-Buyer Relationship	7.0437
19	No Foundation of Legal Entity	7.0071
20	Advance Research	6.9795
21	Test-phases as Cooperation Outcome	6.8590
22	Approached by another company	6.8489
23	Open Outcome	6.8442
25	Medium Investment Requirement	6.7551
24	First-time Cooperation	6.7768
26	Cooperation Share Parity	6.7067
27	Pre-competitive Environment	6.5756
29	Focussed Outcome	6.5093
28	Mixed Intellectual Property Allocation	6.5448
30	HL Active Initiator	6.4253
31	Product Integration	6.3397
32	No Lead Partner & Advisory Group Requirement	6.2036
33	Medium-term Cooperation (2-5 years)	6.1459
34	Test-phases	6.0710
35	Non-published Cooperation	6.0428
36	Multilateral Scope	5.9674
37	Publicly Funded	5.8045
38	HL < others (Cooperation Share)	5.7672
39	Direct Internal Cooperation Influence	5.6846
40	100% HL (Intellectual Property Allocation)	5.6626
41	Flexible Cooperation (open for add. partners)	5.4496
42	Competitive Environment	5.3673
44	Published Cooperation	5.1072
43	New Cooperation (First time)	5.1303

Table 3 Cooperation elements ranking *(Continued)*

Ranking	Cooperation partner	Score
45	Medium Formation Phase (0,5-1 year)	5.0002
46	Complete Dissolution	4.8567
47	HL > others (Cooperation Share)	4.6352
48	Prototypes as Cooperation Outcome	4.6060
49	No Internal Cooperation Influence	4.5305
50	Horizontal Scope	4.4686
51	Exit Potential	4.1966
52	Follow-on Cooperation	3.9417
53	Lead Partner & Advisory Group Requirement	3.7156
54	Long-term Cooperation (5-10 years)	3.6508
55	Technology-based R&D (Tangible)	3.5505
57	Existing Cooperation	3.5003
56	Decentralized Cooperation (Clerk Level)	3.5170
58	Long Formation Phase (>1 year)	3.3222
59	Incorporation at Partner	2.7219
60	National Scope	0.0000
60	No Exit Potential	0.0000
60	Foundation of Legal Entity	0.0000
60	Pilot Project	0.0000
60	Incorporation (e.g. JV)	0.0000
60	Capital Venture	0.0000
60	0% HL (Intellectual Property Allocation)	0.0000
60	Permanent Cooperation (>10 years)	0.0000
60	"Serial" Technology Development	0.0000
60	Viable Co-development	0.0000

Source: Own Illustration

requirement and prevailing uncertainty and further provides the potential of iteratively shaping the industry's regulatory environment (Brünggen 2019; Hartung 2019; Rayner 2019; Kristiansen 2019). Supported by the majority of interviewees, knowledge-based R&D cooperation models are particulary suitable for the current pre-competitive topic exploration stage (Becker 2019; Brünggen 2019; Jahn 2019; Kettelhodt 2019; Mohrdieck 2019; Nagel 2019; Rayner 2019; Smith 2019; De Marchi 2011, p. 3).

Conclusions

This paper provides empirical support to theories investigating the increasingly important research area of environmentally-related R&D cooperation. Based on the large variety of potential R&D cooperation models, the primary concern of this exploratory study was the definition and categorization of the underlying criteria, stakeholders and cooperation elements in order to evaluate the most eligible cooperation model from a shipping company's perspective. Primarily, this revealed that pre-defined cooperation models as such cannot be practically applied, resulting in the essential fragmentation into individual cooperation elements. These elements then allow a modular development of the most suitable cooperation configuration, both in this context but also for interdisciplinary challenges in general (Fig. 3).

A staggered approach was adopted, subdividing the delineated findings into short-term, medium-term, and long-term recommendations (Fig. 3). The devised criteria evaluation methodology suggests an active involvement in knowledge-based R&D cooperation models on a short-term basis, to build the internal transfer capabilities required for the expected technological disruption towards 2050. The resulting enhancement of knowledge of the variety of GHG-reduction alternatives, targeting technological-engineering solutions, energy-based options, and operational measures, should result in a specific solution path and "decarbonization roadmap". Evidence from this study suggests that the development of holistic scenarios in such research-focused cooperation models could support the organization in navigating R&D-driven transformation process. Regarding the stakeholders to be considered for such early-stage cooperation models, the research illustrates the importance of industry-academia partnerships with research organizations and universities on a lateral level. The current developmental stage indicates the potential for generating knowledge-based stimuli through collaborations with classification societies.

On a medium-term basis, this knowledge-based R&D approach provides the framework for actively engaging in a variety of further test-phases, which would result in a supplemental knowledge enhancement concerning the anticipated GHG-reduction alternatives. This correlates with the cooperation requirements of ensuring an in-depth long-term preparation as well as identifying technical challenges. Vertical supplier-buyer cooperation package models with technical stakeholders, including both OEMs and fuel providers, are gaining in importance and support the development of viable decarbonization alternatives on a mid-term basis. This allows the formulation of operative and technological GHG-reduction requirements. Taking these aspects into consideration, such test-phases serve as a bridge between intangible knowledge-based research and tangible technology-based developments. Consequently, the focus switches from evaluating how the IMO GHG-reduction strategy could be achieved to assessing how it can be accomplished. Regarding the long-term perspective towards 2050, this paper indicates the expansion of technology-based R&D cooperation models, targeting e.g. prototypes and pilot projects.

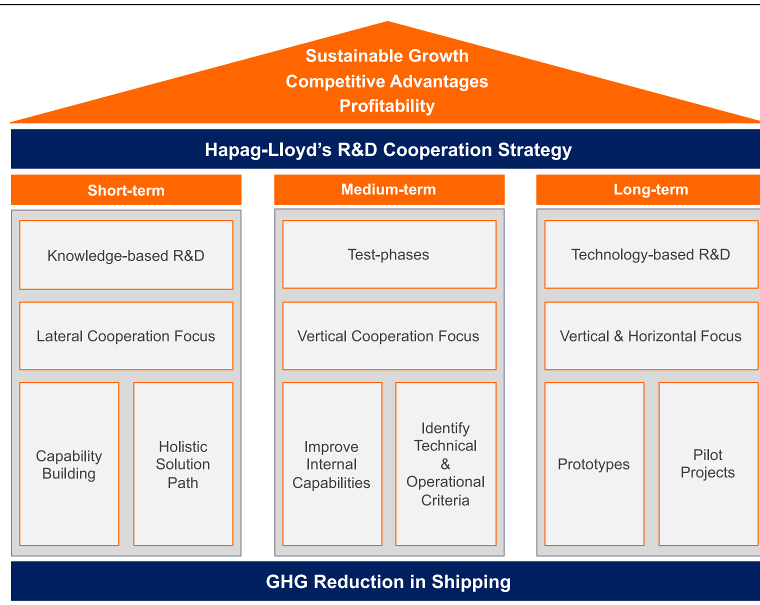

Fig. 3 Cooperation Partner Scoring Risk Assessment (Own Illustration)

Appendix A

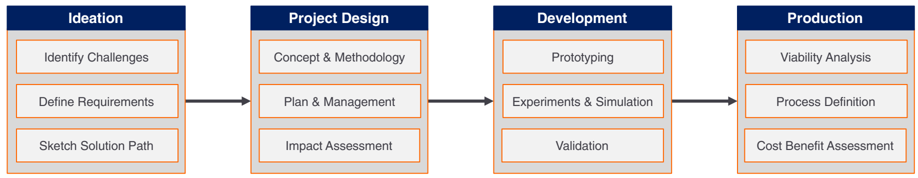

Fig. 4 Proposed R&D Cooperation Strategy (Own Illustration)

Appendix B

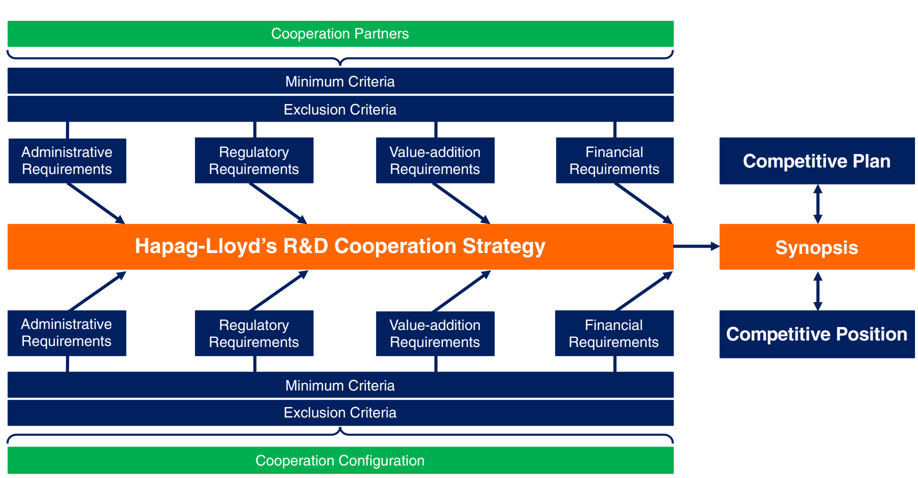

Fig. 5 R&D Value Chain. Source: Own Illustration

Appendix C

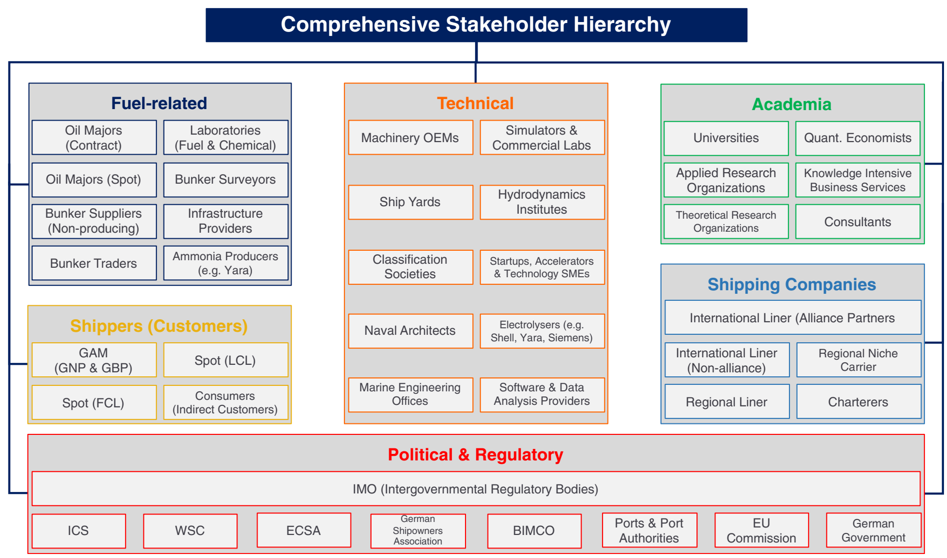

Fig. 6 Generic R&D Cooperation Assessment Model. Source: Own Illustration

Appendix D

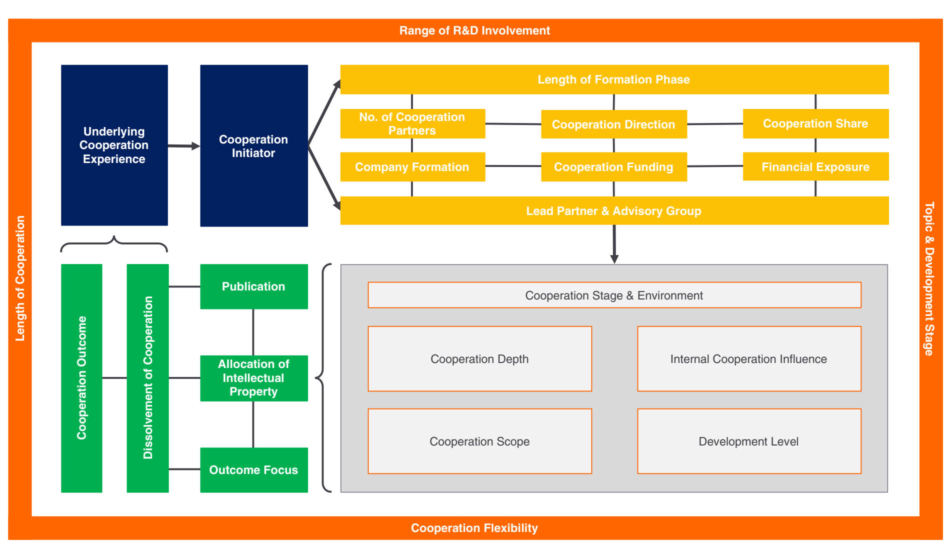

Fig. 7 External Stakeholders and Potential Cooperation Partners. Source: Own Illustration

Appendix E

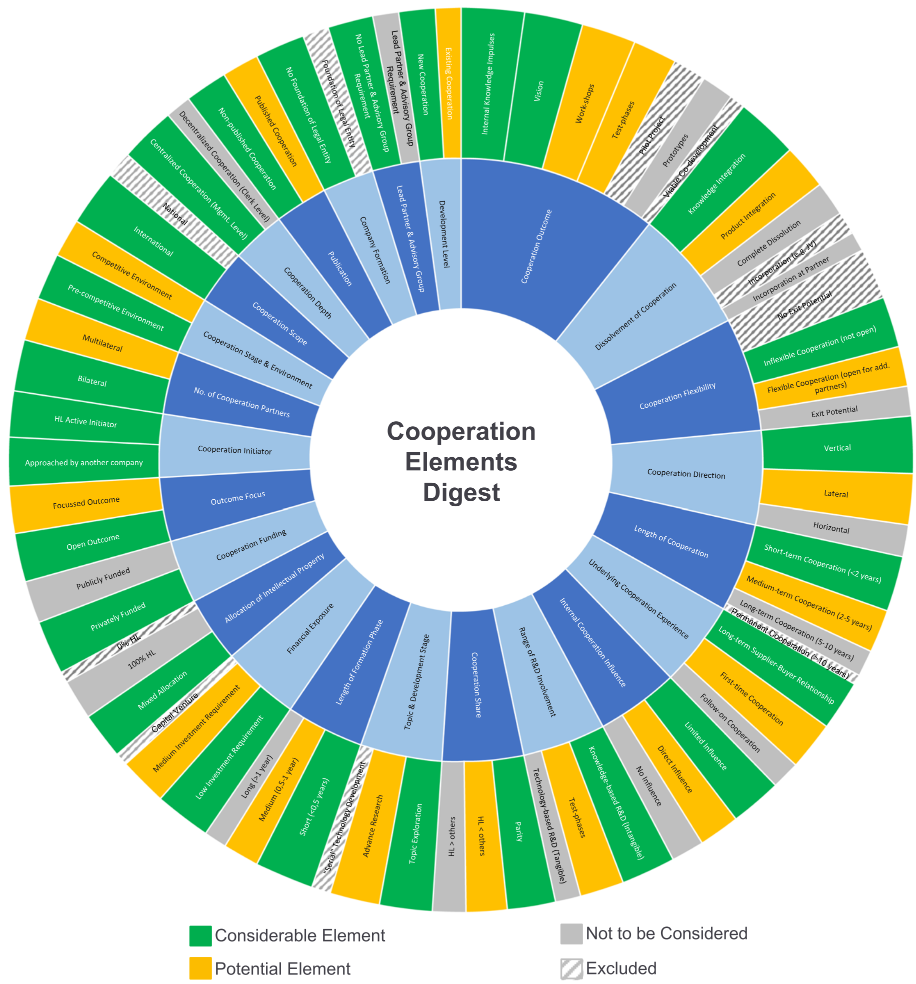

Fig. 8 R&D Cooperation Process. Source: Own Illustration

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Authors' contributions
The information contained in this article does not constitute research or recommendation from any Hapag-Lloyd entity or involved company. Neither Hapag-Lloyd nor any involved company makes any representation or warranty as to the accuracy or completeness of the statements or any information contained in this article. The views expressed in this article are not necessarily those of Hapag-Lloyd or of any involved company. The author(s) read and approved the final manuscript.

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References
ABB (n.d.) “Offerings Marine.” https://new.abb.com/marine/. Accessed 15 May 2019
Adamopoulos A (2019a) Governments pursue new shipping emissions measures. Lloyd’s List Last modified April 12, 2019. https://lloydslist.maritimeintelligence.informa.com/LL1127051/Governments-pursue-new-shipping-emissions-measures
Adamopoulos A (2019b.) “LNG could cut emissions by up to 21%.” Lloyd’s List. Last modified April 11, 2019. https://lloydslist.maritimeintelligence.informa.com/LL1127032/LNG-could-cut-emissions-by-up-to-21
Albani M, Henderson K (2014) Creating partnerships for sustainability. McKinsey & Company, New York City
Badillo E, Moreno R (2016) What drives the choice of the type of partner in R&D cooperation? Evidence for Spanish manufacturers and services. University of Barcelona, Barcelona
Barrett D, Twycross A (2018) Data collection in qualitative research. University of Hull, Hull
Beck M, Junge M, Kaiser U (2017) On the effects of research and development: a literature review. DEA, Copenhagen
Becker M (2019) MD Wärtsilä Deutschland. Interviewed by Carsten Willer. May 6, 2019
Berlepsch RV (2019) Managing Director Fleet Management at Hapag-Lloyd. Interviewed by Carsten Willer. May 10, 2019
Border KC (2002) Brief notes on the arrow-Debreu-McKenzie model of an economy. California Institute of Technology, Pasadena
Bouncken R, Gast J, Kraus S, Bogers M (2015) Coopetition – a systematic review, synthesis, and future research directions. Springer, Berlin
Brünggen A (2019) Senior Account Manager Hapag-Lloyd at Wärtsilä Deutschland. Interviewed by Carsten Willer. April 29, 2019 and May 6, 2019
Burgard N, Hansen N, Michaelis F, Nagel R (2018) Abschlussbericht zum Vorhaben – Nutzung von Methanol als Brennstoff für Ro-Ro Passagierschiffe. Flensburger Schiffbau-Gesellschaft, Flensburg
Business Dictionary (n.d.) “Expert.” http://www.businessdictionary.com/definition/expert.html. Accessed 8 Apr 2019
Cambridge Dictionary (n.d.) (b) “Research and Development.” https://dictionary.cambridge.org/de/worterbuch/englisch/research-and-development. Accessed 5 Apr 2019
Clayton R (2019) Shipping businesses must learn how to collaborate. Lloyd’s List Last modified March 21, 2019. https://lloydslist.maritimeintelligence.informa.com/LL1126721/Shipping-businesses-must-learn-how-to-collaborate
De Marchi V (2011) Environmental innovation & R&D cooperation: empirical evidence from Spanish manufacturing firms. University of Padova, Padova
De Piante HA (1999) A practical R&D project-selection scoring tool. IEEE Trans Eng Manag 46(2):158–170
Deutscher Bundestag (2018) Dokumentation E-Fuels. Wissenschaftliche Dienste des Deutschen Bundestages, Berlin
DNV GL (2017) Maritime forecast 2050 - energy transition. DNV GL AS, Oslo
Dörner N (2019) Senior Manager Fuel & Lubricants at Hapag-Lloyd. Interviewed by Carsten Willer. April 25, 2019
Dudovskiy J (n.d.) Abductive reasoning (abductive approach). Research Methodology https://research-methodology.net/research-methodology/researchapproach/abductive-reasoning-abductive-approach/. Accessed 12 May 2019
Easterby-Smith M, Thorpe R, Jackson P (2015) Management & Business Research. Sage Publications Ltd, London
Expert Conference of the Association of German Engineers (2019) "Ship Technology and Propulsion of the Future." Attended by Carsten Willer, Hamburg
Erdmann JP (2019) Senior Director Sustainability Management at Hapag-Lloyd. Interviewed by Carsten Willer
Fett T, Spiering C (2015) Handbuch Joint Venture. C.F. Müller GmbH, Heidelberg
Fishburn PC (1967) Methods of estimating additive utilities. Manag Sci 13(7):435–453. https://doi.org/10.1287/mnsc.13.7.435
Franco C, Gussoni M (n.d.) Firm’s R&D cooperation strategies: the partner choice. Università de Pisa, Pisa
Fraunhofer CML (n.d.) (d) “Current Projects.” https://www.cml.fraunhofer.de/en/researchprojects/current-projects.html. Accessed 3 Apr 2019
Godwin O (2019) Weighting methods for multi-criteria decision making technique. Journal of Applied Sciences and Environmental Management, Port Harcourt
Greener S (2008) Business research methods. Ventus Publishing ApS, Frederiksberg
Grötsch J (2019) Manager Shell Technology Centre Amsterdam. Interviewed by Carsten Willer. May 3, 2019
Guntermann W (2019) Director Environmental Fleet Management at Hapag-Lloyd. Interviewed by Carsten Willer. May 3, 2019
Hall B (2006) Research and Development. UC Berkeley, Berkeley
Hapag-Lloyd (2016) “Keeping an eye on the fleet.” Last modified June 1, 2016. https://www.hapag-lloyd.com/en/news-insights/insights/2015/06/keeping-an-eye-on-the-fleet_41208.html
Hapag-Lloyd (2017) Prospectus for the public offering. Hapag-Lloyd AG, Hamburg
Hapag-Lloyd (2019b) Fleet Management Organisation Chart. Hapag-Lloyd AG, Hamburg
Hapag-Lloyd (2019d) Press release: Hapag-Lloyd first in the world to convert large container ship to LNG. Hapag-Lloyd AG, Hamburg
Hapag-Lloyd (2019f) Sustainability report 2018. Hapag-Lloyd AG, Hamburg
Hareendran A, Leidy N, Monz B, Winnette R, Becker K, Mahler D (2012) Proposing a standardized method for evaluating patient report of the intensity of dyspnea during exercise testing in COPD. Int J COPD 7:345–355
Hartung M (2019) President Digital Transformation at Target Oilfield Services L.L.C. and former Vice President Technical Data at Shell. Interviewed by Carsten Willer. April 25, 2019
Hellenic Shipping News (2018) “Market consolidation in container shipping: what next?.” Last modified October 6, 2018. https://www.hellenicshippingnews.com/market-consolidation-in-container-shipping-what-next/
Hottenrott H, Lopes-Bento C (2014) (international) R&D collaboration and SMEs: the effectiveness of targeted public R&D support schemes. Res Policy 43(6):1055–1066. https://doi.org/10.1016/j.respol.2014.01.004

IMO (2018) Adoption of the initial IMO strategy on reduction of GHG emissions from ships and existing IMO activity related to reducing GHG emissions in the shipping sector. International Maritime Organization, London
IMO (2019) Reduction of GHG emissions from ships – considerations for effective uptake of alternative low-carbon/zero-carbon/fossil-free fuels under the programme of follow-up actions of the initial IMO strategy on reduction of GHG emissions from ships. International Maritime Organization, London
IMO (n.d.) "Market-based Measures." http://www.imo.org/en/OurWork/Environment/PollutionPrevention/AirPollution/Pages/Market-Based-Measures.aspx. Accessed 20 May 2019
Jahn C (2019) Head of the Fraunhofer Center for Maritime Logistics and Head of the Institute of Maritime Logistics at Hamburg University of Technology. Interviewed by Carsten Willer. April 17, 2019
Joules (n.d.-a) (a) Results from the joules project. This paper was published as part of the Joules Project
Joules (n.d.-b) (b) Deliverable 21–1 – project summary and political recommendations. This paper was published as part of the Joules Project
Katz MM, Ordover J (1990) R&D cooperation and competition. Brookings Papers, Washington D.C
Kermani M, Boufaida M, Paviot-Adet E (n.d.) A model to specify inter-company cooperation. Constantine University and Pierre & Marie Curie University, Constantine
Kettelhodt P (2019) Director Corporate Controlling at Hapag-Lloyd. Interviewed by Carsten Willer. April 11, 2019
Klingebiel R, Joseph J (2015) When First Movers Are Rewarded, and When They're Not. Harvard Business Review Last modified August 11, 2015. https://hbr.org/2015/08/when-first-movers-are-rewarded-and-when-theyre-not
Kristiansen T (2019) Maersk and BW group recommend CO2 tax on shipping. Shipping Watch Last modified April 11, 2019. https://shippingwatch.com/secure/carriers/article11314761.ece
Kullas M, Koch J (2010) BER for Reserach and development agreements. Centrum für Europäische Politik, Freiburg
Kumar A, Sah B, Singh A, Deng Y, He X, Kumar P, Bansal R (2017) A review of multi criteria decision making (MCDM) towards sustainable renewable energy development. Renew Sust Energ Rev 69:596–609. https://doi.org/10.1016/j.rser.2016.11.191
LNG (2019) Technological and Environmental Forum: Economic and Environmental Impacts of LNG. Attended by Carsten Willer, Brunsbüttel February 13, 2019
Maersk (2018) Sustainability report 2017. A.P. Møller – Mærsk A/S, Copenhagen
Maersk (2019) Sustainability report 2018. A.P. Møller – Mærsk A/S, Copenhagen
MAN Energy Solutions (n.d.-a) (a) "Dual Fuel." https://powerplants.man-es.com/fuels/dual-fuel. Accessed 6 Apr 2019
MAN Energy Solutions (n.d.-b) (b) "Dual Fuel Engines.". https://powerplants.man-es.com/products/dual-fuel-engines. Accessed 6 Apr 2019
Marinucci M (2012) A primer on R&D cooperation among firms. Banca d'Italia, Rome
Menges G (1972) Entscheidungsmodelle in den Wirtschaftswissenschaften. Systemtheorie - Forschung und Information, Schriftenreihe der RIASFunkuniversität (ed. by R. Kurzrock):132–140
Menne M (2019) Team Lead Research and Serial Development at Daimler. Interviewed by Carsten Willer. April 29, 2019
Mohrdieck C (2019) Managing Director Corporate R&D Fuel Cells at Daimler. Interviewed by Carsten Willer. May 8, 2019
Moss Kanter R (2010) 15 steps for successful strategic alliances (and marriages). Harvard Business Review Last modified June 1, 2010. https://hbr.org/2010/06/15-steps-for-successful-strate.html%20(15
Nagel R (2019) Head of R&D at Flensburger Schiffbau-Gesellschaft. Interviewed by Carsten Willer. May 14, 2019
OECD and ITF (n.d.) (a) the impact of alliances in container shipping. OECD, Paris
Perkmann M, Walsh K (2007) University–industry relationships and open innovation: towards a research agenda. Int J Manag Rev 9(4):259–280. https://doi.org/10.1111/j.1468-2370.2007.00225.x
Pugh S (1981) Concept selection: a method that works. In: Hubka, V. (ed.), Review of design methodology. Proceedings international conference on engineering design, March 1981, Rome. Zürich: Heurista, blz 497–506
Rayner A (2019) Head of Sales North Europe at Eniram Wärtsilä. Interviewed by Carsten Willer. April 29, 2019
Sames PC (2019) Director of Group Technology & Research at DNV GL. Interviewed by Carsten Willer. May 15, 2019
Saunders M, Lewis P, Thornhill A (2009) Research methods for business students, 5th edn. Pearson Education Ltd, Essex
Saunders M, Lewis P, Thornhill A (2016) Research methods for business students, 7th edn. Pearson Education Ltd, Essex
Schoonenboom J, Johnson R (2017) How to Construct a Mixed Methods Research Design. Springer Last modified July 5, 2017. https://www.ncbi.nlm.nih.gov/pmc/articles/PMC5602001/
Shell Marine (2018) Lowering oil consumption saves Ro-Ro operator US$123,000 annually. Royal Dutch Shell, The Hague
Shell Marine (2019) Shell Lubemonitor helps vessel save US$39,000 a year. Royal Dutch Shell, The Hague
Ship Technology Global (n.d.) "Could Fuel Cells soon be used in Ship Propulsion." https://ship.nridigital.com/ship_mar19/could_fuel_cells_soon_be_used_in_ship_propulsion. Accessed 6 Apr 2019
Smith T (2019) Reader in Energy and Shipping at the University College London Energy Institute. Interviewed by Carsten Willer. May 1, 2019
SMW (2019) Singapore maritime week 2019. Singapore Maritime Week, Singapore
Timmerberg S (2019) Project Head at the Environmental Technology and Energy Economy Department at Hamburg University of Technology. Interviewed by Carsten Willer. April 26, 2019
United Nations (2015) Paris Agreement. United Nations, New York City
Warnecke W (2019) Fuels options for large engines – potential of new Syn fuels. Paper presented at the VDI Expert Conference, Hamburg
Wärtsilä (n.d.-a) (a) "Future Innovation Day – Horizons". https://www.wartsila.com/horizons-oslo. Accessed 15 May 2019
Wärtsilä (n.d.-b) (d) "Wärtsilä Purpose". https://www.wartsila.com/about/strategy/purpose. Accessed 15 May 2019
Wärtsilä (2018) Press Release: Wärtsilä makes significant investment in Finland – the Smart Technology Hub, next-generation innovation and production center, will be built in Vaasa. Wärtsilä Corporation, Helsinki. p. 90
World Shipping Council (n.d.) "About the Council." http://www.worldshipping.org/about-the-council. Accessed 18 May 2019

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