2022-12-21

Developing a MCDM-based framework for achieving circular economy through sustainable ship recycling

Mannan, Bisma

http://hdl.handle.net/10026.1/20534

Proceedings of MARTEC 2022
The International Conference on Marine Technology
21-22 December 2022, BUET, Dhaka, Bangladesh

DEVELOPING A MCDM-BASED FRAMEWORK FOR ACHIEVING A CIRCULAR ECONOMY THROUGH SHIP RECYCLING

Bisma Mannan[1], Md Jahir Rizvi [2], Yong Ming Dai [3]

School of Engineering, Computing and Mathematics,
Faculty of Science and Engineering, University of Plymouth,
Drake Circus, Plymouth, PL48AA, United Kingdom.
[1]E-mail: bisma.mannan@plymouth.ac.uk
[2]E-mail: mdjahir.rizvi@plymouth.ac.uk
[3]E-mail: y.dai@plymouth.ac.uk

ABSTRACT

As a result of the growing global population, concerns about the energy crisis and sustainability issues are studied by researchers and policymakers to make a transit from a linear to a circular economy. However, the recycling of end-of-life (EOL) ships has long been a severely marginalized research area in the field of circular economy, and many EOL ships are still adhering to the outdated linear model. The number, size, and volume of ships being built around the world have consistently increased during the past 20 years. In near future, the global ship recycling volume is anticipated to increase dramatically which will aid the circular economy. Consequently, there is a necessity to develop a framework for ship recycling that will become a roadmap to achieving a circular economy. Hence, this study identifies the factors associated with ship recycling and creates a Multi-Criteria Decision Making (MCDM) framework using Interpretive Structural Modelling (ISM). The framework identifies that the main driving factors for achieving an effective circular economy through ship recycling are the government policies, the environmental and maritime regulations, and the funding for the capacity building.

Keywords: *Ship recycling, Circular economy, Interpretive structural modelling (ISM), Multi-Criteria Decision Making (MCDM), End-of-life (EOL) ships, framework.*

1. INTRODUCTION

The growth of the global economy stimulates both the demand for marine trade and shipping capacity. In recent decades, the ship size and the number have increased tremendously due to the rise in demand. The innovations in maritime sector have also enabled to lower the transportation costs. Since 1990, total Light Displacement Tonnage (LDT) has increased by 3.5 times and the capacity of ships has also expanded concurrently which has resulted increase in international trade and reduction in transportation costs thus in turn reductions in supply chain expenses. To decrease peak traffic at ports, port infrastructure and equipment both have been altered over the years to accommodate the increasing number and size of ships. However, there hasn't been much thought given to the efficiency and capacity requirements of the ship recycling yards [1].

Concerns regarding the ability to recycle larger ships exacerbate the capacity dilemma. Over the past ten years, ships have grown dramatically in size, with freight ships practically doubling in capacity [2]. When it comes to recycling, a sizeable ship would normally demand a facility with appropriate infrastructure capable of handling its larger assets. For shipowners, this brings difficulties in locating facilities with required capability and capacity to handle large ships to recycle in a timely, responsible, and financially viable way. This is especially true for shipowners of EU-flagged vessels, which are required to recycle in EU-approved facilities [3].

Considering the current scenario, non-OECD South Asian countries like Bangladesh, Pakistan and India are more feasible to provide cost-efficient recycling solutions. In these countries, a natural demand for steel combined with lower labour cost and higher recycling capacity offers significantly higher steel-scrap prices to the ship owners. The alternatives available to shipowners for selecting ship recycling yards outside of South Asia are few due to market conditions and capacity limitations [4]. Hence, the current study is carried out to identify the main driving factors for the ship recycling yards in South Asia which would enable these countries to achieve an effective circular economy.

2. SHIP LIFECYCLE AND CIRCULAR ECONOMY

The Ellen MacArthur Foundation describe circular economy as "an economy that is founded on the ideas of designing out waste and pollution, keeping goods and resources in use, and renewing natural systems". The economy is therefore created to be regenerative and restorative [4, 5]. The circular economy's guiding principles make a paradigm shift in our way of thinking. Instead of focusing on the individual components of a system, one must take it into account as a whole system. In practice, this entails starting with the design stage and searching for remedies for the system's problems while considering how a decision may affect partners and operations.

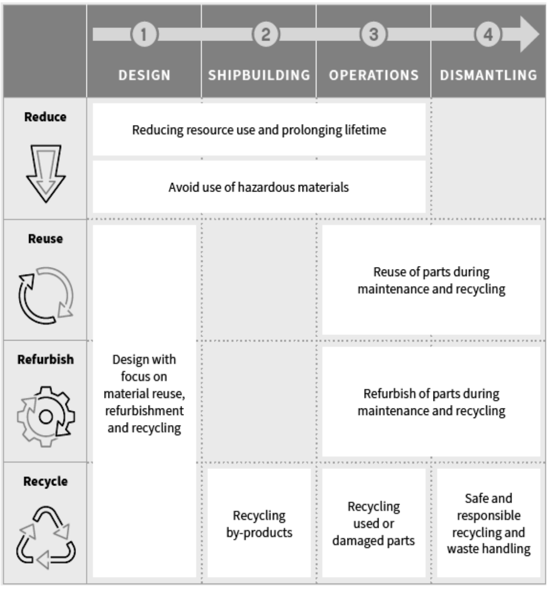

Figure 1: Circular economy implementation on ship lifecycle [4]

To implement the concept of a circular economy R-hierarchies are used. The most used one is the 3Rs which means reduce the use of resource, reuse resource, and recycle resource. In Figure 1, 4Rs are shown, reduce, reuse, refurbish and recycle are used to define circular economy in a ship's lifecycle. More complex hierarchies with up to 10 levels have recently been developed as many sectors strive to understand how circularity concepts may be used in their operations [6].

The lowest level in the hierarchy shown in Figure 1 is recycling steel from ships since it concentrates on processing commodities to produce materials that are identical to or of lesser grade. Reuse and refurbishment are the next two phases in the hierarchy which promote prolonging the lifecycle of ship parts/ components and hence minimizing negative consequences on environment. These procedures can be "built" into the ship throughout the design phase to guarantee that parts will be fixed and can also be changed if required. The top level of the hierarchy is reduction in material use that can also be "built-in" during the design phase to utilise fewer materials and resources.

A strong vision can assist to differentiate between the existing way of reasoning and the drastically changed image of a circular economy, even though such a transition takes time. Starting with the design phase, including circular economy concepts requires the designer to consider methods for reusing, rethinking, and reducing ship components.

The ship's lifecycle and the circular economy are not connected under the current maritime regulations. Both the HKC (Hong Kong Convention) and the EUSRR (European union Ship Recycling Regulation) focus on the ecological responsibility and safer ship recycling, however, they do not consider the design for recycling and the lifespan of ship parts that are repaired or can be reused after recycling of ship. A direct allusion to circularity could not be anticipated because both rules were written at a period when circular economy ideas were not as extensively discussed. They do, however, need to create and maintain the (IHM) Inventory of Hazardous Materials [7, 8]. IHM catalogues many hazardous substances included in a ship's components and structures and which must be transported with the ship from construction to recycling. Irrespective of the number of times ownership of the ship has been changed, IHM is an essential and basic requirement towards collaboration and greater circularity throughout the lifetime. It also provides traceability and responsibility throughout the cycle. To become sustainable, the shipping sector must consider both i.e., the marine environment and the stakeholders that rely on them. The sector operates with accountability and transparency [9]. It must promptly and sustainably collaborate with authorities, investors, owners, and ship recyclers within and outside of the shipping sector for better sustainability. In the design phase, only the working life of a ship is considered, and end-of-life (EOL) is ignored to achieve zero waste but design for circularity is a necessity. Circularity connects all the stakeholders including ship recyclers and increases the design modularity which has a pivotal function in shipping's sustainability journey [4].

3. NEED OF THE STUDY

Through past research, it is evident that a circular economy plays a vital role in sustainable development and there are very few studies that link ship recycling with circular economy. However, there is no study available that identifies factors of ship recycling and develops a framework that helps in achieving a circular economy. Thus, in this study, the main aim is to identify the factors of ship recycling and then develop a framework using Interpretive Structural Modelling (ISM) through which circular economy can be achieved.

4. ISM MODELLING USING CRITICAL FACTORS OF SHIP RECYCLING

In this study, ISM is used to develop Multi-Criteria Decision Making (MCDM) framework. Warfield in 1974 develops the rational logic which was the foundation of this methodology [10]. The fundamental concept of the methodology is to change the complex system into number of subsystems and create a multilevel hierarchical structural model. ISM modelling is done based on the steps given below:

(1) Fourteen critical factors influencing shipowners and ship recycling practitioners for recycling a ship are identified from various sources and documented in Table 1.

Table 1: Critical factors of ship recycling

S No	Critical Factors	Description	Ref
1	Creating direct market opportunities	Ship recycling may boost the local economy and helps to establish SMEs by providing material at a lower cost.	[11-16]
2	Creating in-direct market opportunities	A flea market can be set up for using products that are retrieved through ship recycling which helps to create in-direct market opportunities.	[11-16]
3	Government policies	The government of South Asian countries like India and Bangladesh are making policies that enable ship recycling activities and China government has barred ship recycling activities for foreign ships.	[8, 14, 15, 17, 18]
4	Training & skill development	To learn about the know-how of working-at-height, safe-for-entry, confined-entry, safe-for-hot work, and for safer and environmentally sound ship recycling; training and skill development is essential.	[19-21]
5	Environmental and maritime regulations	Based on the Basel convention and Hong Kong Convention (HKC) different regulations are formed by different countries. However, the EU Ship Recycling Regulation (EUSRR) is globally accepted.	[7-9, 22, 23]
6	Funding for capacity building	Financial instruments, incentives, tax benefits, and global funding are the foundation for building capacity for ship recycling	[12, 14, 24, 25]
7	Ship design	In the design phase, only the operational life of the ship is considered, and end-of-life (EOL) is ignored to achieve zero waste, design for circularity is a necessity.	[2, 4, 26, 27]
8	Ship recycling yard certification	HKC and EUSRR provide certification to shipyards that are recognized and audited according to the set standards.	[7-9]
9	Socio-economic wealth	A hundred thousand jobs are created for both skilled and unskilled workers through ship recycling which built socio-economic wealth	[14, 15, 28, 29]
10	Reduce virgin material liability	Recycling of an average carrier ship generates more than 30000 GT of steel which reduces virgin material liabilities	[1, 26, 30, 31]
11	Decarbonization through ship recycling	Approx. 1 tonne of steel produces 1.25 tonne of $C0_2$ while extracted from iron ore. Global steel production accounts for nearly 8% of total $C0_2$ emissions. If all the ship steel is recycled through ship recycling, then it will help in decarbonization.	[1, 32, 33]
12	Infrastructure development	Infrastructure development is essential for proper waste management and cost-effective ship recycling.	[1, 25, 26]
13	Achieving circular economy	Through ship recycling, while following the 4Rs (reduce, reuse, refurbish and recycle), a circular economy can be achieved.	[4, 6, 26]
14	Standards & guidelines development	The regulations that are developed through the Basel convention, HKC, and EUSRR are the basis of most of the standards and guidelines that are developed for ship recycling.	[2, 9, 33-36]

(2) A structural self-interaction matrix (SSIM) is created for the fourteen factors presented in Table 1 to form Table 2 which depicts the pair-wise relationship between the factors.

In SSIM matrix, the pair-wise comparison between the 14 factors is done by using ‘V’, ‘A’, ‘X’, and ‘O’ where:
V: i^{th} factors will impact j^{th} factor;
A: j^{th} factor will impact i^{th} factors;
X: factor i^{th} and j^{th} impact each other equally;
O: factor i^{th} and j^{th} will have no relation.

Table 2: Structural Self-Interaction Matrix

S.No.	Critical Factors	1	2	3	4	5	6	7	8	9	10	11	12	13	14
1	Creating direct market opportunities		X	A	A	A	A	A	X	V	V	V	A	V	A
2	Creating in-direct market opportunities			A	A	A	A	A	O	V	V	V	A	V	A
3	Government policies				V	X	X	V	V	V	V	V	V	V	V
4	Training & skill development					A	A	V	V	V	V	V	V	V	X
5	Environmental and maritime regulations						X	V	V	V	V	V	V	V	V
6	Funding for capacity building							V	V	V	V	V	V	V	V
7	Ship design								V	V	V	V	X	V	X
8	Ship recycling yard certification									V	V	V	A	V	A
9	Socio-economic wealth										X	V	A	V	A
10	Reduce virgin material liability											V	A	V	A
11	Decarbonization through ship recycling												A	V	A
12	Infrastructure development													V	X
13	Achieving circular economy														A
14	Standards & guidelines development														

(3) Reachability matrix is developed using SSIM matrix. ‘V’‘X’‘A’‘O’ are changed into 0 and 1 which helps to assess driving and dependence power in Table 3.

Table 3: Reachability Matrix (RM)

Critical Factors	1	2	3	4	5	6	7	8	9	10	11	12	13	14	Driving Power
1	1	1	0	0	0	0	0	1	1	1	1	0	1	0	7
2	1	1	0	0	0	0	0	0	1	1	1	0	1	0	6
3	1	1	1	1	1	1	1	1	1	1	1	1	1	1	14
4	1	1	0	1	0	0	1	1	1	1	1	1	1	1	11
5	1	1	1	1	1	1	1	1	1	1	1	1	1	1	14
6	1	1	1	1	1	1	1	1	1	1	1	1	1	1	14
7	1	1	0	0	0	0	1	1	1	1	1	1	1	1	10
8	1	0	0	0	0	0	0	1	1	1	1	0	1	0	6
9	0	0	0	0	0	0	0	0	1	1	1	0	1	0	4
10	0	0	0	0	0	0	0	0	1	1	1	0	1	0	4
11	0	0	0	0	0	0	0	0	0	0	1	0	1	0	2
12	1	1	0	0	0	0	1	1	1	1	1	1	1	1	10
13	0	0	0	0	0	0	0	0	0	0	0	0	1	0	1
14	1	1	0	1	0	0	1	1	1	1	1	1	1	1	11
Dependence Power	10	9	3	5	3	3	7	9	12	12	13	7	14	7	

(4) After that, transitivity is incorporated in Table 4, which signifies the FRA (final reachability matrix). Transitivity means if factor A related to B and B is related to C than A is related to C

Table 4: Final Reachability Matrix (FRM)

Critical Factors	1	2	3	4	5	6	7	8	9	10	11	12	13	14	Driving Power
1	1	1	0	0	0	0	0	1	1	1	1	0	1	0	7
2	1	1	0	0	0	0	0	1*	1	1	1	0	1	0	7
3	1	1	1	1	1	1	1	1	1	1	1	1	1	1	14
4	1	1	0	1	0	0	1	1	1	1	1	1	1	1	11
5	1	1	1	1	1	1	1	1	1	1	1	1	1	1	14
6	1	1	1	1	1	1	1	1	1	1	1	1	1	1	14
7	1	1	0	1*	0	0	1	1	1	1	1	1	1	1	11
8	1	1*	0	0	0	0	0	1	1	1	1	0	1	0	7
9	0	0	0	0	0	0	0	0	1	1	1	0	1	0	4
10	0	0	0	0	0	0	0	0	1	1	1	0	1	0	4
11	0	0	0	0	0	0	0	0	0	0	1	0	1	0	2
12	1	1	0	1*	0	0	1	1	1	1	1	1	1	1	11
13	0	0	0	0	0	0	0	0	0	0	0	0	1	0	1
14	1	1	0	1	0	0	1	1	1	1	1	1	1	1	11
Dependence Power	10	10	3	7	3	3	7	10	12	12	13	7	14	7	

(5) The final Level Partitioning is then created using FRM which is presented in Table 5 after 6 iterations.

Table 5: Final Level Partitioning

Elements (Mi)	Reachability Set R(Mi)	Antecedent Set A(Ni)	Intersection Set R(Mi)∩A(Ni)	Level
1	1, 2, 8,	1, 2, 3, 4, 5, 6, 7, 8, 12, 14,	1, 2, 8,	4
2	1, 2, 8,	1, 2, 3, 4, 5, 6, 7, 8, 12, 14,	1, 2, 8,	4
3	3, 5, 6,	3, 5, 6,	3, 5, 6,	6
4	4, 7, 12, 14,	3, 4, 5, 6, 7, 12, 14,	4, 7, 12, 14,	5
5	3, 5, 6,	3, 5, 6,	3, 5, 6,	6
6	3, 5, 6,	3, 5, 6,	3, 5, 6,	6
7	4, 7, 12, 14,	3, 4, 5, 6, 7, 12, 14,	4, 7, 12, 14,	5
8	1, 2, 8,	1, 2, 3, 4, 5, 6, 7, 8, 12, 14,	1, 2, 8,	4
9	9, 10,	1, 2, 3, 4, 5, 6, 7, 8, 9, 10, 12, 14,	9, 10,	3
10	9, 10,	1, 2, 3, 4, 5, 6, 7, 8, 9, 10, 12, 14,	9, 10,	3
11	11,	1, 2, 3, 4, 5, 6, 7, 8, 9, 10, 11, 12, 14,	11,	2
12	4, 7, 12, 14,	3, 4, 5, 6, 7, 12, 14,	4, 7, 12, 14,	5
13	13,	1, 2, 3, 4, 5, 6, 7, 8, 9, 10, 11, 12, 13, 14,	13,	1
14	4, 7, 12, 14,	3, 4, 5, 6, 7, 12, 14,	4, 7, 12, 14,	5

(6) Figure 2 shows an ISM model which is a MCDM framework for achieving a circular economy through ship recycling and developed by using Table 5.

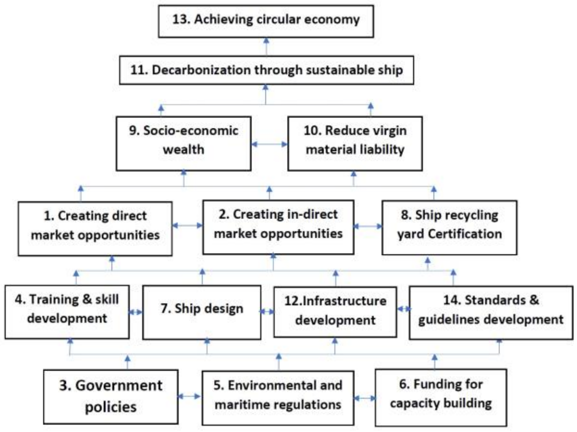

Figure 2: MCDM framework for achieving circular economy through ship recycling.

(6) Figure 3 shows the MICMAC graph which is created using the dependence and driving powers of Table 4 and it helps to identify dependent, independent, and linkage factors.

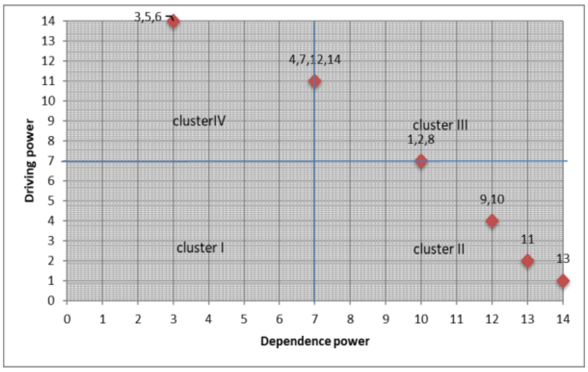

Figure 3: MICMAC graph showing dependent (cluster II), linkage (cluster III), and independent (cluster IV) factors

From the MCDM framework and MICMAC graph, it is found that factors 3 (Government policies), 5 (Environmental and maritime regulations), and 6 (Funding for capacity building) have high driving power and they are independent factors that come under cluster IV; factors like 4 (Training & skill development), 7 (Ship design), 12 (Infrastructure development), 14 (Standards & guidelines development), and 1 (Creating direct market opportunities), 2 (Creating in-direct market opportunities), 8 (Ship recycling yard certification) are linkage factors as they come in cluster III and factors like 9 (Socio-economic wealth), 10 (Reduce virgin material liability) also 11 (Decarbonization through ship recycling) and 13 (Achieving circular economy) are in cluster II with high dependence power and there is no factor in cluster I that means there is no autonomous factor.

5. RESULT AND DISCUSSION

The framework shows that the main driving factors of ship recycling are government policies, environmental and maritime regulations, and funding for capacity building. The outcome of the framework advocate that if the policies of government are friendly for ship recycling as well as if there are enough financial instruments, incentives, tax benefits, and global funding available for building the capacity and there are unified and coherent environmental regulations then it will aid in achieving other critical factors and finally will help in decarbonization and achieving a circular economy.

6. CONCLUSION

When it comes to understanding and implementing circular economy ideas across the ship lifespan, the shipping industry is still in its initial stage. The sector is simultaneously dealing with fast evolving decarbonization initiatives, a surge in global shipbuilding and the need for more ship recycling capacity, regulatory changes, and the shift to global sustainability. Together, these factors provide the shipping sector a chance to implement circular economy ideas throughout the supply chain. If suitable consideration is given to the critical factors identified in the study and constructive efforts are applied in ship recycling while considering the MCDM framework, then achieving a circular economy is not as far as it seems.

7. ACKNOWLEDGMENT

The authors would like to acknowledge the financial support provided by the University of Plymouth to conduct this research within the School of Engineering, Computing, and Mathematics. The authors also would like to extend thanks to Dr. Sonal Khurana (VIPS, India) and Dr. Shahbaz Khan (GLA University, India) for their valuable comments.

9. REFERENCES

[1] UNCTAD, "Review of Maritime Transport 2020," 2020. [Online]. Available: https://unctad.org/system/files/official-document/rmt2020_en.pdf

[2] *IMO Guidelines on ship recycling*, I. M. ORGANIZATION, 2004.

[3] OECD, "Ship recycling an overview," *OECD Science, Technology and Industry Policy Papers*, vol. 68, no. April 2019, 2019, doi: 10.1787/397de00c-en.

[4] SSI, "Exploring shipping's transitionto a circular industry," 2021. [Online]. Available: https://www.sustainableshipping.org/wp-content/uploads/2021/06/Ship-lifecycle-report-final.pdf

[5] S. Ahasan, F. N. Zaman, and T. Ahmed, "Perspective of Circular Economy in Bangladesh: A Comprehensive Review Towards Ship Demolition Industry," in *4th European International Conference on Industrial Engineering and Operations Management, IEOM 2021*, M. Fargnoli *et al.*, Eds., 2021: IEOM Society, pp. 2375-2385. [Online]. Available: https://www.scopus.com/inward/record.uri?eid=2-s2.0-85126232358&partnerID=40&md5=d5bf90d80d2af0a32c35cd3169768f45.

[6] S. M. M. Rahman and J. Kim, "Circular economy, proximity, and shipbreaking: A material flow and environmental impact analysis," (in English), *Journal of Cleaner Production,* Article vol. 259, 2020, Art no. 120681, doi: 10.1016/j.jclepro.2020.120681.

[7] HKC. "The Hong Kong International Convention for the Safe and Environmentally Sound Recycling of Ships." https://www.imo.org/en/About/Conventions/Pages/The-Hong-Kong-International-Convention-for-the-Safe-and-Environmentally-Sound-Recycling-of-Ships.aspx (accessed 17/08/2022, 2022).

[8] EUSRR. "Regulation (EU) No 1257/2013 of the European Parliament and of the Council of 20 November 2013 on ship recycling and amending Regulation (EC) No 1013/2006 and Directive 2009/16/EC Text with EEA relevance." https://eur-lex.europa.eu/eli/reg/2013/1257/oj (accessed 17/08/2022, 2022).

[9] IMO. "Guidelines for the development of the inventory of hazardous materials, 15 May 2015." https://www.imorules.com/MEPCRES_269.68.html (accessed 17/08/2022, 2022).

[10] B. Mannan, S. Khurana, and A. Haleem, "Modeling of critical factors for integrating sustainability with innovation for Indian small- and medium-scale manufacturing enterprises: An ISM and MICMAC approach," *Cogent Business & Management*, vol. 3, no. 1, 2016, doi: 10.1080/23311975.2016.1140318.

[11] M. Sarraf, Stuer-Lauridsen, F., Dyoulgerov, M., Bloch, R., Wingfield, S.,Watkinson, R.,, "The Ship Breaking and Recycling Industry in Bangladesh and Pakistan," The World Bank, 2010. [Online]. Available: https://openknowledge.worldbank.org/bitstream/handle/10986/2968/582750ESW0Whit1LIC1011098791web1opt.pdf?sequence=1&isAllowed=y

[12] IMO, "Ship recycling in Bangladesh leaps forward with third phase of key project signed," ed, 2020.

[13] B. Mannan, M. J. Rizvi, and Y. M. Dai, "Ship Recycling in Developing Economies of South Asia: Changing Liability to a Commodity," in *2022 International Conference on Resource Sustainability (icRS 2022)*, University of Michigan (Virtual), M. Xu, Ed., 1-4 August 2022, pp. 164-165. [Online]. Available: https://www.icrsconf.com/images/icrs/icRS_2022_Abstract_Book.pdf.

[14] ET, "Budget 2021: Ship Recycling capacity to double by 2024, generate 1.5 lakh jobs," 01/02/02/2021. [Online]. Available: https://economictimes.indiatimes.com/industry/transportation/shipping-/-transport/ship-recycling-capacity-to-double-by-2024-generate-1-5-lakh-jobs/articleshow/80629751.cms

[15] TWB, "The ship breaking and recycling industry in Bangladesh and Pakistan," 2010. [Online]. Available: https://documents.worldbank.org/en/publication/documents-reports/documentdetail/872281468114238957/the-ship-breaking-and-recycling-industry-in-bangladesh-and-pakistan

[16] K. P. Jain and J. Pruyn, "An Overview of the Global Ship Recycling Industry," in *Encyclopedia of Renewable and Sustainable Materials*, 2017, pp. 626-647.

[17] Z. Nan, "Scrapping scrap, saving earth." [Online]. Available: https://www.chinadaily.com.cn/a/201812/24/WS5c2037e7a3107d4c3a0025ea.html

[18] C. M. Rizzo *et al.*, "Current practices and recent advances in condition assessment of aged ships," *Ships and Offshore Structures*, vol. 2, no. 3, pp. 261-271, 2007, doi: 10.1080/17445300701423486.

[19] K. Jain and A. M. Hiremath. "Training in Alang's Ship Recycling Industry." The maritime excutive https://maritime-executive.com/editorials/training-in-alang-s-ship-recycling-industry (accessed 23/08/2022, 2022).

[20] SENSRECreport, "Final report curricula, training strategy and training needs," 2016. [Online]. Available: https://wwwcdn.imo.org/localresources/en/OurWork/PartnershipsProjects/Documents/Ship%20recycling/WP4a%20Curricula%20-%20Training%20strategy%20-%20Training%20needs.pdf

[21] G. Neşer, D. Ünsalan, N. Tekoğul, and F. Stuer-Lauridsen, "The shipbreaking industry in Turkey: environmental, safety and health issues," (in English), *Journal of Cleaner Production*, Article vol. 16, no. 3, pp. 350-358, 2008, doi: 10.1016/j.jclepro.2006.08.018.

[22] BC. "Basel Convention on the Control of Transboundary Movements of Hazardous Wastes and their Disposal." http://www.basel.int/TheConvention/Overview/tabid/1271/Default.aspx (accessed 16/08/2022, 2022).

[23] BAN. "Third Meeting of the Conference of the Parties to the Basel Convention." http://www.basel.int/TheConvention/ConferenceoftheParties/Meetings/COP3/tabid/6152/Default.aspx (accessed.

[24] E. Yujuico, "Demandeur pays: The EU and funding improvements in South Asian ship recycling practices," *Transportation Research Part A: Policy and Practice*, vol. 67, pp. 340-351, 2014, doi: 10.1016/j.tra.2014.07.015.

[25] Q. Zhou, Z. Du, J. Liu, J. Liang, and Y. Jiao, "Factors influencing green ship recycling: A conceptual framework and modeling," *Journal of Cleaner Production*, vol. 322, 2021, doi: 10.1016/j.jclepro.2021.129155.

[26] H. Sornn-Friese *et al.*, *Creating circular economy clusters for sustainable ship recycling in Denmark*. CBS MARITIME, 2021.

[27] USEPA, "A Guide for Ship Scrappers: Tips for Regulatory Compliance. ," United states Enivironmental Protection Agency Washington, 2000. [Online]. Available: http://purl.access.gpo.gov/GPO/LPS15690

[28] M. Sujauddin, R. Koide, T. Komatsu, M. M. Hossain, C. Tokoro, and S. Murakami, "Characterization of ship breaking industry in Bangladesh," (in English), *Journal of Material Cycles and Waste Management*, Article vol. 17, no. 1, pp. 72-83, 2015, doi: 10.1007/s10163-013-0224-8.

[29] FE, "Shipbreaking - a potential growth driver," W. AHMED, Ed., ed, 2022.

[30] B. Fahimnia, J. Sarkis, and H. Davarzani, "Green supply chain management: A review and bibliometric analysis," *International Journal of Production Economics*, vol. 162, pp. 101-114, 2015, doi: 10.1016/j.ijpe.2015.01.003.

[31] N. Mikelis, "The Recycling of Ships," 2018.

[32] McK&Co, "Decarbonization challenge for steel," June 3, 2020. [Online]. Available: https://www.mckinsey.com/industries/metals-and-mining/our-insights/decarbonization-challenge-for-steel

[33] P. Rousmaniere and N. Raj, "Shipbreaking in the developing world: Problems and prospects," (in English), *int. J. Occup. Environ. Health*, Article vol. 13, no. 4, pp. 359-368, 2007, doi: 10.1179/oeh.2007.13.4.359.

[34] A. E. Moen, "Breaking Basel: The elements of the Basel Convention and its application to toxic ships," (in English), *Marine Policy*, Article vol. 32, no. 6, pp. 1053-1062, 2008, doi: 10.1016/j.marpol.2008.03.002.

[35] S. Alam and A. Faruque, "Legal regulation of the shipbreaking industry in Bangladesh: The international regulatory framework and domestic implementation challenges," (in English), *Marine Policy*, Article vol. 47, pp. 46-56, 2014, doi: 10.1016/j.marpol.2014.01.022.

[36] F. Demaria, "Shipbreaking at Alang-Sosiya (India): An ecological distribution conflict," (in English), *Ecol. Econ.*, Article vol. 70, no. 2, pp. 250-260, 2010, doi: 10.1016/j.ecolecon.2010.09.006.