Using digitalisation to achieve decarbonisation in the shipping industry
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ABSTRACT
The maritime industry has been under tremendous pressure to reduce carbon emissions since the time the Paris Agreement came into force. Though IMO gave the basic guidelines and timelines in 2016, to date, there is no concrete method or technology that can help the maritime industry achieve the desired decarbonisation even though numerous technology, operational, and incentive methods have been experimented with. Since the next Industrial Revolution is evolving around the digital technology and the ships have already moved towards digitalisation due to safety and economic concerns, it is considered that digitalisation can help decarbonisation of the shipping industry. It is with this understanding that the article aims to address the involvement and impact of digitalisation on decarbonisation of the shipping industry both in the shipping and the ports and support structures.

Introduction
Ships have offered the cheapest and the most versatile mode of transport for centuries. In addition, they have been carriers of cultural and religious influence to far-off places (Agarwala 2021a). Today, globalisation and maritime trade has allowed the benefits of trade and commerce to be spread evenly thereby helping developing nations to witness growth, sustainable development and uplifting their people from poverty. They have helped create jobs and opportunities for numerous people while helping many to improve their living standards. Aply so, the maritime transport sector has become the backbone of global trade and the global economy. It is no wonder that in the last four decades, seaborne trade has quadrupled in size to regularly move nearly 80% of global trade by volume and over 70% by value (UNCTAD 2018). This increase has been feasible due to over 50,000 merchant ships registered in over 150 nations moving on the oceans internationally. This increased cargo movement has necessitated the construction and use of larger and larger ships that demand increased energy by use of mechanical systems for propulsion (or thruster load) and electronic systems for service loads of communication, navigation, hotel (lighting systems, air-conditioning system and so on), control systems, and auxiliary loads. It is important to mention that to produce electricity, mechanical systems are used on ships. However, when required, the stored electricity can also be used to produce mechanical energy.

Of these, the mechanical system was introduced to ships when steam engines began to be used in the shipping industry in the 1850s. On the other hand, electricity, as a source of energy, was utilised on ships as early as the 1870s. By the 1930s, as part of the Second Industrial Revolution, the use of electricity became widespread for various auxiliaries and turbo-electric drives (to drive shafts using electric motors) (Skjong et al. 2015). This helped the development of the electric propulsion systems (Paul 2020) and power system solutions to cater for the varying power requirements of various electronic systems. Since then, new technologies have been developed and used at a blistering pace, thereby improving navigation, communication, and safety to help save lives of hundreds of seafarers. However, in all these developments, the backbone fuel used was fossil fuel which forms a major portion of the life-cycle cost of the ship even today. The overall dependence on fossil fuels is so high that studies have shown that the fuel demand of ships has increased by about 1.6% per year between 2000 and 2015 (UNCTAD 2016).

With the increase in fuel consumption, there is increased pressure on the industry to improve fuel economy and reduce anthropogenic emissions. Additionally, with the UNFCCC Paris Agreement setting, an ambitious target of limiting the global temperature rise to “below 2°C” by 2050, the pressure is on the shipping industry to reduce its Greenhouse gas (GHG) emission footprints. Accordingly, the International Maritime Organisation (IMO) agreed in October 2016 to develop a comprehensive strategy to address GHG emissions from international shipping. The resulting strategy aims to follow a long-term goal of reduction of GHG emissions when compared to 2008 as the baseline year. To achieve this, the industry...
plans to reduce GHG emissions to 50% by 2050 with a 40% reduction of CO₂ emissions by 2030 and 70% by 2050 (IMO, n.d.). This has led to the use of power electronic based drives for management of energy of various ship energy loads. Today, many commercial ships such as passenger ships, tankers, ice-breakers, cable laying ships, and floating offshore platforms are built with power electronic drives for greater efficiency and energy management that would help support decarbonisation of the maritime transport industry (Ginn 2015).

In order to achieve these targets and ensure decoupling of carbon emissions from economic growth, policy makers have begun to focus, encourage, and foster the five Ds, namely, democratization, decarbonisation, deregulation, decentralization, and digitalisation (Dash 2016). It is essential to mention that in some discussions four Ds are considered, viz. decarbonisation, deregulation (or democratization), decentralization, and digitalisation (DEEP 2018), while in others three Ds, viz. decarbonisation, decentralization, and digitalisation are discussed (PowerGen 2017). Of these, decarbonisation and digitalisation as a system are of relevance to the ships at sea while all the remaining Ds with these two, as a system, are relevant to the ports and support systems of the shipping industry.

It is with this understanding that the article aims to address the involvement and impact of digitalisation on decarbonisation of the shipping industry both in the shipping and the ports, and support structures such as inland transportation.

Background

Use of fossil fuels is considered to be one of the greatest contributors of anthropogenic emissions that are deteriorating the environment. As the type of fuel changes, so does the emission of CO₂, SOx, NOx, and methane with inefficient ships emitting the maximum pollutants akin to vehicles on the road. Even though, unlike the road transportation that contributes to nearly 18% of the global CO₂ emissions (12% from passenger vehicles and 6% from transportation vehicles) (Ritchie 2020), the maritime sector contributes merely 2.6% of the global GHG emissions (OECD 2018) and nearly 2.2% of the global CO₂ emissions (Saul 2019), it remains a matter of concern to meet the overall target of zero emissions as laid out by the Paris Agreement.

Accordingly, to address SOx emissions from Heavy fuel oil (HFO) that has high sulphur content, the International Convention for the Prevention of Pollution from Ships (MARPOL) had set a reduction of sulphur content in bunker fuel from 4.5% in 2000 to 0.5% by 2020. Similarly, to address NOx emissions from distillate fuels like marine gas oil (MGO) and marine diesel oil (MDO), MARPOL has set up Emission Control Areas (ECA) where the emission regulations are extremely stringent.

In addition to these efforts, IMO through the Marine Environment Protection Committee (MEPC) has planned short-term, medium-term, and long-term measures to incentivise reduction of emissions from international shipping (IMO, 2018a). The short-term measures (2018–2023) are three-pronged. The first effort is to adopt the Energy Efficiency Design Index (EEDI) for new ships and the Ship Energy Efficiency Management Plan (SEEMP) for operational ships (MEPC 62). The second aims to promote technical cooperation and transfer technology to encourage energy efficiency of ships through various programmes (MEPC 65). The third collects data on fuel oil consumption to improve the existing strategy (MEPC 70). Based on these short-term measures, the medium (2023–2030) and long-term (beyond 2030) measures aim to implement market-based-mechanisms. To make the effort successful and encourage greater clarity and participation, IMO has identified a number of candidate areas that need to be addressed as seen in Figure 1.

However, when one plots the likely outcome of the envisaged short-term efforts against the target to be achieved, as seen in Figure 2, one notices a huge gap that needs to be addressed through innovative measures, operational changes, fuel change, and new technology. Along with these regulations, there is an increasing social and political pressure on ship-owners and ship-operators to address and reduce CO₂ emissions. However, there is no clear consensus on what is possibly the most effective path to tread since the environmental cost associated with generating CO₂ is not clearly assigned to either the energy producer or to the user.

Digitalisation and decarbonisation

Since digital technologies are transforming every aspect of our life, and with the next Industrial Revolution evolving around “digital technology,” it is appreciated that digitalisation could possibly help address this dilemma of emission control and reduction. Hence, the concept of “Ds” that is based on five foundational pillars is being encouraged. These include development of transition architecture from the existing system to low carbon system; increasing use of alternate fuels and renewable energy; encouraging energy storage devices; extensive use of data and analytics to empower users; and creation of individual users as power generating systems. While the concept exists, one realises that it is difficult to implement due to non-existent systems and hence requires some serious efforts to achieve the desired low-carbon economy. In this regard, an increased use of technology for a more decentralised and digitalised scenario is considered a good opportunity to create the required transition architecture for the energy system (Sánchez 2019).
So as to better appreciate how digital technologies and hence digitalisation can assist in decarbonisation of the shipping industry, we first take a look and understand the term digitalisation, since at times it is confused by many with digitisation. Once done, we will look at the efforts already made in decarbonisation in the shipping industry before looking at the digital tools available that can support further decarbonisation.

**Digitalisation**

With increased focus on digital systems, the terms digitisation, digitalisation, and digital transformation have become a part of our daily vocabulary where at times these terms are used interchangeably even though each one of them is unique and has a different meaning.
For clarity, digitisation is about creating a digital version of analogue/physical information so as to be available for use by a computing system. Digitalisation, on the other hand, refers to enabling, improving and/or transforming operations, functions, processes and/or activities, by utilising digitised data to obtain actionable knowledge with a specific benefit in mind. When referring to digital transformation, it occurs when a business moves to doing a digital business to improve processes, value for customers, and innovation. Industry 4.0 is the European form of digital transformation and digitalisation.

Of these, digital change began in the early 1990s with the spread of the Internet and the emergence of their services. Subsequently, digitalisation prospered as a result of the availability of high-speed Internet, mobile data access, 5G mobile Internet combined with technologies of the Internet of Things (IoT), and Artificial Intelligence (AI) that encouraged the development and use of robotics.

**Efforts of decarbonisation in the shipping industry**

Since 2016 when the IMO committed to reduce emission levels, a number of efforts have been made to make shipping greener. Accepting the IMO commitment, companies such as Proman and Maersk have taken special initiatives to embrace methanol as a fuel (Green Cargo Congress 2021; Frankie 2021). This has permitted the elimination of sulphur and reduction in NOx by 60% and 10 to 15% for CO2 from the emitted emissions. For this, the propulsor has been suitably designed to operate with dual fuel. On the development front, studies by the International Transport Forum show that deployment of presently known technologies can make decarbonisation of the shipping industry possible by 2035 (ITF 2018) but only with environment friendly and modified operating philosophies. The possible efforts and their maturity for use in this direction are summarised in Tables 1–9. One realises that over the years a number of methods and technologies have been demonstrated successfully. However, for these to be successful, strong policies and financial incentives are considered essential.

As discussed, the present target of decarbonisation can be achieved by using nearly all the available technologies; however, there are no clear acceptable technological solutions to achieve this decarbonisation. This essentially demands that the search for workable solutions should continue. Furthermore, since digitalisation is considered as the new source of the next Industrial Revolution, it is essential that the technologies and decarbonisation measures to be developed and employed need to be focused around digitalisation. Hence, as a logical progression, we look at the digital tools available to humanity and can be employed towards decarbonisation of the shipping industry.

**Digital tools available**

The role of digital technology is rapidly changing. Today, they have become enablers of innovation and disruption by supporting new business models from

| Table 1. Energy efficiency measures (Source: Winkel, van Den Bos, and Weddige 2015). |
|---------------------------------|---------------------------------|---------------------------------|---------------------------------|---------------------------------|---------------------------------|---------------------------------|
| Category                        | Measure                          | Estimated efficiency (range) | Efficiency at average circumstances | Ease of installation | Payback time | Investment | Implementation |
|--------------------------------|---------------------------------|--------------------------------|---------------------------------|---------------------------------|---------------------------------|---------------------------------|---------------------------------|
| Hull                            | Bow optimisation                 | 2.5–20%                        | 10%                             | all ship types                 | short (<3 years)               | Medium                          | conventional technology         |
| Hull                            | Hull coating                     | 1–9%                           | 5%                              | all ship types                 | short (<3 years)               | Low                             | conventional technology         |
|                                | Air lubrication                  | 5–15%                          | 9%                              | new build only                 | medium (4–15 years)            | Medium                          | conventional technology         |
| Propellers and rudders          | Ducted propeller                 | 1–20%                          | 10%                             | all ship types except ferry and cruises only special ship types | medium (4–15 years) | Medium | conventional technology |
|                                | Contra-rotating propellers       | 6–20%                          | 13%                             | all ship types                 | short (<3 years)               | Medium                          | conventional technology         |
|                                | Wheels                           | 10%                            | 10%                             | all ship types except ferry and cruises only special ship types | medium (4–15 years) | Medium | conventional technology |
|                                | Rudder bulb                      | 2–5%                           | 4%                              | all ship types                 | medium (4–15 years)            | Low                             | conventional technology         |
|                                | Post swirl fins                  | 2–5%                           | 4%                              | all ship types                 | short (<3 years)               | Low                             | conventional technology         |
|                                | Twisted rudder                   | 2–4%                           | 3%                              | all ship types                 | medium (4–15 years)            | Low                             | conventional technology         |
| Control systems                | Waste heat recovery              | 6–10%                          | 8%                              | new build only                 | medium (4–15 years)            | Medium                          | conventional technology         |
| Main engines                    | Wind power                       | 5–44%                          | 20%                             | only special ship types        | long (>15 years)               | High                            | experimental technology         |
|                                | Main engine de-rating 2–4        | 3%                             |                                 | all ship types                 | medium (4–15 years)            | Low                             | conventional technology         |
|                                | Common rail upgrade              | 0.1–0.5%                       | 0.3%                            | all ship types                 | medium (4–15 years)            | Very low                        | conventional technology         |
|                                | Common rail upgrade              |                                 |                                 |                                 |                                 |                                 |                                 |
**Table 2. Machinery Technologies (Source: GLOMEEP, n.d.).**

| Measure                     | Function                                                                 | Technical Maturity | Applicability                                      |
|-----------------------------|--------------------------------------------------------------------------|--------------------|---------------------------------------------------|
| Auxiliary systems optimization | Optimizing auxiliary systems to actual operational profiles, not design conditions | Semi-mature         | All vessels                                        |
| Engine de-rating            | De-rating an engine for reduction of the vessel’s maximum speed to increase its efficiency by limiting the potential power output | Semi-mature         | Vessels sailing 10–15% slower than design speed   |
| Engine performance optimization (automatic) | Automatic increase of engine efficiency through testing and tuning according to actual operational load and conditions | Semi-mature         | Mainly for two stroke engines                     |
| Engine performance optimization (manual) | Manual increase of engine efficiency through testing and tuning according to actual operational load and conditions | Mature              | All vessels                                        |
| Exhaust gas boilers on auxiliary engines | Exhaust gas boilers recover the heat from the exhaust gas of auxiliary engines to generate steam, hot water or heat for process heating | Semi-mature         | Vessels without shaft generator                   |
| Hybridization (plug-in conventional) | Use of electricity to replace various modes of power consumption | Semi-mature         | Vessels with large fluctuations in power output (ferries, offshore vessels, tugs) |
| Improved auxiliary engine load | Increase of the auxiliary engines’ load and efficiency by reducing the number of auxiliary engines running | Semi-mature         | All vessels                                        |
| Shaft generator             | Produce electricity from the main propulsion engine                      | Mature              | Vessels with high power needs and long transits   |
| Shore power                 | Use of cold ironing in ports to reduce fuel consumption on power producing engines | Semi-mature         | For smaller vessels and in ports with developed solutions for larger vessels |
| Steam plant operation improvement | Improve operations and maintenance of steam plant system saving fuel on oil fired boiler | Mature              | Mainly crude and product tankers                  |
| Waste heat recovery systems | Recover thermal energy from the exhaust gas and convert it into electrical energy | Semi-mature         | All vessels with engines above 10 MW              |

**Table 3. Propulsion and hull improvements (Source: GLOMEEP, n.d.).**

| Measure                      | Function                                                                 | Technical maturity | Applicability                                      |
|------------------------------|--------------------------------------------------------------------------|--------------------|---------------------------------------------------|
| Air cavity lubrication       | Use of air injection on the wetted hull surfaces to improve a ship’s hydrodynamic performance | Semi-mature         | Most vessels in deep sea trade                    |
| Hull cleaning                | Removal of fouling on the hull to increase the vessel’s hydrodynamic performance | Mature             | All vessels                                        |
| Hull coating                 | Optimizing the hull’s resistance through water                          | Mature              | All vessels                                        |
| Hull formoptimization        | Retrofitting of the bulbous bow, optimizing thruster tunnels or bilge keel to reduce resistance | Mature             | All vessels                                        |
| Hull retrofitting            | Retrofitting the propeller to increase efficiency                       | Mature              | All vessels                                        |
| Propeller polishing          | Removal of fouling on the propeller                                     | Mature              | All vessels                                        |
| Propeller retrofitting       | Installation of propulsion improving devices                            | Semi-mature         | All vessels                                        |
| Propulsion Improving Devices (PIDs) | Use of energy efficient lighting equipment, such as LED light, to increase efficiency and remove heat loss from light devices | Semi-mature         | All vessels                                        |

**Table 4. Energy consumers (Source: GLOMEEP, n.d.).**

| Measure                              | Function                                                                 | Technical maturity | Applicability                                      |
|--------------------------------------|--------------------------------------------------------------------------|--------------------|---------------------------------------------------|
| Cargo handling systems (Cargo discharge operation) | Reduction of energy consumption while discharging crude oil by use of model-based studies of the discharge operation | Semi-mature         | Tankers                                           |
| Energy efficient lighting system     | Use of energy efficient lighting equipment, such as LED light, to increase efficiency and remove heat loss from light devices | Semi-mature         | All vessels                                        |
| Frequency controlled electric motors | Regulating the frequency of the motors in order to adapt the motor optimized load | Semi-mature         | All vessels                                        |

**Table 5. Energy recovery (Source: GLOMEEP, n.d.).**

| Measure                          | Function                                                                 | Technical maturity | Applicability                                      |
|----------------------------------|--------------------------------------------------------------------------|--------------------|---------------------------------------------------|
| Fixed sails or wings             | Use sails or wings to replace some of the propulsion systems             | Not mature         | Vessels with enough place on deck (general cargo, tankers, bulker) |
| Flettner rotors                  | Use Flettner rotors to generate power from wind energy                   | Not mature         | Dependent on trading area and sufficient free deck-surface |
| Kite                             | Use a kite to replace some of the propulsion power needed                | Not mature         | All vessels                                        |
| Solar panels                     | Install solar panels for conversion of solar energy to electricity       | Not mature         | Dependent on trading area and sufficient free deck-surface |
### Table 6. Technical solutions for optimizing operation (Source: GLOMEEP, n.d.).

| Measure                      | Function                                           | Technical maturity | Applicability                   |
|------------------------------|----------------------------------------------------|--------------------|----------------------------------|
| Autopilot adjustment and use | Use of an automatic system to control the vessel’s rudder in a more energy efficient manner | Mature             | All vessels                      |
| Combinator optimizing        | Use of optimized pitch settings and propeller speed for optimized efficiency of propulsion system | Mature             | For vessels with controllable pitch propeller |
| Efficient DP operation       | Optimize the operation in DP mode                  | Semi-mature        | Vessels with DP mode             |
| Trim and draft optimization  | Management of the vessel’s speed in the most efficient manner | Semi-mature        | All vessels                      |
| Weather routing              | Including weather conditions when planning a voyage | Mature             | All vessels                      |

### Table 7. Alternate fuels – possible usage and limitations (Source: Authors).

| Fuel                        | Function                                      | Usage/limitations                                                                 |
|-----------------------------|------------------------------------------------|-----------------------------------------------------------------------------------|
| Liquid Natural Gas (LNG)    | An attractive option.                          | Considered best short-term solution. Will increase climate impacts.               |
|                             | Produces lower CO2 emissions (approx. 20% lower). |                                                                                  |
|                             | Has zero-sulphur content. |                                                                                  |
|                             | Has issues of bunkering, storage & handling when compared with traditional marine fuels. |                                                                                  |
|                             | Construction of an LNG vessel requires significant investment. |                                                                                  |
| Bio-fuels                   | Two well-known biofuels used                   | Considerable public debate about their use exists.                                |
|                             | - heavy vegetable oil (HVO)                    |                                                                                  |
|                             | - biodiesel (FAME or fatty acid methyl ester). |                                                                                  |
|                             | Barriers for use – environmental, economic & technical |                                                                                  |
| Renewable energy fuel cells | Wind & solar power.                            | Not practical to power main engines.                                             |
| Nuclear                     | A possible alternative.                        | Current capacities limited.                                                      |
| Methylol                    | Considered technically feasible for merchant ships & 100% decarbonisation. | Issues – safety, security & support infrastructure costs.                         |
| Hydrogen                    | Can reduce CO2 emissions by 50%.               | Limited production – not easily available.                                       |
|                             | Storage & handling is much simpler compared to other known alternate fuels. |                                                                                  |
| Ammonia                     | Provides zero carbon emissions.                | To be generated from renewable energy.                                           |
|                             | Produced using energy-intensive processes – costly. |                                                                                  |

### Table 8. Operational solutions for reduced emissions (Source: Authors).

| Operations                  | Functionality                                      | Usage/ Limitations                                                                 |
|-----------------------------|----------------------------------------------------|-----------------------------------------------------------------------------------|
| Slow steaming               | Reduced speed – reduced fuel consumption & emission. | Benefits – vary with platform type & route.                                      |
|                             | 10% reduction – reduces 19% of emission.           | Downside – increased fouling & resistance.                                        |
| Speed optimisation          | Adequate speed to achieve maximum fuel efficiency & minimum GHG emissions. | Speed optimisation ensures                                                        |
|                             | Speed defined by sea-state & route to ensure cargo reaches in time. | - Required objectives of the ship.                                               |
| Trim & draft optimisation   | Trim/ draft influences resistance & hence fuel consumption | Achieved by                                                                      |
|                             | Correct cargo loading to optimise trim & draft, fuel can be saved & emission reduced. | - Training the crew                                                              |
| Operational efficiency      | Correct/ planned movement of a ship can reduce fuel consumed. | - Use dedicated trim optimiser.                                                  |
| Cold Ironting               | Stop power-generating machinery in harbour         | Improve                                                                          |
|                             | Power from shore-based supply.                    | - Cargo loading/ unloading                                                        |
|                             |                                                    | - Weather routing                                                                 |
|                             |                                                    | - Arrivals/ departures in the harbour                                             |

### Table 9. Incentive initiatives to encourage reduced emissions (Source: Authors).

| Incentives                  | Functionality                                      | Result                                                                 |
|-----------------------------|----------------------------------------------------|------------------------------------------------------------------------|
| Bank financing – “Poseidon Principles” | Loans only to owners who comply with emission regulations. | Will force owners to - Scrap inefficient vessels - Order new ships. Will force governments to take emission reduction seriously. |
| Reduced taxation            | Encourage ships to adopt green technology. Complying ships in port - 15% reduction in port dues. - 25% reduction if compliance for entire stay. | e.g., The Maritime Singapore Green Initiative (MSGI) – Singapore |
| Green fund                  | Create fund in form of carbon credits. Each Flag State – to show reduction. If target not met - purchase carbon credits from efficient Flag States. | Will force governments to take emission reduction seriously. |
being mere enablers for greater efficiency of traditional schemes. In addition, the huge computational power and vast amounts of data gathered from different sources helps development of new algorithms and services for the customers (Noussan, Hafner, and Tagliapietra 2020). Accordingly, the Fourth Industrial Revolution has blurred the lines between physical, digital, and biological spheres. This has resulted in the development of numerous digital tools as seen in Figure 3. While some of these technologies have a direct use for activities on a ship, others are a link between the ship and the shore for better logistic management and safer financial transactions. To add to these, technologies such as the 5 G that aim to provide high data speeds with low latency are revolutionising the commercial shipping industry in more ways than one (Agarwala and Guduru 2021).

Though it is clear that digital technology will transform many industries including the otherwise slow to adapt shipping industry, there are a number of challenges that need to be understood and overcome. It is envisaged that this digital transformation would bring about numerous changes in customer expectations, cultural transformation, learning processes, and many more. Hence, in order to reap the benefit of this technology, policy-makers would need to provide the necessary policy and financial support to unlock the substantial benefits digital technology offers the society and the industry.

**Digitalisation for decarbonisation of the shipping industry**

The shipping industry is known to be a follower as far as utilisation of disruptive technologies is considered (Agarwala 2021b). However, in order to address high operating costs, safety, security, and health of crew, nearly two-third of the shipping industry has gradually begun to use digital technology in their business (Durkin 2021) for activities other than efficiency enhancement supported by data gathered from numerous sensors and sources. Such a use is successfully assisting the industry to monitor, control and make decisions. This has encouraged the industry to look at utilising digital innovations for a number of other activities such as supply chain management, emission data recording and management, decarbonisation and others for economic gains.

However, currently, use of this technology for decarbonisation is challenged by the lack of accurate, objective, and accessible data. With the acceleration of digitisation and increased use of digital platforms as a result of the pandemic COVID-19, it is envisaged that the requisite tools and solutions for reporting emissions are emerging and will help to address lack of actionable data (KPMG 2020). Furthermore, activities such as supply chain too impact carbon emissions and are required to be controlled for decarbonising the shipping industry, it is essential to discuss nearly all such activities and more for an improved understanding as to how digitalisation can be used and encouraged for successful decarbonisation of the shipping industry.

While we try to look at digitalisation as a solution to address decarbonisation, it is important to understand that savings through increased energy efficiency by way of use of new technologies tend to result in a rebound effect as sometimes the planned savings do not materialise or are limited due to increased utilisation. Furthermore, increased digitalisation requires higher electricity demands and hence greater pollution levels, unless the electricity is from green or clean sources. This rebound effect may at times cause a loss of 10–30% benefits. It is hence essential that such a rebound effect is avoided or kept to a minimum.

As discussed in the preceding section and as seen in Figure 3, there are numerous digital tools that have been developed in the recent years that can be used in the shipping industry. Most of these tools can produce the desired results of reducing carbon emission and hence decarbonisation in shipping either independently or in conjunction with other digital technologies. To enhance this understanding, we look at these digital tools that can support and encourage decarbonisation.

**For ships at sea**

Since a ship is self-sustaining, each ship has its carbon emission footprint. At sea, a ship is usually considered an “independent,” “forgotten,” “left to itself,” “responsible for its own upkeep and maintenance” unit. This has led to ships to use digitalisation extensively to help them operate smoothly, safely and economically at sea. While discussing ships at sea, even warships and other vessels in the role of constabulary, survey, patrolling and safeguarding the EEZ need to be discussed. However, the present discussion is limited to commercial ships as warships and constabulary vessels in general tend to follow regulations when implemented and available to the shipping industry. To make the discussion clearer, we discuss the available digital tools independently.

(a) Numerous sensors on the ship produce and transmit digital information of various nature that need to be analysed and processed to improve Machine Learning for a reliable Artificial Intelligence to address various systems. Such humongous data are defined as Big Data that has the required potential to understand, analyse and fine tune the working of various ship systems so as to effectively help reduce carbon emissions and hence encourage decarbonisation of the shipping industry.
(b) Digital twinning is a digital tool that permits the availability of a digital replica of the ship in real-time with the operators on shore. Such a tool allows real-time monitoring of the ship and its machinery with predictive tools ensuring that predictive maintenance is provided to the machinery to ensure an efficient and a non-polluting ship with reduced carbon emissions (Lind, et al. 2020).

(c) A blockchain digital ledger allows efficient and fool-proof movement of cargo from one port to another on ships thereby ensuring faster and designated loading and unloading operations (King Boison and Antwi-Boampong 2020). This effectively increases efficiency of the vessel and reduced time in harbour leading to reduced emissions and hence pollution (Czachorowski, et al. 2019).

(d) The Cloud technology permits data computing and data storage to improve business agility. Together with Big Data analysis, the Cloud helps analyse a great amount of data for generating a real-time picture of the ship. Using this information along with IoT, the ship can be better controlled from shore remotely both for navigation and maintenance (Di Silvestre et al. 2018).

(e) 5G allows lower latency and higher speed of transfer of data between machines and is considered an essential support tool for the digitalisation effort of the shipping industry. This technology would allow easier and faster data transfer between ship and shore and between systems internal to both the ship and the port. This would allow faster reaction time, efficient material handling, faster financial transactions, remote pilotage, video surveillance, remote control of cargo handling facilities, and monitoring of goods in transit using IoT (Agarwala and Guduru 2021). These digitalisation efforts will eventually help in greater efficiency and hence reduced carbon emissions and help in decarbonising.

(f) Internet of Things (IoT) is a digital technology that allows the control of machinery remotely by using machine to machine communication using digital signals. When IoT is used on ships, it allows remote and unmanned operations of machines thereby making the operation safer and efficient, reducing maintenance, downtime, and fuel consumption. This effectively allows the reduction of carbon emissions as a result of efficient operations (Plaza-Hernández, et al. 2021).

(g) Edge Computing can assist in faster computing of future navigation routes and in decisions to take and initiate evasive actions against obstacles at sea without the help of digital environments of the Cloud and 5G (Gakpo, et al. 2019). Such an environment would make the ships independent in decision making, transitioning them to “autonomous” vessels thereby making them more efficient, economical, and environment friendly which would eventually help in achieving the greater effort of decarbonisation. Furthermore, it would assist in monitoring the performance real time, optimise fuel oil consumption, reduce carbon emissions, and help optimise strategic decision making by the ship-owner and ship-operator for greater efficiency, safety, and environmental friendliness. This technology not only enables substantial improvements in vessel performance monitoring but also

Figure 3. Available digital technologies for the Maritime Domain (Source: Agarwala 2021b).
helps optimize fuel oil consumption and hence reduction of CO₂ emissions. Using edge computing coupled with AI-driven analysis and modelling in the Cloud, one can assist real-time diagnosis and on-board predictions.

(h) *Energy storage* on ships is slowly gaining importance with the emergence of electric ships and ships that use renewable energy for their operations. With digitalisation, these energy storage systems can be made SMART that would disallow excessive operation of fossil fuel machinery when the energy storage is not required thereby reducing the carbon emission from such ships.

(j) *3D printing* using digitised drawings of machinery parts allows the manufacture of these machinery parts on the ship itself. This would reduce the spares carried and ensure that defective machinery can be repaired and made to operate efficiently and generate minimum carbon emissions (Kostidi and Nikitakos 2018).

(k) *Environment-sensing devices* that are either passive (sensing) or active (actuating) are essential to make digitalisation work effectively. They may be used for collecting real-time information of events such as environmental conditions, temperature, wind speed and direction, salinity, carbon emissions, obstacles, other ships, and objects in the vicinity and others. This information can be considered as the initial information for the realisation of both unmanned ships and then subsequent Machine Learning for autonomous ships.

(l) *Novel materials* with embedded sensors allow the virtual monitoring of the ship for features such as resistance, surface heating, faster data transfer and more which have a direct bearing of fuel consumption and hence carbon emissions. If the speed and air conditioning for the ship can be suitably controlled using these inputs, fuel consumption can be suitably controlled to achieve greater efficiency and hence greater decarbonisation.

(m) *Virtual Reality (VR) and Augmented Reality (AR)* can be used as tools to reduce costly maintenance work, thereby reducing the increased fuel consumption due to faulty machinery/ equipment. To add to this, if VR and AR are combined with digital twinning, the maintenance work can be effectively completed while the ship is at sea, achieving advantage of decarbonisation. In recent years, there has been a phenomenal adoption of AR/VR technologies in terms of ship designing, construction, training, and maintenance (Chhabra and Rana 2020). The capability and flexibility offered by the present generation AR/VR can be seamlessly used to model the diagnostics of emission data. This data can be further used for prognosis and can effectively lead to improvisation of engine design and operations to eventually reduce emissions. With the availability the 5 G spectrum bandwidth, the data can be shared with the designer and the operator in real time for timely tuning, repairs or even overhaul to address the faulty emission parameters.

(n) *Voice controlled and virtual assistants* on ships can help easier search of information in a totally digital environment making availability of data faster for the remote operator for unmanned ships or for the operator on bridge to ensure quicker and safer decisions. These actions would effectively help improve the efficiency and environmental friendliness of the ships thereby helping the very cause of decarbonisation (International Shipping News 2019).

(p) *Artificial Intelligence* helps perform tasks with greater ease and efficiency after being trained by historic dataset collected by ship sensors. These tasks provide greater efficiency and safety to the user making the process environment friendly and hence lower on carbon emissions. One such use is in power supply systems which can use autonomous decision making to optimise energy production and consumption thereby ensuring greater efficiency of the energy generation system leading to lesser fuel consumption and hence greater decarbonisation.

(q) *Machine to machine communication* allows the monitoring of machines for automated and efficient operations of machine parts and reducing maintenance costs thus minimising carbon emissions.

(r) *Use of Drones* either underwater (UUV) or in air (UAV) help physical surveying and analysis of the maritime space where the ship operates to assist better decision making and domain awareness either from the ship or from shore to ensure greater safety and efficiency of the ship. This effectively helps avoid an accident at sea and efficient passage for the ship encouraging decarbonisation.

(s) *Adopting Maritime 4.0.* Maritime 4.0 is the equivalent of Industry 4.0 for the maritime sector that aims to digitalise systems and help automate the shipping industry by using Cloud and cyber-based network structure systems to optimise maritime operations. This system aims to improve efficiency and cut down operating cost for the industry of which fuel cost is one major component (Sullivan, et al. 2020). By utilising a functional Maritime 4.0, decarbonising ships would be feasible. The adoption of Maritime 4.0 could be through unmanned ships, autonomous ships, or smart ships. These ships would monitor their own health, establish, and communicate what is around it and makes decisions based on that information to achieve efficient navigation at sea and in harbour thus reducing maritime disasters and fuel consumption to eventually ensure decarbonising.
For ports and inland transportation industry

Even though the ships are considered independent, they are not entirely delinked and disconnected from the terrestrial support systems especially when it comes to carbon emissions. It is thus considered essential that the associated facilities and systems are understood to appreciate how they can be improved by using digitalisation to achieve reduced carbon emissions and hence decarbonisation of the shipping industry.

(a) Cold ironing. One notices that a ship in harbour for fuelling, cargo loading/unloading and maintenance mostly operates its own machinery, if available, for meeting its power requirements. This effectively causes high pollution levels in the port city and eventually is considered an area of concern (Zis, et al. 2014). One of the major reasons for using own machinery is the inability of the port to meet the power requirement and at times the varying voltage requirement of these ships.

Through the use of AI and digitalisation, the available power supply in port can be optimised to ensure that the requirement of the ship can be met. Additionally, by digitally controlling surplus energy produced by renewable sources (solar, wind, tidal, wave etc.), (Agarwala 2021c) the energy produced during non-peak hours can be stored. A smart communication system on the ship would help better, efficient, and smoother communication with the grid, thereby reducing the carbon emissions in harbour.

(b) Supply chain. Supply chain management is known to be another carbon emissions emitter for the shipping industry. By activities such as on-shoring (relocating business to low cost location within the nation) and near-shoring (relocating business to low cost location outside the nation) of the supply chain, reduction of carbon emission near the shore can be encouraged. Using digitalisation to control the displaced supply chain, the required efficiency and availability can be ensured. By shifting the supply chain to remote location would allow more efficient and environmentally friendly procedures which otherwise were not feasible in the congested port areas.

(c) Blockchain. By using digital trust technologies like blockchain, the speed and ease with which carbon emissions can be tracked, aggregated, and reported (KPMG 2020) is high. By ensuring that the basic information of the extent of emission is known and made public can help in creating greater awareness amongst the public thereby ensuring reduction of emission levels as was observed in China (Agarwala 2021d). Similarly, such digital trust technologies would assist in pin-pointing the culprit ship with adequate proof and levy necessary damages and encourage higher compliance through deterrence. Such efforts along with AI would further assist in fighting marine environmental pollution (Agarwala 2021e).

(d) Creating transparency. Digitalisation is a tool that enables economically sustainable shipping through automation, analysis, optimisation, and improved planning and execution. Through greater transparency it creates greater faith amongst stakeholders helping the shipping industry to become smarter, safer, and more efficient (LR 2019).

(e) Entering and leaving harbour. Entering and leaving harbour is considered to be one of the most dangerous and inefficient evolutions for a ship. By using digitalisation, this process can be made safer. Furthermore, by ensuring that the speed of the ship is adjusted during the passage itself the carbon emissions by a ship during anchorage and awaiting clearance to enter port can be avoided which effectively will help in the decarbonisation of the shipping industry (Merk 2014).

(f) Cargo handling in port. Using digitalisation in containers and cargo handling facilities in port will facilitate easier and faster cargo handling in port, thereby reducing time in harbour, increasing the efficiency of ships and hence reducing carbon emissions from both the ship and the cargo handling equipment.

Way ahead

By upgrading existing core systems on the ships and in the port to digital systems, emission reduction and hence decarbonisation of ships can be achieved. However, in an effort to achieve decarbonisation of the shipping industry through digitalisation, the following need to be kept in mind.

At the field/ tactical level

(a) For a platform where emissions are to be to monitored and controlled, a digital model of digital data acquisition, digital diagnostics, digital prediction, and remote initiation of maintenance to control abnormal parameters need to be diligently formulated, as seen in Figure 4. Once the model is formulated, these four elements of the model need to interact seamlessly to achieve reduced emissions through greater harmony and synergy.

(b) In order to address GHG emissions, the digital data collected should account for both external and internal (direct and indirect) data as seen in Figure 5. While the data acquisition mechanism needs to be from multiple sensors, the final picture to the operator should be a single synthesised picture. Further, to ensure integrity and quality of data, the data so collected needs to be subjected to QoS filters.

(c) The shipping industry as on date faces a lack of standardisation for use of digital data collected from various sensors. Each equipment manufacturer provides its own “black box” which is not compatible to the “black box” of another manufacturer. Such “black
Figure 4. AI and Big data analytics based prediction and maintenance model for ships (Source: Authors).

Figure 5. Categorisation of digital data for GHG emission analysis (Source: Authors).
“black boxes” are available in every aspect of the shipping industry right from machinery components onboard to port and terminal activities. While these “black boxes” are driven by economics, it is essential that for a digitalised shipping industry, open or common standards are defined and adopted as is done by the telecommunication industry.

(d) When upgrading, designing, or building smart ships, one need to ensure that the systems and hardware used can be supported. Similarly, the expected data volumes and processing requirements should be supportable for seven years as a minimum after installing.

(e) Since the major port cities have committed to reduce GHG emissions through the World Port Climate Initiative (WPCI), they need the active support of the shipping industry to achieve this goal and hence are under immense pressure to cut their GHG emissions (Mega 2019). It is hence imperative that the shipping industry encourages decarbonisation. With digitalisation being the future of technological revolution and having already made inroads into the shipping industry to increase efficiency and safety, the use of digitalisation should be encouraged to a maximum.

(f) While we may look at developing the technology to achieve digitalisation that can support decarbonisation, we should not forget to train the operator and equip him/her with the desired knowledge to handle digitally advanced systems to extract full benefits of digitalisation. This essentially means that the existing marine qualified personnel need to be equipped with the changing and evolving technology to be future compliant.

(k) Inclusion of decarbonisation by means of Maritime 4.0 technologies as part of doctrines would lay underpinning emphasis for the future policies and tangible action plans.

For future initiatives

(l) In the recent years, Blue Economy and sustainability have taken centre stage. In addition, there is increasing pressure on institutions to address the commitments of the Paris Agreement. This has caused ocean energy to become an area of interest in policy debates to provide the requisite clean and green energy (Agarwala 2021c). While digitalisation may support efficient usage of resources, it cannot create clean and green resources. It is hence essential that such clean and green energy sources are studied and researched to ensure their availability and use especially in port for the shipping industry to achieve overall decarbonisation.

(m) While digitalisation can help achieve decarbonisation in the shipping industry, it cannot achieve much traction until the requirements of emission control and monitoring are not included into the maritime regulations of the nation states. Though the UN Sustainable Development Goal-13 towards Climate Change has percolated in government strategies and policy documents of several nations (NITI 2007), they have not made inroads into the maritime doctrines of the nation, a must to achieve meaningful decarbonisation of the shipping industry through the use of digitalisation.

At the policy level

(g) In order to advance decarbonisation of the shipping industry, clear and ambitious emissions-reduction target need to be promulgated by governments. Since the gains are prospective, they need to be encouraged with policy measures that address technology, operations, and alternative energy, while providing economic incentives.

(h) Adequate processes need to be put in place to ensure that the current lack of digital information with regard to carbon emission from shipping platforms can be addressed. One such method could be the use of digital trust technologies like blockchain. With such information available, there would be greater awareness of the carbon emissions from shipping which would encourage public participation, deter defaulters and help to address emissions.

(j) GHG emissions as an issue are a global issue and cannot be limited to a specific nation or a region. Hence, it requires the intervention and guidance of international organisations such as IMO to be successful and effective.

Conclusion

Not achieving zero-emission economy is no more an option but has become an essentiality for the very sustenance of humanity on Earth. While the contribution of the shipping industry is negligible when compared with other transportation methods, the required decarbonisation has to be achieved within the laid out timeline given by the IMO. This said one needs to realise that while the terrestrial and air transportation systems can absorb and implement drastic policy changes, the shipping industry cannot do so due to the inherent costs and time associated with the construction, operations and training for a ship.

It is only time before systems that encourage full digital ships that can support unmanned and autonomous operations would become a reality. There too, the wide range of potential is still a matter of debate. Currently, smaller sized vessels have been tested and tried successfully. It can hence be said with conviction that it will not be long before such vessels will replace the existing fleet of manned vessels both on the high seas and in inland waterways.
This transition from manned to unmanned vessels seems feasible due to the advances made in digitalisation onboard ships. Though digitalisation began on ships with a concern towards economic returns and safety of ships, the advantages accrued from it have allowed thinkers and developers to move forward for greater returns. It is only a matter of time, some dedicated support followed by dedicated efforts that the concerted use of this technology on ships would help in the decarbonisation of the shipping industry. But for this to happen there is a need for a mind shift among ship owners and ship operators to exhibit trust in data driven decisions and realise the huge potential that this technology has in addressing our woes of carbon emissions. For now, it is essential that the advantages of this technology are disseminated for greater awareness and public participation.

Endnotes
1. Data which impacts internal data of the ship as a result of interaction of ship with internal factors/ systems is categorized as Direct Internal Data
2. Data which impacts internal data of the ship as a result of interaction of ship with the external environmental parameters is categorized as Indirect Internal Data

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