WMU Studies in Maritime Affairs 6

Aykut I. Ölçer · Momoko Kitada
Dimitrios Dalaklis · Fabio Ballini *Editors*

Trends and Challenges in Maritime Energy Management

WMU WORLD MARITIME UNIVERSITY

Springer

WMU Studies in Maritime Affairs

Volume 6

Series editors
Maximo Q. Mejia, Jr.
Aykut I. Ölçer
Jens-Uwe Schröder-Hinrichs

More information about this series at http://www.springer.com/series/11556

Aykut I. Ölçer • Momoko Kitada •
Dimitrios Dalaklis • Fabio Ballini
Editors

Trends and Challenges in Maritime Energy Management

Springer

Editors
Aykut I. Ölçer
World Maritime University
Malmö, Sweden

Momoko Kitada
World Maritime University
Malmö, Sweden

Dimitrios Dalaklis
World Maritime University
Malmö, Sweden

Fabio Ballini
World Maritime University
Malmö, Sweden

ISSN 2196-8772 ISSN 2196-8780 (electronic)
WMU Studies in Maritime Affairs
ISBN 978-3-319-74575-6 ISBN 978-3-319-74576-3 (eBook)
https://doi.org/10.1007/978-3-319-74576-3

Library of Congress Control Number: 2018936748

© Springer International Publishing AG, part of Springer Nature 2018
This work is subject to copyright. All rights are reserved by the Publisher, whether the whole or part of the material is concerned, specifically the rights of translation, reprinting, reuse of illustrations, recitation, broadcasting, reproduction on microfilms or in any other physical way, and transmission or information storage and retrieval, electronic adaptation, computer software, or by similar or dissimilar methodology now known or hereafter developed.
The use of general descriptive names, registered names, trademarks, service marks, etc. in this publication does not imply, even in the absence of a specific statement, that such names are exempt from the relevant protective laws and regulations and therefore free for general use.
The publisher, the authors and the editors are safe to assume that the advice and information in this book are believed to be true and accurate at the date of publication. Neither the publisher nor the authors or the editors give a warranty, express or implied, with respect to the material contained herein or for any errors or omissions that may have been made. The publisher remains neutral with regard to jurisdictional claims in published maps and institutional affiliations.

Printed on acid-free paper

This Springer imprint is published by the registered company Springer International Publishing AG part of Springer Nature.
The registered company address is: Gewerbestrasse 11, 6330 Cham, Switzerland

Foreword

The World Maritime University and Maritime Energy Management

Humanity is currently experiencing an era of unprecedented climate change, calling for urgent and coordinated action in order to ensure a sustainable future. Within academia and the international scientific community, it is widely accepted that greenhouse gases (GHGs) are the main drivers of climate change, contributing to the increase of global temperatures. The earth will continue to experience sea level rise, droughts, floods, increased heat, intense storms, and hurricanes (as experienced in 2017) despite our best efforts to significantly reduce GHG emissions. We all have an important responsibility in relation to future generations and our home planet to allocate sufficient resources and dedication to minimize the negative effects of climate change.

The shipping industry plays an essential role in the facilitation of world trade, being the most fuel-efficient mode of mass cargo transport. However, the expected growth of world trade represents a challenge to meet future emission targets that are required to achieve stabilization of global temperatures. According to the International Maritime Organization's (IMO) Third GHG study (2014),[1] the total annual amount of CO_2 emitted from international shipping is reported as 2.7% of the total CO_2 emissions produced worldwide. Without changes, the negative externalities of shipping will increase. This study predicts that CO2 emissions will increase by between 50% and 250% by 2050, depending on future economic and energy developments. Under a business-as-usual scenario, and if other sectors of the economy reduce emissions to keep global temperature increase below 2 °C, shipping could by 2050 represent 10% of global GHG emissions. Therefore, measures have to be taken to secure a sustainable future for mankind and ensure a competitive

---

[1] IMO. (2014). *Third IMO Greenhouse Gas Study.* London: International Maritime Organization.

maritime transport industry. Given the importance of international rules and regulations for ensuring sustainable shipping on clean oceans, as well as the importance for the maritime industry to remain competitive, the question arises as to how the maritime industry can best move forward to ensure a low carbon and energy efficient future.

On a global level, IMO is addressing air pollution through the International Convention for the Prevention of Pollution from Ships (MARPOL), particularly its Annex VI which limits emissions from ships, including sulfur oxides, nitrogen oxides, ozone-depleting substances, and volatile organic compounds. Measures are also in place for more energy efficient future ships as outlined in MARPOL Annex VI Chapter 4, including the Ship Energy Efficiency Management Plan (SEEMP) and Energy Efficiency Design Index (EEDI) which entered into force on 1st January 2013. The European Union (EU) has also adopted a regulation on monitoring, reporting, and verification (MRV) of CO_2 emissions, which will enter into force in January 2018. These regulatory measures will increase costs related to shipping operations, providing an important incentive toward energy efficient solutions. In recognition of this shift, the industry must work closely with researchers and innovators who can deliver cutting-edge solutions needed to comply with the new legal requirements. Those who do will be ahead of the competition.

Low carbon shipping provides three interrelated routes that can reduce GHG emissions:

- Increasing the energy efficiency level of ships
- Employing renewable energy on-board ships to propel fully (or, at least partially) a commercially sized merchant ship, and
- Using cleaner fuels or emission abatement technologies on-board ships such as LNG or scrubbers, respectively.

For the shipping industry, energy management is thus a key priority for energy efficient and environmentally friendly shipping that enhances profitability while operating within a tightening regulatory framework. It is very clear that significant action, including market-based measures, needs to be taken by the maritime industry in order to be able to reach a fossil fuel free industry by the end of this century.

The global importance of energy management was recognized at the 2015 COP 21 Climate Change Conference in Paris, where the IMO presented a report on its extensive efforts to address GHG emissions from shipping. The world will benefit from reduced GHG emissions with IMO's adoption of the only global, legally binding energy efficiency measures that will require ships built as of 2025 to be 30% more energy efficient than they are today. Energy management is also essential for the achievement of UN Sustainable Development Goals (UNSDGs), and in particular Goal 7: ensure access to affordable, reliable, sustainable, and modern energy for all; Goal 12: ensure sustainable consumption and production patterns; Goal 13: take urgent action to combat climate change and its impacts; and Goal 14: conservation and sustainable use of the oceans, seas, and marine resources for sustainable development.

The World Maritime University (WMU) has a strong commitment to the UNSDGs and works to support the achievement of a sustainable and energy efficient maritime and ocean industry. WMU was founded in 1983 by IMO. The fundamental objective of the university is to provide the international maritime community, and in particular developing countries, with a center for advanced maritime and ocean education, research, scholarship, and capacity building and an effective means for the sharing and transfer of technology from developed to developing maritime countries, with a view to promoting the achievement, globally, of the highest practicable standards in matters concerning maritime safety and security, efficiency of international shipping, the prevention and control of marine pollution, including air pollution from ships, and other marine and related ocean issues.

WMU aims to build knowledge, skills, and competences to enhance shipping efficiency, maritime safety and security, and the prevention of marine pollution. Since 1983, WMU has grown substantially, today offering seven specializations within the Malmö-based MSc program, two MSc programs in China, and a fast growing PhD program. In 2016, the new well-received specialization in Maritime Energy Management was launched. In line with UNSDG 7, the key pillars of the specialization are energy efficiency, renewable and clean energy, research, technology, and innovation. The programme provides a comprehensive understanding across the spectrum of maritime energy management, from on-board ships to onshore facilities such as ports and shipyards; it covers theoretical and practical aspects of maritime energy management as well as the relevant regulatory framework. Through cutting-edge research and dissemination of insights into the profitable management of alternative forms of marine and ocean energy, WMU contributes significantly to the objective of affordable, reliable, and sustainable modern energy for all.

It is clear that the demands for the shipping industry to become more energy efficient will have a broad effect across the maritime and oceans fields. The abovementioned high-level initiatives demonstrate that a significant interest has developed in energy efficiency, renewable energy, and alternative fuels, creating an upward momentum across the shipping industry with a wide range of technical, operational, and commercial measures already implemented or under development. These demands concern actors from the private and public sectors as much as stakeholders of international organizations, NGOs, and academia. WMU is a committed partner and go-to place for informed discussion, capacity building, exchange of ideas, and applied research.

I invite you to read the chapters of this book which contains insights and analysis on how the maritime and ocean industry can achieve an energy efficient and low carbon future. Please visit our website (www.wmu.se) to get more acquainted with the World Maritime University and what it offers.

World Maritime University
Malmö, Sweden

Cleopatra Doumbia-Henry

Acknowledgments

This book is a selection of peer-reviewed papers from the International Conference on Maritime Energy Management (MARENER 2017), held in Malmö, Sweden, 24–25 January 2017, and organized by the World Maritime University (WMU). The editors would like to take advantage of this opportunity to acknowledge the contribution and assistance of numerous individuals, such as maritime professionals, academics and researchers, MSc students of the Class of 2017 specializing in Maritime Energy Management (MEM) at WMU, and many other contributors, whose efforts led to the successful execution of MARENER 2017 and, in turn, made the publication of this book possible. MARENER 2017 provided a platform for all relevant maritime stakeholders to identify and discuss trends, opportunities, and challenges in the field of maritime energy management with the aim of achieving an energy efficient and low carbon future for the maritime industry.

The editors would first like to extend their thanks to the keynote speakers of MARENER 2017, in order of their presentations during the conference: WMU's President Dr. Cleopatra Doumbia-Henry; Secretary General of the International Maritime Organization (IMO) Mr. Kitack Lim; Mr. Cem Melikoğlu, CEO of Türk Loydu Foundation; Mr. Metin Kalkavan, Chairman, Turkish Chamber of Shipping; Mr. Carl-Johan Hagman, Head of Shipping and Ferries Stena AB; Mr. Tom Sundell, Vice President, NAPA Group; Dr. Jan Otto de Kat, Director, Energy Efficiency and Vessel Performance, ABS; Dr. Hermann J. Klein, President, German Society for Maritime Technology; Ms. Katharina Stanzel, Managing Director INTERTANKO; Ms. Anna Johansson, Minister for Infrastructure, Sweden; Mr. Johan Röstin, CEO, Copenhagen Malmö Port; Rear Admiral Paul Thomas, Assistant Commandant for Prevention Policy, U.S. Coast Guard; and Professor Dr. Mehmet Atlar, University of Strathclyde.

Our sincere appreciation is extended to the sponsors of MARENER 2017, in alphabetical order: Copenhagen Malmö Port, International Maritime Organization (IMO), MITIGATE (European Union-(EU) funded research project under the Horizon 2020 Framework), and Türk Loydu Foundation. Their generous support greatly enhanced the success of the event. Our appreciation and thanks are also extended to the MARENER 2017 media partners, in alphabetical order: Baltic Transport Journal;

Baltic University Network; DNV GL; GoLNG (EU-funded research project under the Interreg Baltic Sea Region); Harbour Review; International Association of Maritime Universities (IAMU); International Windship Association (IWSA); Motus Foundation; On-the-MoS-Way (Digital Multichannel Platform); and Ocean Renewable Power Company.

The editors would further like to thank Mr. Craig Eason, Editorial Director of Fathom, for moderating the keynote sessions, and all session chairs for their professionalism, including, in alphabetical order: Associate Professor Dr. Michele Acciaro, Kühne Logistics University; Mr. Gavin Allwright, International Windship Association; Professor Dr. Karin Andersson, Chalmers University of Technology; Professor Dr. Mehmet Atlar, University of Strathclyde; Dr. Fabio Ballini, WMU; Dr. Dimitrios Dalaklis, WMU; Dr. Jan Otto De Kat, Director, Energy Efficiency and Vessel Performance, ABS; Former Associate Professor Patrick Donner, WMU; Professor Dr. Massimo Figari, University of Genoa; Dr. Edmund Hughes, Head of Air Pollution and Energy Efficiency, IMO's Marine Environment Division (MED); Dr. Momoko Kitada, WMU; Professor Dr. Francesco Munari, University of Genoa; Professor Dr. Aykut I. Ölçer, WMU; Professor Dr. Harilaos N. Psaraftis, Technical University of Denmark; and Professor Dr. Osman Turan, University of Strathclyde.

A special thanks is extended to the members of the Scientific Committee who reviewed abstracts and full papers of the conference, in alphabetical order: Dr. Michele Acciaro, Dr. Karin Andersson, Dr. Özcan Arslan, Dr. Mehmet Atlar, Dr. Fabio Ballini, Dr. Baris Barlas, Dr. Raphael Baumler, Dr. Riccardo Bozzo, Dr. Helen Cabalu, Dr. Monica Canepa, Dr. Dimitrios Dalaklis, Dr. Jan Otto de Kat, Dr. Aref Fakhry, Dr. Massimo Figari, Mr. David Haynes, Dr. Lawrence Henesey, Dr. Mustafa Insel, Dr. Henning Jessen, Dr. Larry Hildebrand, Dr. Momoko Kitada, Dr. Dimitris Konovessis, Dr. Cristiano Morini, Dr. Francesco Munari, Dr. Takeshi Nakazawa, Dr. Nikitas Nikitakos, Dr. Aykut I. Ölçer, Dr. Harilaos N. Psaraftis, Dr. Burak Seker, Dr. Osman Turan, and Dr. Anne Marie Warris. The editors also express deep gratitude to Ms. Anne Pazaver, WMU Lecturer, who kindly proofread all the chapters in this cumulative research effort.

The editors further appreciate WMU's President Dr. Cleopatra Doumbia-Henry, for providing the leadership and vision to support the MARENER 2017 conference. Additionally, a very heavy workload was carried by the respective Organizing Committee (Aykut I. Ölçer (Chair of the Committee), Momoko Kitada, Dimitrios Dalaklis, Fabio Ballini, Josefin Madjidian, Mia Hedin, Neil Bellefontaine, Raphael Baumler, Megan Drewniak, Burak Şeker) and relevant WMU supporting staff (Erik Ponnert, Katharina Serrano, Maia Brindley Nilsson, Chris Hoebeke, Ammar Jaber, Saul Isaacson, Solveig-Karin Erdal, and René Engström). We also extend our thanks to the MSc Class of 2017 specializing in Maritime Energy Management for their assistance during the sessions and for their support of the event; they are Mark Philip Cassar, Olumide Bolarinwa Ajayi, Quang Khanh Bui, Yaser Bayoumy Abdelwahab Farag, Reza Karimpour, Maryam Mohamed Kidere, Hyuntae Kim, Edwin Nii Oduah Mensah, John Churchill Omondi, Oyegbenga Afeez Oyewunmi, Eko Maja

Priyanto, Md Abu Hasan Rony, Mohamed Said S.H. Rowihil, Wandifa Saidyleigh, Joshua Rafale Tolin, and Jing Yu.

We also express our deepest gratitude to the more than 300 participants whose valuable input and opinions contributed to active discussions and enhanced the quality of the MARENER 2017 conference. The conference looked into different topics related to Maritime Energy Management including Regulatory Framework, Energy Efficient Ship Design and Operation, Energy Management in Ports, Economics of Energy Efficiency, Social and Human Dimensions of Energy Management, Theoretical Aspects of Maritime Energy Management, Alternative Fuels and Marine Renewable Energy Including Ocean Energy.

Last but not least, the editors thank the authors of each chapter in this book for their insights and efforts in bringing trends and challenges affecting the advancement of maritime energy management to the forefront of discussions. These contributions can serve as a stimulus for further development and study of maritime energy management.

Malmö, Sweden
November 2017

Aykut I. Ölçer
Momoko Kitada
Dimitrios Dalaklis
Fabio Ballini

Contents

Introduction to Maritime Energy Management 1
Aykut I. Ölçer

Part I Regulations: Challenges and Opportunities

MARPOL Energy Efficiency: Verging on Legal Inefficiency? 15
Aref Fakhry and Belma Bulut

Analyzing Approaches to Set Greenhouse Gas Reduction Targets in Anticipation of Potential "Further Measures" for International Shipping 29
Seijiro Morimoto

An Analysis of Non-conformities with the Objective of Improving Ship Energy Efficiency: Case Studies of Turkish Shipping Companies 41
Özcan Arslan, Elif Bal Beşikçi, Fırat Bolat, and Koray Yaş

Real Time Awareness for MRV Data 53
Nikitas Nikitakos, Dimitrios Dalaklis, and Petros Siousiouras

Overcoming the Challenges to Maritime Energy Efficiency in the Caribbean 65
Vivian Rambarath-Parasram, Sukhjit Singh, and Deniece Aiken

Energy Efficient Operations of Warships: Perspective of the Indian Navy 83
Amit Batra and Rohit Prakash

Mexico's Reorganisation of Maritime Security Regime: A New Role for the Navy and Emphasis on Energy Related Infrastructures 95
Adriana Avila-Zuñiga Nordfjeld and Dimitrios Dalaklis

Part II Energy Efficient Ship Design

Numerical Studies on Added Resistance and Ship Motions of KVLCC2 in Waves 111
Mingyu Kim, Osman Turan, Sandy Day, and Atilla Incecik

An Investigation of Fuel Efficiency in High Speed Vessels by Using Interceptors 127
Ahmet G. Avci, Baris Barlas, and Aykut I. Ölçer

A Decision Support System for Energy Efficient Ship Propulsion 143
Mustafa Insel, Serhan Gokcay, and Ahmet Ziya Saydam

Energy Integration of Organic Rankine Cycle, Exhaust Gas Recirculation and Scrubber 157
Fredrik Ahlgren, Marcus Thern, Magnus Genrup, and Maria E. Mondejar

Lighting Standards for Ships and Energy Efficiency 169
Efe Akyurek

Part III Energy Efficient Ship and Port Operation

An Integrated Vessel Performance System for Environmental Compliance 185
Soren Hansen and Stamatis Fradelos

Energy Efficient Ship Operation Through Speed Optimisation in Various Weather Conditions 199
Tong Cui, Benjamin Howett, Mingyu Kim, Ruihua Lu, Yigit Kemal Demirel, Osman Turan, Sandy Day, and Atilla Incecik

Underlying Risks Possibly Related to Power/Manoeuvrability Problems of Ships: The Case of Maritime Accidents in Adverse Weather Conditions 213
Nikolaos P. Ventikos, Konstantinos Louzis, and Alexandros Koimtzoglou

Simulation-Based Support to Minimize Emissions and Improve Energy Efficiency of Ship Operations 231
Michael Baldauf, Syed Raza Ali Mehdi, Michele Schaub, Knud Benedict, Gerd Milbradt, Georg Finger, and Sandro Fischer

Fuel Saving in Coastal Areas: A Case Study of the Oslo Fjord 245
Karina Hjelmervik, Halvor Schøyen, Hao Wang, and Ottar Osen

A Bayesian Belief Network Model for Integrated Energy Efficiency of Shipping 257
Onder Canbulat, Murat Aymelek, Osman Turan, and Evangelos Boulougouris

Smart Micro-Grid: An Effective Tool for Energy Management in Ports 275
Monica Canepa, Giampaolo Frugone, and Riccardo Bozzo

Energy Manager Role in Ports 295
Fabio Ballini and Aykut I. Ölçer

Part IV Economics and Social Dimensions of Maritime Energy Management

The Impact of SECA Regulations on Clean Shipping in the Baltic Sea Region 309
Eunice O. Olaniyi, Gunnar Prause, and Jan Boyesen

Life Cycle Assessment of Marine Coatings Applied to Ship Hulls 325
Yigit Kemal Demirel, Dogancan Uzun, Yansheng Zhang, and Osman Turan

The Human and Social Dimension of Energy Efficient Ship Operation 341
Martin Viktorelius

The Need for Education and Training in Maritime Energy Management in Myanmar 351
Thet Hlaing Swe, Momoko Kitada, and Aykut I. Ölçer

The Role of Maritime Transport from the Perspective of Energy and Gender: The Case of the Pacific Islands 367
Momoko Kitada, Kuini Rabo, Ore O. Toua, and Thierry Nervale

Part V Alternative Fuels and Wind-Assisted Ship Propulsion

Developing a Strategy for Liquefied Natural Gas Powered Transport Corridors in the Baltic Sea Region 383
Josefin Madjidian, Dimitrios Dalaklis, Vytatutas Paulauskas, Lawrence Henesey, Aykut I. Ölçer, Fabio Ballini, and Momoko Kitada

LNG Fueled Barge for Cold Ironing: Feasibility Study for the Emission Abatement in the Port of Genoa 401
Michele Laviola, Massimo Figari, Marco Altosole, and Stefano Savio

Decision Framework for Shipowners to Comply with Air Emission Reduction Measures: A Case Study of Methanol as a Fuel 415
Aditya Srivastava, Aykut I. Ölçer, and Fabio Ballini

Commercial Wind Propulsion Solutions: Putting the 'Sail' Back into Sailing 433
Gavin Allwright

Part VI Marine Renewable Energy

A Multipurpose Marine Cadastre to Manage Conflict Use with Marine Renewable Energy 447
Séverine Michalak

Ocean Energy: Seeking the Balance Between States' Exclusive Rights of Exploitation and Marine Biodiversity Conservation 463
Wellington Tebar

Learning from Humpback Whales for Improving the Energy Capturing Performance of Tidal Turbine Blades 479
Weichao Shi, Mehmet Atlar, and Rosemary Norman

CFD Simulation of a Passively Controlled Point Absorber Wave Energy Converter 499
Minghao Wu, Weizhi Wang, Johannes Palm, and Claes Eskilsson

A Framework to Improve the Coexistence of Maritime Activities & Offshore Wind Farms 513
Raza Ali Mehdi, Jens-Uwe Schröder-Hinrichs, Aykut I. Ölçer, and Michael Baldauf

Editorial Conclusion 527
Aykut I. Ölçer, Momoko Kitada, Dimitrios Dalaklis, and Fabio Ballini

Annex 533

Introduction to Maritime Energy Management

Aykut I. Ölçer

1 Environmental Protection

Considering that the seas and oceans of our planet are associated with the most fuel-efficient method of dealing with humanity's transport needs, it is a rather self-evident fact that international shipping is crucial to world trade and the normal operation of the global economy. However, seaborne transportation is also responsible for production of greenhouse gas (GHG) emissions (like all other modes of transportation) along with the emissions of various air pollutants such as sulphur oxides (SO_x), nitrogen oxides (NO_x) and particulate matters (PMs). Hence, the maritime transport industry's environmental footprint -especially in regard to air pollution, including both GHGs and air pollutants- is not seen as very positive. Although less than 3% of the total global CO_2 emissions are associated with international shipping, shipping emissions could continue to increase by 50–250% by 2050, if everything follows the so-called "Business As Usual" scenario (IMO 2014).

It is also true that GHGs are produced by both natural procedures and man-made activities. However, an important dimension of the problem is that anthropogenic (man-made) GHGs are the main cause of global warming and temperature rise, responsible for climate change, which has been resulting in weather pattern changes, increased sea-level rise, and more frequent floods (IEA 2015). According to the latest report published by WMO (2017), CO_2 concentration in the atmosphere reached 403.3 parts per million (ppm) in 2016, which is the highest amount in the last 800,000 years. It should be noted that the figure was 400.00 ppm in 2015.

A. I. Ölçer (✉)
World Maritime University, Malmö, Sweden
e-mail: aio@wmu.se

A. I. Ölçer et al. (eds.), *Trends and Challenges in Maritime Energy Management*,
WMU Studies in Maritime Affairs 6, https://doi.org/10.1007/978-3-319-74576-3_1

Within the maritime energy management context, there is no technology that can entirely remove GHGs resulting from the operations of the maritime industry. Medium to large-scale ships will indisputably continue to burn fossil fuels, including "*cleaner*" ones (like LNG) in the foreseeable future. Therefore, the vast majority of efforts in the maritime industry have been directed towards decreasing GHGs rather than eliminating them completely. Energy management, also referred to in the literature as energy efficiency or energy conservation, is accepted at IMO and within the wider maritime community to be the main mechanism to serve the purpose of reducing GHGs. Regardless of what it is called, managing energy in an optimal way or increasing the energy efficiency of a ship generally constitutes the reduction of its fuel consumption.

Concepts such as "how to reduce fuel consumption" or "how to become more energy efficient" can be dealt with during ship design, but also during regular ship operation. The biggest potential lies in the design phase, whereas ship operation also has room for improvement. It is indicative that an optimised hull form or a good coating decided during design reduces total ship resistance. The same ship can further reduce its resistance with effective hull maintenance (operational measure). Selection of the best propeller and/or propulsion system during design will lead to having more thrust available with the same input (or the same thrust with less input). Similarly, propeller cleaning (operational measure) might contribute further to increasing the propeller's efficiency. Numerous other examples can be included in the same equation; according to IMO, the combined CO_2 reduction potential of ship design and operation is between 50 and 75% (IMO 2009).

2 IMO Response and Drivers

In order to fully explore the above-mentioned potential, IMO came up with two measures (technical and operational) within Chap. 4 of the International Convention for the Prevention of Pollution from Ships (MARPOL) Annex VI, which entered into force on 1 January 2013. The one to be complied with during new ship design is an index called Energy Efficiency Design Index (EEDI); the one requiring a plan for ship operations, namely Ship Energy Efficiency Management Plan (SEEMP), is to be kept on-board existing ships. This only applies to certain ship types of certain gross tonnage. Chap. 4 of the MARPOL Annex VI is the only international binding regulation covering both design and operation of ships for GHGs resulting from international shipping.

It should be noted here that emission control areas (ECAs) introduced in Chap. 3 of MARPOL Annex VI contribute to reduction of air pollutants such as SO_x and NO_x emissions while contributing to GHG reduction. For Sulphur-ECAs, this is accomplished by the use of alternative fuels such as LNG/methanol, as well as using low sulphur fuel or emission abatement technologies.

In addition to the above-mentioned compulsory measures, measures of an economic nature, called market based measures (MBM), were also discussed, but have not yet come into force. Market based measures is a proposed mechanism based on the principle of “polluter pays”. Prior to the future implementation of this mechanism, the European Union (EU) and IMO took an initiative on a scheme called MRV (Monitoring, Reporting and Verification) of ships’ CO2 emissions; that regulation entered into force on 1 January 2018 by EU and will be in force on 1 January 2019 by IMO, with a different name, Data Collection System (DCS).

Over and above mitigating the negative impacts of GHGs, energy management can also be driven by numerous economic and business drivers. Volatility of fuel oil price, rising energy demand and high prices, scarcity of the fossil fuel trio (gas, coal, oil) are considered to be a few of those economic drivers. Potential benefits resulting from applying energy management, such as decreasing energy costs, and thereby operational costs, and increasing profits or reducing waste, are considered business drivers (Oung 2013).

The United Nations (UN) released its 2030 agenda, called UN2030 agenda, to promote sustainable development in the world while focusing on a set of actions for the 3Ps (People, Planet and Prosperity). The agenda has 17 sustainable development goals (SDGs), each of which has a number of targets, totaling 169 targets for 17 the SDGs. The SDGs have become drivers for the maritime industry to become more environmentally friendly and energy efficient in order to be able to meet the targets set under each SDG, in particular SDGs 7 (affordable and clean energy), 12 (responsible consumption and production) and 13 (climate action) (UN 2015). Needless to mention, the world population, which can be considered as the main driver of all these initiatives, continues to expand and to push the planet’s boundaries (UN DESA 2015).

Those above-mentioned legislative and non-legislative motivational factors (or drivers) are the bases for energy management or energy efficiency. All these drivers have led the maritime industry to become (more) energy efficient in the way ships are designed, as well as in the way seagoing vessels are operated/maintained; producing energy for maritime transport and managing its consumption in an optimal way is simply called maritime energy management (Ölçer and Ballini 2018). This includes employing renewable energy, increasing energy efficiency through optimal design and application of “good” operation/maintenance practices, installing and using energy efficient machines and equipment as well as new innovative technologies, creating awareness for on/shore personnel, setting an energy management strategy and its objectives/targets, having top management commitment, and a combination thereof. Non-legislative drivers and compulsory technical and operational measures accompanied by the UN2030 Agenda are schematically presented in Fig. 1.

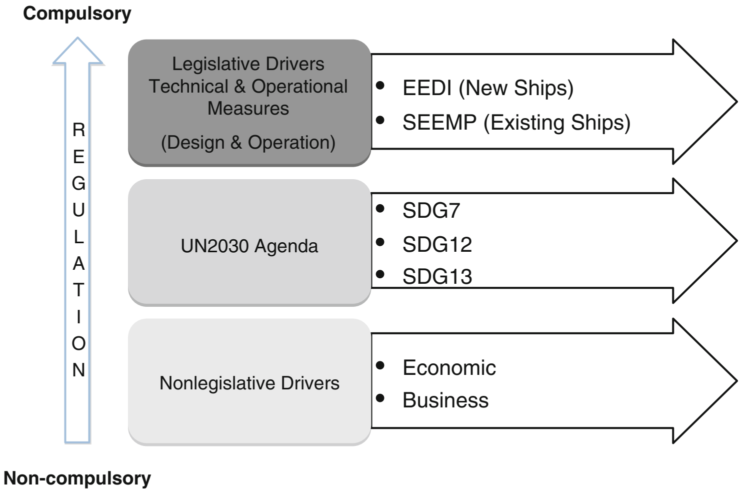

Fig. 1 Legislative and non-legislative drivers of maritime energy management

3 Technical and Operational Measures

A ship can operate with the execution of its functions, including cargo loading, power generation, manoeuvring, providing hotel facilities for people on-board and many more, which require the transformation of energy sources (chemical, renewable, nuclear etc.), shown in Fig. 2, into various different forms of energy such as electricity, heat or mechanical energy to be used by energy consumers (like pumps or cargo handling equipment) (Woud and Stapersma 2002). Surely this transformation will have losses since there is no 100% efficient technology or system. The efficiency of a main propulsion engine will be around 40% while the rest (around 50%) is lost as heat and exhaust (Fig. 3), which can be recovered by using technologies like WHR (Waste Heat Recovery) (IMO 2009). The power released to shaft (P_B) and

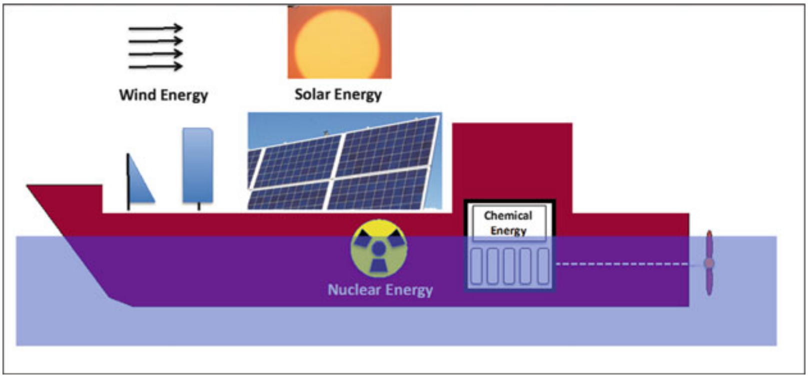

Fig. 2 Main energy sources onboard a ship

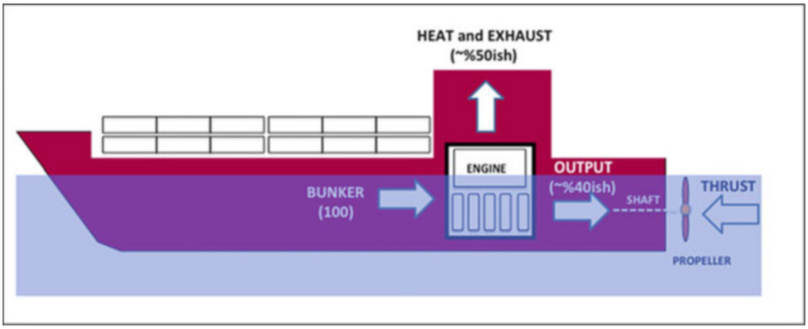

Fig. 3 Efficiency of a main propulsion engine

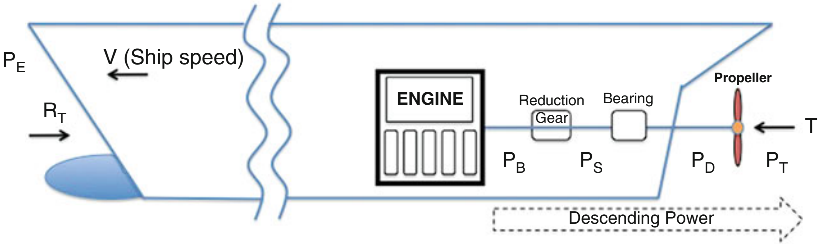

Fig. 4 Descending power from P_B to P_T

then propeller (P_D) will have further losses including mechanical losses and those resulting from propeller-hull interaction. Power losses from engine to propeller are in descending order of $P_B > P_S > P_D > P_T$ as shown in Fig. 4 where

P_B: Break power of main engine
P_S: Shaft power
P_D: Delivered power
P_T: Thrust power.

Every improvement in this chain in terms of decreased losses will contribute to increasing the ship's overall energy efficiency. Technical and operational measures are meant to be the means serving that goal.

Technical measures primarily target improvements in ship resistance and propulsion areas during the ship design phase. In very simple terms, less ship resistance or increased propulsion efficiency generally constitute less required engine power and, thereby, less fuel consumption (see Eq. 1 Molland et al. 2011):

$$P_B = P_E/(\eta_D \times \eta_{TR}) = (R_T \times V_S)/(\eta_D \times \eta_{TR}) \tag{1}$$

where

P_E: Effective power
R_T: Total ship resistance
V_S: Ship service speed
η_D: Quasi propulsive coefficient (P_E/P_D)
η_{TR}: Transmission efficiency

Reduction of total ship resistance (R_T) relies on the efforts of two major resistance components: (a) wave-making resistance; and (b) viscous resistance. Wave-making resistance is generally reduced through hull form optimization, whereas the potential for viscous resistance decrease is on minimisation of wetted surface area (such as air cavity or air film) or modification of the boundary layer (such as riblets or compliant surfaces) (Gokcay et al. 2004; Yang 2009). It is obvious from the above-relation Eq. (1) that lower speed is another important contributor to the reduction of fuel consumption. Speed optimization in ship design and slow steaming in ship operation are the two main methods of speed reduction.

As stated above, increased propulsion efficiency will also contribute to engine power reduction (see Eq. (1)). Quasi propulsive coefficient is the function of open-water propeller efficiency, hull efficiency and relative rotative efficiency as shown in the Eq. (2) (Molland et al. 2011). Obviously, increase in each efficiency element in the Eq. (2) will contribute to increased η_D and so propulsion efficiency.

$$\eta_D = \eta_O \times \eta_H \times \eta_R \tag{2}$$

Where

η_O: Open-water propeller efficiency
η_H: Hull efficiency
η_R: Relative rotative efficiency

In this regard, energy efficient ship propulsion starts with the selection of an efficient propeller, which is referred to as open-water propeller efficiency. Open-water propeller efficiency is used to assess propeller performance without the presence of a hull. Torque and thrust characteristics of a propeller are measured and plotted against advance coefficient (J), hence K_T-K_Q-J diagrams are produced, which are then used to select the best propeller giving the highest efficiency (η_O). Here K_T is thrust coefficient and K_Q is torque coefficient. Contributing parameters to this efficiency are propeller characteristics such rake, skew, pitch, number of blades, diameter, profile sections and so on.

A propeller with the presence of a hull meaning “a propeller operating behind a hull” has different efficiency and hydrodynamic characteristics than an open-water propeller. This is an outcome of the wake gain, thrust deduction, and relative rotative efficiency, which is also referred to as propeller-hull interaction in the literature. The hull efficiency (η_H) is the function of wake fraction (w) and thrust deduction (t) factors, and expressed as in the Eq. (3) (Molland et al. 2011).

$$\eta_H = (1-t)/(1-w) \tag{3}$$

Many propulsion improvement devices have been developed to increase hull efficiency. A few indicative examples are thrust augmentation devices, wake equalizing and flow separation alleviating devices, pre-swirl devices, post-swirl devices, and propeller bos cap fins (Prins et al. 2016).

Some of these technical measures are more mature than others; similarly, some are more (or less) costly to apply, or more (or less) environmentally friendly to consider. Hull form optimization is a mature and traditional design tool, whereas air lubrication or sharkskin mimicked coating is a new technology, which requires more research in order to become a commercially viable option in the market.

It should be emphasized here that even the most energy efficient ship design has potential for improvement during the operational life of the vessel. Fuel consumption during ship operation can be reduced through three main ways (Ölçer and Ballini 2018): Optimal handling of ships; Voyage optimisation or fuel-efficient journey; Good hull, engine (main and auxiliary engines) and propeller maintenance.

There are many operational measures that can be employed during a ship's journey. Here, a few samples are provided in order to familiarise the reader with their nature and wide spectrum. For example, to reduce stresses (safety) and/or to reduce fuel consumption through trim change (energy efficiency), ships are required to deal with ballast exchange processes, which have potential for fuel saving and hence need to be handled in an optimal way. If a ship uses a controllable pitch propeller, having the optimal combination of pitch and rpm reduces fuel consumption marginally. Environmental conditions of the route that a ship takes might have significant impact on its fuel consumption. Therefore, the Captain's role in this case is to find the best route, which will cause the least fuel consumption. There are already algorithms and on-board software developed for weather routing, which takes weather and sea conditions into consideration prior to the journey. Another measure is just in time arrival (or virtual arrival), which is based on effective communication between ship and port of call; this can achieve significant fuel saving and decrease off-hire time. Roughness formed due to fouling (marine organism growth) over the years can increase fuel consumption significantly, up to 30% (or more) in severe cases. Advanced paints and periodic dry-docking as an operational measure can help reduce the roughness of a hull surface.

As highlighted before, the list is long. Nevertheless, it is necessary to bear in mind that safety should never be compromised while trying to increase energy efficiency of ships during both design and operation phases. Since energy efficiency of ships is all about reducing GHGs, every little (from pitch optimisation to slow-steaming) measure can help. Last but not least, it is important to highlight that every technical or operational measure has a different impact that varies from one ship type to another.

4 Barriers and Trade-Off

Despite the fact that there is a wide variety of technical and operational measures available and with different maturity levels, certain barriers exist that prevent their effective implementation. These barriers can be categorised into individual, behavioural barriers created by people, and organizational, barriers at the company level. In addition, financial and technological barriers can hinder implementation of those measures. The important thing is to eliminate all the barriers to be able to benefit from implemented measures (Kitada and Ölçer 2015; Thollander and Palm 2012).

Up to now, the GHG reduction mitigation measures applicable to ships have been explained only from an environmental point of view. However, each technical and operational measure will also create a socio-economic impact (Ballini et al. 2017). Without taking these dimensions (socio-economic and environmental) into consideration, simultaneously, it will be very difficult to make rational multiple-criteria decisions; for example externality cost versus payback time versus GHG reduction of an LNG fuelled ship retrofitted with a dual fuel engine. Therefore, the economic and social dimensions of maritime energy management must be included in the selection and implementation of technical and operational measures, in addition to the environmental dimension. However, making an evaluation in a three-dimensional domain is an analysis under a trade-off environment, where each dimension's aspects are conflicting with each other (Ölçer and Ballini 2015).

The trade-off analysis or impact assessment requires operational research methodologies to be applied, spanning from multiple criteria decision making, to monte-carlo simulation, to payback calculation, to life-cycle cost evaluation, to externality modeling and simulation, to multiple objective optimization and so on. In order to be able to increase efficiency, called maximization of efficiency in the optimization terminology, an optimization algorithm needs to be selected and employed. Sometimes, a decision has to be taken under conflicting requirements, which entails a multiple attribute decision-making methodology to be applied. Or, fuel consumption prediction will be a probabilistic estimation due to the uncertainties associated with ship and environment related parameters. Therefore, theoretical ground is inherent to maritime energy management.

The previous sections dealt with energy efficiency of ships. From here, the topics of energy efficient port operations and Marine Renewable Energy (MRE) are touched upon, which are also within the coverage of the maritime energy management field as well as this book. MRE is about producing electricity by using marine resources such as offshore wind, waves or ocean currents to be used in homes, buildings and land industry. Once electricity is produced, it can be transferred to shore grids with the use of appropriate transformers. The family of MRE is rather expanded and includes offshore wind energy and ocean energy. Ocean energy involves employing advanced technologies that convert wave energy, current energy, tidal energy, ocean thermal and salinity gradient into electricity. Among renewable energy technologies, ocean energy is the least mature one apart from tidal energy, which follows a similar development cycle to hydropower. Nevertheless, it is a relatively young and growing renewable energy sector and has great potential to decarbonise electricity production.

Energy efficient port operations use similar principles to energy efficient ship operations. Energy efficiency at ports can be achieved through using energy efficient equipment, having good operational practices, lean management and improved port processes, employing renewable energy options to produce electricity, setting port energy management strategy and its objectives/targets, having top management commitment and a combination thereof (Ölçer et al. 2017).

5 Motivation and Layout of the Book

In addition to some of the above-mentioned challenges, it is important to appreciate and foresee trends in the maritime energy management field. Technology is not the applications and equipment/systems that humanity relied upon one century, or even two decades ago. Those technologies have been changing at an exponential rate since the beginning of the industrial revolution. New and advanced innovative technologies solve problems or overcome challenges that humankind was not capable of easily resolving in the past. Renewable energy options started to find applications both onboard ships and at ports. The challenge as of today for renewable energy is that its capacity is not able to propel a commercially sized merchant ship. However, renewable energy, batteries, fuel cells, or their combination, depending on their technological developments, without traditional powering can be options to propel merchant ships in the future. The potential synergy between autonomous ships and the disciplines of energy efficiency and safety is not yet entirely known. Other important questions are the following: is it correct that maritime industry devotes effort toward autonomous ships rather than overcoming the huge GHG emissions related challenges? Shouldn’t a zero emission ship be better than an autonomous ship emitting pollution? In the near future, should our focus be placed on carbon capture and treatment on-board a ship in addition to all the effort placed on the developed GHG emission mitigating measures? These answers are definitely not straightforward or easy to find.

The Editors hope that this book can help to identify answers to the questions previously asked, or of a similar nature, and can serve the purpose of familiarizing the reader with trends in the maritime energy management field as well as finding solutions to overcome the related challenges. That is the main motivation behind this book. As of today, there is no book in the literature of the maritime academic community with similar content, or even one with a title including “maritime energy management”. This book will position itself as a pioneering work in the field of maritime energy management where the focus is given to trends and challenges. The layout of the book comprises six parts, whose descriptions are given below:

Part 1 (Regulations: Challenges and Opportunities) broadly discusses the regulatory framework of maritime energy management. The starting point is the identification of the “appropriate” way forward in relation to GHG reduction. Examination and evaluation of the impact of rather recent IMO initiatives, such as the EEDI and the SEEMP, also takes place. Additionally, the EU’s MRV system of CO_2 emissions is discussed, as it is part of the same equation. Finally, under a forward-looking approach, challenges and appropriate responses to ensure energy efficient and optimized performance for the wider maritime industry are put forward.

Part 2 (Energy Efficient Ship Design) focuses purely on naval architecture and marine engineering related energy efficiency improvement areas from the ship design point of view. This part starts with numerical studies conducted during the ship design phase as well as studies on integration of emission abatement technologies into design. Computational Fluid Dynamics (CFD) results are demonstrated for computationally expensive processes such as (added) resistance assessment. Model tests as the most commonly used traditional validation tool are presented to substantiate the numerical results of a particular energy efficiency measure. Decision support systems, which are necessary to make rational decisions, after the settlement of numerical assessments along with their validation, are also presented for a real case study in this part.

Part 3 (Energy Efficient Ship and Port Operation) offers an analysis of energy efficiency in shipping and port operation focusing on the energy impact of those operations while complying with relevant regulations. It begins with studies related to the operational aspects of ship energy efficiency such as the minimisation of fuel consumption and risk analysis of ship performance. Several case studies are discussed and analysed with a focus on ship navigation and optimisation under particular weather conditions. Ship-port interface and micro-grids approach to energy management in ports as well as the role of the Energy Manager in ports are also covered in this part.

Part 4 (Economics and Social Dimensions of Maritime Energy Management) begins with economic and environmental implications of fuel consumption and savings from a life-cycle perspective. A case study in the Baltic Sea Region examines the impact of a particular regulation on Sulphur Emission Control Area (SECA). Human and social dimensions of energy efficient ship operation offer a good introduction to this aspect of study. Capacity building efforts to support maritime energy management in Myanmar is discussed. Gender implications of maritime transport and energy to support rural women entrepreneurs are also touched upon for Pacific Island States.

Part 5 (Alternative Fuels and Wind-Assisted Ship Propulsion) examines alternative fuels, with a special focus on their environmental benefits as well as an outlook for wind-assisted ship propulsion. Discussion of LNG and Methanol, two very promising future alternative fuels, along with brief examination of their application to ships and ports is also taking place.

Part 6 (Marine Renewable Energy) deals with renewable energy applications in the marine industry including offshore wind farms. MRE is discussed in detail, in particular Ocean Energy applications from wave energy converters to tidal energy. Besides, legal framework in EU countries with regards to MRE as well as the States' rights of exploitation and marine biodiversity conservation are discussed.

References

Ballini, F., Ölçer, A. I., Brandt, J., & Neumann, D. (2017). Health costs and economic impact of wind assisted ship propulsion. *Ocean Engineering, 146*(1), 477–485.

Gokcay, S., Insel, M., & Odabasi, A. Y. (2004). Revisiting artificial air cavity concept for high speed craft. *Ocean Engineering, 31*(3–4), 253–267.

IMO. (2009). *Second GHG Study 2009*. London, UK: International Maritime Organization (IMO). April 2009; Buhaug, Ø., Corbett, J. J., Endresen, Ø., Eyring, V., Faber, J., Hanayama, S., Lee, D. S., Lee, D., Lindstad, H., Markowska, A. Z., Mjelde, A., Nelissen, D., Nilsen, J., Pålsson, C., Winebrake, J. J., Wu, W., Yoshida, K.

IMO. (2014). *Third GHG Study 2014*. London, UK: International Maritime Organization (IMO). April 2015; Smith, T. W. P.; Jalkanen, J. P.; Anderson, B. A.; Corbett, J. J.; Faber, J.; Hanayama, S.; O'Keeffe, E.; Parker, S.; Johansson, L.; Aldous, L.; Raucci, C.; Traut, M.; Ettinger, S.; Nelissen, D.; Lee, D. S.; Ng, S.; Agrawal, A.; Winebrake, J. J.; Hoen, M.; Chesworth, S.; Pandey, A.

International Energy Agency (IEA). (2015). Energy and climate change, World energy outlook special report.

Kitada, M., & Ölçer, A. (2015). Managing people and technology: The challenges in CSR and energy efficient shipping. *Research in Transportation Business & Management, 17*, 36–40.

Molland, A. F., Turnock, S. R., & Hudson, D. A. (2011). *Ship resistance and propulsion: Practical estimation of propulsive power*. Cambridge: Cambridge University Press. ISBN: 9781107641259.

Ölçer, A., & Ballini, F. (2015). The development of a decision making framework for evaluat-ing the trade-off solutions of cleaner seaborne transportation. *Transportation Research Part D: Transport and Environment, 37*, 150–170.

Ölçer, A., & Ballini, F. (2018). Energy management in the maritime industry. In L. L. Froholdt (Ed.), *Corporate social responsibility in the maritime industry* (Chap. 8). Heidelberg: Springer.

Ölçer, A., Baumler, R., Ballini, F., & Kitada, M. (2017). Maritime energy management. In I. D. Visvikis & P. M. Panayides (Eds.), *Shipping operations management* (Chap. 8). Heidelberg: Springer.

Oung, K. (2013). Energy management in business the manager's guide to maximis-ing and sustaining energy reduction, part 1, ISBN: 9781409452454.

Prins, H. J., Flikkema, M. B., Schuiling, B., Xing-Kaeding, Y., Voermans, A. A. M., Müller, M., et al. (2016). Green retrofitting through optimisation of hull-propulsion interaction – GRIP. *Transportation Research Procedia, 14*, 1591–1600.

Thollander, P., & Palm, J. (2012). *Improving energy efficiency in industrial energy systems an interdisciplinary perspective on barriers, energy audits, energy management, policies, and programs*. New York: Springs International Publishing. ISBN: 9781447141617.

UN General Assembly. (2015). Transforming our world: The 2030 agenda for sustainable development, 21 October, A/RES/70/1. Available at: http://www.refworld.org/docid/57b6e3e44.html. Accessed 29 Nov 2017.

United Nations, Department of Economic and Social Affairs, Population Division. (2015). World population prospects: The 2015 revision, key findings and advancetables. Working Paper No. ESA/P/WP.241.

WMO. (2017). The state of greenhouse gases in the atmosphere based on global observations through 2016, Greenhouse Gas Bulletin, No. 13 | 30 October 2017, ISSN 2078-0796.

Woud, H. K., & Stapersma, D. (2002). *Design of propulsion and electric power generation systems, Chapter 4*. London: Institute of Marine Engineers.

Yang, S. Q. (2009). Drag reduction in turbulent flow with polymer additives. *Journal of Fluids Engineering, 13*, 051301.

Part I
Regulations: Challenges and Opportunities

MARPOL Energy Efficiency: Verging on Legal Inefficiency?

Aref Fakhry and Belma Bulut

1 Introduction

This chapter analyses legal aspects pertaining to ship energy efficiency measures adopted as part of the International Convention for the Prevention of Pollution from Ships 1973, as amended by the Protocols of 1978 and 1997 thereto (MARPOL) (UNTS 1983; UK 1999). The measures discussed in this work consist of the Energy Efficiency Design Index (EEDI) and the Ship Energy Efficiency Management Plan (SEEMP). These two measures were introduced pursuant to the International Maritime Organization's (IMO) Resolution MEPC.203(62), adopted on July 15, 2011, as part of a new Chapter 4 titled "Regulations on Energy Efficiency for Ships" within MARPOL's Annex VI (IMO 2011a). The latter Annex deals with air pollution from ships. The new Chapter came into force on January 1, 2013.

The chapter presents a historical recount of the development of MARPOL leading up to the adoption of the energy efficiency standards in Annex VI. EEDI and SEEMP are then described and dissected as regards their scope, legal nature, effectiveness and enforceability. A discussion of the relevance of EEDI and SEEMP in ship chartering, sale and building contracts ensues.

A. Fakhry (✉)
World Maritime University, Malmö, Sweden
e-mail: af@wmu.se

B. Bulut
Maritime Law Expert, Istanbul, Turkey

A. I. Ölçer et al. (eds.), *Trends and Challenges in Maritime Energy Management*,
WMU Studies in Maritime Affairs 6, https://doi.org/10.1007/978-3-319-74576-3_2

2 Historical Background

MARPOL is a living instrument that has evolved over the years. The original International Convention for the Prevention of Marine Pollution from Ships, 1973, as modified by the Protocol of 1978 relating thereto, contained five Annexes numbered I to V and covering pollution by oil, noxious liquid substances in bulk, harmful substances carried in packaged form, sewage and garbage.

In the late 1980s, scientific studies verifired that ships were a source of air pollution even though the effects of ships' exhaust gases on human health and ecosystems were not immediately visible and surfaced over a long term (IMO 1998). With the aim of reducing ships' emissions and their contribution to global air pollution, IMO's Marine Environment Protection Committee (MEPC) was invited to urgently develop legally binding measures (IMO 1991).

In 1997, at an international conference of Parties to MARPOL, a new Annex VI entitled "Regulations for the Prevention of Air Pollution from Ships" was added to the Convention (IMO 1997a). The new Annex entered into force on May 19, 2005. As of November 7, 2017, 88 States representing 96.16% of world tonnage were party to the new Annex (IMO 2017).

The 1997 international conference adopted Resolution 8 entitled "CO_2 Emissions from Ships" inviting MEPC to identify and develop greenhouse gas emission strategies (IMO 1997b). In 2000, an IMO Study on Greenhouse Gas Emissions from Ships showed that 1.8% of the world's total CO_2 emissions were caused by ships (IMO 2000). Although it was highlighted that shipping was the most energy-efficient mode of cargo transport, the Study suggested that further measures could be taken to reduce CO_2 emissions (IMO 2000). The Study recommended resort to operational measures, such as optimal utilisation, and technical measures, including improved hull shape or propeller design, as potential solutions for the reduction of emissions.

MEPC was later urged to identify and develop measures to limit or reduce greenhouse gas emissions from ships (IMO 2003a). In 2009, MEPC developed technical and operational measures consisting of EEDI and SEEMP (IMO 2009a). In 2011, those measures were adopted and incorporated as a separate Chapter 4 in Annex VI of MARPOL (IMO 2011a). The Regulations on Energy Efficiency for Ships entered into force on January 1, 2013.