



Safety of Electrical (Battery-Powered) Ships: An Overview of IMO's Safety Regulations and Class Rules/Requirements

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Abstract

Today, 85-90% of global trade of food, energy, goods and raw materials carried by ships at sea. Shipping and maritime transportation by ships are vital to the global economy, trade and supply-chain. In recent years, the international community has a growing concern about global climate change. The International Maritime Organization (IMO) efforts to reduce greenhouse gas (GHG) emissions from ships of international shipping which produces 2-3% of global total anthropogenic CO₂ emissions. The first milestone to prevent air pollution from ships of international shipping was adoption of MARPOL Annex-VI to limit emissions of Sulphur oxides and Nitrogen oxides from ship exhausts, to ban the deliberate emission of substances that deplete the ozone layer and to designate emission control areas. The IMO updated the "2018 Initial IMO Strategy", the first of which started to be implemented in 2018, and adopted the "2023 IMO GHG Strategy" in 2023. One of ambitions of this current GHG strategy (2023) is "uptake of zero or near-zero GHG emission technologies, fuels and/or energy sources...". Accordingly, the maritime industry's search for alternative fuels, such as LPG, LNG, ammonia, methanol etc., and new technologies based on renewable energy sources such as electrical energy, solar energy and wind energy etc., has increased considerably in recent years. Lithium-ion battery technology is also one of the new technologies with zero or near-zero GHG emissions addressed by the IMO. In recent years, the use of electrical (battery-powered) ships has become increasingly widespread on ferries, Ro-Ro/Ro-Pax ships in particular that transport passengers and cargo in short distance between ports/terminals, especially in Northern European countries. But on the other hand, fire and explosion risks arising from battery system and other risks/failures arising from electricity require an international regulatory framework, strict rules/requirements for the safety of battery-powered ships. Therefore, it is important to better understand the international regulatory framework for the safety of battery-powered ships through a systematic review. With that aim, this paper provides an overview of the IMO's efforts to reduce GHG emissions from international shipping and to develop a regulatory framework for the safety of battery-powered ships and also rules/requirements of the International Association of Classification Societies (IACS) member classification societies in relation to safety of battery-powered ships.

Keywords: Maritime Management, Maritime Safety, Safety of Electric (Battery-Powered) Ships, IMO GHG Strategy, Class Rules.

1. INTRODUCTION

Shipping and maritime transportation by ships are vital to the global economy, trade and supply-chain. Because %85-90 of global trade of food, energy, goods and raw materials are being carried by ships [1]. On the other hand, the international community has an increasing concern about global climate change in recent years. The Paris Agreement on Climate Change, which was adopted by the United Nations Framework Convention on Climate Change (UNFCCC) in 2015 and entered into force in 2016, set a goal of "to limit global warming to 1.5°C" [2]. The International Maritime Organization (IMO), specialized agency of the United Nations (UN) in maritime affairs, took action and adopted a resolution MEPC.304(72) dated 13 April 2018 on "2018 Initial IMO Strategy" [3].

In fact, the first milestone to prevent air pollution from ships of international shipping was "Annex-VI" which was added as a new annex to "International Convention for the Prevention of Pollution from Ships (MARPOL)". 1997 Protocol to amend MARPOL was adopted for adding a new Annex-VI which came into effect on 19 May 2005. The Annex VI determined limits on emissions of sulphur oxides (SO_x) and nitrogen oxides (NO_x) from ship exhausts and banned the deliberate emission of

substances that deplete the ozone layer; designated emission control areas (ECAs) set stricter standards for SO_x, NO_x and particulate matter. Since its entry into force, MARPOL Annex-VI has been amended many times to further increase the energy efficiency of ships and to declare much more ECAs.

IMO also conducts periodic studies to estimate greenhouse gas (GHG) emissions from ships of international shipping. Meanwhile, the document MEPC 82/7/3 dated 27 June 2024 contains the preparation details of “Fifth IMO GHG Study” commissioned by IMO [4]. IMO’s previous GHG studies between 2000 and 2020 [5, 6, 7, 8] show that emissions from ships of international shipping account for no more than 2-3% of global total anthropogenic CO₂ emissions. Figure 1 indicates the share of international shipping in global total anthropogenic CO₂ emissions [5-8].

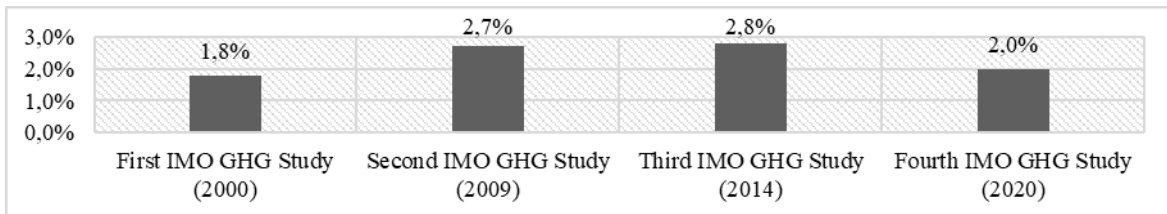


Figure 1. Share of international shipping in global total anthropogenic CO₂ emissions (Source: IMO [5-8]).

In accordance with United Nations (UN) Sustainable Development Goal 13 (SDG 13), “to take urgent action to combat climate change and its impacts”, IMO adopted a resolution MEPC.377(80) dated 7 July 2023 on “2023 IMO GHG Strategy” was adopted at MEPC 80 and this current strategy includes the following ambitions [9]:

1. “Carbon intensity of the ship to decline through further improvement of the energy efficiency for new ships to review with the aim of strengthening the energy efficiency design requirements for ships;
2. Carbon intensity of international shipping to decline to reduce CO₂ emissions per transport work, as an average across international shipping, by at least 40% by 2030, compared to 2008;
3. Uptake of zero or near-zero GHG emission technologies, fuels and/or energy sources to increase uptake of zero or near-zero GHG emission technologies, fuels and/or energy sources to represent at least 5%, striving for 10%, of the energy used by international shipping by 2030; and
4. GHG emissions from international shipping to reach net zero to peak GHG emissions from international shipping as soon as possible and to reach net-zero GHG emissions by or around, i.e. close to, 2050, taking into account different national circumstances, whilst pursuing efforts towards phasing them out as called for in the Vision consistent with the long-term temperature goal set out in Article 2 of the Paris Agreement.”

IMO’s efforts are also integral to the UN Sustainable Development Goal 14 (SDG 14), “conserve and sustainably use the oceans, seas and marine resources for sustainable development”, which includes some targets related to blue economy, marine protected areas and decarbonization in particularly shipping and fishing etc. IMO is collaborating with United Nations Development Programme (UNDP) in a global effort to help the shipping sector move towards a lower-carbon future through the GloMEEP project, which helps developing countries implement energy efficiency measures adopted by IMO [10]. IMO also running many capacity-building programs and global projects such as “GreenVoyage2050”, “GHG SMART”, “Global MTCC Network (GMN)”, “IMO CARES”, “GloFouling Partnerships”, “FIN-SMART”, “Zero-and Low-Emission Innovation Forum” to support the decarbonization of world shipping [11]. Figure 2 shows some alternative solutions to reduce GHG emissions from ships.

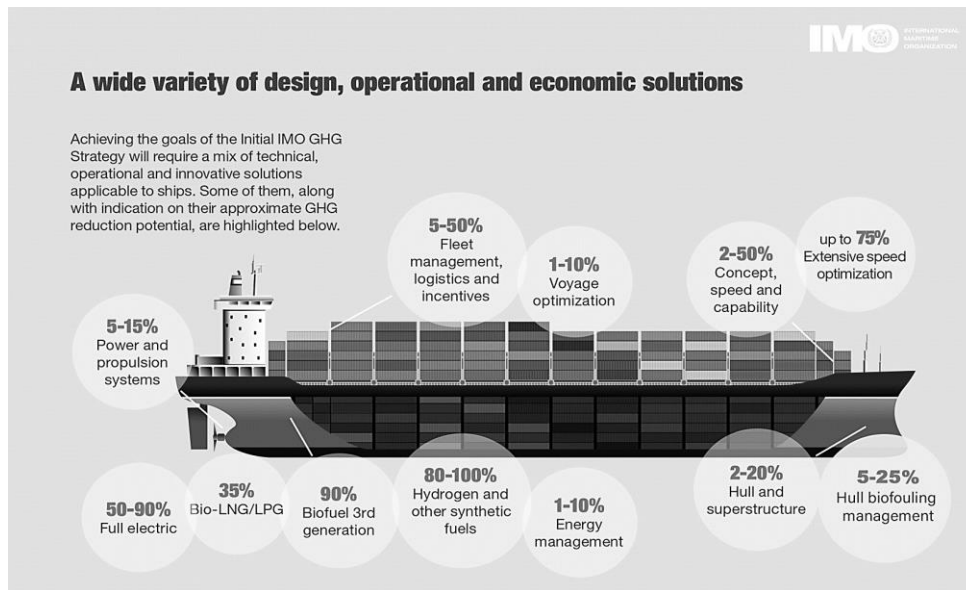


Figure 2. Alternative solutions to reduce GHG emissions from ships (Source: IMO [11])

From above, it can be stated that to achieve the UN/IMO's goals, targets and ambitions, alternative fuels such as LPG, LNG, ammonia, methanol etc. and environmentally friendly renewable energies such as electrical energy, solar energy and wind energy etc. should be promoted as source of power of ships. Lithium-ion battery technology is also one of the zero or near-zero GHG emission technologies/energy sources pointed out by the IMO. In recent years, the use of electrical (battery-powered) ships has become increasingly widespread on ferries, Ro-Ro/Ro-Pax ships in particular that transport passengers and cargo in short distance between ports/terminals, especially in Northern European countries. But on the other hand, there are fire and explosion risks arising from lithium-ion batteries and other risks/failures arising from electricity. In 2021, a fire accident was occurred onboard a such ship [12]. Therefore, an international safety regulatory framework, strict regulations/rules/requirements are required for the safety of battery-powered ships as well as for others.

In this context, an overview of the IMO's efforts, initiated by December 2024, to develop a safety regulatory framework for battery electric vessels (BEVs) carried at sea by ships, with the potential to include ships carrying lithium-ion batteries as their main sources of power is presented in Section 2. An overview of the rules/requirements of the International Association of Classification Societies (IACS) member classification societies in relation to safety of battery-powered ships and its summary are presented in Section 3. Observations as a result of both overviews and the Author's recommendations are presented in Section 4. Some limitations of study are presented in Section 5.

1.1. Aim of study

To better understand the international regulatory framework for the safety of battery-powered ships, the aim of this study is to provide an overview of:

- i) IMO's efforts to reduce GHG emissions from international shipping and to establish a safety regulatory framework for electric battery technology and battery-powered ships; and
- ii) Rules/requirements of the IACS member classification societies in relation to safety of battery-powered ships.

In terms of this study, the term "battery" refers to rechargeable lithium-ion battery technology and the term "battery-powered" refers to the use of the battery system as source of main and/or auxiliary power of a ship.

1.2. Material & Method

In this study, document analysis approach has been applied as a qualitative research technique and a systematic overview has been conducted of:

- i) IMO's GHG studies and MEPC meeting reports available on the IMO's website;
- ii) IACS's unified requirements (URs) available on the IACS's website;
- iii) The references to Class rules/requirements available on their websites and internet.

2. OVERVIEW OF IMO'S EFFORTS TO DEVELOP A SAFETY REGULATORY FRAMEWORK FOR BATTERY ELECTRIC VESSELS (BEVs) CARRIED AT SEA

The carriage of Battery Electric Vessels (BEVs) at sea by ships is new relatively and in the last few years some very serious fire accidents have occurred on ships carrying BEVs, including those that resulted in deaths and major financial losses, such as the Fremantle Highway (2023), Felicity Ace (2022) and Sincerity Ace (2019) [13]. On July, 2023, a fire broke out on the ship "Fremantle Highway", which was carrying vehicles, including BEVs, and one of the crew members died [14]. On February, 2022, a fire broke out on the ship "Felicity Ace", which was carrying vehicles, including BEVs, and the ship was lost [15]. On January, 2019, a fire broke out on the ship "Sincerity Ace", which was carrying vehicles, including BEVs, and five of the crew members was lost or died [16].

There is currently no international safety regulatory framework for the carriage of BEVs by ships that can be widely applied worldwide, apart from safety guidelines published by some governments and regional organizations [17]. At its 10th session (SSE 10) of IMO's Subcommittee on Ship Systems and Equipment (SSE), held from 4 to 8 March 2024, a roadmap and target-based approach to develop fire safety systems and regulations to reduce the fire risk of ships carrying new energy vehicles, including BEVs was approved. With a goal-based approach of minimizing the risk of fire in vehicle, ro-ro and special category compartments of ships carrying new energy vehicles, including BEVs, the aforementioned roadmap of the SSE aims to conduct a preliminary review of scientific reports, new technologies, accident reports, etc., identify hazards associated with new energy vehicles, including BEVs, and identify and address gaps in existing regulations (SOLAS II-2, etc.), if any [13]. The report of SSE 10 was submitted to the IMO's Maritime Safety Committee (MSC 109), held from 2 to 6 December 2024, for consideration, and MSC 109 approved the addition of a new category on "replaceable traction lithium-ion battery containers" to develop a safety regulatory framework to be discussed at MSC 110 and subsequent sessions [18].

SOLAS II-1 allows "accumulator battery" as an "emergency source of power" of a ship, however; it does not address whether the battery would be allowed to be used as a ship's main and/or auxiliary source of power. Moreover, lithium-ion batteries are considered dangerous because they are within the scope of the IMDG Code.

3. OVERVIEW OF RULES/REQUIREMENTS OF IACS MEMBER CLASSIFICATION SOCIETIES IN RELATION TO SAFETY OF BATTERY-POWERED SHIPS

3.1. IACS's Unified Requirements (URs)

A flag State is primarily responsible and obligated for the conduct of surveys and inspections of ships, flying its flag, in accordance with international maritime conventions and regulations. A flag State may delegate its authority to a recognized organization (RO) as well. A Classification Society (hereafter referred to as "Class") is an organization which publishes and applies its own classification rules/technical requirements related to the design, construction and survey of ships. A class may also be an RO authorized by a Flag Administration as listed accordingly in the IMO-GISIS database [19]. IACS is an international association of Classification Societies that currently has 12 members [20]. IACS published its unified requirements (URs) [21]. As a result of a review of the URs with the keywords "battery" and "electric"; a few requirements are found related to batteries using as emergency source of power of conventional SOLAS ships but no specific requirements are found related to battery-powered ships and their battery systems using as main and/or auxiliary source of power. In addition, a few verbal interviews have been done with industry professionals to verify this result. The following sub-chapters (in alphabetical order) provide an overview of Class rules, limited to classification/notation and safety requirements for battery-powered ships.

3.1.1. ABS (American Bureau of Shipping)'s Rules & Requirements

It seems that ABS applies two types of class notations to battery-powered ships, "Hybrid" and "All-Electric". Class Notation Hybrid includes not only conventional sources of power such as internal combustion engines driven generators, main engine driven shaft generators etc. but also one or a combination of non-conventional sources of power such as lithium-ion battery, solar PV, fuel cell system, supercapacitor, wind power, etc. Class Notation "All-Electric" includes one or a combination of non-conventional sources of power only but generators may be used in emergency only. For both, a risk assessment is required for design, installation and safe operation of electrical power systems, and for that, several techniques such as HAZID, HAZOP, FMEA may be conducted. Also, a risk assessment for battery system is required in accordance with "Lithium-ion Batteries Requirements" of ABS [22, 23]. Additionally, an advisory on hybrid electric power systems (ABS) [24] and a best practice for transportation of electric vehicles on board ships [25] were published by ABS.

3.1.2. BV (Bureau Veritas)'s Rules & Requirements

It seems that BV applies two types of class notations to battery-powered ships, “*Electric Hybrid*” and “*Electric Hybrid Prepared*”, in accordance with its rules “*Electric Propulsion or Power Supply*” and “*Battery Energy Storage Systems and Chargers*”. Class Notation “*Electric Hybrid*” is to ships installed with a battery system for electric propulsion and/or the main electrical power. Class Notation “*Electric Hybrid Prepared*” is to ships intending to install such a battery system. For both, a risk analysis, based on HAZID study, to identify hazards regarding battery system installation is required. Also, a risk analysis in accordance with FMEA to identify functional failures of main propulsion system and its elements, including propulsion electric motor, is required. A risk assessment to identify hazards regarding electric vehicle onboard charging is also required [22, 26, 27].

3.1.3. ClassNK (Nippon Kaiji Kyokai)'s Rules & Requirements

It seems that ClassNK applies its rules “*Accumulator Battery Systems*” to battery-powered ships, which also includes the additional requirements of battery systems for the use electrical propulsion, main and emergency electrical power purposes and “*safety requirements*” which require the risk assessments to verify the risks to arising from the use of battery systems. ClassNK also applies a notation “*Safety Transportation of Electric Vehicles*” to ships carrying electric vehicles onboard [22, 28]. Additionally, a guideline for the safe transport of electric vehicles was also published by ClassNK in 2024 [29].

3.1.4. DNV (Det Norske Veritas)'s Rules & Requirements

It seems that DNV applies two types of class notations to battery-powered ships, “*Battery (Power)*” and “*Battery (Safety)*”, separately or together, depending on whether the ship’s propulsion system is dependent on battery power or not. Class notation Battery (Safety) includes the requirements to ensure the safety of shipboard battery systems with a nominal capacity of 20 kWh or more, and class notation Battery (Power) includes the requirements to verify the capacity of shipboard battery system that provides propulsion power required for the safe operation of a ship [22, 30]. In other words, if a ship will be fitted with a battery system, class notation Battery (Safety) requirements should be met. If the power required for the propulsion of that ship will be provided by her own battery system, class notation Battery (Power) requirements should be met in addition to class notation Battery (Safety) requirements. DNV’s class notation Battery (Safety) requirements also includes guidelines on “*safety philosophy*” which also addresses the Failure Mode and Effects Analysis (FMEA) to identify and assess potential hazards and safety barriers to be considered in design, construction and operation. Additionally, a technical report on explosion risk and fire suppression for lithium-ion batteries was published by DNV in 2019 [31].

3.1.5. LR (Lloyd's Register)'s Rules & Requirements

It seems that LR applies basically its rules of “*Electrical Engineering*” to battery-powered ships, which also includes rules for “*Batteries*” to identify and manage internal and external hazards to/within the lithium-ion battery system and rules for “*Hybrid electrical power systems*” for design, construction and integration of safe and dependable hybrid electrical power systems with various configurations. LR’s aforementioned rules require a safety risk assessment/management in accordance with “*ISO 31010, Risk management – Risk assessment techniques*” such as HAZID, FMEA etc., “*IEC 60812, Analysis techniques for system reliability – Procedure for failure mode and effects analysis (FMEA)*” and “*ShipRight Procedure Risk Based Certification (RBC)*” [22, 32, 33, 34]. A guidance note on key hazards of battery installations was also published by LR in 2016 [35].

3.1.6. RINA (Registro Italiano Navale)'s Rules & Requirements

It seems that RINA applies its rules “*Battery Powered Ships*” with an additional notation “*Hybrid Propulsion Ship (HYB-...)*” to battery-powered ships with a hybrid propulsion system having two or more sources of power, such as mechanical, electrical and hydraulic powers. A risk assessment according to “*RINA Guide for Risk Analysis*” is required to identify and assess potential hazards of batteries and a FMEA analysis [or other equivalent risk analysis methods] is required for the reliability of hybrid propulsion system [25, 36].

3.1.7. Türk Loydu (Turkish Lloyd)'s Rules & Requirements

It seems that Türk Loydu (Turkish Lloyd) applies basically its “*Additional Rules for the Certification, Installation and Testing of Lithium Batteries*” to battery-powered ships. These additional rules apply to lithium-ion battery installations with a capacity of 20 kWh or more for all-electric ships or for the ships or ships with hybrid power systems and where batteries are used for propulsion and/or a backup power source is used for main power. These rules also include safety requirements for shipboard

battery systems and point out that battery spaces should be defined as “hazardous” according to IEC 60079-10-1 [37]. In addition to that, Turkish Lloyd also applies “Additional Rules for Electrical Ship Propulsion Equipment” to ships with electric main propulsion equipment if the main drive energy of the propellers is provided by the electric propulsion motor or if the motor temporarily provides all the propulsion power [38].

3.2. Summary of overview

Table 1 contains a summary of overview of the Class rules/requirements in relation to safety of battery-powered ships, based on [22-38], to illustrate the general picture. It is worth emphasizing that the basic information contained in the Table 1 is only that reviewed in this study and may not be limited to those as the Classes may have restricted private databases other than those reviewed in this study and/or there may be many other details related to the safety of battery-powered ships embedded in their existing rules/requirements.

Table 1. Summary of overview of the Class rules/requirements in relation to safety of battery-powered ships

Class	Rules/Requirements*	Notations*	Risk Analysis Techniques*
ABS	“Hybrid” “All-Electric”	“Hybrid” “All-Electric”	HAZID, HAZOP, FMEA etc.
BV	“Electric Propulsion or Power Supply”, “Battery Energy Storage Systems and Chargers” etc.	“Electric Hybrid” “Electric Hybrid Prepared”	HAZID, FMEA etc.
ClassNK	“Accumulator Battery Systems” “Safety Transportation of Electric Vehicles” etc.		“Safety requirements”
DNV	“Battery (Power)” “Battery (Safety)”	“Battery (Power)” “Battery (Safety)”	FMEA etc.
LR	“Electrical Engineering” “Hybrid electrical power systems”		ISO 31010, IEC 60812, RBC etc.
RINA	“Battery Powered Ships”	“Hybrid Propulsion Ship (HYB-...)”	FMEA etc.
Türk Loydu (Turkish Lloyd)	“Additional Rules for the Certification, Installation and Testing of Lithium Batteries”, “Additional Rules for Electrical Ship Propulsion Equipment” etc.		IEC 60079-10-1 etc.

* those only reviewed in this study and may not be limited to those listed in this table.

A couple of observations can be made from the Table 1. First, while some Classes prefer to apply various/different notations and the rules/requirements under these notations specific to electric-powered ships, others prefer to apply additional rules/requirements embedded in their existing rules/requirements without any specific notation. Second, preferences regarding risk analysis techniques vary from Class to Class.

4. CONCLUSION AND RECOMMENDATIONS

4.1. Conclusion

As a result of general overview conducted in this study, it has been observed that:

- i) IMO has just started to develop a safety regulatory framework for BEVs (electric cars etc.) carried at sea due to their risks of fires onboard Ro-Ro/Ro-Pax ships over the last few years; however, it is not clear whether this framework will also include the batteries carrying by ships as their own source of power;
- ii) There is no internationally adopted terminology for ships using battery system as a source of power so that there is terminological/conceptual confusion for such ships (Examples used: “electrical ship”, “electric ship”, “electric-powered ship”, “all-electric ship”, “hybrid ship”, “hybrid-powered ship”, “battery-powered ship”, “battery-hybrid powered ship”, “battery electric ship” etc.);
- iii) Although there are no internationally adopted specific regulations/requirements, the Class rules/requirements (reviewed in this paper), as part of electrical installation and/or separately, include the rules/requirements in relation to the safety of battery-powered ships and battery systems; however, it would be better to establish a unified understanding/approach to classification/notation and risk assessment of such ships.

4.2. Recommendations

Each Class can publish and apply its own classification rules/technical requirements, and these rules/requirements do not have to be exactly the same. But it is also noteworthy that IMO's efforts to develop a regulatory framework for the safe carriage of BEVs at sea may be an opportunity to develop an international terminology and safety regulatory framework for battery-powered ships and to establish a unified understanding/approach to the classification/notation and risk analysis/assessment of such ships as well. Additionally, it is also necessary to address and identify the specific inspection areas of battery-powered ships to be focused on in port State controls (PSC).

In this context, the Author would like to express the following recommendations to the maritime industry:

i) IMO may initiate a safety regulatory framework study for battery-powered ships, in parallel or separately from the regulatory framework for the safe carriage of BEVs at sea, thus providing a clear definition of the usability of lithium-ion batteries as main/auxiliary source of power of ships, focusing primarily on SOLAS Chapter II, and setting internationally adopted specific regulations for battery-powered ships. These regulations may include structural and fire safety requirements for the spaces on board where such batteries are to be installed, monitoring and warning systems, risk analysis/assessment of hazards, training of seafarers against risks, and other details may be described by reference to relevant codes such as the International Fire Safety Systems Code (FSS Code).

ii) IACS may publish the unified requirements (URs) on classification/notation of battery-powered ships, thus establishing a unified understanding/approach for the Classes.

iii) The regional Memorandums of Understanding on PSC, in particular the Paris MoU and Tokyo MoU, may address and identify the specific inspection areas for battery-powered ships to be focused on in PSCs.

5. LIMITATIONS OF STUDY

This study has some limitations. The first one is related to lack of previous research studies on the topic. Further research studies are needed on the safety of battery-powered ships. Future studies can address this topic with more detailed reviews of the Class rules/requirements, not only for the safety of battery-powered ships but also for the safety of ships using one or a combination of solar PV, fuel cell system, supercapacitor, wind power, etc. in addition to battery system. The second one is related to limited access to data. This study reviewed only the URs published by IACS and Class rules/requirements published by each Class on their websites and internet, and if there were any others that are restricted or embedded in private databases, they could not be reviewed. The third one is related to difficulty of comparison. The fact that Class rules/requirements had different and various classifications/notations and definitions regarding the ships using battery system as a source of power does not make a comparative analysis possible. Therefore, this study does not aim to compare the Classes in terms of their rules/requirements or practices. The last limitation is related to the terminological confusion. The use of the term "Electric (Battery-Powered) Ship" in this study may also be criticized, as there is no internationally adopted terminology for such ships.

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1- Study design 2- Data collection 3- Data analysis and interpretation 4- Manuscript writing			

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