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# Reducing Methane Emissions on Livestock Ships in Order to Mitigate Greenhouse Gas Emissions and Promote Future Maritime Sustainability

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ABSTRACT: One of the main causes of climate change and global warming is greenhouse gas emissions. Livestock makes up 15% of the world's greenhouse gases (GHG), whereas maritime shipping accounts for 3%. Cattle can produce about 500 grams of methane a day per cow. This study demonstrates that livestock ships are an extremely high source of methane emissions. This study also offers innovative scientific techniques for lowering methane gas emissions from livestock ships. The MV Gelbray Express Livestock ship is selected to investigate the overall emissions generated by the main engine and the livestock on board. Main engine CO2 emissions and livestock CO2 equivalent emissions are theoretically calculated during 24-hour sailing under engine full load and livestock full capacity. The study revealed that livestock CO2 equivalent emissions account for 43% of the total CO2 emissions emitted by the engine and the livestock. To decrease livestock methane emissions, ZELP (Zero Emissions Livestock Project) has patented a unique catalytic technique for capturing and neutralizing methane generated during enteric fermentation in ruminant animals such as cows. Theoretical results show that using the ZELP mask reduces CO2 equivalent emissions by 58 000 kg per day at a livestock capacity of 4000 cattle onboard the MV Gelbray Express Livestock ship.

## 1 INTRODUCTION

Nowadays, global climate change is a significant issue. It causes the planet's average yearly temperature to gradually rise, an event that started with the industrial revolution (Mikhaylov et al., 2020). The primary source of greenhouse gas (GHG) emissions into the atmosphere is the production and consumption of energy. Global warming and climate change have been dramatically impacted by the rise in emissions caused by the increased usage of fuel-burning energy sources (Elmallah et al., 2023). By 2050, the world's temperature is expected to rise by roughly 1.5 degrees Celsius, and by 2100, it will rise by 2-4 degrees (Meinshausen et al., 2009). As a result, international policies and the majority of research have focused on the need to reduce global warming through the implementation of laws, the use of innovative technologies, and the utilization of clean, renewable energy sources. Carbon dioxide (CO2), methane (CH4), nitrogen oxides (NOx), hydrofluorocarbons (HFCs), perfluorocarbons (PFCs), and sulfur oxides (SOx) are the six GHGs listed in the Kyoto Protocol. CO2, CH4, and NOx contribute more than half of the GHG impact. Between 1990 and 2014, global annual CO2 emissions rose from 22.15 Gt to 36.14 GT, and the amount of CH4 emissions rose from 6.67 to 8.01 Gt CO2 equivalent (Liu et al., 2019). According to climate impact and global warming, CH4 is considered to be 30 times equivalent to CO2 (IPCC, 2021). Due to the ongoing growth in emissions and atmospheric concentrations of CH4, early reduction of CH4 would significantly increase the chances of mitigating global warming (Mar et al., 2022). Approximately 3% of the world's GHG emissions are produced by maritime transport (Lindstad et al., 2021). In 2018, the International Maritime Organization (IMO) adopted the Initial Strategy on reduction of greenhouse gas (GHG) emissions from ships, which commits the IMO to reduce the overall GHG emissions of shipping by at least 50% by the year 2050 (Serra & Fancello, 2020). The IMO controversy focused on mitigating the emissions of CO2 from the ship's main engine, which is considered the first direct source of emissions, although there are other crucial indirect emission sources, especially in livestock ships. Livestock produces about 15 percent of the total emissions of greenhouse gases (Króliczewska et al., 2023). In comparison to 2010, agricultural CH4 emissions are expected to rise by roughly 30% in 2050. The rising human population and rising demand for animal protein are the causes of these increases (Reisinger et al., 2021). Livestock methane emissions are 90% through burps and only 10% through animal manure, and these emissions are a result of enteric fermentation (Brouček, 2014). Domesticated animals, such as cattle, sheep, and goats, naturally produce CH4 during their physiological digestive processes. A cow emits 500 g of methane emissions daily, which is considered a high amount, especially when it comes to livestock ships that can carry more than 4000 cattle. In an attempt to decrease the negative impacts of methane emissions from the livestock industry, ZELP (Zero Emissions Livestock Project), a startup company in the UK, invented a methane-reduction device and certification system. ZELP has created a patented wearable apparatus that instantly oxidizes methane emissions into carbon dioxide (Grove & Clouse, 2021). As the IMO is concerned about providing low-emission shipping by implementing many regulations regarding the ship's propulsion system and its energy and operational measures, it is also essential to be concerned about indirect emission sources, especially the emissions that are caused by livestock ships. This study demonstrates the CO2 emissions of the main engine and the CH4 emissions of the livestock onboard the MV Gelbray Express Livestock ship. The study represents the total CO2-eq emissions of the main engine and livestock during a 24-hour sailing period under full engine load and full livestock capacity. The study also highlights the significant environmental effects of using the ZELP burp-catching mask.

Nomenclature

| | |
|---|---|
| *EM* | Total ship emission |
| *t* | Operation trip time |
| $P_w$ | Main engine power |
| $L_f$ | Load factor |
| $P_{f,i}$ | Pollution factor |
| *i* | Type of emission |
| *f* | Type of fuel |
| $P_{co2}$ | Fuel carbon content |
| *SFC* | Specific fuel consumption |
| *CF* | Conversation factor |
| *ME $CO_2$ emissions* | $CO_2$ emission for main engine |
| $P_{ME}$ | Output power |
| $E_{CH4}$ | Total cattle methane emission |
| $M_{CH4}$ | Methane emission per cow |
| $N_{cattle}$ | Number of cattle |
| $MMTCDE_{CH4}$ | Million Metric Tonnes of Carbon Dioxide Equivalents |
| $MMT_{CH4}$ | Million Metric Tonnes of a $CH_4$ |
| $GWP_{ch4}$ | Global Warming Potential of $CH_4$ |

Abbreviations

| | |
|---|---|
| *GHG* | Greenhouse gas |
| *$CO_2$* | Carbon dioxide |
| *$CH_4$* | Methane |
| *NOx* | Nitrogen oxides |
| *HFCs* | Hydrofluorocarbons |
| *PFCs* | Perfluorocarbons |
| *SOx* | Sulfur oxides |
| *IMO* | International Maritime Organization |
| *ZELP* | Zero Emissions Livestock Project |
| *CCS* | Carbon Capture and Storage |
| *CCU* | Carbon Capture and Utilization |
| *MBOE* | Million Barrels of Oil Equivalent |
| *MtCO2eq* | Million Tons of Carbon Dioxide Equivalent |
| *EEDI* | Energy Efficiency Design Index |
| *SEEMP* | Ship Energy Efficiency Management Plan |
| *EEOI* | Energy Efficiency Operational Indicator |
| *EEXI* | Energy Efficiency Existing Ship Index |
| *CI* | Carbon Intensity |

## 2 AN OVERVIEW OF GREENHOUSE EMISSIONS IN THE MARITIME TRANSPORTATION SECTOR

The primary source of air pollution and the greenhouse effect in the maritime industry is the excessive worldwide production of greenhouse gases (mostly carbon dioxide, CO2, and methane, CH4), particularly as a result of the burning of fossil fuels for energy and power generation. This has ultimately led to several types of hazards that will impact people's daily lives, such as global warming and climate change (Jeffry et al., 2021). Numerous strategies, such as Carbon Capture and Storage (CCS), Carbon Capture and Utilization (CCU), reducing the use of fossil fuels, and promoting the use of clean and renewable energy, have been contributed forth in an effort to tackle and conquer the sharp increase in GHG emissions (Alqarni et al., 2021; Hussin & Aroua, 2020). Maritime transport remains the most economical means of shipping goods around the globe and continues to be the backbone of global trade. More than four-fifths of all trade, by volume, is transported by sea. These days, the use of fossil fuels by maritime vessels is equivalent to around 2.2 million barrels of oil equivalent (MBOE) or over 1000 million tons of carbon dioxide equivalent (MtCO2eq) (Santos et al., 2022). There are several approaches to reduce emissions in the maritime sector, some emphasize the use of alternative energy, while others emphasize on other decarbonization strategies (Al-Enazi et al., 2021; Xing et al., 2020). To reduce GHG in the maritime sector, most studies took into account the ship's propulsion system and looked at the key features of several propulsion systems in terms of fuel consumption and emissions production, while other studies assessed how operational research methods were used in the energy sector (Huan et al., 2019; Fazlollahi & Maréchal, 2013; Sangaiah et al., 2019; Hwangbo et al., 2017; Fazlollahi et al., 2012). The IMO is playing a significant role in decreasing GHG emissions caused by shipping. As stated in the IMO Initial Strategy, the organization is committed to lowering greenhouse gas emissions from international shipping and will persist in its efforts to phase them out over the duration of the next century. The Initial Strategy aims to mitigate the volume of total annual greenhouse gas emissions from international shipping by at least 50% by 2050, compared to 2008. The IMO recently implemented stricter controls on international maritime transport activities. In an effort to reduce greenhouse gas (GHG) emissions, the IMO has started to implement obligatory measures such as the Energy Efficiency Design Index (EEDI), the Ship Energy Efficiency Management Plan (SEEMP), the Energy Efficiency Operational Indicator (EEOI), and the Energy Efficiency Existing Ship Index (EEXI). Enhancing energy efficiency, lowering the Carbon Intensity (CI) of new ships, enhancing the Energy Efficiency Design Index (EEDI), and improving Energy Efficiency Operation Index (EEOI) are the major methods used to accomplish the goals (Joung et al., 2020; Rehmatulla et al., 2017). In their implementations, the IMO primarily focuses on lowering GHG emissions from the primary engine; however, there are other parameters that have a significant impact on the environment as well. Livestock ships have a magnificent source of CH4 that need to be considered. Cattles are considered as a major source of global methane emissions. Figure one shows the sources of global human-induced methane emissions. The agriculture source represents 40% ,33% from livestock and 27 from cultivation of rice (Mundra & Lockley, 2023).

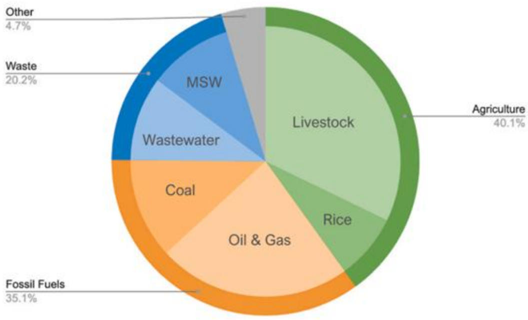


Figure 1. Sources of global human-induced methane emissions

To encourage the transition towards a sustainable maritime transport sector, Policymakers should start to pay more attention to the harmful environmental impact of cattle emissions onboard livestock ships. Growing levels of methane cause stratospheric water vapor to rise, which lowers the ozone layer. This is because stratospheric water vapor causes polar stratospheric clouds and hydrogen oxide radicals (HOx), which accelerate ozone depletion (Revell et al., 2016). (Mundra & Lockley, 2023). Microbiological digestion in the rumen emits 90% of livestock methane emissions through breathing (Burping) (Mundra & Lockley, 2023; Kumari et al., 2016; Thorpe, 2008; Chow et al., 2020). ZELP mask is a novel strategy to decrease the environmental impact of livestock methane. Produced by ZELP™, this wearable device is utilized to identify, capture, and catalytically oxidize methane (Mundra & Lockley, 2023). An adjustable harness covers the cow's head, and the mask initiates the oxidation process by detecting burps through sensors.

## 3 METHODOLOGY

This study provides a new method to decrease the methane emissions on livestock ships since the methane environmental impact is 30 times greater than the CO2 impact. Encouraging livestock ships to require mask-wearing among their cows will reduce methane impact by 30 times since the burp-catching masks will convert methane to carbon dioxide. Figure two shows the design of the mask.

Figure 2. The design of ZELP burp-catching mask

In this study, the MV Gelbray Express Livestock ship is selected to study the total emissions generated by the main engine and the cattle onboard. MV Gelbray Express is the third livestock carrier built by Cosco Guangdong Shipyard, based in China. Vroon Offshore Services, a Dutch company, contracted with Cosco Guangdong Shipyard, to build six livestock ships at an estimated cost of $28.25 million in 2011. With five decks and a total gross pen area of around 4,500 m², the vessel can accommodate about 4,000 cattle at a weight of 350 kg each. There is around 495 m² of deck area available to hold up to 1,200 m³ of feed. Table 1 shows the general ship particulars.

Table 1. Ship particulars MV Gelbray Express carrier

| | |
|---|---|
| GENERAL | |
| Year built | 2014 |
| Builder | Cosco Guangdong, China |
| Flag | Portugal |
| IMO | 9621211 |
| PRINCIPAL DIMENSIONS | |
| Length Overall (LOA) | 134.80 m |
| Beam Moulded | 19.60 m |
| Depth | 14.80 m |
| Summer Draft | 6.80 m |
| MACHINERY & PROPULSION | |
| Main Engine | 6090 kW Wartsila W7X35 |
| Service speed Auxiliary Engines | 16.75 knots |
| Auxiliary Engines | 3x1100 kW |
| Shaft Generator | 1050 kW |
| Bow Thruster | 750 kW |
| TONNAGES | |
| Dead Weight Tonnage (DWT) | 5225 t |
| Scantling Draft | 6.8 m |
| Design Draft | 5.8 m |
| Gross Tonnage | 10421 t |
| Net Tonnage | 3126 t |

| CARGO CAPICITIES & EQUIPMENTS | |
|---|---|
| Total Gross Pem Area | 4511 m2 |
| Number of Decks | 5 |
| Deck Space Fodder | 495 m2 |
| Fodder (Silo) | 1200 m3 |

MV Gelbray Express is propelled by 6090 kw of power produced by Wärtsilä X35 engines. The smallest low-speed engine in Wärtsilä's lineup is the Wärtsilä X35. It is a low-speed, electronically controlled two-stroke marine engine that is among the most efficient in its class. Compact engine size, straightforward engine operation, and the ability to power ships with shallow draft requirements were the key goals in the design of the Wärtsilä X35. The power output of the engine ranges from 3,475 to 6,960 kw, with a cylinder arrangement of 5-8 cylinders. The specific fuel consumption (SFC) of the engine is 170 g/kwh. Table 2 shows the main engine characteristics of MV Gelbray Express.

Table 2. The characteristics of the main engine

| Wärtsilä X35 | |
|---|---|
| Cylinder bore | 350 mm |
| Piston stroke | 1550 mm |
| Speed | 142–167 rpm |
| Mean effective pressure | 21.0 bar |
| Stroke / bore | 4.43 |
| Number of cylinders | 7 |
| Rated power | 6090 KW at 167 rpm |
| Weight in tonnes | 95 |

A calculation of the engine and cattle emissions during a 24-hour sailing under engine full load and livestock full capacity will take place to show the results of the CO2-eq emissions.

Equation (1) can be used to determine the total emission for ships during a single voyage (Ammar & Seddiek, 2020).

$$EM_{trip,i,f} = \sum\left[t\left(P_w \cdot L_f \cdot P_{f,i}\right)\right] \tag{1}$$

where $EM$ is the total ship emission, $t$ is the operation trip time in (hours), $P_w$ is the main engine power in (kW), $L_f$ is the load factor, $P_{f,i}$ fuel pollution factor in (g/kWh), $i$ is the type of emission, and $f$ the type of fuel.

Equation (2) determines the fuel carbon content (Elkafas et al., 2020). The primary factor used to determine a fuel's pollution factor for CO2 emissions is the fuel's carbon content.

$$P_{co2} = SFC \cdot CF \tag{2}$$

where CF is the conversation factor, and SFC is the specific fuel consumption (g/kwh).

Equation (3) shows the CO2 emission for main engine.

$$ME\ CO_2\ emissions = \left\{\sum_{i=1}^{nME} P_{ME(i)} \cdot C_{FME(i)} \cdot SFC_{ME(i)}\right\} \tag{3}$$

where $P_{ME}$ is the Power output from main engine. $C_{FME}$ is the fuel conversation factor from fuel consumption to $CO_2$ *emission* $SFC_{ME}$ is the specific fuel consumption for main engines.

Equation (4) shows the total amount of methane emission per livestock capacity

$$E_{CH4} = M_{CH4} \cdot N_{cattle} \tag{4}$$

The total amount of cattle methane emission is calculated by multiplying the mass of CH4 emitted by each cow with the total number of cows. Where $E_{CH4}$ is the total CH4 cattle emission $M_{CH4}$, the mass of CH4 emitted per cow, and $N_{cattle}$ is the total number of cows.

A carbon dioxide equivalent (CO2-e) is a metric measure that is used to convert amounts of other gases to an equivalent amount of carbon dioxide with the same Global Warming Potential (GWP) in order to compare emissions from different greenhouse gases based on their GWP. Million Metric Tons of Carbon Dioxide Equivalent (MMTCDE) is the standard way to represent carbon dioxide equivalents.

Equation (5) shows the CO2-e of CH4 gas.

$$MMTCDE_{CH4} = MMT_{CH4} \cdot GWP_{CH4} \tag{5}$$

The carbon dioxide equivalent of methane is calculated by multiplying its tons by the corresponding GWP. Where $MMTCDE_{CH4}$ is the million metric tonnes of carbon dioxide equivalents, $MMT_{CH4}$ is the million metric tonnes of CH4, and $GWP_{CH4}$ is the global warming potential of CH4.

## 4 RESULTS AND DISCUSSION

This study shows a comparison between the cattle methane emissions and the main engine emissions and highlights the high amount of cattle methane emissions on livestock ships. The study highlights the positive environmental impact of using the ZELP burp-catching mask on reducing methane emissions on livestock ships and the importance of developing this novel strategy and considering it in maritime transport regulations. The results show a high percentage of livestock emissions among the total emissions caused by the main engine and the livestock onboard the MV Gelbray Express. The results demonstrate the role of ZELP masks in reducing the number of livestock CO2-eq emissions. Figure three shows the CO2 emissions of the main engine. The highest amount of CO2 can be reached during sailing at an engine load of 6090 kw. The results show that the engine CO2 emissions are about 80000 kg at engine load 6090 kw and about 52224 kg at engine load 4000 kw.

Figure four represents the amount of livestock methane emissions. The maximum amount of CH4 emissions is about 2000 kg per day at a livestock capacity of 4000 cattle.

Figure five shows the CO2-eq emissions generated by livestock onboard. The CO2-eq at full capacity of livestock is about 60000 kg, which is about 75% of the engine's maximum $CO_2$ emissions. These results indicate the high danger of the livestock emissions since they are as high as the $CO_2$ emissions of the main engine.

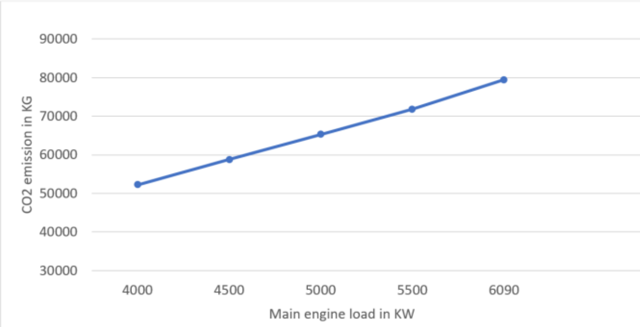


Figure 3. $CO_2$ emission of the main engine

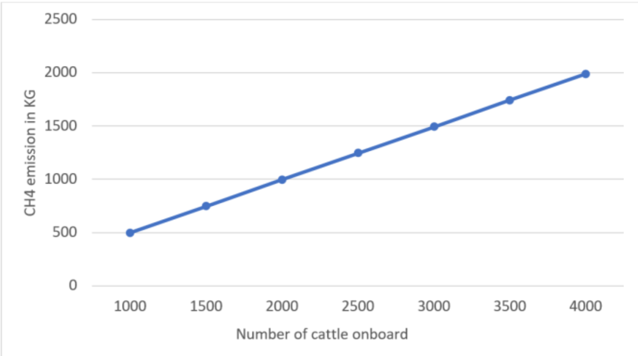


Figure 4. Methane emissions from cattle

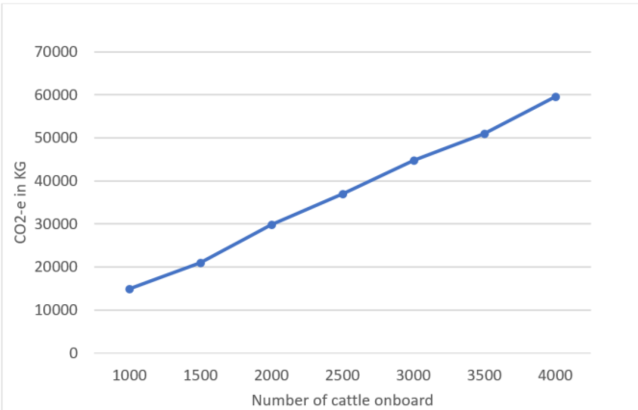


Figure 5. $CO_2$-eq emissions of cattle

Figure six shows a comparison between $CO_2$-eq engine emissions and $CO_2$-eq livestock emissions. These emissions are calculated at full livestock capacity and a different engine's load. The environmental impacts of livestock emissions are just as hazardous as those from engine emissions.

Figure seven shows the total $CO_2$-eq emissions of the engine and cattle together. The cattle $CO_2$-eq emissions are 43% of the total emissions. The maximum $CO_2$-eq engine emissions are about 80000 kg per day, and the maximum $CO_2$-eq livestock emissions are about 60000 kg per day.

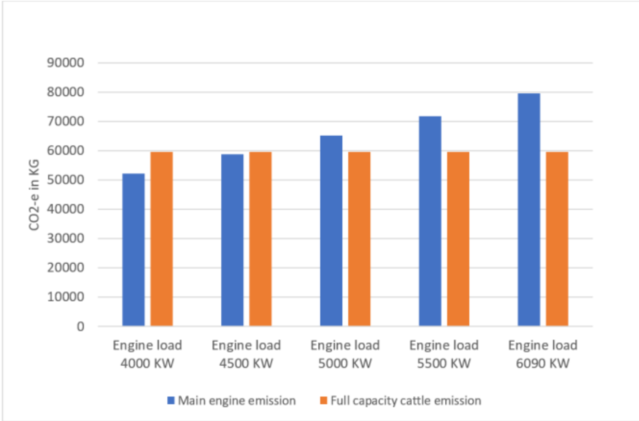


Figure 6. $CO_2$-eq emissions from engine and cattle

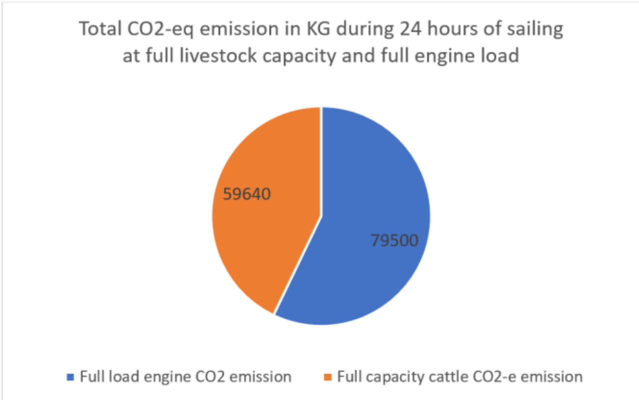


Figure 7. Total $CO_2$-eq emissions of the engine and cattle together

Figure eight shows the $CO_2$-eq of livestock methane emissions during the use of the ZELP burp-catching mask. The findings demonstrate the huge reduction of cattle methane $CO_2$-eq emissions during the use of the ZELP mask. The maximum $CO_2$-eq of cattle methane emissions without using the ZELP mask is about 60000 kg per day, while the maximum $CO_2$-eq of cattle methane emissions while using the ZELP mask is about 2000 kg per day. The ZELP mask enhanced the reduction of $CO_2$-eq emissions by 58000 kg. These findings prove the importance of this novel innovation and the importance of developing and applying this technology as a mandatory regulation for these types of ships.

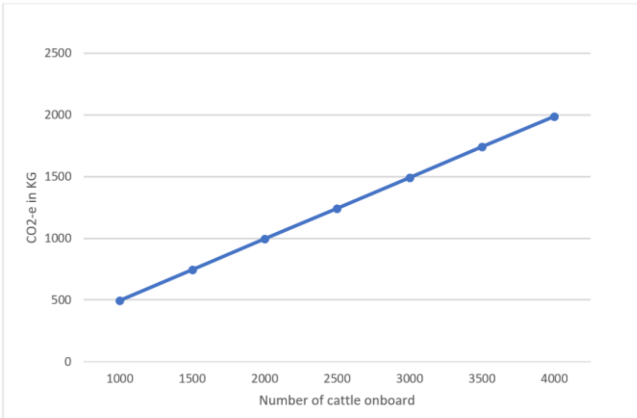


Figure 8. $CO_2$-eq of livestock methane emissions during the use of the ZELP

Figure nine shows the total CO2-eq emissions of the engine and the cattle during the use of the ZELP mask. The results of figure nine are calculated during 24 hours of sailing under the engine full load and the livestock full capacity while using the ZELP mask to illuminate the huge reduction in CO2-eq livestock emissions.

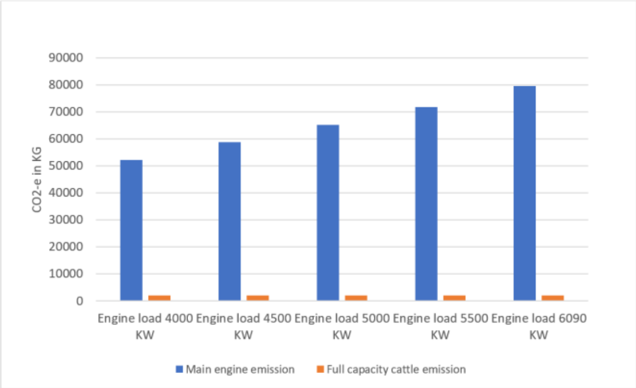


Figure 9 CO2-eq emissions of the engine and the cattle during the use of the ZELP mask

Figure ten shows the total CO2-eq emissions of the engine and cattle together. The cattle CO2-eq emissions during the use of ZELP are 2.4% of the total emissions.

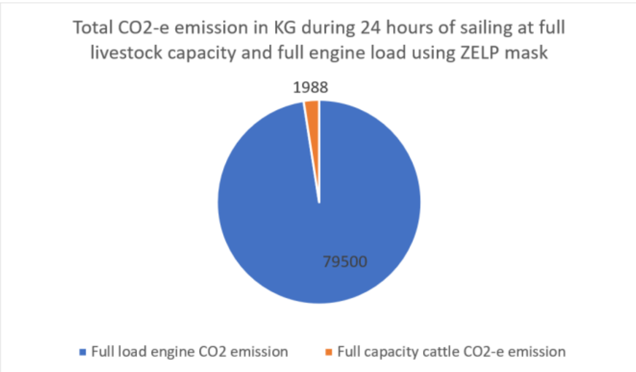


Figure 10. CO2-eq emissions of the engine and cattle together during the use of ZELP

Figure eleven shows the livestock CO2-eq emissions with and without the ZELP mask.

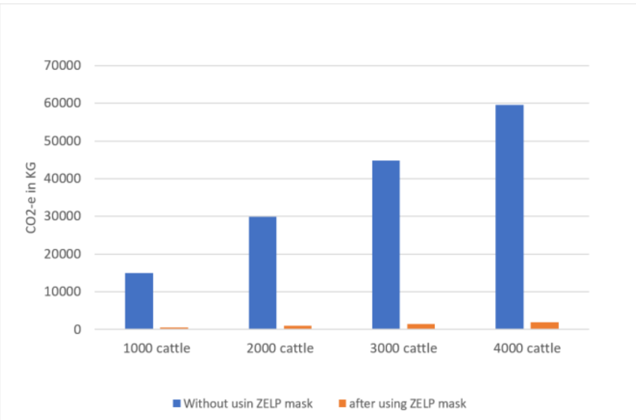


Figure 11. Livestock CO2-eq emissions with and without the ZELP mask

Table three clarify the results of the theoretical CO2-eq calculations per 24-hours of sailing under engine full load and livestock full capacity.

Table 3. Theoretical results of CO2-eq emissions without the use of ZELP mask

| | |
|---|---|
| Engine full load | 6090 KW |
| Cattle capacity | 4000 Cattle |
| Main engine CO2 emission | 79500 Kg |
| Cattle CO2-e emission without the use of ZELP | 59640 Kg |
| Cattle emissions as a percentage of the total emissions of CO2-eq | 43% |

Table four demonstrates the results of the theoretical CO2-eq calculations per 24-hours of sailing under engine full load and livestock full capacity, during the use of ZELP mask.

Table 4 Theoretical results of CO2-eq emissions during the use of ZELP mask

| | |
|---|---|
| Engine full load | 6090 KW |
| Cattle capacity | 4000 Cattle |
| Main engine CO2 emission | 79500 Kg |
| Cattle CO2-e emission during the use of ZELP | 1988 Kg |
| Cattle emissions as a percentage of the total emissions of CO2-e | 2.4% |

## 5 CONCLUSION

The world is presently making scientific, political, and environmental contributions towards mitigating climate change and global warming. climate change and global warming are triggered by the release of GHG emissions into the atmosphere. Reducing methane emissions could achieve the 1.5°C global warming target set forth in the Paris Agreement. The IMO is working hard to develop legislation and plans that contribute to lowering emissions in the maritime sector, in order to slow down the rate of emissions that are predicted to rise in the future. One of the most popular kinds of vessels employed in maritime transportation is the livestock vessel. The purpose of this study was to determine the rate of emissions from the main engine and the livestock on board the MV Gelbray Express Livestock ship during the 24-hour period of sailing. The analysis demonstrates that livestock CO2-eq emissions are higher than 60,000 kg per day at a capacity of 4000 cattle. The results emphasize that the main engine CO2-eq emissions are about 80000 kg during a 24-hour sailing period at full engine load. According to the study, the quantity of livestock emissions is massive and practically as hazardous as engine emissions. The ZELP mask increased the reduction of CO2-eq emissions by 58,000 kg. These results highlight the significance of this innovative innovation as well as the need to develop and implement this technology as a mandatory policy for these sorts of ships. These theoretical results illuminate the importance of cooperation between policymakers and ZELP to provide maritime sustainability by decreasing the emissions impact of livestock ships.

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