

EFFECT ON CO2 EMISSIONS IN MARITIME CONTAINER TERMINALS USING NEW VESSEL MOORING SYSTEM BY VACUM. EMISSIONS BY TEU

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Abstract

Taking into account the increase in the emission of greenhouse gases produced by ships, during navigation and maneuvering in the port, a direct consequence of the increase in maritime traffic, the international community has developed a broad set of regulations to limit such emissions.

The installation in commercial ports of automatic mooring systems by means of vacuum suction cups (AMS), thus reducing considerably the time required to carry out the mooring and unmooring maneuvers of ships, is a factor that is considerably influencing the decrease in Emissions of polluting gases in commercial ports with high traffic.

The objective of the present work is to verify the influence of the use of the AMS on the emissions of polluting gases produced in the facilities destined to the traffic of container ships.

It examines the CO2 emissions of container ships that call in the only three container ports equipped with AMS: Salalah (Oman), Beirut (Lebanon) and Ngqura (South Africa). Between them, these three ports supported the transit of 6 million TEUS in 2017.

The calculation of emissions is made taking into account the time saved when performing the mooring maneuvers using the new AMS system compared with when it is not used.

To do this, two different calculation methods are used: EPA and ENTEC to then compare the results of the two and thus obtain the reduction in emissions per TEU in these terminals during the mooring maneuvers.

The paper concludes with a discussion on the values of the reductions in emissions obtained and the advantages of the installation of AMS in commercial ports located near population centres.

Keywords

Maritime transport; Automatic mooring system; Container vessel; TEU; CO₂ emissions.

1. Introduction

To reduce the CO₂ emissions of ships, measures have been taken in relation to speed control, the quality of the fuel used, the state of conservation of the ship's hull, the time required to perform the mooring and unmounting maneuvers (Wen et al., 2016).

Nowadays, new and innovative automatic mooring systems by vacuum suction cups (AMS) are being developed, leading to a saving in the maneuver times of the ships. These systems are already installed and operating in 23 docks in 12 different countries and different types of terminals such as general cargo, roro / pax, container, jetty or locks. This study focuses on specialized container terminals used by container ships. The three ports in which this automatic mooring technology is currently being used are Salalah in Oman, Beirut in Lebanon and Ngqura in South Africa.

The average time devoted to the berthing maneuver of a ship to moor and unmount again, is reduced from 30 minutes to about 30 seconds by changing the method of mooring from the traditional to the AMS.

The objective of this study is to quantify the reduction of CO₂ emissions at container terminals during ship mooring operations, using the AMS.

Two different "bottom-up" methodologies, the EPA and the ENTEC, are used to calculate the emissions, and thus make a comparison between the results obtained by the two methods.

Once the CO₂ emissions into the atmosphere produced by the container ships have been calculated, the emissions per TEU¹ transported can be determined.

¹ The TEU is the unit of measurement of capacity of maritime transport for container ships and port terminals for containers. The letters TEU (acronym in English for Twenty-foot Equivalent Unit) represents the carrying capacity of a standardized metal container or box, which can be easily transferred between different forms of transport such as ships, trains and trucks. The outer dimensions of this container are: 20 feet (6.1 m) long by 8 feet (2.4 m) wide by 8.6 feet (2.6 m) in height. Its external volume is 1,360 cubic feet equivalent to 38.51 cubic meters. Its capacity is 1,165.4 cubic feet equivalent to 33 cubic meters. The maximum weight of the container is 26,000 kg approximately, but subtracting the tare or empty weight, the load inside can weigh up to 23,600 kg. Apart from the 20-foot container, which is computed as a TEU, there is another one of 40 feet (12.2 m long) which is the most frequently used and which is calculated as equivalent to 2 TEU or 1 FEU (Forty-foot Equivalent Unit).

2. Background

According to data from the World Bank (World Bank, 2018), maritime container traffic has gone from 225 million TEUs¹ in 2000 to 700 million TEUs in 2016, the number and size of the vessels also increasing: in the year 2000, the largest vessels were able to transport some 7,000 TEUs while currently they can carry up to 18,000. In the last decade, the capacity of the fleet has increased by 240%, reaching 19.7 million TEU at the end of 2015, and it is expected to reach 20 million in 2018, according to the international maritime association BIMCO.

Taking into account that today the largest volume of non-bulk merchandise is transported in containers, it is not surprising that there are numerous studies that deal with the problem of the gas emissions to the atmosphere generated by container traffic by sea.

In 2004, a study was published (Bailey and Solomon, 2004) that aims to establish a precautionary approach concerning air pollution related to ports, promoting the local production of goods to reduce maritime traffic, proposing a more ecological design for new terminals and cutting-edge approaches to emission control that have proven to be successful in ports around the world.

In 2007, a study by Yang (Yang et al., 2007) estimated the total CO₂ emissions in 2003 at the port of Shanghai at 3 million tons. The total number of vessels studied was approximately 1.3 million, of which 57% were ships sailing through the Inland port and 43% were ships in the Outer Port.

In 2015, Acciaro and McKinnon published a paper (Acciaro and McKinnon, 2015) aimed at helping both shipping companies develop plans to reduce carbon emissions and governments to design appropriate policies to encourage decarbonization of the maritime sector.

The study published in 2016 by Cullinane (Cullinane et al., 2016) estimates the atmospheric emissions emitted by container ships during the mooring operations in 2012, in the three largest container ports in Taiwan: Kaohsiung, Keelung and Taichung. It was estimated that approximately 58.65% of emissions occur in Kaohsiung, however the emissions per container in this port were the lowest, compared to the other two ports of the study.

Another study also from 2016 (Wen et al., 2016) that examines how to reduce vessel emissions and air pollution in the process of entering and leaving the port, applies the

research on the relation between the emissions of polluting gases from the vessel, its speed and the journey made and calculates the emissions of the vessels through a quantitative calculation model.

There are other studies that focus on the operational side of container transport, such as the work by Hou in 2017 (Hou, 2017a) that establishes as the main problem of the port operator the optimization of intermodal container transport in port, also studying the possibility of reducing emissions by improving operational efficiency. The same author (Hou, 2017b) highlights the common challenge faced by both the container terminal operators and the shipowners: how to reduce vessel emissions during the period of navigation, mooring and loading or unloading.

In 2017, another study (Sim, 2018) obtained as results that in the Busan container terminal in South Korea an average of 108.2 million kg of CO₂ equivalent emissions are produced annually in five types of processes: 51.1% in the maneuvering process of the vessel, 0.57% in the process of securing the vessel to its berth, 37.3% during the loading and unloading of the vessel, 1.0% in container transport by truck through the terminal, and 9.9% during the process of receiving and delivering the container. This study indicates that more than 50% of CO₂ emissions in container terminals are the product of operations with vessels.

More recently in 2018, two studies have been presented, one of which analyzes the total carbon emissions in the container terminals, in their installations, trucks, cranes and docked vessels, concluding that the most polluting part in this total is the maritime part (Peng et al., 2018) and in the other the emissions of post-Panamax container ships are calculated in navigation using different methods (Cheng et al., 2018).

3. Description of the Automatic Mooring System (AMS)

The Ports of Salalah in Oman, Beirut in Libya and Ngqura in South Africa use an innovative Automatic Mooring System (AMS) developed by Cavotec, which instead of the traditional ropes, uses vacuum suction cups to secure the vessel to the dock, providing the physical coupling between them in a safe and controlled manner.

The system consists of robots equipped with vacuum suction cups, which can be remotely controlled, can be installed on the edge of the pier or above it, are joined by arms with a

vertical and horizontal movement, hydraulically operated, which allows the fixing the hull to the pier through the vacuum suction cups in a few seconds.

It is a very fast system and can be activated or deactivated by operating a single button, offering, among others, environmental benefits, since it reduces the maneuver time and in cases of contrary winds avoids the need for the use of tugs to push the ship against the dock to secure the vessel.

In the port of Salalah, it was decided to install the AMS because the system can work with generators independent of the electric network and because the monsoon season, which usually begins in July and lasts three months, brings with it swells, low visibility and a unique set of challenges for that port.



*Fig. 1. Automatic Mooring System by vacuum cups in Salalah.
Source: Cavotec*

In general, the loading of container ships is a very precise and difficult operation for the person operating the crane if the vessel is moving, a situation which is normally due to the effects of the meteorology or the currents, so that it is at times necessary to suspend loading operations until the vessel is totally stationary. This problem is solved with the AMS since it not only cushions the movement of the vessel but it also makes the mooring more resistant to inclement weather.

4. Methodology

To carry out the present work it is necessary to have evidence-based information on the movement of container ships in terminals equipped with AMS; therefore, two databases are required, one database containing info on ports equipped with AMS container terminals and a second database to relate the vessels operating in those terminals and the frequency of stopovers adding some technical characteristics obtained from the database in Fairplay (Ltd 2015)

Next, we have to calculate CO₂ emissions of the container ships to the atmosphere whilst a ship is moored, taking into account that those operations cover the total time elapsed to complete mooring maneuvers.

The calculations take into consideration two different methods of mooring. Firstly, assuming if the vessel moors with traditional mooring methods; ropes in bow and stern and secondly, if the vessel moors with AMS.

Once we have the results for both methods of mooring, we may compare the total emissions in order to obtain the total of reduced CO₂ emissions when using automatic mooring systems.

With the average value of CO₂ reductions resulting of the arithmetic mean between the two methods and information already gathered from the yearly TEUS sea transport in ports with AMS and the capacity of vessels in TEUS, we can obtain the exact value of reduced emissions by TEU when using both methods AMS and traditional system of mooring container ships.

Finally, the value of reduced emissions using AMS by TEU has been extrapolated and implemented in the maritime traffic of containers in ports in the most important countries in the world. This is how we have been able to calculate yearly emissions by every TEU. To conclude the calculations of emissions, two different methodologies have been employed, EPA and ENTEC already used in previous studies that have been published in the past (Díaz-Ruiz-Navamuel et al., 2018a; Oria Chaveli, 2016; Ortega Piris et al., 2018)

The following formulas have been included in the calculations of average emission in each port depending on the method used:

$$AE_{Ropes} = (E_{ropesEPA} + E_{ropes ENTEC})/2 \quad [1]$$

$$AE_{AMS} = ((E_{AMS EPA} + E_{AMS ENTEC})/2) \quad [2]$$

AER_{1..n} stands for the difference in CO₂ emissions when mooring using AMS and ropes in every chosen port

$$AER_{1..n} = AE_{ropes} - AE_{AMS} \quad [3]$$

TER is the sum of AER_{1...n}, these are the total of reduced emissions in every chosen port.

$$TER = (\sum_n^1 AER)/n \quad [4]$$

To calculate the reduction in emissions by TEU, we have considered the average occupancy in vessels per call once we already know the data of yearly TEUS maritime transport in ports with AMS and the capacity of the vessels in TEUS

$$ER_{TEU} = TER / N^{\circ} TEUS \quad [5]$$

Being ERTEU equal to the average reduction in CO₂ emissions by TEU during the time saved by doing the manouver of mooring with AMS and n° TEUS moved in chosen ports by the vessels operating in a month.

5. Case study: Container Ships

The data on the ports used to develop this work, the year of installation of the AMS and the times used for the maneuvers with AMS were provided to us by Cavotec, the company that supplies the AMS all over the world.

As mentioned above, automatic mooring systems are currently installed in the container terminals of Salalah in Oman, Beirut in Lebanon and Ngqura in South Africa, ports that have supported an average movement of 424,000 TEUs per month in the last four years (Africaports, 2018; Port of Beirut, 2018; Salalah port, 2018).

The calculations of CO₂ emissions to the atmosphere shown below have been carried out applying the methodologies described above, are those produced during the month of May 2017, produced by the 225 container ships that have operated in the selected ports, in the time taken for the mooring phase during the mooring maneuvers, for a total of 280 calls.

These calculations have been made for two different situations: using the AMS to tie the ship to the dock and mooring the dock by means of ropes or cables, that is, by the traditional system.

Table 1 shows the data for the average movement of vessels and TEUS in the ports selected for the study, for the period 2014-2017.

In the port of Salalah, in May 2017, there were a total of 158 stopovers, carried out by 140 different ships, with a total theoretical capacity among all the ships that arrived of 945,944 TEUs, which represents an average of 5,987 TEUs per stop, with an average percentage of occupation of the loading spaces of the vessels of 28.35%. The vessel with the largest tonnage that moored that month in the container terminal was the MSC La Spezia with a GT of 153,115 tons, a length of 365 meters and a load capacity

of 14,036 TEUs, its power installed in the main engine being 72,240 Kw and in its auxiliary engines, 15,600 Kw. The vessel with the lowest tonnage was the Alice Rickmers of 2,631 tons of GT and a length of 195 meters, a load capacity of 1,850 TEUs and a power installed in the main engine of 12,000 Kw and in its auxiliary engines, 3,500 Kw. In Beirut, in this same month, the number of vessels that stopped at their container terminal was 66, making 84 stopovers, with a total capacity in TEUS of 320,420, which gives an average of 3,814 TEUs per ship, with an average occupation of the vessel capacities of 31.16%.

Table 1: Average traffic volumes of TEUS and vessels in the ports of Salalah, Beirut and Ngqura.

	Port	Salalah	Beirut	Ngqura
May 2017	N° Vessels	140	66	19
	N° Calls	158	84	38
	GT (Tons)	65,989	42,416	98,076
	Length (m)	277	214	314
	ME (KW)	43,566	24,289	51,442
	AUX E (kW)	8,585	6,230	15,123
	TEUS per call	5,987	3,814	9,277
Average in the last 4 years	Vessels per month	137	90	39
	Vessels per year	1,648	1,077	937
	TEUS per month	268,217	99,866	55,918
	TEUS per year	3,218,606	1,198,397	671.0
	TEUS per vessel	1,953	1,112	1,433

Source: Self-made by authors

The vessel with the largest tonnage that landed that month in the container terminal was the MSC New York with 176,490 tons, a length of 399 meters and a load capacity of 16,652 TEUs, with a power installed in the main engine of 53,802 Kw and in the auxiliary engine, 17,380 Kw. The vessel with the lowest tonnage was the Shuttle 2 with 2,900 tons of GT and a length of 98 meters, a load capacity of 366 TEUs, with a power installed in the main engine of 2,940 Kw and in the auxiliary engine of 1,102 Kw.

Finally, the data recorded in the port of Ngqura in May 2017, tell us that the number of vessels that called at their terminal was 19, making 2 calls per ship, with a total capacity of 352,520 TEUS, or in other words, with an average of 9.277 TEUs per vessel, with an average percentage of occupation of the loading spaces of the vessel of 16%.

The vessel with the largest tonnage that moored that month in the container terminal was the Eugen Maersk with 171,542 tons, with a length of 398 meters and a load capacity of 17,816 TEUS, with a power installed in the main engine of 80,080 Kw and in the auxiliary engine, 29,240 Kw. The vessel with the lowest tonnage was the MOL Proficiency of

71,906 tons of GT and a length of 293 meters, a load capacity of 6,350 TEUs, with a power installed in the main engine of 62,920 Kw and in the auxiliary engine, 10,000 Kw. Parallel to the port data, a database has been made with the 225 container ships that have operated in these three ports in the month of May 2017, the month from which we have obtained all the necessary data on the total traffic, which includes all their technical characteristics (length, Gross Tonnage, power of the main engines, ME, and auxiliary engines, AE, in kW, ports where they operate and capacity of each vessel in TEUS). These data are gathered in Table 2, where the average values are shown based on the number of stops recorded.

Since some vessels made more than one stop in the same port, the total number of stops registered was 280.

The names of the vessels used in this study were obtained from the various webpages of the three ports selected (Africaports, 2018; Port of Beirut, 2018; Salalah port, 2018), and these pages also provided data on the traffic for that month. The Fairplay (Limited, 2015) data base was consulted using the names of the vessels in order to obtain their characteristics.

In order to verify the times required for the maneuvers performed using the traditional mooring methods, acting officers on board the vessels of this type were consulted, providing us with sufficient data to establish an average time for such maneuvers. The result of these surveys was that as an average value, the times employed for mooring operations with ropes was 30 minutes and, according to the specifications of the manufacturer, when the AMS are installed, the time required is 30 seconds, the average time it takes to secure a vessel to the dock with this system. Thus, the reduction in emissions is made in those 29.5 minutes saved when performing the mooring operation with the AMS, a time in which CO₂ would no longer be emitted into the atmosphere.

6. Results

This section presents the results of the calculations of the CO₂ emissions emitted by the vessels selected in each port, obtained using the EPA and ENTEC methods, both for the maneuver with ropes and for that with the AMS. Once these values are known, the value of the reduction in CO₂ emissions due to the use of AMS can be calculated for the total of the maneuvers that the vessels perform in the ports selected for the study, thus obtaining the amounts of CO₂ whose emission is avoided per day, week, month and year.

Finally, and since the number of TEUs that are moved annually in these ports, the average reduction in emissions per TEU during the time saved by performing the mooring maneuvers with the AMS can be calculated, both for the vessels and for the selected ports.

6.1 Emissions of CO₂ during mooring operations and calculation of average emissions when using ropes and when using AMS

Table 2 presents the results of the calculations of the CO₂ emissions produced in the total of the vessels selected in each port per month, week, day and year, obtained using the EPA and ENTEC methods, both for the maneuver with ropes and for that with the AMS, as well as their average value (AE).

Taking into account the calculations made using the ENTEC methodology, when adding the daily emissions made by the vessels using the AMS in the three ports equipped with the system, the total is 0.6 tons of CO₂ as compared to the 36 tons that would have been emitted if the maneuvers had been made with ropes.

The results per day using the EPA methodology provide CO₂ emission figures of 0.7 tonnes using the AMS, while for the maneuver with ropes, this figure is 45.3 tons.

The difference in the emissions when using one system or the other is 0.2 tons of CO₂ per day using the AMS and 9.34 tonnes of CO₂ when mooring with ropes.

6.2 Calculation of the reduction in emissions in container ports with AMS.

Table 2 shows the values of the reduction in CO₂ emissions due to the use of the AMS for the total of maneuvers made by the vessels in each port and according to the different calculation methods.

Table 2. Emissions of CO₂ in tonnes in the mooring operations with ropes and with the AMS and Reduction in CO₂ emissions (ER) in tons using the AMS with the EPA and ENTEC methods EPA and ENTEC Methods.

PORTS	Frequency	CO ₂ emissions with Ropes			CO ₂ emissions with AMS			ER= Reduction in CO ₂ emissions	
		E ENTEC	E EPA	AE ropes	E ENTEC	E EPA	AE AMS	ENTE ER Tons	EPA ER Tons
Salalah	PER DAY	21.7	26.4	24.1	0.4	0.4	0.40	21.3	26.0
	PER WEEK	162.8	198.1	180.5	2.7	3.3	3.0	160.1	194.8
	PER MONTHS	651.3	792.5	722.0	10.9	13.2	12.0	640.4	779.3
	BY YEAR	7,815.3	9,509.7	8,662.5	130.3	158.5	144.4	7,685.1	9,351.2
Beirut	PER DAY	7.1	9.3	8.2	0.1	0.1	0.1	7.0	9.1
	PER WEEK	53.5	69.4	61.5	0.9	1.2	1.0	52.6	68.3
	PER MONTHS	214.0	277.8	245.9	3.6	4.6	4.1	210.4	273.2
	BY YEAR	2,568.0	3,333.5	2,950.7	42.8	55.6	49.2	2,525.2	3,277.9
Ngqura	PER DAY	7.1	9.7	8.4	0.1	0.2	0.1	7.0	9.5
	PER WEEK	53.6	72.4	63.0	0.9	1.2	1.0	52.7	71.2
	PER MONTHS	214.6	289.7	252.2	3.6	4.8	4.2	211.0	284.9
	BY YEAR	2,574.9	3,477.1	3,026.0	42.9	58.0	50.4	2,532.0	3,419.1

Source: Self-made by authors

In view of the results obtained, the average monthly value of the reduction in CO₂ emissions in each port due to the use of AMS can be determined, as well as the aggregate values of the three ports (Table 2).

From the data obtained, expressed in annual terms, we get an average amount of reduction in CO₂ emissions of 14,395.3 tons, the amount of emissions per year without using the AMS being 14,639.2 tons, while when using it this value is 243.8 tons. From this data, it can be inferred that the ports in which the AMS are installed are reducing their emissions by 98%.

6.3 Calculation of the reduction in emissions per TEU in ports with AMS installed.

In Table 3, by applying formula [5], the average reduction in emissions per TEU is made for the 29.5 minutes saved by performing the mooring maneuvers with the AMS with respect or the maneuver with ropes in the selected ports with their respective traffic.

Table 3. Calculation of emissions with ropes and with the AMS and reduction in emissions per TEU.
Monthly reduction in CO₂ emissions (Results in Kilograms of CO₂)

Ports	AE ropes	AE AMS	AER	N° TEUS	AE ropes TEU	AEAMS TEU	TER _{TEU}
Salalah	721,880	12,030	709,850	268,217	2.7	0.05	2.6
Beirut	245,890	4,090	241,800	99,866	2.5	0.04	2.4
Ngqura	252,160	4,200	247,930	55,918	4.5	0.07	4.4
Media	406,643	6,773	399,860	141,334	2.9	0.05	2.9

Source: Self-made by authors

7. Discussion

When a vessel arrives at the port to carry out operations, whether they are loading or unloading, the mooring maneuver begins, in which several auxiliary vessels may be involved, such as pilot boats, mooring vessels and tugboats, as well as the vessel itself. During this maneuver, two phases can be differentiated, one following after the other, the first being the approach phase of the vessel to the dock during which the auxiliary vessels have a more active role and the second being the actual mooring operation. The latter will have a more or less prolonged duration in time depending on the means used to secure the vessel to the dock. Today, two completely different models are available: on the one hand, the mooring of the ship to land using the traditional rope system and, on the other

hand, the vacuum systems that secure the vessel to land by means of suction elements (AMS).

New European regulations are currently being drawn up (Cullinane, Cullinane 2013, Johansson, Jalkanen et al., 2013) to limit greenhouse gas (CO₂) emissions in the case of the emission of pollutants harmful to health produced by vessels during the approach to port and the mooring and unmooring maneuvers. The fluctuations in the emissions in these different stages depend on different factors such as the engine speed or speed control (Chang and Chang, 2013; Eide et al., 2013, 2011), the quality of the fuel used, the state of conservation of the vessel and the hull or the times taken to carry out the maneuvers of mooring or unmooring with ropes (Bocchetti, Lepore et al., 2015, Celo, Dabek-Zlotorzynska et al., 2015).

Currently, there are serious limitations on CO₂ emissions from vessels in port, as the main commercial ports are often very close to urban centers.

Previous studies have determined the suitability of the use of AMS as a system that contributes significantly to the reduction in the levels of greenhouse gas emissions, in particular of CO₂ emissions, in multimodal terminals (Diaz et al. , 2016) and in terminals of regular line Ro-Ro / Pax vessels (Díaz-Ruiz-Navamuel et al., 2018). As a follow-up to these studies, in this paper we have focused on those container ship terminals which, according to the AMS manufacturer, have the AMS installed in them: Beirut, Ngqura and Salalah.

From the results shown in Table 3, it can be deduced that the emissions of the vessels that operate monthly in the aforementioned ports, would amount to a total of 1,220 tons of CO₂ if they performed the maneuvers with ropes, compared to the 20 tons that they emit when mooring with the AMS. This result clearly shows the effectiveness of the application of these modern mooring systems with respect to the traditional methods, since for just one month, and in just three ports, the savings in emissions would be around 1,200 tons of CO₂.

As we have available the data on the traffic of container ships that move monthly in these ports (Table 3), it is possible to obtain a highly significant datum, never previously calculated, which is what each TEU that is transported in a container terminal contributes in terms of CO₂ emissions, both when mooring the vessel with ropes and with the AMS and, thus, the savings in emissions that the use of the vacuum cup system implies. Between the three ports, an average value of emission reduction of 2.9 Kg of CO₂ per TEU transported is obtained.

If we look back, we obtain the amounts whose emission has been avoided since the AMS system was installed in each of the ports until December 2017. In the port of Salalah, the system was installed in 2015, transporting since then just over 9,840,000 TEUS, which means that the savings in emissions have been around 26,000 tons. Similarly, in the port of Ngqura, also since 2015, the saving has been around 8,800 tons for a traffic of near two million containers. And finally, the most veteran of the ports with AMS, Beirut, has transported since 2014 a total of 4,800,000 TEUS with a saving in emissions of 11,600 tons.

In total, we can say that thanks to the installation of the AMS system in these three ports, the reduction in CO₂ emissions to the atmosphere can be estimated at over 46,400 tons.

Table 4. Calculation of RE_{TEU} in different economic areas (Tonnes of CO₂).

Country	TEUS 2016	TEU/month	AE ropes	AE _{AMS}	TER _{TEU}
China	199,565,501	16,630,458	47,895.7	831.5	47,064.2
European Union	108,015,289	9,001,274	25,923.7	450.1	25,473.6
United States	48,381,723	4,031,810	11,611.6	201.6	11,410.0
Singapore	31,688,000	2,640,667	7,605.1	132.0	7,473.1
Republic of Korea	26,373,000	2,197,750	6,329.5	109.9	6,219.6
Malaysia	24,570,000	2,047,500	5,896.8	102.4	5,794.4
South Asia	22,726,505	1,893,875	5,454.4	94.7	5,359.7
United Arab Emirates	20,413,200	1,701,100	4,899.2	85.1	4,814.1
Japan	20,257,000	1,688,083	4,861.7	84.4	4,777.3
Spain	16,964,285	1,413,690	4,071.4	70.7	4,000.7

Source: Self-made by authors

Table 4 provides an assessment of the reduction in emissions that would have been achieved in 2016 if the AMS had been installed in container terminals in different countries of the world, taking into account container traffic and the average reduction in CO₂ emissions per TEU calculated.

8. Conclusions

From the results obtained from the research described above, the following conclusions have been obtained:

1. The saving in the emission of CO₂ (in tons) to the atmosphere is 21,295 in Salalah, 10,157 in Beirut and 7,438 in Ngqura, this means that around 38,890 tons of CO₂ have been emitted into the atmosphere since the installation of the AMS in those ports.

2. In the ports where AMS is installed, the reduction of CO₂ emissions during mooring operations can be estimated at 98%
3. The countries that contribute the most to the lowering in CO₂ emissions are those that have the most container traffic, although the size of the vessels is also a major factor.
4. It has been estimated that with the installation of an AMS in a container port, a reduction of 2.9 Kg of CO₂ per TEU transported is obtained.
5. Port Authorities should encourage the installation in the commercial docks of these automatic mooring systems.

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