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סקר היתכנות להפחתת זיהום אוויר מכלי שיט בנמלי חיפה ואשדוד

Feasibility Study for Reducing Marine Vessels' Air Pollution at Haifa and Ashdod ports

דו"ח מסכם

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מוגש למדען הראשי
המשרד להגנת הסביבה

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Forward

This document summarizes the final results of a study regarding the feasibility of reducing marine vessels' air pollution at Haifa and Ashdod ports.

The study was carried out by AVIV AMCG and financed by the Israeli Ministry of Environmental Protection as part of 2016 call for research on the environmental pollution at different mediums in the Haifa bay area.

תקציר מורחב בעברית

הפעילות הימית בישראל הכרוכה ביבוא ויצוא של סחורות נשענת כיום על שני נמלים מרכזיים, חיפה אשדוד. פעילות זו צפויה להתרחב בשנים הקרובות עם מימוש תכניות להקמת נמל המפרץ ונמל הדרום. מדובר בפעילות חיונית ביותר שכמעט כל סקטור במדינה מושפע ממנה, אך הכרוכה בתנועה ועגינה של כלי שיט מקומיים ובינלאומיים המייצרים זיהום אוויר שההערכות לגבי היקפו עד היום לא היו ברורות די הצורך, לרבות אמצעים שניתן באמצעותם לטפל בדבר.

בהתאם לכך, בעבודה זו נדרשנו לארבע שאלות עיקריות:

1. מהו היקף זיהום האוויר הנפלט כיום מסקטור כלי השיט בנמלים חיפה ואשדוד.
2. האם סביר כי זיהום זה משפיע בפועל על איכות האוויר באזורים מאוכלסים בחיפה ואשדוד.
3. באילו דרכים ניתן לנקוט על מנת להפחית את היקף הזיהום, בכלל זה: אמצעי הפחתה טכניים, אמצעים תפעוליים, אמצעי אכיפה ומדיניות וכיו"ב.
4. לאילו יעדי הפחתת זיהום ניתן לשאוף בראי ההיתכנות היישומית של אמצעי ההפחתה השונים.

על בסיס מענה ל 1-4, הוצג מתווה ראשוני אפשרי להפחתה הדרגתית בזיהום האוויר מסקטור כלי השיט. המתווה מהווה בסיס להמשך בחינת הנושא וגיבוש של תכנית הפחתה סדורה ומפורטת.

תוצאות העבודה מבוססות על איסוף וניתוח מעמיק של נתונים רבים ועדכניים, וביצוע של חישובים והערכות מעודכנות שלהערכתנו טרם בוצעו עד היום באופן שבוצע בעבודה זו[1]. מתוצאות העבודה עולה, כי נכון ל-2018, זיהום האוויר הנוצר מכלי השיט בנמלי חיפה ואשדוד הנו זיהום כבד הדומה בהיקפו לתחנת כוח גדולה המוסקת באמצעות סולר (שהנו דלק מזהם ביותר המותר להפעלה בתחנות כוח בישראל במצבי חירום בלבד). במקרה של נמל חיפה, ניתן להשוות את סך הפליטות הרגעיות בשעת עומס לפליטות של תחנת כוח על סולר בהספק ייצור של כ- 1,000 מגה וואט ובמקרה של אשדוד מדובר בתחנה על סולר בהספק של כ- 700 מגה וואט.

נכון להיום, זיהום זה כולל בנמל חיפה ואשדוד בהתאמה:

- כ- 11,100 ו -7,250 טון/שנה פליטות NO_X
- כ- 9,000 ו- 6,250 טון/שנה פליטות SO_X
- כ-1,800 ו- 1,130 טון/שנה פליטות CO
- כ- 900 ו- 560 טון/שנה פליטות $PM_{2.5}$
- כ-450 ו- 280 טון/שנה פליטות VOC

כ-50%-65% מפליטות אלה נובעות מפעילות העגינה (hoteling) בנמל , כ-30% מפעילות התנועה וההמתנה (maneuvering and stand-by) בנמל והיתר (5%-20%) משלב השיוט (cruising) של כלי השייט במרחקים קצרים מהנמל ובתחום המים הטריטוריאליים של ישראל.

מניתוח והערכה ראשונית של סיכויי הסעת מזהמים אלה (בדגש על NO_X ו-SO_X) לאזורים מאוכלסים בסביבת הנמלים[2], עולה כי קיימת סבירות גבוהה לכך שהזיהום הנ"ל גורם בפועל להשפעה משמעותית על איכות האוויר

[1] העבודה לא כללה ניטור של זיהום אוויר והרצת מודל רחב של פיזור מזהמים (כפי שהוצע על ידנו לעשות), אולם ניתן להשלים את הדבר בעתיד.

[2] תוך שקלול ראשוני של גובהי מקורות הפליטה ונתונים מטאורולוגיים וטופוגרפיים שונים

בשימושי קרקע רגישים בקרבת הנמלים ובאזורים נוספים ברדיוס השפעה משמעותי[3]. יתרה מזאת, מחישוב של תרחיש פליטות "עסקים כרגיל" (המתייחס למצב שהמדינה לא מתערבת באופן אקטיבי להפחתה דרסטית של הזיהום), עולה כי היקף פליטות NO_X אינו צפוי לרדת באופן משמעותי (אם בכלל) ב- 15 השנים הקרובות לפחות, וזאת על רקע שתי סיבות עיקריות: האחת, קצב החלפה איטי מאוד של אניות ישנות מזהמות במיוחד באניות חדשות (מזהמות פחות), והשנייה, רגולציה בינלאומית קיימת המתירה כרגע פליטות יחסית גבוהות של NO_X אפילו באניות חדשות יותר. לעומת זאת, במקרה של SO_X ו-PM, פליטות אלה צפויות לרדת באופן משמעותי בשנים הקרובות (בכפוף לאכיפה ישראלית שתידרש להתבצע בנושא), וזאת על רקע רגולציה בינלאומית שתיכנס ב- 2020 ואשר מתירה שימוש בדלק מופחת גופרית בלבד.

מסקירה של שיטות ואמצעים שונים הניתנים ליישום כדי לטפל בפליטות ה- NO_X, עולה כי ישנן דרכים שניתן באמצעותן להביא להפחתה רבה מאוד בפליטות, ויש נמלים בעולם המשלבים אותן כחלק מתכניות לטיפול בנושא. יתרה מזאת, שורה של נמלים בעולם הגדירו בהכרזה את שטח נמליהם כאזורי NECA (NO_X Emission Control Area) בהם פליטת NO_X הנה מוגבלת, ועקב כך, רק אניות העומדות בתקן פליטה מסוים, מתאפשרת כניסתן, בין אם על בסיס שנת יצור האנייה או על בסיס התקנה של אמצעי הפחתת פליטת NO_X. יחד עם זאת, להערכתנו לישראל יש כרגע קושי לבצע מהלך דומה וגורף של הכרזת נמלי חיפה ואשדוד כאזורי NECA, וזאת על רקע שורה של סוגיות כלכליות ורגולטוריות הקשורות גם בכפיפות לאמנות בינלאומיות בנושא. יתרה מזאת, בכלל להערכתנו הטיפול בזיהום האוויר הנובע מסקטור כלי השיט הנו מאתגר בצורה יוצאת דופן וכנראה אינו דומה כלל לטיפול באף אחד מהסקטורים המזהמים האחרים במדינה.

הסיבות לכך הן רבות, והעיקריות שבהן:

- התמודדות בכל רגע נתון בכל נמל עם עשרות מקורות פליטה נייחים וניידים (פליטות הנובעות מעגינה, תנועה והמתנה של האנייה בנמל). לכל אחד ממקורות פליטה אלה השפעה משמעותית על כלל הפליטות הנובעות מסקטור זה באזור הנמל, כמוסבר בדו"ח.
- רישום של חלק ניכר מהאניות במדינות אחרות (כפיפות רגולטורית של האניות לאותן מדינות בהן אין דרישה להתקנת אמצעי הפחתה).
- העלות הגבוהה מאוד של יישום אמצעי הפחתה, כמפורט בדו"ח.
- רגולציה בינלאומית בלתי תומכת כיום, כמפורט בדו"ח.
- ישראל הנה מדינה קטנה בשוק הסחר העולמי ולא ברור האם ובאיזה אופן יכולה לנקוט באופן חד צדדי באמצעים דרסטיים שניתן לנקוט בארה"ב, סין וחלק ממדינות אירופה.

ולמרות אלה, גם לאחר ההרחבות העתידיות הצפויות בפעילות של שני הנמלים, עבודה זו מראה כי ניתן ליישם מספר פעולות משולבות במסגרת תכנית הדרגתית וארוכת טווח, שתאפשר עד 2030 להביא להפחתה משמעותית מאוד בפליטות של NO_X הן ביחס להיקף הפליטות היום, והן ביחס לפליטות הצפויות בתרחיש עסקים כרגיל ב- 2030. תכנית זו יכולה עד 2030 להביא ביחס להיום (או ביחס ל- 2030 בתרחיש עסקים כרגיל), להפחתה של כ- 50%-70% בפליטות הצפויות של NO_X הן בנמל חיפה והן בנמל אשדוד. בהתאם לכך, פליטות NO_X מנמל חיפה ירדו לטווח של- 3,200-5,000 טון/שנה ומנמל אשדוד הן ירדו לטווח של - 2,000-3,300 טון/שנה. כמו-כן, במסגרת התכנית ניתן עד 2030 גם להביא לירידה של כ- 50% בפליטות של SO_X ביחס לתרחיש עסקים כרגיל (שבו כבר

[3] אולם כדי לבסס ולדייק את הדבר יש להשלים הרצה רחבה של מודל פיזור מזהמים בשני הנמלים.

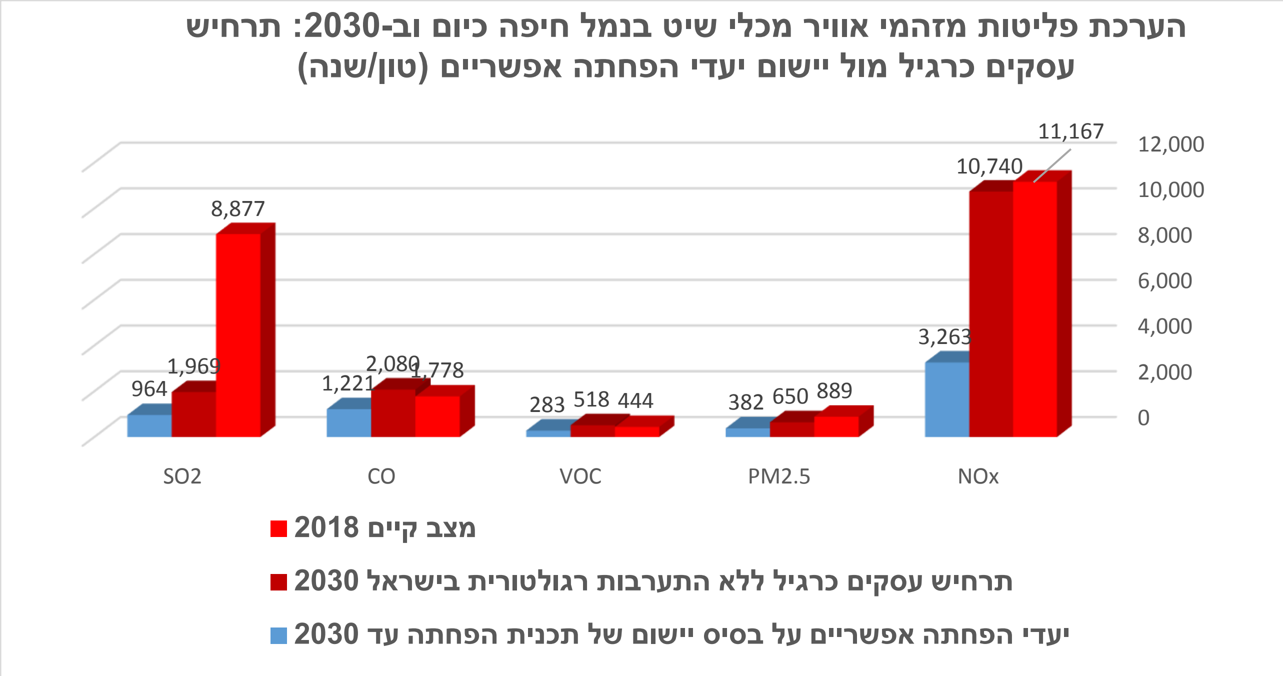
תתרחש ירידה של כ-80% ביחס לפליטות כיום), וכן להביא לירידה של עשרות אחוזים בפליטות של יתר המזהמים שנבחנו בעבודה, וזאת כתלות בסוג והחלק היחסי של אמצעי ההפחתה השונים שיינקטו בתכנית (הדו״ח סוקר שורה של אמצעי הפחתה אפשריים ומשווה בין היתכנותם, עלותם ויעילותם הכלכלית).
המתווה לתכנית ההפחתה שאנו מציגים גם כולל יעדי הפחתה בשלב ביניים לשנת 2025. יעדי הפחתה אלה וכן היעדים המוצעים ל-2030, מבוססים על נקיטה של מספר פעולות עקרוניות שהן מאתגרות מאוד, אך יש להן היתכנות ובהחלט ניתן לקדם אותן. הדו״ח מציג מתווה ליישום של פעולות עקרוניות אלה ופוטנציאל ההפחתה שיושג עם יישומן בהתאם, אך את הדבר עוד נדרש בהמשך לתרגם לתכנית פעולה מקיפה ומפורטת. תכנית זו, תוכל להערכתנו לסטות במידת מה מהמתווה (תוך שתכלול תמהיל שונה של אמצעי הפחתה מאלה המוצגים במתווה) ועדיין לעמוד ביעדיי ההפחתה המוצגים בדו״ח. יחד עם זאת, להערכתנו בכל תכנית מפורטת שתגובש ע״מ לעמוד ביעדים המומלצים לשנת 2030, ידרשו ארבעה מרכיבים בסיסיים:

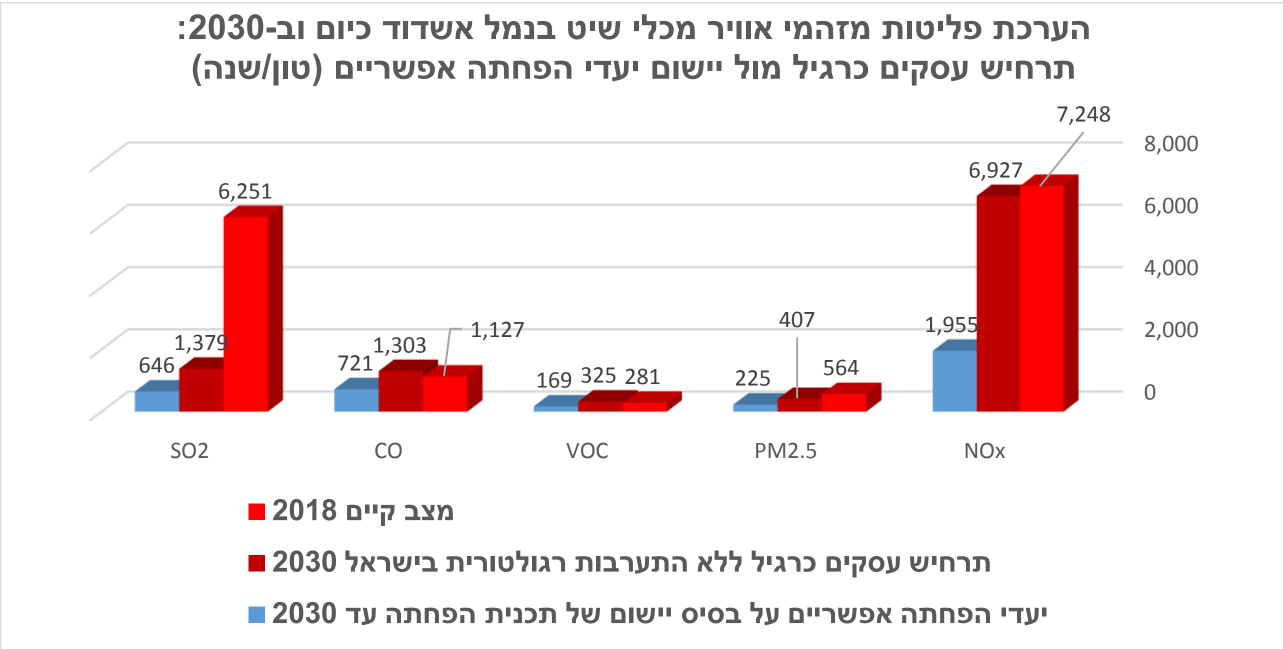
1. דרישה ו/או עידוד של כ-70% מהאניות המזהמות יותר כיום בנמלים להתקין אמצעים להפחתת NO_X, או לעשות שימוש בתחליפי דלק, או להסב את המנוע הפועל בזמן העגינה להתחברות למערכת חשמל ESP (Electric Shore Power) בזמן עגינה ממושכת בנמל.
2. הרחקה מהנמלים של אניות מזהמות, תוך מניעת המתנתן לעגינה במרחק הקצר מ- 5 ק״מ מהנמל.
3. יישום שורה של פעולות תפעוליות נוספות שאינן קשורות למרכיב טכנולוגי (כמפורט בדו״ח) כלפיי כלל האניות במסגרת כללים ונהלים שיוגדרו ע״י כל נמל וע״פ הנחיית המשרד להגנ״ס.
4. הקמת מערך ניטור, בקרה ואכיפה על הפליטות של האניות בנמלים, עם סמכויות למתן קנסות גבוהים לאניות שיחרגו מנהלי איכות הסביבה בנמל, מערכי פליטה מסוימים, לרבות במקרה של שימוש בדלק שאינו דל גופרית.

המדינה תידרש להשקיע סכומים בלתי מבוטלים ע״מ ליישם תכנית כזו וזאת למשל לצורך מימון של הפעולות הבאות:

- השקעה בתשתית ESP שתהיה בכל נמל.
- מתן תמריצים כלכליים להתקנת אמצעי הפחתה, זאת במקרה ומתגלה כי יצירת דרישה מחייבת בנושא (ללא מתן תמיכות), עלולה להיתקל בקשיים כלכליים ורגולטוריים. את הדבר יש לבחון לעומק בהמשך.
- עלות מערך הניטור והאכיפה הייעודי לנושא זה.

לסיכום, סקטור כלי השיט בנמלים חיפה ואשדוד, מייצר זיהום אוויר כבד שבסבירות גבוהה גורם להשפעה משמעותית על איכות האוויר באזורים מאוכלסים. להערכתנו, היקף הזיהום בשני הנמלים הנו גבוה יותר מהערכות קודמות שהיו ידועות בנושא, כשהמזהם העיקרי והמאתגר ביותר להפחתה הוא NO_X בעוד שזיהום ה-SO_X הנו גם גבוה מאוד, אך צפוי לרדת בשנים הקרובות על רקע רגולציה בינלאומית בנושא. לעומת זאת, במקרה של NO_X, ללא התערבות אקטיבית של המדינה, תוך יישום של תכנית דרסטית להפחתתו, מידת הזיהום ממנו ב-20 השנים הקרובות תישאר דומה להיום (אם לא תחמיר). ביחס לסקטורים מזהמים אחרים במדינה שטופלו עד היום, ואשר חלו בהם שיפורים לאורך השנים, המקרה הנ״ל הוא כרגע חריג מאוד ודורש תשומת לב מיוחדת מצד הרגולטור הישראלי.
יישום תכנית להפחתת הפליטות מהסקטור תאפשר הן לטפל ב- NO_X, כמו-גם, ביתר המזהמים שנבדקו בהם VOC, $PM_{2.5}$ ו- CO, בהיקף אשר יושפע מתמהיל אמצעי ההפחתה המסוים שיבחר (כמפורט בדו״ח).





למרות שקיימים אמצעים שונים אותם ניתן לנקוט לשם עמידה ביעדיי ההפחתה המוצעים ביחס ל- NO_x ויתר המזהמים, להערכתנו מדובר באתגר משמעותי מבחינה כלכלית ורגולטורית. בהתאם לכך, כדי להתחיל ולקדם את הנושא, מומלץ להשלים את הפעולות הבאות:

- הרצת מודל פיזור מזהמים ליצירת הערכה מדויקת יותר של השפעת זיהום האוויר של כלי השיט בנמל ובדרכם לנמל על אזורים מאוכלסים במרחקים שונים מכל נמל.
- ניתוח של הנזק הכלכלי הנובע מהזיהום.

- הערכה מדויקת יותר של עלות יישום אמצעי ההפחתה השונים שנמצאו ישימים יותר בדו״ח, בדגש על SCR, ESP, ותחליפים מסוימים של דלקים.
- בחינה השוואתית של מנגנונים כלכליים ורגולטוריים שונים (בין אם חלופיים או משלימים), אותם כדאי ליישם במסגרת תכנית ההפחתה, בכלל זה: מנגנוני עידוד/סובסידיה, שינוי ברגולציה, קנסות וכיו״ב. הערכת ההתאמה והאפקטיביות הצפויה של כל מנגנון למקרה הנבחן.
- הערכת הנטל הכלכלי אותו ניתן להטיל על האניות שייכנסו לנמל כדי לעודד אותן להתקין אמצעי הפחתה או לגבות מהן את מחיר הזיהום שהן מייצרות. בחינה של המשמעות הכלכלית והמשפטית של הטלת מיסים או קנסות בגדלים משתנים.
- בחינה משפטית ממוקדת ביחס ליכולת של ישראל להכריז על נמלי חיפה ואשדוד (או את כל החוף הישראלי) כאזורי NECA, וכן ניתוח של המשמעויות הכלכליות של מהלך כנ״ל.
- בחינה של אילו ערכי הגבלת פליטה בדיוק ניתן לדרוש מהאניות השונות בנמלים, וניתוח באם אניות אלה יוכלו לעמוד בערכים אלה על בסיס דרישה שתקבע, או רק בתנאי שיקבלו סבסוד מסוים לדבר.
- גיבוש הצעדים המפורטים שיינקטו במסגרת תכנית הפחתה ל-11 שנים, בכלל זה התקציב שיידרש על מנת ליישם אותה.

בתום גיבוש התכנית, התחלת יישום הדרגתי שלה כדי לעמוד ביעדיי ההפחתה המומלצים לשנים 2025 ו-2030.

Extended Executive Summary

Israel's marine import and export activities are currently dependent on two main ports, Haifa and Ashdod. With Haifa's "HaMifratz" port plan and the establishment of the "HaDarom" southern port, all marine activities at the Israeli shore, are expected to extend in the upcoming years. While these activities are crucial and almost every sector in the country is affected by them, they are associated with intensive marine vessels' cruising, maneuvering and hoteling which create air pollution at very high levels. So far, these levels were not adequately clear, nor means of reducing them.

Accordingly, this study was designed to achieve the following goals:

1) Analyze the marine vessels' activities creating air pollution emissions in both Haifa and Ashdod ports, and update previous information and notion regarding this aspect.
2) Examine the importance of mitigating the pollution, based on the emissions' potential of affecting the air quality of public and residence areas surrounding the ports.
3) Examine various technological and operational solutions for reducing the pollution and compare their feasibility.
4) Present several future emissions' scenarios in relation to different strategies for emissions' mitigation.

Based on 1-4, present a feasible framework for achieving a gradual reduction in

In the air pollution at each port. The purpose of this framework is to serve a basis for a compensative and detailed mitigation plan to be established at a later stage.

The results of this study show, that the air pollution created by the marine vessels at Haifa and Ashdod ports are extremely high and similar in scope to a large power plant running exclusively on diesel fuel oil (which is a highly polluting fuel allowed to be combusted at power plants only during emergencies). The total instantaneous emissions during a peak hour can be compared to a 1,000 MW diesel fuel oil power plant emissions in Haifa Port and to a 700 MW diesel fuel oil power plant emissions in Ashdod port.

Accordingly, in 2018, these levels of pollution include at Haifa and Ashdod ports respectively:

- 11,100 and 7,250 ton/year emission of NO_X
- 9,000 and 6,250 ton/year emission of SO_X
- 1,800 and 1,130 ton/year emission of CO
- 900 and 560 ton/year emission of $PM_{2.5}$
- 450 and 280 ton/year emission of VOC

Based on first analysis regarding the chance for these emissions to reach populated areas at different distances from the ports, it is estimated that there is a high probability for this pollution to significantly affect the air quality at these receptors (specifically regarding NO_X and SO_X). Furthermore, based on the BAU scenario examined (which assumes no government regulatory intervention), NO_X emissions are not expected to be significantly reduced (if reduced at all) due to two main reasons: one, is a very slow rate of changeover from old vessels to newer vessels that are less polluting. Second, is current international regulations, which allow relatively high emissions even on newer vessels. However, SO_X and PM emissions are expected to significantly decrease due to new international regulations from 2020 restricting the content of sulfur in marine fuel.

After reviewing various methods that allow reducing the NO_X emissions, we found that there are feasible ways to substantially reduce them, and there are ports that include these methods as part of plans for controlling NO_X emissions. Furthermore, considerable number of port authorities around the world declared their port areas as NECA (NO_X Emission Control Area), where NO_X emissions are limited and hence allow only certain vessels to enter the port (complying with certain emission standards[4]) . However, we suspect that for Israel it would be difficult to implement a similar step, due to several economic and regulatory aspects related to international agreements and treaties. Furthermore, we concluded that tackling the air pollution from the marine sector, will be very difficult, due to many reasons, including:

- Every moment at each port there is a need to cope with dozens of different changing emissions' sources either stationary or in motion (emissions from hoteling, cruising, maneuvering and stand-by). As shown in the report, each of these types of emissions have a significant contribution on the total emissions at the port.
- Large number of vessels being flagged (registered) at other countries, where regulations do not require emission abatement techniques.
- The high cost and technical complexity of installing after treatment techniques (as detailed in the report).
- Insufficient supporting international regulations (excluding new regulations regarding SO_X emissions)

[4] Based on engine generation or instalments of NO_X after treatment techniques

- Trade-wise, Israel is a relatively small country and therefore maybe limited in its ability to to impose drastic restrictions (by its own) that bigger players can (such as: China and various states in the U.S. and the E.U.)

However, with all the aforementioned challenges, we concluded that even after the expected future extensions of marine activities at each port, it is possible to implement a combination of steps as part of a long term and gradual mitigation plan that will enable to achieve by 2030 a significant pollution reduction of NO_X. This decrease can be at significant levels compared to both emissions today and emissions expected at the BAU scenario in 2030. Such a plan can achieve reduction of 50%-70% in NO_X emissions at both Haifa and Ashdod ports. Accordingly, NO_X emissions at Haifa port can be reduced to levels of 3,200-5,000 ton/year and at Ashdod port, it can be reduced to levels of 2,000-3,000 ton/year. In addition, this plan can achieve reduction of approximately 50% in SO_X emissions compared to BAU emissions (in which 80% reduction is expected to be achieved compared to 2018). Furthermore, the plan can enable to substantially reduce the other air pollutants examined in this study. The extent decrease of these pollutants depends on the exact combination of mitigation measures that will be applied.

The mitigation framework we present also includes midterm reduction targets for 2025. The 2025 and 2030 targets are based on implementing several steps that will be very challenging, yet they are feasible and certainly can be pushed forward. The framework presented in this report specifies the main mitigation-measures' principles that can be implemented, yet at a later stage, these measures must be translated into a comprehensive and detailed mitigation plan. Such plan can considerably deviate from the presented framework (by including a different mix of mitigation measures mentioned in the framework), yet we concluded that any form of a plan that will be further established to achieve the RMTs (Recommended Mitigation Targets), will have to include four main components:

1. Requiring or incentivizing approximately 70% of more polluting vessels at each port, to install NO_X after treatment techniques, or use attentive fuel or convert hoteling engines to electric auxiliary engines powered by ESP (Electric Shore Power).
2. Move away relatively more polluting vessels form the port, allowing them to stand-by for porting at distance of at least 5 km from each port.
3. Implement a number of additional operational activities mentioned in the report, as part of new environmental management requirements and procedures that will be enforced at each port in accordance with guidance provided by MoEP.

4. Establishment a task force operation for monitoring and controlling vessels' emission limits at each port. This force should be able to enforce requirements on emission standards at the ports, including the use of proper fuel with limited Sulfur content.

Accordingly, the government will have to allocate considerable amounts of budgets for supporting the following steps:

- Establishment of ESP infrastructure at each port
- Economic incentives or subsidies for emissions reduction (using any of the optional techniques), assuming that due to economic and legal reasons, it is concluded that enforcing new emission limits at the ports can't be achieved with no financial support. This aspect will have to be further examined.
- The cost of the proposed new monitoring and controlling task force.

In summary, the marine sector at both Haifa and Ashdod ports is creating high magnitudes of air pollution, which are likely damaging the air quality of populated areas at different distances from each port. We suspect that the extent of this pollution is higher than previously thought. NO_X polluting levels are the highest and most challenging to combat, while SO_X pollution being also very high but expected to significantly decrease due to new international regulations expected to enter in 2020. However, in the upcoming 20 years (at least), if no special efforts by the government are made for reducing NO_X level of pollution, it will not significantly decrease (if not increase). Implementation of the presented emissions reduction plan will also reduce other air pollutants, including $PM_{2.5}$, VOC and CO, depending on the selected mitigation techniques. Although there are a number of steps that can be taken in order to meet the RMTs presented in this report, it appears to be a highly difficult challenge from both the regulatory and economic standpoints. Accordingly, in order to begin promote these efforts, the following steps should be first completed:

- Run an air pollution dispersion model to assess the level of impact that the current vessels air pollution (in the port and in the territorial waters) has on populated areas at different distances from the sources of pollution.
- Estimate the damage costs of the pollution
- Investigate in more detail the technical challenges of the various mitigation alternatives and their costs. We recommend that it should currently focus on SCR, ESP and perhaps other options of alternative fuels.

- Study in more detail different modes of local intervention, for example: economic incentives that are possible to provide to fewer polluting vessels versus penalties (fines) to more polluting vessels; and compare the potential effectiveness of each model.
- Assess the levels of economic burden that are possible to impose on polluting vessels and address possible consequences of imposing such penalties.
- Examine legal and economic framework possibilities for declaring NO_X -ECA at Haifa and Ashdod ports (or all the Israeli coastline).
- Examine if and to what extent it would be possible to require vessels to comply with local emission limits, with different levels of governmental assistance provided as subsidies (if any). Then, estimate the financial support that will be needed to support the RMT efforts.
- Detail the exact fundamental steps require to include in an 11-year mitigation plan, including budges that will require for realizing this plan.

Finally, once the mitigation plan is established, begin its gradual implementation in order to meet the RMTs for 2025 and 2030.

Key terms and abbreviations

1.Haifa Bay area	2. Air pollution	3. Marine vessels
4. Carbon dioxide (CO_2)	5. Nitrogen oxides (NO_X)	6. Carbon monoxide (CO)
7.Volatile Organic Compounds (VOCs)	8. Sulfur Dioxide (SO_2)	9. Respirable Particulate Matter ($PM_{2.5}$)
10. Marine diesel	11. heavy fuel oil (HFO)	12. Israeli Clean Air Act
13. Air pollution dispersion model	14. Radius of impact	15. Sensitive receptors
16. Mitigation measures	17. International Marine Organization (IMO)	18. Emission Restricted Area (ECA)
19. Electric Shore Power (ESP)	20. Selective Catalytic Reduction (SCR)	21. NOx Tier III emission limits
22. 12 nautical miles (Territorial waters)	23. Emission Mitigation Costs (EMC)	24. Emission Mitigation Sufficiency (EMS)
25. Emission Mitigation Efficiency (EME)	26. Business As Usual (BAU)	27. Recommended Mitigation Targets (RMT)

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1. Introduction

Ambient, or outdoor air pollution, is the second environmental health risk in the world, with about 3.7 million deaths per year (indoor air pollution is the first, with 3.3 million deaths). Air pollution is strongly linked to cardiovascular diseases (such as strokes and ischemic heart disease), cancer, and respiratory diseases (1). Furthermore, in developed countries in particular ambient air pollution is the major cause for an environmental health risk. Estimation in Israel for 2010, it caused more than 2,500 deaths a year, a loss of more than 40,000 Disability-Adjusted Life Years lost (DALYs), and an economic cost of about 33 billion NIS- per year (2)

Due to its heavy air pollution and highly populated nature, people who live and work around the Haifa Bay area, are subjected to higher risks for air pollution associated diseases. The Ministry of Environmental Protection (MoEP) has set a goal for air pollution reduction in the area. In 2015, the government has approved a national plan to reduce air pollution in the Haifa Bay area (3-4). One of the main air pollution contributors in this area, are marine transportation and vessels that harbor at the Haifa port. Furthermore, sources of significant marine emissions exist also at Ashdod port. Each port sources of pollution are potentially affecting the air quality of workers at the port as well as residential areas that are located at relatively shorter distances from each port.

Most marine vessels usually rely on combusting residual oil fuel, also called heavy fuel oil (HFO). HFO is a low grade fuel that emits high level of air pollution in the burning process that occurs in the engine. Moreover, it is common that other materials, such as hazardous chemicals, waste oil and motor oil, are blended with the HFO. The use of this mixed fuel is even worse (6)

Most of the air pollution created by marine vessels in ports is not from the relatively short phases of transport into and out of the port (although it is also a significant air pollution contributor), rather due to the electricity production usually generated by marine diesel burning in the auxiliary engines to power communication devices, lighting, ventilation and other devices- while at berth (6-7).

Although marine diesel is cleaner than HFO, it is still a very dirty fuel that creates enormous levels of pollution.

Previous studies regarding marine vessels emissions in Israel (2010), show that this activity creates 3-9 times more air pollution than their relative CO_2 share. The problem is even worse, as these emissions are not spread evenly across the country, but are centered in Israel's main ports- Haifa and Ashdod (11). For comparison, In 2010, SO_2 emissions from marine vessels in the Haifa port, were practically the same as those from Oil Refineries Ltd (ORL or BAZAN) (11-12). Furthermore, although ORL's emissions have decreased since then due to more strict regulations (for example- SO_2 emissions dropped by 80% between 2010 and 2014), it is likely that marine vessels' emissions have increased as a result of lack of specific regulation and the growth in demand for marine transportation. As we show in this study, all emissions of NO_X, SO_X, $PM_{2.5}$, CO and VOC are suspected to be significantly higher than previous estimations. In addition, we present high-level estimations concerning Ashdod port. Furthermore, we estimate future emissions based on several scenarios, in which we take into account that in the upcoming years, marine activities at both Haifa and Ashdod areas, are expected to increase due to plans of extending Haifa port and establishing the southern port (14-19).

While global NO_x and SO_2 emissions are declining from most anthropogenic sources, they are on the rise from marine vessels. Marine vessels' NO_x and SO_2 emissions represent about 15% of the global air pollution from these sources- 5 times more than marine vessels' CO_2 share. 70% of all marine vessels PM emissions occur within 40 km off shore, and can reach the land (8). It is estimated that in the absence of relevant policies, marine vessels' emissions might grow by 50-250% until 2050 (7, 9-10). One of the main reasons for this potential future increase is that Marine air pollution is one of the last air pollution sources to be globally regulated by international standards. There are several reasons for this delayed regulation (listed in the report), and while local jurisdictions can restrict air pollutant emissions within 12 nautical miles from their shorelines (territorial waters), they cannot dictate design, structure, staffing and equipment. Only the International Maritime Organization (IMO) can approve air pollutant emissions restriction beyond that (within exclusive economic zone and international waters). This makes any local jurisdiction attempt to establish feasible emissions' restrictions on marine vessels (within the 12 nautical miles), to be highly dependent on IMO's related decisions and actions. For example, in the case of SO_X emissions, following the establishment of the North Sea SECA in 2007 (limiting sulfur fuel content from 4.5% to 1.5%), Sulfur emissions from ships dropped by 45% after 2007 (20). Lowering the sulfur limit within the North Sea ECA from 1% to 0.1%, was followed by a further 3 fold reduction in the relative ships SOx contribution to air pollution (21). In the case of NO_X emissions, Within Nitrogen ECAs (NECAs), (if declared by a local jurisdiction) NO_X emissions are restricted. The SECAs and NECAs, are based on implementing the full International Convention for the Prevention of Pollution from Ships (MARPOL), which includes IMO's Tier iii MARPOL Annex VI regulation 13 (6-8, 12, 16). For complying with these standards (concerning NOX emissions), several NO_X mitigation strategies are proposed, including: switching to Tier III standard engines (32), switching to alternative fuels, installing NOx emissions' reduction technologies and more. The present NECAs are the same as the SECAs in North America, the United States and France Caribbean sea areas. However, most other countries, including all countries in the Mediterranean Sea are currently not included in NECAs (32)

Therefore, for Israel at the present time to restrict NO_X emissions in a similar manner that it is being done in NECAs, can be a very challenging task. However, this study shows that reducing NO_X emissions from both Haifa and Ashdod ports is important, and there are feasible ways to gradually achieve significant emission mitigation targets. By implementing a number of approaches for reducing NO_X emissions at each port, other emissions such as: SO_X, $PM_{2.5}$, CO and VOC , can also be substantially reduced.

2. Study's goals

This study was designed to achieve five main goals

1. Analyze the marine vessels' activities creating air pollutants emissions in both Haifa and Ashdod ports, and update previous notion regarding this aspect.
2. Examine the importance of mitigating the pollution, based on the emissions' potential of affecting the air quality of populated areas surrounding the ports.
3. Examine various technological and operational solutions for reducing the pollution and compare their feasibility.
4. Present several future emission scenarios in relation to different strategies for emission reduction.
5. Establish policy recommendations for achieving cost-effective reduction levels of emissions from the marine sectors at Haifa and Ashdod ports.

Based on 1-5, present a feasible framework for achieving a gradual decrease of
the air pollution at each port. The purpose of this framework is to serve a basis for a compensative and detailed mitigation plan that to be established at later stage.

3. Work plan and methodology

3.1 Assessment of marine activities at Haifa and Ashdod ports

Four main sources of data and methodology approaches were used to estimate the current activities at each port:

- Daily tracking information available at "Marine Traffic. Com". This was the main source with most valuable data. This data is based on real time (live map) tracking of marine transportation at many ports worldwide including Haifa and Ashdod (relying on Big Data information based on vessels' connection to GPS). Daily statistics regarding number of "vessels in port" and "expected arrivals" were tracked on dozens of random days during different hours in a 4 month period of time[5]. This data was used to estimate the average number of vessels hoteling at the port as well as the average number of vessels at stand-by. In addition, statistics regarding port congestion and weekly statistics regarding average arrivals and departures by hour of the day (as a weekly average), were obtained and furtherly calculated to estimate daily average traffic by hour (as an average number of vessels arrivals + departures by hour during 24 hours). Average size, type and year of vessels (by number) as well as acceptable time spent for cruising, maneuvering, stand-by and hoteling, were estimated by looking at several sources of information: acceptable averaged fleets around the world, by sampling daily updates provided at each port at Marine Traffic.Com and by related information mentioned at Haifa's' port EIA documents regarding its plans for expansion.
- Previous surveys with information published concerning number and type of vessels at each port.
- Related questions referred to officials.

[5] Between September and December 2018

3.2 Emissions calculations at each port

After characterizing the marine activities at each port (see stage 3.1), related emission factors were attributed to the different type of vessels activities at each port. Based on stage 3.1, the following main variables were analyzed and characterized for using related emission factors:

1. Number of vessels by type of vessel, size of engine, year of vessel, fuel type and engine duty.
2. Average time spent for cruising, maneuvering, stand by and hoteling.
3. Other physical parameters such as: stacks heights, gas temperature and velocity, emissions rate and more (see variable examined in appendix 2).

Relevant specific emission factors for NO_x, SO_2, $PM_{2.5}$, CO and VOCs were taken from Entec Ship Emissions Inventory (106) and U.S. EPA AP-42 Emission Factors (107). These emission factors were normalized in accordance with 1-3 variables as well as additional variables detailed in appendix 2.

Eventually the total emissions of each pollutant (from each type of vessel) were divided by three operational regimes: cruising (in territorial waters ~ 20 km), maneuvering and stand by (up to 3 km from the port) and hoteling (in the port). The emission rates and total volumes are strongly dependent on these operational regimes/type of navigation.

For a single navigation, the emissions can be expressed as:

$$E_{vessel} = E_{cruising} + E_{manoeuvring} + E_{hoteling}$$

Fuel types are BFO (Bunker Fuel Oil), MDO (Marine Diesel Oil) and MGO (Marine Gas Oil). When fuel consumption for each navigation phase is known, the emissions of pollutant i, can be calculated by the following equation:

$$\boldsymbol{E_{vessel,i,e,f}} = \sum_{\boldsymbol{p}} \left(\boldsymbol{FC_{e,f,p}} \times \boldsymbol{EF_{i,e,f,p}} \right)$$

Where:

E_{vessel} = overall emission from a vessel (ton)

FC = feul consumption (ton)

EF_i = emission factor for pollutant i (kg/ton)

i = pollutant (NOx / CO / VOC / PM2.5 / SOx)

f = fuel type (BFO / MDO / MGO)

e = engine type (slow- / medium- / high- speed diesel or gas turbine)

p = phase of the navigation (cruising, manoeuvring, hoteling)

Advanced calculation method was applied in cases where fuel consumption per operational regime were not known. In such cases, the emissions were calculated based on the engine duty installed (power and operation time) at the different phases.

In the case of emissions from installed auxiliary engines, we assumed a load factor and total time in hours for each phase using the following equation:

$$\boldsymbol{E_{vessel,i,e,f}} = \sum_{p}\left[\boldsymbol{T} \times \boldsymbol{P} \times \sum_{ec}\left(\boldsymbol{P_{ec}} \times \boldsymbol{LF_{ec}} \times \boldsymbol{EF_{i,ec,e,f,p}}\right)\right]$$

Where:

E_{vessel} = overall emission from a vessel (g)

EF_i = emission factor for pollutant i (g/kWh) (see table 1.2.1-1, appendix 2)

LF = engine load factor (%)

P = engine nominal power (kW)

T = time (hour)

ec = engine category (main / auxiliary)

i = pollutant (NOx / CO / VOC / PM2.5 / SOx)

f = fuel type (BFO / MDO / MGO)

e = engine type (slow- / medium- / high- speed diesel or gas turbine)

p = phase of the navigation (cruise, manoeuvring, hoteling)

3.3 Assessment of air pollution potential impacting air quality at sensitive receptors

This study did not include running a full air pollution dispersion model. Nevertheless, this stage included an attempt of obtaining first indications regarding the chance and extent to which the marine pollution is affecting the actual air quality at populated areas around Haifa port[6]. This was done based on a qualitative analysis of several fundamental factors affecting air pollution dispersion, which were examined in an air modelling technique implemented for this research. In this model, various factors were taken into account, including: the substantial emission rates, the relatively low stacks heights (10-50 m) and several types of environmental data (such as

[6] Similar assessment for Ashdod was not carried out as it was not included in the project's scope

meteorological data, topographic information, etc), as well as distances of populated areas from the sources of emissions and the typical air quality around these areas. For this analysis, environmental data including topographical data from NASA's Shuttle Radar Topography Mission STRM3 (~90 m resolution), and meteorological data from the Haifa Bay area meteorological stations, were collected and analyzed. The outcome was an "expert view" regarding the probability and extent of NO_X emission sources affecting its air concentrations at different distances from the port

3.4 Study of trends in international regulations and policies concerning marine air pollution

The study focused on examining various technological, economic and regulatory trends associated with the marine sector. Firstly, it was based on a comprehensive literature review in which the following information was investigated:

a) Cost of marine vessels
b) Costs of marine transport operations
c) Average life span of a vessel.
d) Typical age mix of vessels at international fleets.

Investigating these aspects allowed to characterize this sector with respect to the complexity of imposing new regulations with cost burdens. In addition, specifically based on c and d, it was possible to estimate the rate of which old vessels are replaced by new vessels with improved emission standards.

Secondly, we investigated the current and future expected international regulations and standards concerning marine emissions of NO_x, SO_2, $PM_{2.5}$, CO and VOCs, as well as the international bodies (and their legal status) in charge of establishing these standards. In addition, we examined other ports' local regulations/policies and frameworks implemented in practice in order to control and reduce marine air pollution.

3.5 Review and analysis of marine air pollution mitigation techniques, costs and cost-effectiveness

This stage included a review of various potential mitigation techniques that can be applied on vessels in order to reduce NO_x, SO_2, $PM_{2.5}$, CO and VOCs emissions. Since new vessels from 2016 have to meet more strict emission standards, we've focused on techniques that can be retrofitted on existing vessels (highly polluting vessels) as well as other non-technological "soft" methods related for example to: port congestion management, control on vessels speeds, imposing green taxes related to specific emissions and other type of management and operational aspects that can affect air pollution performance around ports areas. In addition, we have gathered first information regarding the costs associated with the different techniques as well as other technical requirements. Finally, we examined the techniques' cost-effectiveness by taking into account their potential reduction capabilities relative to their costs.

3.6 Mitigation techniques analysis feasibility

This analysis was based on six fundamentals that were examined with respect to each technique:

- Is the method technically feasible (as a retrofit)?
- Was the technique ever implemented successfully by vessels and by what extent?
- To what extent the technique reduces the pollutant emissions (emission mitigation sufficiency), and to what extent it's important to reduce the pollutant at the Haifa and Ashdod ports (based on the results of previous stages)
- Cost range of the technique and its cost-effectiveness (compared with other techniques), estimating: Emission Mitigation Costs (EMC), Emission Mitigation Sufficiency (EMS) and Emission Mitigation Efficiency (EME)
- Was this technique included (and used in practice) as part of requirements by other ports who declared ECA concerning a related pollutant?

3.7 BAU and RMT scenarios calculations

Based on all the previous stages, we have examined several future emission scenarios for the years 2025 and 2030. Two scenarios were examined with respect to each pollutant and year: Business As Usual (BAU) scenario, which assumes that no special active government intervention is applied; and Recommended Mitigation Target (RMT), which represent reduced emissions' targets, which we concluded, are feasible to achieve assuming a mitigation plan is implemented. The details of the various assumptions with regard to the components that can be included in the mitigation plan are detailed in 5.1.3.2, 5.1.2.3 and 5.5. Various mitigation components that can be included in a general mitigation plan were examined. These components can substantially differ in some fundamentals (mainly related to the techniques that can be implemented). We present RMT as a total reduction potential that can be achieved, relying on two different mitigation techniques' alternatives, that if both are implemented at a certain mix (presented as RMTA1 and RMTA2, see paragraph 5.1.3.2, 5.1.2.3) with additional other components (see paragraph 5.5), then RMT can be achieved. Alternatively, if only one of the alternatives is applied (RMTA1 or RMTA2), then we present also the estimated emissions for each RMTA by its own. This was done in order to demonstrate the variations in performance between different alternatives, and how by combining both of them in one plan (RMTA1 and RMTA2) at some level of mix, certain RMT can be achieved. A different mix of each RMTA would potentially achieve a different estimated outcome. Each RMTA evolves between 2025 and 2030, and has some difference in performance at each port (as discussed in more detail in the report).

5. Results and discussion

5.1 Emission calculations and analysis by scenarios at Haifa port

5.1.1 Current state of marine emissions at Haifa port

The current total estimated air pollution emissions from marine vessels activities at Haifa port are very high. The pollutants mostly emitted are NO_X and SO_X with 11,167 and 8,877 ton/year respectively (see figure 1) with all other pollutants examined ($PM_{2.5}$, VOC and CO) reaching lower values of 889, 444 and 1,778 ton/year respectively.

Furthermore, all pollutants are also emitted at substantial rates, and based on the air modelling data we analyzed for this study[7], we conclude that it is highly likely that these emissions have a significant impact on the actual air quality (concentration of pollutants in the air) of various populated areas at different distances from the port (see more details in appendix 1).

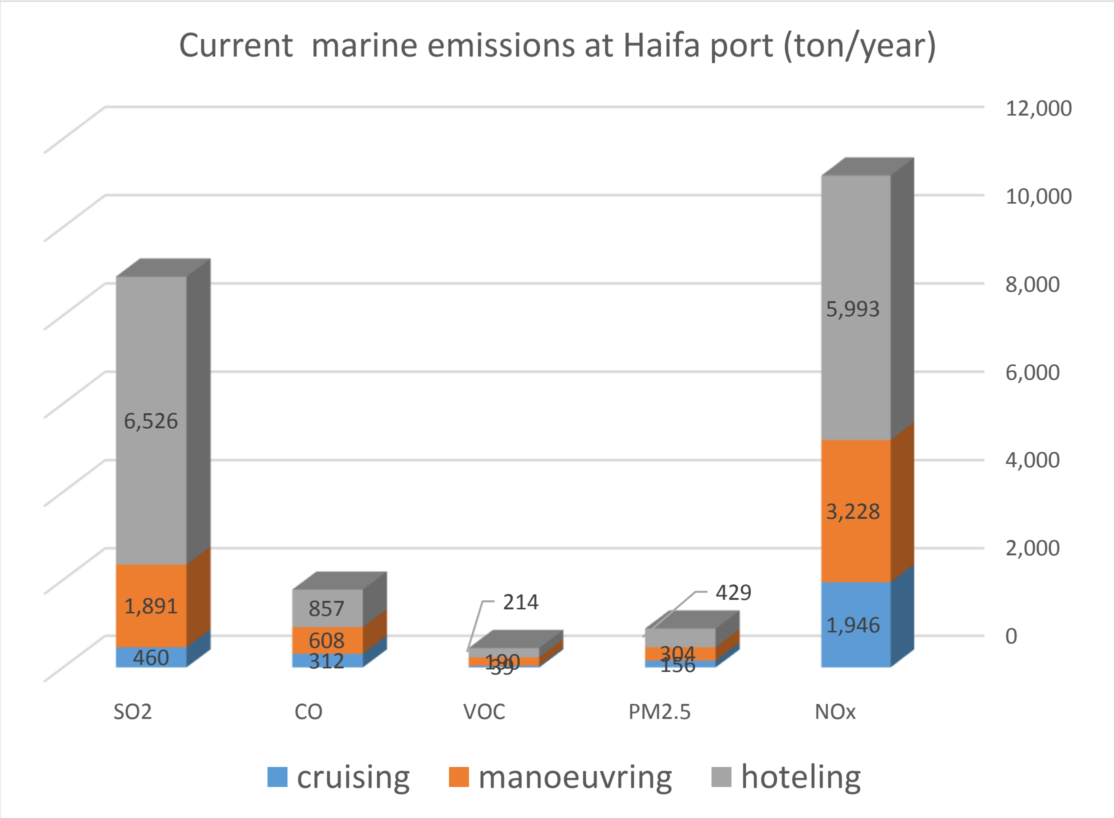

Figure 1. Current marine emissions at Haifa port (ton/year) estimated for 2018.
Emissions are divided between the three different main operational activities of the vessels in the port, which create different emissions' rates (cruising, maneuvering &stand-by and hoteling).

[7] That takes into account the typical atmospheric conditions and topography at the Haifa bay area.

For perspective, the NO_X emissions from all vessels at the port during the hoteling, maneuvering and stand-by stages, are similar to a 1,000 MW power plant exclusively running on diesel fuel oil, which is a very polluting fuel, allowed to be used in power plants only during emergencies. When taking into the cruising activities of ships on their way to the port, the emissions are even higher. The current 8,877 ton/year of SO_X emissions (together for all operational activities) are also considered very high, however based on upcoming international regulations, these emissions are expected to be significantly reduced (see figure 2). All other emissions of either CO, VOC and $PM_{2.5}$ are also significant, especially when combined together.

5.1.2 Marine emissions at Haifa bay after expansion of the port (2025)

5.1.2.1 <u>BAU Scenario</u>

In accordance with the current plan of expanding the Haifa port, after this expansion (in 2025), in a BAU scenario (assuming no special mitigation plan is applied) NO_X emissions are expected to stay approximately the same compared to 2018 (11, 167 ton/year in 2018 versus 11,119 ton/year in 2025, see figure 2), while CO and VOC are expected to slightly increase and PM2.5 to slightly decrease (see figure 2). However, SO_X emissions are expected to decrease dramatically from 8,877 ton/year in 2018 to 1,968 ton/year, that is due to upcoming new international regulation limiting the content of sulfur in vessels' fuels (see paragraph 5.3.4.2). The usage of this type of fuel is also the reason for the small decrease in PM2.5.

CO and VOC emissions estimated increase, is a result of Haifa port expected expansion in 2025, while taking into account that by this time only limited number of newer vessels are estimated to replace older vessels (see more information in paragraph 5.3.7), and that in any case CO and VOC emissions from newer fleets are not as reduced as NO_X emissions are reduced (from 2016) when compared to older fleets (more data on these aspects in paragraph 5.3). Accordingly, NO_X emissions stable estimates for BAU in 2025 (compared to 2018) is a result of a calculation , that takes into account the current reality of a relatively slow rate of changeover to newer fleets (see paragraph 5.3.7). In addition, it takes into account that any vessel that will replace an old vessel (even if limited in its number) will emit 70%-90% less NO_X.. Both these factors together are estimated to offset the moderate increase in the total number of all vessels expected at the expanded port, so by 2025, NO_X emissions will basically stay the same (additional information on the various data and assumptions used for BAU calculation in 2025, is provided in appendix 2).

5.1.2.2 RMT Scenario 2025

Unlike the case of SO_X and $PM_{2.5}$ that are expected drop due to new international regulations on Sulfur content in marine fuel, mitigating NO_X emissions entails substantial technical, economic and regulatory challenges, and therefore will be much limited. NO_X emissions at ports belonging to countries in the Mediterranean Sea are currently not expected to be sufficiently regulated at an international level (see paragraph 5.3.4.2). The only current main international regulations that can reduce NO_X emissions at local ports in the Mediterranean Sea, concern stricter NO_X emissions standards by new manufactured vessels from 2016. However, as mentioned previously and explained in more detail in paragraph 5.3, the rate of fleets' passive changeover from older to newer vessels is relatively slow. In addition, costs of retrofitting older vessels with after treatment techniques is costly enough (see paragraph 5.4) to not happen by choice, but only with either highly effective economic incentive and/or a mandatory requirement. Therefore, achieving substantial emissions reduction compared to BAU must include a local policy and regulatory intervention. We propose to act with a combination of measures in order achieve such reduction. As discussed in paragraphs 5.3 and 5.4, we concluded that although these measures are challenging, they are feasible to be implemented, and without implementing them, reduction of marine emissions will be very small (if any). However, implementation of a mitigation plan which is based on the fundamentals discussed in paragraphs 5.1.2.3 and 5.5, should allow achieving Recommended Mitigation Targets (RMTs). Meeting these RMTs is based on combining two different main methods; however, we also present two other RMT alternatives (RMTA) that each one of them is based only on one of the fundamental methods of the RMT. These RMTAs (RMTA1 and RMTA2) present how different methods of action can achieve certain targets, and how a combination of both methods can be especially effective, while avoiding reliance on only one entire method which might be hard to implement on all vessels.

By implementing the fundamental measures suggested in paragraphs 5.1.2.3 and 5.5 for 2025 RMT, we estimate that it's feasible to reduce NO_X emissions by approximately 48% to levels of 5,738 ton/year compared to 11,119 ton/year as estimated in a 2025 BAU scenario. The RMT will also allow reducing VOC, CO, PM2.5 and SOX by 22%-26% compared to BAU.

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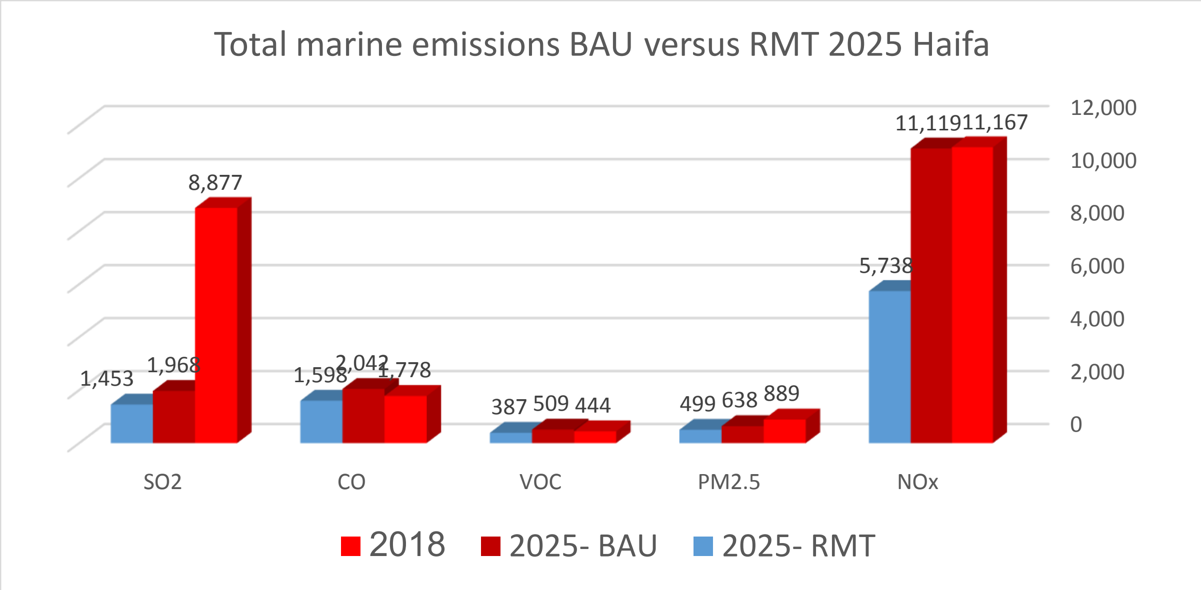

Figure 2. Estimated annual marine emissions at Haifa port in 2018 compared to 2025 BAU (Business As Usual) and RMT (Recommended Mitigation Targets) scenarios. Emissions represent total values from all three main vessels' activities creating emissions (cruising, maneuvering& stand-by and hoteling).

5.1.2.3 Recommended Mitigation Target Alternatives (RMTAs) for Haifa port 2025

Realizing the RMT for Haifa port in 2025, will require significant inputs from both the government and the fleets. We introduce a framework in which a combination of actions will have to be followed, and with emphasis on specific activities associated with RMT-Alternatives (presented as "RMTA1" or "RMTA2") allowing to achieve final recommended mitigation targets (presented as "RMT").
The 2025 RMTAs assumes the following compared to BAU:

RMTA1

- Infrastructure for Electric Shore Power (ESP) (see more information paragraph in 5.4), is established at the port and 30% of vessels are using it on a routine basis, so 30% of emissions from hoteling are eliminated from the port.
- A port policy is enforcing older polluting vessels to stand-by at a longer distance away from the port (reducing their stand-by time closer to the port by 30%).
- Other measures are applied and enforced in accordance with the details provided in the mitigation framework (paragraph 5.5).

RMTA2

- The same of RMTA1, excluding the implementation of ESP, but instead, 50% of old vessels at the port, are forced or incentivized to be replaced with either new vessels from 2016 or vessels with retrofitted engines or with SCR/other related after treatment techniques (see paragraph 5.4).

RMT

- Both ECP and after treatment techniques are equally implemented on 50% of existing vessels. Half of more polluting vessels are using an after treatment technique while other polluting vessels are using ECP. In addition, other measures are applied and enforced in accordance with the details provided in the mitigation framework (paragraph 5.5).

As presented in figure 3, the two RMTAs for 2025 are associated with some variation in the calculated reduced emissions that can be achieved. Establishing the electric shore power infrastructure has the most potential to reduce emissions. However, assuming that the infrastructure is successfully built by 2025, we suspect that only a limited number of vessels will exploit this option and invest in converting their hoteling engine to electricity (not more than 30% as RMTA1 suggest). We take into account the likelihood of which more vessels will choose at this stage to implement the currently leading technique for reducing NO_X, which is SCR (as RMTA2 suggest). However, since for the longer term, ESP can make the most beneficial difference, we recommend that special efforts will be made to promote this option at higher capacity for 2030 (see paragraph 5.5).

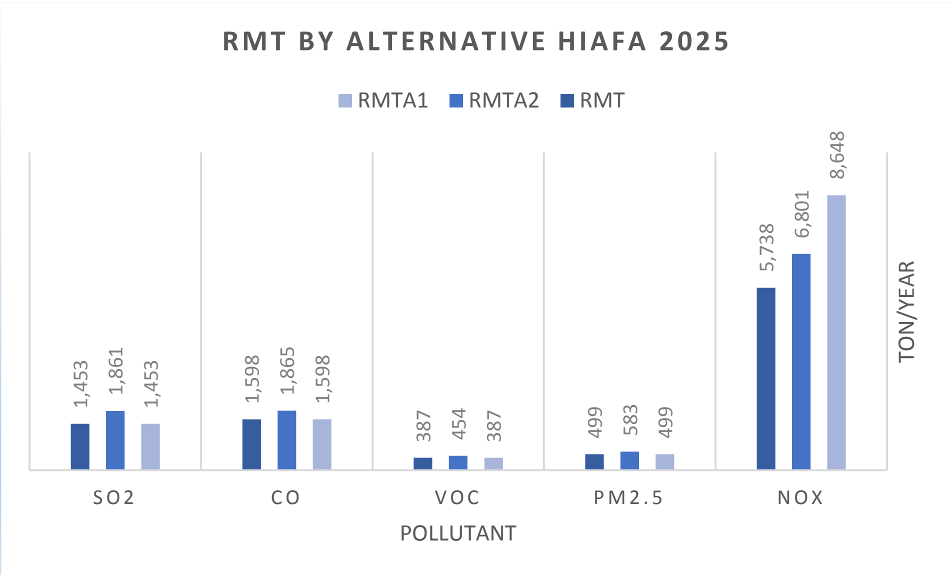

Figure 3. Recommended Mitigation Targets by Alternatives (Haifa port 2025).
RMTA1- RMT alternative that is mainly based on 30% of vessels using ESP in addition to other non-technological measures detailed in in paragraph 5.5.
RMTA2- RMT alternative that is mainly based on 50% of more polluting vessels installing NOX after treatment techniques, in addition to other non-technological measures detailed in in paragraph #.

RMT- Assumes that both techniques are equally implemented (50% of existing vessels are using one of them) in addition to other non-technological measures detailed in in paragraph 5.5.

5.1.3 Marine emissions at Haifa port in 2030

5.1.3.1 BAU versus RMT scenarios 2030

As explained previously, by taking into account the typical life span of a vessel, the current distribution of vessels' age and the current/upcoming international emission standards and regulations, we conclude that even after 2030, "passive processes" (such as more strict international emissions' standards that are expected to take place), will be very limited in reducing the total vessels' NO_X emissions and the their impact on the air quality at public receptors surrounding the Haifa bay. However, we conclude that by 2030, it is feasible to achieve much lower NO_X emission targets aiming at 3,263 ton/year compared to 10,140 ton/year at the BAU scenario (which is a reduction of approximately 70% compared to 2030 BAU, see figure 4). In addition, significant reductions of approximately 40%-45% can be achieved compared to BAU concerning VOC, PM2.5 and CO emissions (see figure 4).

Such RMT can be realized by continuing to implement the main solutions suggested in this study (see paragraphs 5.1.3.2 and 5.5) during an 11 year mitigation plan. However, in the case of SO_X, we conclude that the current upcoming new international regulations regarding Sulfur content in fuel, will allow to achieve in BAU scenario a major decrease (of approximately 80% compared to 2018, see figure 4) with no need for much further steps to be taken by MoEP. Yet, by implementing some of the main solutions recommended for reducing NO_X emissions, an additional and significant decrease in SO_X commissions can be achieved (approximately 50% decrease in SO_X emissions compared to BAU, see figure 4) reaching levels of 964 ton/year at RMT 2030 compared with 1,969 ton/year at BAU 2030.

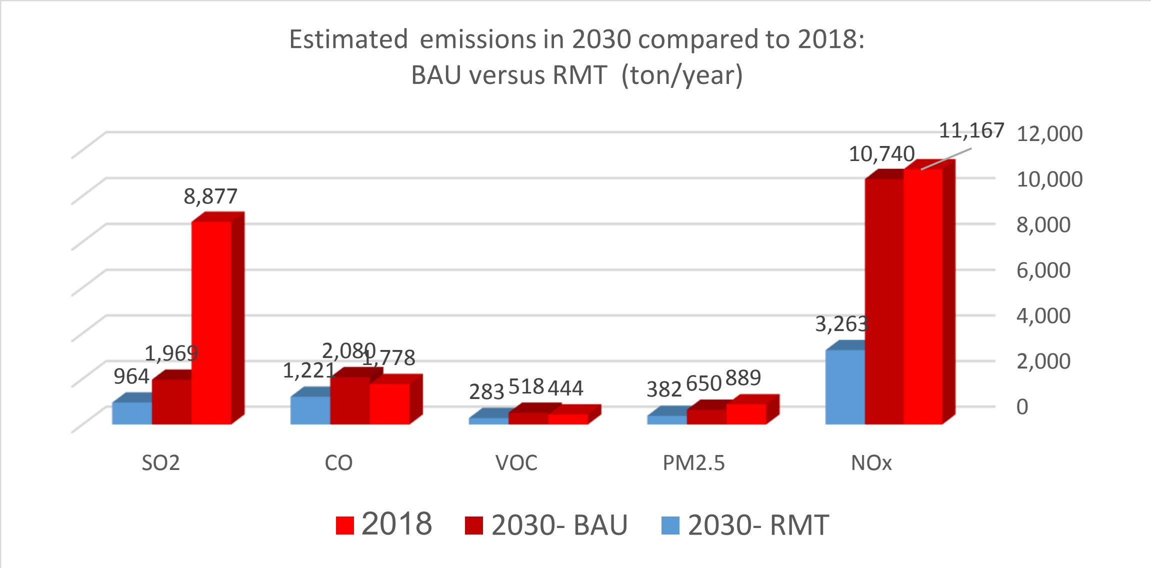

Figure 4. Estimated annual marine emissions at Haifa port in 2018 compared to 2030 BAU (Business As Usual) and RMT (Recommended Mitigation Targets) scenarios. Emissions represent total values from all three main vessels' activities creating emissions (cruising, maneuvering& stand-by and hoteling).

5.1.3.2 Recommended Mitigation Target Alternatives' (RMTAs) for Haifa port 2030

Realizing the RMT for Haifa port in 2030, will require significant additional and continuing inputs from both the government and the fleets. The RMT framework suggested for 2025 continues and extended so by 2030, more decrease of all pollutants is achieved compared to BAU 2030. Similar to 2025, it includes a combination of further actions associated with RMT-Alternatives (presented as "RMTA1" or "RMTA2") allowing to achieve final recommended mitigation targets (presented as "RMT").

The 2030 RMTAs assumes the following compared to BAU:

RMTA1

The same for RMTA1 2025 with the following amendments:

- ESP is extended to 50% of vessels hoteling the port, so 50% of all emissions from hoteling are eliminated from the port.
- Stand by time closer to the port of more polluting vessels, is reduced by 60%.
- Other measures are applied and enforced in accordance with the details provided in the mitigation framework (paragraph 5.5)

RMTA2

The same for RMTA2 2025 with the following amendments:

- 70% of old vessels at the port are forced or incentivized to be replaced with either new vessels from 2016 or vessels with retrofitted engines or with SCR/other related after treatment techniques.
- Stand-by time closer to the port of more polluting vessels is reduced by 60%.

<u>RMT</u>

Both ECP and after treatment techniques are equally implemented on 70% of existing vessels. Half of more polluting vessels are using an after treatment technique while other polluting vessels are using ECP. In addition, other measures are applied and enforced in accordance with the details provided in the mitigation framework (paragraph 5.5)

As presented in figure 5, the two RMTAs for 2030 are associated with some variation in the calculated reduced emissions that can be achieved.

Since most emissions are emitted from the hoteling stage (see figure 1), more reliance on ESP in 2030 can be especially beneficial and more practical to achieve (compared to 2025). When comparing RMTA1 and RMTA2, it doesn't necessarily seems to be the case for NO_X (10% more reduction is achieved by RMTA2), however, when taking into account all other emissions, reaching a target where 50% of all vessels are using ESP (RMTA1 for 2030) is more beneficial than reaching a target where 70% of all vessels are either from 2016 or retrofitted with new engines/after treatment techniques (RMTA2 for 2030). It is manifested by RMTA1 (when compared to RMA2) being lower at emissions of $PM_{2.5}$, VOC, CO, SO_2 by approximately 25%-30% (based on figure 5). However, as these emissions are significantly lower than NO_X (at both RMTAs), perhaps a mitigation strategy that is more cost-effective when focusing on NO_X emissions is preferred. In any case, we suggest of promoting both RMTAs with optional changes within each alternative on the expense on the other, but while achieving the final RMT presented in this report, which can be based on some form of combination of both RMTAs. It is likely that promoting ESP will be more beneficial for the longer run (after 2030), yet more costly and complicated to apply (see paragraph 5.4). However, this estimation should be furtherly examined in more detail at a later stage.

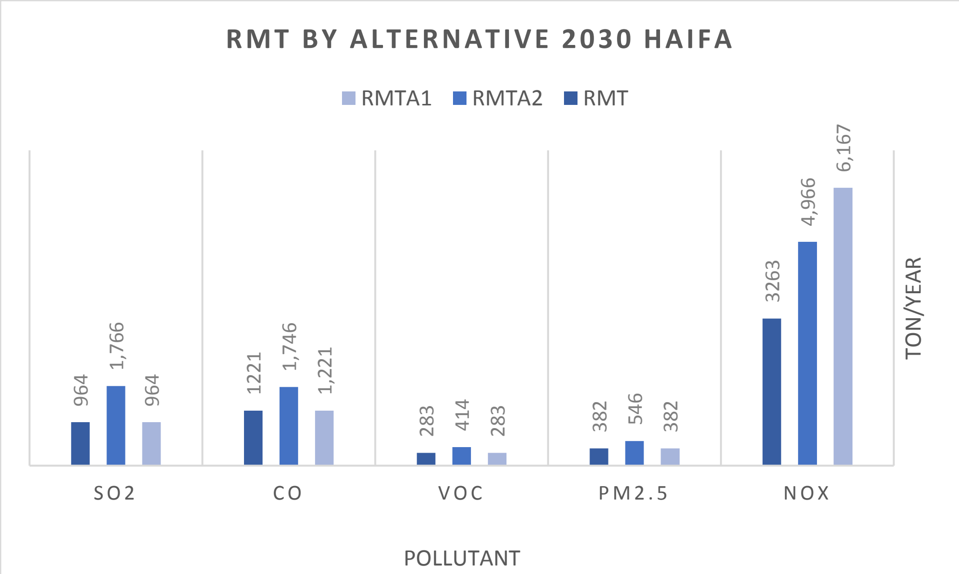

Figure 5. Recommended Mitigation Targets by Alternatives (Haifa port 2030).
RMTA1- RMT alternative that is mainly based on 50% of vessels using ESP in addition to other non-technological measures detailed in in paragraph 5.5.
RMTA2- RMT alternative that is mainly based on 70% of more polluting vessels installing NO_X after treatment technique, in addition to other non-technological measures detailed in in paragraph 5.5.
RMT- Assumes that both techniques are equally implemented, so 70% of existing vessels are using one of them in addition to other non-technological measures detailed in in paragraph 5.5.

5.2 Emission's calculations and analysis by scenarios at Ashdod port

5.2 .1 Current state of marine emissions at Ashdod port

Current marine emissions at Ashdod port were found to be also very high with annual emissions of SO_X and NO_X of 7,245 and 6,251 ton/year respectively, while other emissions such as $PM_{2.5}$, VOC and SO_2 were found to be significantly lower with levels of 564, 281 and 1,127 respectively . All current emissions from Ashdod port are lower than at Haifa port (approximately 54% difference in the case of NO_X total emissions), and especially emissions from cruising and maneuvering which are approximately double at Haifa compared to Ashdod. That is due to higher congestion at Haifa port which a result of approximately 25% more vessels hoteling at Haifa (at any time on average) compared to Ashdod and a much higher average number of vessels arrivals and departures per hour (of approximately double in Haifa than Ashdod) and approximately 40% more total number of vessels hoteling + on stand-by to port (data not shown[8]). Furthermore, compared to Haifa port, the chance of Ashdod's marine emissions affecting air quality of public receptors is indicated to be

[8] Available at excel appendix to this report.

lower[9]. This is mainly due to major differences in the topography of Ashdod port surrounding area compared to Haifa, in addition to the differences in emission rates and environmental conditions. However, as this aspect was not examined in this report (with regard to Ashdod), it cannot be ruled out that also at Ashdod port the marine emissions have a substantial impact on actual air quality on various populated areas.

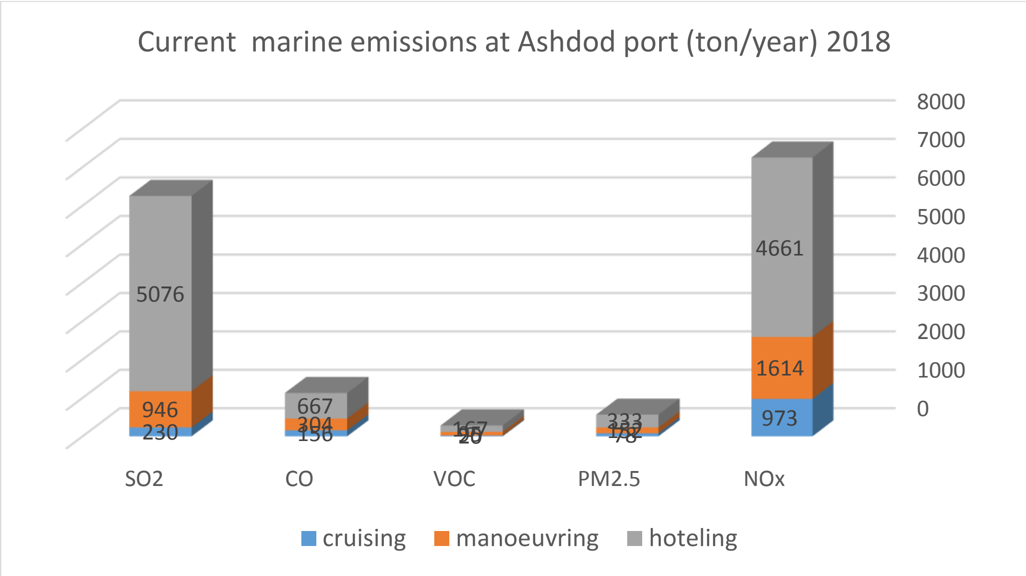

Figure 6. Current marine emissions at Ashdod port (ton/year) estimated for 2018. Emissions are divided between the three different main operational activities of the vessels which are responsible for different emissions' rates (cruising, maneuvering and hoteling).

5.2.2 <u>Marine emissions at Ashdod port 2025</u>

Taken into account a moderate expansion of activities at the port, it's estimated that in a BAU scenario, Ashdod's NO_X emissions in 2025 will not significantly change. However, SO_X and PM emissions are expected to have a major drop (of approximately 80% and 34% respectively) due to the upcoming implementation of the new international regulations concerning Sulfur content in vessels' fuel (see paragraph 5.3).

[9] Based on a limited air quality model implemented for this study. This model was not included at the scope of this research but was used at a rough level for receiving first indications on the matter. A complete model should be completed for confirming this conclusion.

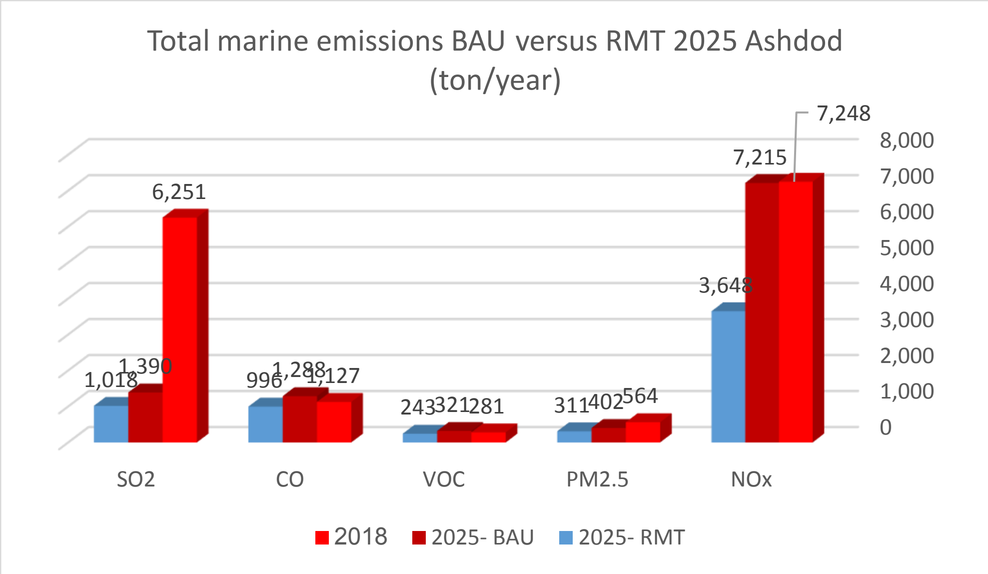

Figure 7. Estimated annual marine emissions at Ashdod port in 2018 compared to 2025 BAU (Business As Usual) and RMT (Recommended Mitigation Targets) scenarios. Emissions represent total values from all three main vessels' activities creating emissions (cruising, maneuvering and hoteling).

We recommend that similar measures that are suggested to be applied in the case of Haifa port for 2025 (see paragraphs 5.1.2.3 and 5.5) will be applied in the case of Ashdod port for 2025. Accordingly, by implementing the fundamental measures suggested in paragraph 5.1.2.3 for 2025 RMT for Haifa port, we estimate that at Ashdod port it's feasible to reduce NO_X emissions by approximately 50% to levels of 3,648 ton/year compared to 7,215 ton/year as estimated in a 2025 BAU scenario (see figure 7). The RMT will also allow reducing VOCs, CO, $PM_{2.5}$ and SO_X by 23%-27% compared to BAU (see figure 7).

5.2.2.1 <u>RMTAs Scenarios 2025 Ashdod port</u>

We recommend that same RMTA1 and RMTA2 as in the case of Haifa port for 2025 (see paragrph 5.1.2.3), will be applied for RMT 2025 at Ashdod port. Similar to Hiafa port, RMTA1 and RMTA2 at Ashdod are expected to have some differences in their performance as can be seen in figure 8

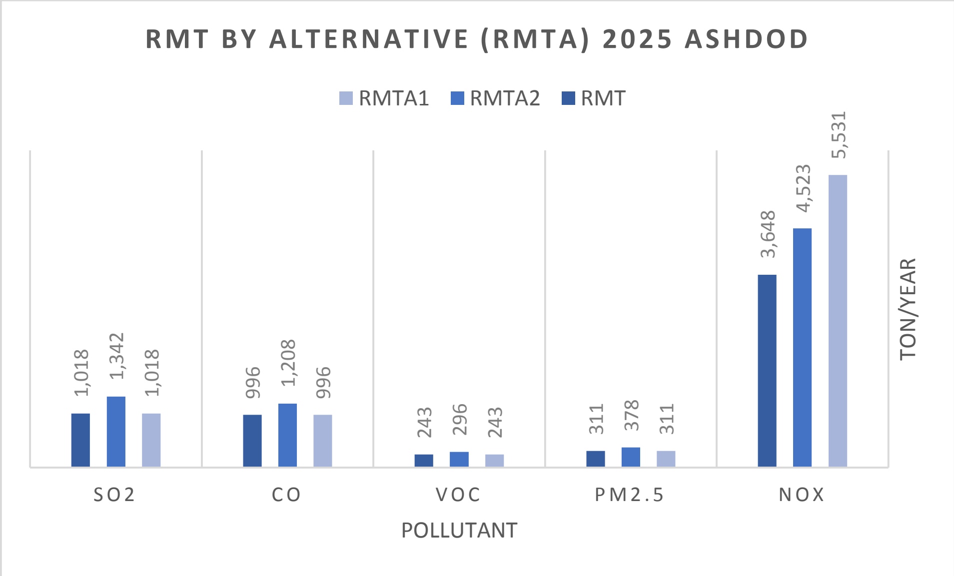

Figure 8. Recommended Mitigation Targets by Alternatives (Ashdod port 2025).
RMTA1- RMT alternative that is mainly based on 30% of vessels using ESP in addition to other non-technological measures detailed in in paragraph 5.5.
RMTA2- RMT alternative that is mainly based on 50% of more polluting vessels installing NOX after treatment technique, in addition to other non-technological measures detailed in in paragraph 5.5.
RMT- Assumes that both techniques are equally implemented (50% of existing vessels are using one of them) in addition to other non-technological measures detailed in in paragraph 5.5.

5.2.3 Marine emissions at Ashdod port in 2030

5.2.3.1 BAU versus RMT scenarios 2030

As explanted previously regarding Haifa port, also in the case of Ashdod port, we conclude that even after 2030, "passive processes" (such as more strict international emission standards that are expected to take place), will be very limited in reducing the total vessels' NO_X emissions. However, we suggest that by 2030, it is feasible to achieve much lower NO_X emission targets aiming at 1,995 ton/year compared to 6,927 ton/year at the BAU scenario (which is approximately 72% less NO_X emissions compared to 2030 BAU, see figure 9). In addition, significant decrease of approximately 45%-48% can be achieved compared to BAU concerning VOC, PM2.5 and CO (see figure 9).

Such RMT can be realized by continuing to implement the main solutions suggested in this study (see paragraphs 5.1.3.2 and 5.5) during an 11 year mitigation plan. However, in the case of SO_X, we conclude that the current upcoming new international regulations regarding Sulfur content in fuel, will allow to achieve in the BAU scenario a major decrease (of approximately 80% compared to 2018, see figure 9) with no need for much further steps to be taken by MoEP. Yet, by implementing some of the main solutions recommended for reducing NO_X emissions, an additional and significant decrease in SO_X commissions can be achieved (approximately 53%

decrease in SO_X emissions compared to BAU), reaching levels of 646 ton/year at RMT 2030 compared with 1,379 ton/year at BAU 2030 (see figure 9)

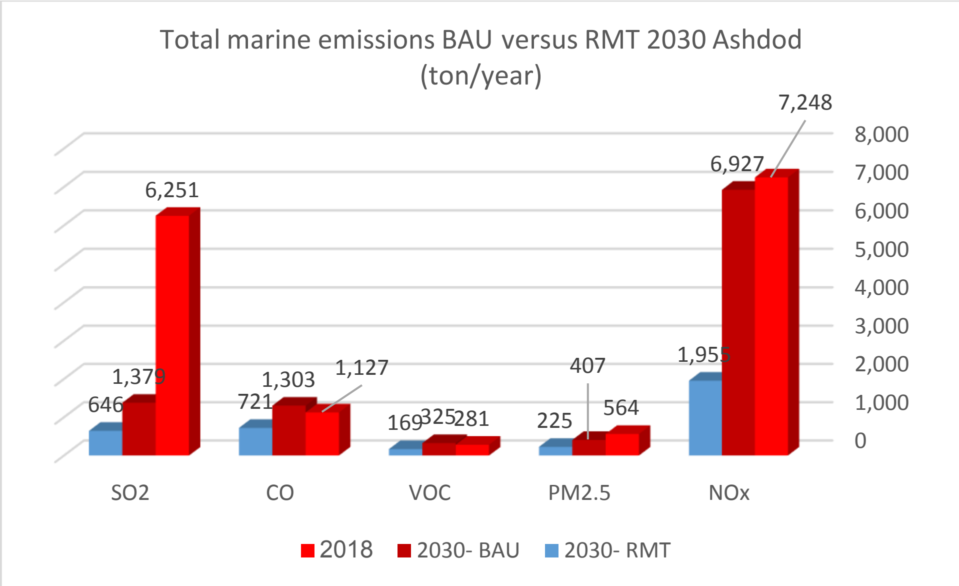

Figure 9. Estimated annual marine emissions at Ashdod port in 2018 compared to 2030 BAU (Business As Usual) and RMT (Recommended Mitigation Targets) scenarios. Emissions represent total values from all three main vessels' activities creating emissions (cruising, maneuvering and hoteling).

5.2.3.2 RMTAs' Scenario 2030 Ashdod port

We recommend that same RMTA1 and RMTA2 as in the case of Haifa port for 2030 (see paragraph 5.1.3.2), will be applied for RMT 2030 at Ashdod port. Similar to Haifa port, RMTA1 and RMTA2 at Ashdod are expected to have some differences in their performance as can be seen in figure 10.

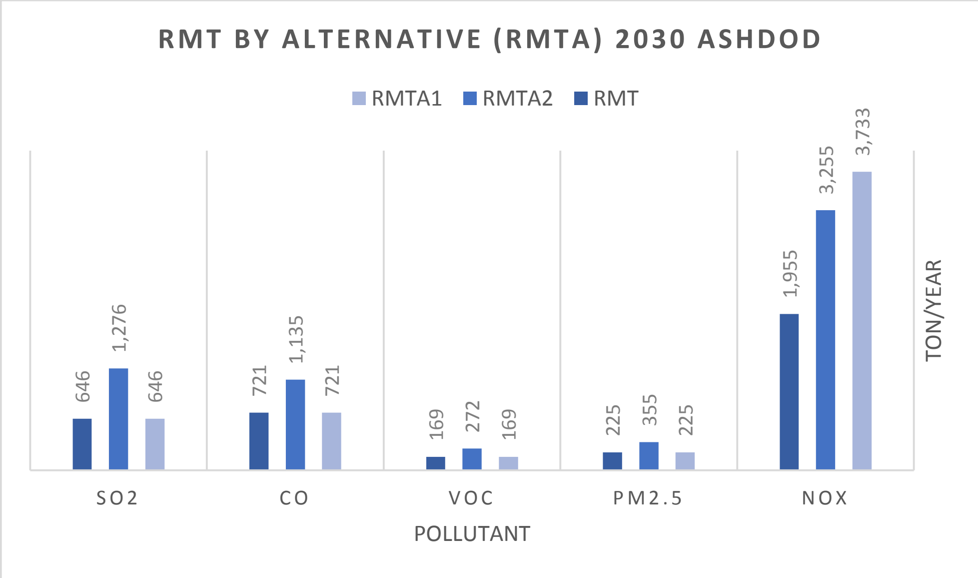

Figure 10. Recommended Mitigation Targets by Alternatives (Ashdod port 2030).

RMTA1- RMT alternative that is mainly based on 50% of vessels using ESP in addition to other non-technological measures detailed in in paragraph 5.5.

RMTA2- RMT alternative that is mainly based on 70% of more polluting vessels installing NO_X after treatment technique, in addition to other non-technological measures detailed in in paragraph 5.5.

RMT- Assumes that both techniques is equally implemented (70% of existing vessels are using one of them) in addition to other non-technological measures detailed in paragraph 5.5

5.3 Related international policy and regulations' review and analysis

5.3.1 General

Marine air pollution is one of the last air pollution sources to be regulated throughout the world. There are a few reasons for this. First, most of the marine air pollution occurs in the sea or in the ocean, away from populated areas. People are moved to promote restrictive regulatory action generally, when they see, hear, smell or feel an adjacent disturbance. For example, when they experience air pollution from cars in the nearby street, or from the neighboring power plant. Second, marine transportation is mostly international transportation, whereas vehicle transportation is local in essence. For a country it is easier to regulate local vehicle air pollution, for example, by regulating local vehicle sales within the country, by regulating local vehicle fuel sales, or by regulating transportation within a city or a quarter. On the contrary, marine vessels are usually not manufactured or sold in one's home country. Furthermore, it is almost impossible for one country to impose regulations on international marine vessels that 99% of their activity is executed oversees. Also, it is usually harder for developing countries to comply with environmental regulations, compared to developed countries. Third, the low cost of heavily polluting marine fuels, is one of the reasons why global marine trade is relatively cheaper. Any restrictions on marine vessels can potentially rise the cost of global trade. Oil refineries may also suffer financially if they can't sell their low-grade fuels to the marine transportation sector.

Countries can restrict air emissions only within 12 nautical miles from their shorelines (territorial waters), but they cannot dictate design, structure, staffing and equipment. Only the International Maritime Organization (IMO) can approve air pollutant emissions restriction beyond that (within exclusive economic zone and international waters) (25).

5.3.2 Examples of local policies and regulations

LA port. The port of Los Angeles has initiated a voluntary vessel speed reduction (VSR) program in 2001, within 40 nautical miles from the port. The voluntary program turned mandatory on 2006 (The Port of Los Angeles, 2018). A VSR zone is expected to reduce sailing vessels' CO_2 and NO_x, $PM_{2.5}$ and SO_x emissions by 60%, 35-55%, 70% and 70% respectively.

EU ports. Since 2010, marine vessels at berth in European Union ports, are allowed to use only marine fuels with up to 0.1% Sulfur in mass (see figure 11). Note that apart from lowering acidification effects of SO_x, reducing SO_x emissions also reduces PM emissions.

China DECAs. One of the measures China has applied to combat its extreme urban air pollution, was restricting marine fuel usage near and within 3 domestic emission control areas (DECAs) containing its main ports (Pearl River Delta, Yellow River Delta, and the Bohai Rim). Between 2016 and 2019, China will phase in a 0.5% sulfur marine fuel limit within 12 nautical miles from these coastlines (25; 26; 43).

5.3.3 Regulations in countries

China. During 2018, China has declared that it will widen its local ports DECAs to all its coastline. Starting in 2019, within 12 nautical miles from all of China's coastline, only marine fuel with up to 0.5% Sulfur can be used in marine vessels (40). A Chinese study found that in order to improve the coastline air quality without increasing the fuel cost dramatically, this strategy is more cost-effective compared to expanding the port DECAs to 200 nautical miles from the coastline (without changing the width of the DECA coastline). This is expected to reduce SO_x concentrations in the coastline by 5-45%, and $PM_{2.5}$ by 1-16% (43).

5.3.4 Continental regulations

5.3.4.1 EU Ports

The EU ports SO_x emissions reduction, although local in effect (see paragraph 5.3.2 Local regulation), is a form of continental regulation.

5.3.4.2 Emission control areas (ECAs)

ECAs are widespread marine areas with strict marine vessels emissions restrictions. ECAs were first introduced in the revised MARPOL Annex VI (see figure 11, and paragraph 5.3.5.1)

- **Within Sulfur ECAs (SECAs),** SO_x and PM emissions are restricted, by allowing up to 0.1% Sulfur in the fuel since 2015 (see figure 12). Marine vessels can use a high sulfur fuel, if a proper SO_x emission mitigation technology is applied instead (e.g. scrubber). The present SECAs are comprised of most coastal waters up to 200 nautical miles (exclusive economic zone- EEZ) in North America, the United States and France Caribbean Sea areas, the Baltic Sea (Europe), and the North Sea (Europe) (32, 51).

  In the USA west coast, marine vessels $PM_{2.5}$ emissions dropped by 45-50% within a year of implementation of the North American SECA in 2012 (41). Another study analyzed high-sulfur residual fuel oil (RFO) associated $PM_{2.5}$ emissions following the reduction of sulfur limit to 1% in 2012 and to 0.1% in 2015. The high-sulfur residual fuel oil associated $PM_{2.5}$ emissions dropped all around U.S coasts by an average of 74% annually between 2011 and the end of 2015 (42).

  Following the establishment of the North Sea SECA in 2007 (limiting sulfur fuel content from 4.5% to 1.5%), Sulphur emissions from ships dropped by 45% after 2007 (44). Lowering the sulfur limit within the North Sea ECA from 1% to 0.1%, was followed by a further 3 fold reduction in the relative ships SO_x contribution to air pollution (44).

- **Within Nitrogen ECAs (NECAs),** NO_x emissions are restricted. This, by allowing several strategies: switching to Tier III standard engines, switching to natural gas, or by installing NO_x emission reduction technologies. The present NECAs are the same as the SECAs in North America, the United States and France Caribbean Sea areas.

  Future ECAs suggestions are along Mexican (Pacific and Atlantic) coastlines, all of the Norwegian coastline (Norwegian Sea), all of the Mediterranean Sea, all of the Japanese coastline (Sea of Japan, Pacific Ocean), all of the Australian coastline (Pacific and Indian Oceans; Tasman, Timor, Coral and Arafura Seas), part of the Chinese coastline around Hong-Kong (South China Sea), and the Malaysian and Indonesian coastline around Singapore (South China Sea) (32, 39).

A recent research confirmed early concerns that ECAs might reduce ports efficiency and would have negative economic impacts. It found that European ports within the European ECAs, suffer 15-18% efficiency loss. The authors speculate that this efficiency loss is relatively high because European ports within the ECAs have relative high percentage of short trips. Therefore, efficiency loss in North America and China that have much lower short trips percentage, might not suffer as much (24).

Figure 11. SO_X emission control areas (ECAs) map. Based on (IMO, 2018c; KeywordsKing, 2017)

5.3.4.3 EU passenger vessels

EU passenger vessels is another EU continental regulation. Since 2010, any passenger vessel that operate to or from any EU port, must not use fuel with more than 1.5% Sulphur outside of the ECAs (EMSA, 2012a), to protect the passengers and crews

5.3.4.4 EU waters 2020

All marine vessels within EU waters must not exceed 0.5% Sulphur in their fuel from 2020 and on (EMSA, 2012b). This directive was signed in 2012 and was set to make sure member states will comply with the IMO 2020 regulation (see 5.3.5).

5.3.5 Global regulation

The United Nations International Maritime Organization (IMO), is a specialized UN agency responsible for safety and security in shipping, and for pollution prevention by ships. Its main aim is to promote a fair, effective, universally adopted and universally implemented regulatory framework for the shipping industry (35).

The International Convention for the Prevention of Pollution from Ships (MARPOL) is the main international convention covering prevention of pollution by marine vessels (34).

5.3.5.1 Air pollution measurements

In 2005, MARPOL Annex VI entered into force. It limits the content of exhaust gas major air pollutants (including SO_x and NO_x), prohibits deliberate emissions of ozone depleting substances, regulates shipboard incineration, and regulates emissions of volatile organic compounds (VOCs) from tankers. The revised MARPOL Annex VI entered into force in 2010. It progressively reduces SO_x (from 3.5% in 2010, to 0.5% in 2020), NO_x ("Tier I" emission limit for engines on ships constructed since 1990-2000, "Tier II" emission limit for engines on ships constructed since 2015) and PM emissions (36-37) . SO_x emissions can be lowered either by using a low Sulphur fuel (diesel, natural gas, or methanol), or by installing scrubbers to remove SO_x from the flue gas.

IMO MARPOL Annex VI regulation 13, concerning NOx Tier III limits. In effect in North American and U.S Caribbean ECAs from January 1st, 2016 regarding new vessels with engine output of ≥130kW.

Table 1. IMO's Tier 1-3, NOx emission standards

Tier	Ship construction date on or after	Total weighted cycle emission limit (g/kWh) n = engine's rated speed (rpm)		
		n < 130	n = 130 - 1999	n ≥ 2000
I	1 January 2000	17.0	$45 \cdot n^{(-0.2)}$ e.g., 720 rpm – 12.1	9.8
II	1 January 2011	14.4	$44 \cdot n^{(-0.23)}$ e.g., 720 rpm – 9.7	7.7
III	1 January 2016	3.4	$9 \cdot n^{(-0.2)}$ e.g., 720 rpm – 2.4	2.0

The Tier III controls apply only to the specified ships while operating in Emission Control Areas (ECA) established to limit NOx emissions, outside such areas the Tier II controls apply. In

accordance with regulation 13.5.2, certain small ships would not be required to install Tier III engines.
A marine diesel engine that is installed on a ship constructed on or after the following dates and operating in the following ECAs shall comply with the Tier III NOx standard:

1. 1 January 2016 and operating in the North American ECA and the United States Caribbean Sea ECA; or

2. 1 January 2021 and operating in the Baltic Sea ECA or the North Sea ECA.

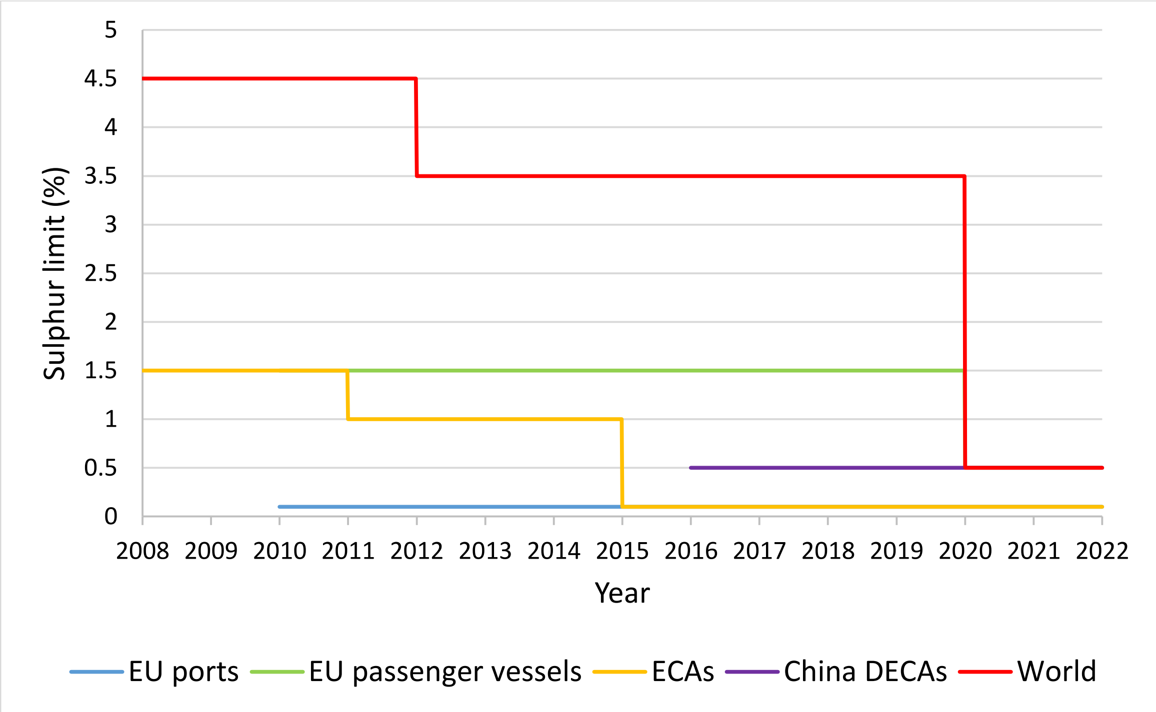

Figure 12: Global marine fuels sulfur limit roadmap. Limit for Sulphur percentages (%) out of fuel mass. Based on (EMSA, 2012a; IMO, 2018c, 2018h; Liu et al., 2018; US EPA, OAR, 2018).

There is a high chance that the 2020 IMO regulations will be implemented widely and globally, as the main shipping giants: China, North America and Europe are already enforcing marine air pollution restrictions (27; 32; 40; 43; 16-18). Also, shipping companies are already preparing for the 2020 IMO regulations, by changing their fuel, installing scrubbers, building new vessels with cleaner engines and by replacing old engines (45;48-49). However, scrubbers installation is still slower than expected, as only 4% of vessels have installed them by March 2018 (29).

5.3.5.2 Energy efficiency and climate change measurements

Energy efficiency and climate change mitigation measurements can also reduce air pollution. The IMO was the 1st international body to adopt a sector-wide mandatory energy-efficiency strategy. During 2013 a suite of operational and technical requirements entered into force. By 2025, all new marine vessels will be at least 30% more energy-efficient compared to those built in 2014 (33, 36). To better its (and its member states) environmental regulation abilities, since 2018, the IMO have imposed on every marine vessel of 5,000 gross tonnage and above, to deliver fuel oil consumption reports to a central data collection system. The IMO will issue an annual report on the matter (31). During 2018, the IMO adopted a long-awaited climate change strategy for shipping. Even though it mainly targets marine transportation greenhouse gases emission, its adoption is expected to greatly reduce marine transportation air pollution by 2050, and to completely eliminate them by 2100. 30,38). The strategy will promote transition of marine vessels towards alternative fuels and/or energy sources, and energy efficiency.

5.3.6 Enforcement

Regulation enforcement within the economical or territorial waters is carried by the local country\state. Within international waters, the IMO has no enforcement authority. Only flag states (the state were the vessel is registered) have authority to enforce open oceans compliance. However, there might be new enforcement mechanisms: by providing authority to port states (the vessel's origin and destination ports), by a possible loss of insurance coverage, and by public pressure on large corporations (29)

In Denmark, Sweden, The Netherlands and Belgium, the ECA is enforced using drones, sniffers and fuel sampling. In the USA, the higher the Sulphur content, the higher the fine (25, 29).

5.3.7 Future regulation

A European study (see figure 13) compared between applying different NO_x mitigation tactics in Europe (23).

a) It found that continuing business as usual (BAU, Tier II is the standard), will result in only a slight 12% reduction in NO_x emissions until 2040 (due to gradual Tier 0 and I vessels decommissioning).

b) If a levy of 2€/kg NO_x emitted will be applied, a dramatic 70% reduction in NO_x emissions is expected already in 2025. This is because marine vessels will be encouraged financially to decrease their NO_x emissions (by installing Tier III engines, SCR, etc). The cost for the marine sector is about 1 billion € per year. It can be significantly reduced by subsidizing NO_x emissions reduction technologies.

c) If, instead of a NO_x emissions levy, the European ECAs (that are now only SECAs), will be also declared as NECAs, and new vessels from 2021 and on will have to be built by the Tier III standard, a significant decrease in NO_x emissions is expected, at a pace of ~4% per year, culminating in over 60% until 2040. Even though this measure is slower to reduce NO_x emissions compared to measure b, it will be quick to reduce NO_x emissions in the NECAs.

d) Adding a 2€/kg NO_x emissions levy to measure c (NECA and Tier III), is essentially the same as measure b (BAU and 2€/kg NO_x emissions levy) but is more complexed to implement.

e) Regulated slow steaming (slowing down marine vessels to reduce fuel consumption and NO_x emissions), can reduce NO_x emissions by 35% in 2025, with half the cost (500 million € per year) compared to measure b (2€/kg NO_x emissions levy). Half the benefit with half the cost.

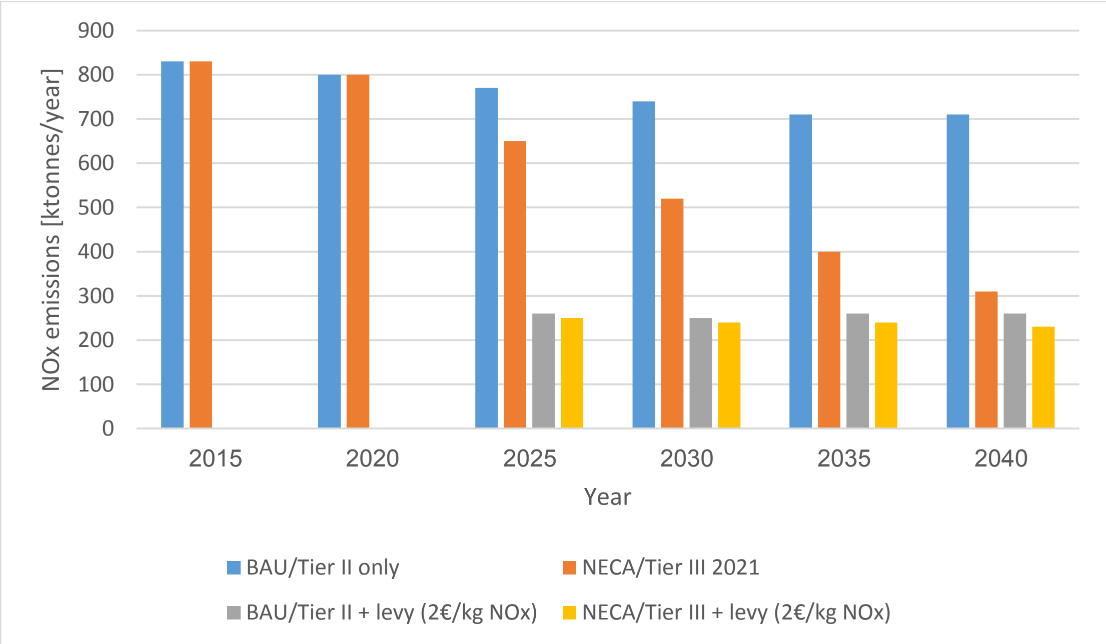

Figure 13: Projected NOx emissions to 2040 in 4 NOx regulation scenarios. Values are in NOx emissions [ktonnes/year]. Blue- Business as usual (BAU, new vessels are equipped with Tier II engines); Orange- Establishing NECAs in the North Sea, the Baltic Sea and the English Channel *(*starting in 2021, all new vessels are equipped with Tier III engines); Grey- Business as usual (BAU, new vessels are equipped with Tier II engines) plus a 2€/kg NOx levy; Yellow- Establishing NECAs in the North Sea, the Baltic Sea and the English Channel (starting in 2021, all new vessels are equipped with Tier III engines), plus a 2€/kg NOx levy. Based on: (Abbasov, 2016).

A study on the Marmara Sea and the Turkish Straits, analyzed the environmental and health effects of restricting marine fuel in the region to up to 0.1% Sulphur. This restriction is predicted to reduce ship sourced PM_{10} and $PM_{2.5}$ in Istanbul by 67%, and SO_x by 90%. This reduction is expected to annually reduce 500 hospital admissions and 30 premature deaths (23).

5.4 Mitigation techniques: review and feasibility analysis

5.4.1 General

In-port emissions, represent only a fraction of global shipping emissions (29), but their effect on the population and ecosystems is acute (57, 60). Onboard solutions (that affect only one vessel at a time) can reduce a fraction of the emissions from vessels in ports, vessels cruising along the shores and cruising far from land. Onshore solutions can reduce all of the emissions, but only for in-port vessels. During regular cruise, a ship's main engines usually power all of its electric systems, through a power generator. However, when it slows down to maneuver into port, the main engines slow down and cannot support the power generator. Therefore, an auxiliary generator is switched on to supply electricity to the ship. Once the ships docks, this auxiliary generator keeps supplying the ship with electricity needed at port (called "hoteling load"). This electricity powers refrigerators, lights, pumps, air conditioning, etc. As shown in paragraph 5.1, the hoteling stage is responsible for 54% and 64% of NO_X emissions at Haifa and Ashdod ports respectively. Maneuvering and stand-by contribute approximately 20%-30% of emissions at each port, while the rest (10%-15%) originate from cursing.

5.4.2 Holistic mitigation techniques

Holistic mitigation techniques reduce all air pollutants emissions: SO_x, NO_x, PM, VOCs, CO_2, and CO. These techniques are comprised of changing the power source (shore power, natural gas), and changing vessel operation (onboard incineration, speed, hoteling time).

5.4.2.1 Electric Shore Power (ESP) for Vessels

5.4.2.1.1 Technique's description

ESP ("cold ironing"), is supplying ships at the port with electricity from the shore. This electricity is used by the ship's systems instead of using its own air polluting auxiliary generator. This technique can significantly reduce air pollution in ports (54, 61, 74)

The technology requires dedicated infrastructure onshore: transmission cables, additional power generation capacity, high voltage berth connection point, high voltage sub-station. On the ship, transmission cable and onboard transformer is required (66). Because many ports still do not have shore power, the vessels cannot concede their auxiliary generators.

Vessels that do not need a gantry crane to load and unload cargo (like cruise, tanker, vehicle carriers), can be connected to shore through a berth connection point adjacent\ parallel to the vessel. Cargo vessels that require a gantry crane to load and upload cargo, can't be connected to a berth connection point adjacent\ parallel to the vessel. That is because it will obstruct the operation of the gantry crane. Therefore, they need to be connected first to a barge that can be at either ends of the vessel, and the barge is connected to an adjacent\ parallel connection point on the berth (53, 54). This technique has been used by the US Navy for decades. It is also implemented commercially in the world (53, 66, 70). In the USA, there are 16 ports with ESP, with up to 60 MW of capacity per port (71). A US shore power calculator calculates the benefits of connecting a vessel for shore power. It can be found here below (71).

5.4.2.1.2 General potential of emissions reduction

Dramatic reduction in noise, vibration, and air pollution exposure for ships crews, port workers, local residents and the environment. Overall improvement in working conditions (64, 66). This technology can eliminate all port air pollution originated in vessels hoteling (not including onshore transportation, dust from loading and unloading cargo, power supply).

5.4.2.1.3 Inputs and Costs

Table 2: ESP costs and savings (66)

	Costs		Port of Göteborg (Wilske, 2009), EUR$_{09}$*
	Bunker price USD$_{16}$/ metric ton		\$640 USD$_{09}$
Ship auxiliary engine	Bunker\ fuel		277316 /year
	Maintenance		0
	CO_2		0
	Externalities		0
	Sum		**277316**
Shore power	Ship	Retrofit	400000
		Capital cost	54347 /year
		Electricity	297024 /year
		Maintenance	0 /year
	Port	# of quays	2
		Investment for all quays	280000
		Capital cost	38043 /year
		Maintenance	0 /year
	Sum shore power		**389414 /year**
Total cost/saving			**-112099 /year**

* Bunker 640 $/tonne (Oct 2009), 4 calls/week, 16,800 kWh/call, 1 ship, electricity = 0.17 EUR_{09} /kWh, 10 years pay-off time, 6% investment interest, calculated only for using electricity or fuel (not a life cycle analysis)
In Israel, the electricity is cheaper (at least compared to Sweden), and is ~0.15 USD_{16}/kWh. It doesn't include the proper externalities costs, and thus does not reflect the electricity use environmental and health impacts. This low electricity price can reduce the shore power annual electricity cost by ~25%. Compared to the Swedish case, in can reduce the annual cost of shore power by ~75000 EUR_{09}, with a total cost of only ~38000 EUR_{09} /year (assuming all other costs are the same).

Vessel retrofit cost varies between 400,000 € (36), 500,000$ USD (64), and 300,000-2,000,000$ USD- cheaper for newly build and smaller vessels (53, 73).
Berth retrofit cost varies between 300,000 € (36), 4,000,000$ USD (73), and 5,000,000$ USD (23)
Retrofitting the electricity network outside the port cost from either almost zero investments (54) to 5,000,000$ USD (73) depending on the electricity network.
Operation and maintenance are calculated as 12% of the shore side investments: 36,000-600,000$ USD for 15 years (53, 73, 66, 74)

Table 3. Estimated costs of ESP (based on table 1 in 64).

Vessel type		**Container and Bulk Cargo**	**Tankers and Vehicle Carriers**	**Cruise**
Costs	Vessel retrofit (thousand USD/vessel/year)	-$41	-$38	-$59
	Berth retrofit (thousand USD /berth/year)	-$732	-$219	-$327
Benefits (thousand USD/vessel/ year)	Fuel savings	$13	$21	$140
	Total environmental benefits (NO_X, SO_2, PM2.5, CO_2)	$124 (EASIUR and APEEP)	$67 (EASIUR) $61 (APEEP)	$368 (EASIUR) $138 (APEEP)
Net private benefit (vessel fuel savings minus retrofit cost) (thousand USD/vessel/year)		-$28	-$17	$81

Assuming marine fuel costs $680 USD/ton.

5.4.2.1.4 Cost effectiveness

ESP is generally considered more cost-effective for vessels that spend longer times at port and/or use a lot of energy for hoteling, and/or frequently call the same ports (71).

Early studies and reports from the 1st decade of the millennium concluded that ESP is generally not cost-effective. For the 12 vessels studied, the average cost was 69,000$/ton of pollutant reduced, while the threshold for cost-effectiveness was 15,000$/ton of pollutant reduced. This is due to past low marine fuel prices, lacking air pollution externalities and carbon cost calculations, lighter regulation, ignored benefits at other ports, and outdated calculation of air pollution health risks (53, 71, 74, 76). For example, all of the emissions were treated as equals, with the external cost of 1 ton of PM_{10} was equal to that of 1 ton of $PM_{2.5}$ (53). Today we know that 1 ton of $PM_{2.5}$ is much worse for health compared to 1 ton of PM_{10}, and therefore more costly.

However, even back then, shore power is generally cost-effective with vessels that spend a long time at ports (over 1.8 million kWh of annual power consumption at port), and that the added cost of the vessel's power shore retrofitting is less than $15,000/ton of air pollutant/year (53). Shore power was found to be cost-effective for 5 out of the 12 vessels studied in the port of Long Beach. And this, even when each of these vessels got a “private” landside power shore facility at a specific berth. If more than one vessels will use each power shore facility, the technology will be even more cost-effective (54)

Since then, petroleum prices have increased (but it is volatile and can drop), marine vessels are transforming to cleaner but more expensive fuels, the effect of air pollution on health is better understood, air pollution regulation is tighter, carbon cost is taken more and more into account, and experience in shore power is increasing worldwide (74)

A newer report calculated the cost of reducing air pollutant by shore power in the ports of Los Angeles, Long Beach and Oakland, California. The cost of a ton of NO_x and a ton of PM, was 11,000-71,000$ and 400,000-2,500,000$ respectively (74), the ranges represents differences between the different ports and different marine vessels.

A recent report on shore power in Shenzhen, China, calculated the cost to be 56,000$, 1,400,000$, 290,000$ and 2,300$ for reducing a ton of NO_x, PM, SO_x and CO_2 respectively (73).

Today, if 25-67% of the vessels that call at mainland US ports would use shore power, $70-150 million US dollars in air quality benefits (environmental and health benefits) could be achieved, plus $30 million US dollars in fuel savings- annually. These benefits are balanced by the cost of vessels and ports retrofit, with no net cost to society. Per port, the environmental and health benefits vary between $1-38 million US dollars annually, depending on the proximity to inhabitants and their number, the size of the port, the types of the vessels (74).

Table 4. Estimated benefits of ESP based on various case-studies (based on 74 and 85)

Port	TEU (million units/ year)	Volume (million metric tons/ year)	EASIUR (millions USD/year)		APEEP (millions USD/year)	
			Maximize net total benefit	Maximize total benefit	Maximize net total benefit	Maximize total benefit
Oakland	2.3	17	10	11	9	11
Charleston	2	17.3	1	1	1	1
Ashdod	1.3	19.6				
Haifa	1.2	24				
Miami	0.9	-	7	10	6	7
Port Everglades	0.9	19.1	8	17	4	8
Jacksonville	0.9	14	1	1	1	1

The range of environmental and health benefits in port similar in size to Haifa and Ashdod ports, for applying shore power for 25-67% of all vessels, is between $1-17 million USD/year. The average benefit is $5.8 million USD/year/port. In the Haifa port, due to the problematic topography, wind patterns, population spread and other factors (see appendix 1), we generally estimate that the environmental and health benefits are in the upper range. At Ashdod, it might be at a lower range yet this requires further investigation. It should be noted, that the more Israel fuel mix for electricity production, will rely on natural gas (as forecasted and planned), the potential benefits of ESP will increase.

5.4.2.1.5 Feasibility

This technique requires investments done by vessels owners and ports authorities, while the benefits are enjoyed mostly by near ports residents and workers, governmental spending on health, and the environment. 80% of the vessels are expected not to compensate for their retrofitting by fuel savings. They can increase their freight cost, to include these expenses (eventually the consumers will be charged). Alternatively, policy makers could implement incentives and regulations to encourage a shore power use (74).

In 2009, there were more than 10 shipping companies with shore powered vessels. In 2015, 21 ports where already using shore power (12 in Europe, 9 in North America) (64, 66-69, 73) So, there might already be vessels that call at Israeli ports with the proper infrastructure for shore power installed, and this transition can be less expensive for some vessels.

5.4.2.2 Repowering vessels with natural gas or dual-fuel engines.

5.4.2.2.1 Technique's description

In this technique, the vessel's regular engine is replaced (or the vessel is built in advance) with a natural gas or dual-fuel engine. Natural gas engines drastically reduce air emissions for all voyages. This is a holistic solution from the vessel's point of view, that doesn't only solve air pollution in ports like ESP, but also during close to shore cruises and away from shore (76)

Dual-fuel engines can use either liquid fuel or natural gas. They can use cheap polluting fuel away from shore, and switch to cleaner natural gas close to shore. This way, the energy cost for this type of vessel is lower compared to natural gas only engine, and it can fuel itself in ports without natural gas fueling infrastructure. This is a mature technology (53, 77)

5.4.2.2.2 General potential of emissions reduction

Using natural gas can reduce SO_x emissions by 99%, PM emissions by 94%, and NO_x emissions by 90%. This represents Tier IV performances (53, 77, 78)

5.4.2.2.3 Inputs and Costs

The capital cost for replacing an engine and for natural gas fueling infrastructure was estimated in 2002 to be \$165-\$202 /kW (78). A 2004 report calculated the capital cost for retrofitting a vessel with a new LNG\Dual fuel engine is 240,000-4,625,000\$, or 184\$/kW on average (53).

The prices of petroleum and natural gas are fluctuating, and affect the profitability of this technique. But, between 2006-2015, the prices of LNG and HFO were relatively similar, despite of fluctuating fuels prices. Since 2006, the price difference was no more than 30% (150\$ USD), with an estimated average difference of only 10% (50\$ USD) (see Figure). In some years LNG is cheaper (77, 80). Thus, the transition is expected to be even more cost-effective. The expected increase of Israeli natural gas production might ensure relatively low marine LNG prices in Israeli ports.

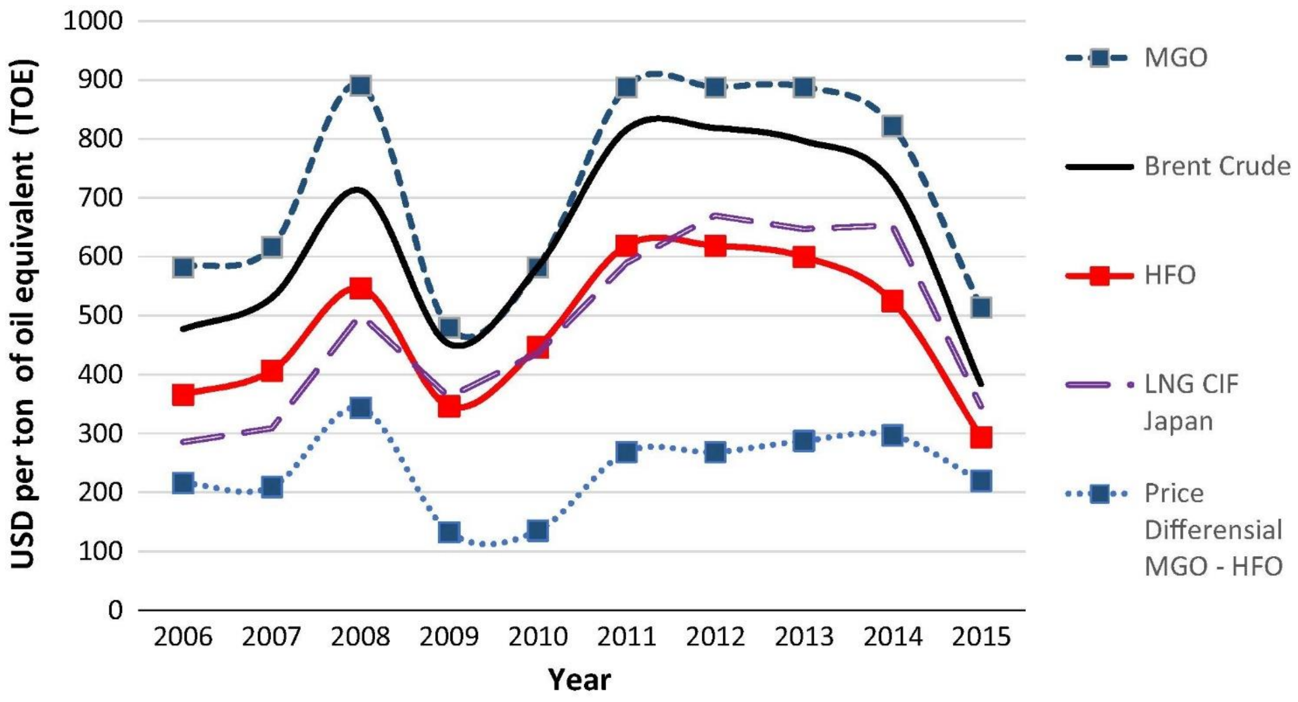

Figure 14. Development of Fuel prices per ton og oil equivalent (TOE) from 2006-2015 (79).

The capital cost (CAPEX) of a small LNG onshore facility (shore tank to ship TPS, LNG production and bunkering station) that delivers 60 tonnes of LNG/day, can be 27,000,000$ USD (7,450$/day). The OPEX of this facility is 4,200$ USD/day. The total daily cost CAPEX+OPEX = 11,650$ USD/day. The added cost per tonne of LNG delivered is 194$ USD, or an added cost of 3.7$/mmBTU. This does not include connecting a pipeline to the port (80).

A larger LNG facility, with a 100,000 gallons (160 tonnes) per day production capacity, can cost 50,000,000$ (CAPEX). Assuming a 4$/mmBTU natural gas price, it can sell LNG for 10.5$/mmBTU or 15.5$/mmBTU, at the dock or at sea respectively (80). There is a 15% energy penalty for producing LNG. In other words, a ton of natural gas on land is transformed to 0.85 ton of LNG on the ship.

The capital cost (CAPEX) of a small ship to ship (STS) system is 54,000,000$ USD, with a total daily cost CAPEX+OPEX = 20,000$ USD/day. The added cost per tonne of LNG delivered is 333$ USD (50). If Israel will decide to build a big LNG production facility for export, it could be used also to fuel LNG ships (81).

5.4.2.2.4 Cost effectiveness

According to 23, this technique was cost-effective in reducing hoteling emissions for 11 out of 12 vessels examined. This, as the average added cost of replacing the engine with natural gas/ dual-fuel engine was $9,000/ton of reduced air pollutant/year.

A more recent study calculated the cost to be (-2,242)-(17,406) €/tone of reduced NO_x (77). The negative value represents a reduction in operations cost compared to a conventional MGO powered engine (or in other words- gains), and is for building a new vessel with an LNG powered engine. This is due to the low expected cost of LNG. The high value represents retrofitting an existing MGO powered vessel with a new LNG engine.

5.4.2.2.5 Feasibility

Feasibility is medium to low. On one hand it is drastically improving air quality in ports, reduce health costs, and can be incentivized by the government. On the other hand it requires large capital investments and loss of cruising time at sea while repowering is taking place.

A huge disadvantage of all natural gas engine option is the relatively low availability of natural gas fueling options in the world port. Until a large number of ports is equipped with natural gas fueling options, this solution is problematic. This option also requires costly storage of natural gas (pressurized or liquefied), in larger volumes compared to liquid fuel (as natural gas is less energy dense).

The downside of the dual-fuel engine option, is that this vessel can't store neither very large quantities of liquid fuel nor natural gas. It can take relatively short cruises with either of these fuels, but for long cruises it might have to store both fuel types.

As a general rule, using natural gas raises issues of operating safety, as it is considered less safe than diesel or heavy oil fuel (53). Having said that, the number of LNG marine vessels was increasing at a fast annual rate of over 30% between 2014-2018. A fast growth rate is expected at least until 2021. In 2018, there were 223 LNG\Dual Fuel marine vessels globally (see figure 15). Most operate in Europe, but it is already a global phenomenon (66, 72, 73)

LNG bunkering can be done from a truck to a ship, from a ship to a ship and from shore to ship. In 2017, there were about 60 locations (sea ports and LNG bunker vessels) with LNG bunkering, again- mostly in Europe. This number is expected to double in the next few years (see figure 16), with at least 139 LNG ports in Europe alone (at least one per sea shore country) (76, 82, 74-76). Moreover, there are hundreds of non-bunkering LNG facilities- LNG facilities that are not designated for ship fueling. Many of these facilities could be easily and cheaply be fitted for ship fueling. Here in Israel we have the Hadera LNG terminal, were LNG storage ships supply natural gas to the Israeli natural gas network. Also, because natural gas pipelines are present at both Ashdod and Haifa, there is no need to invest much in connecting these ports to the national natural gas network.

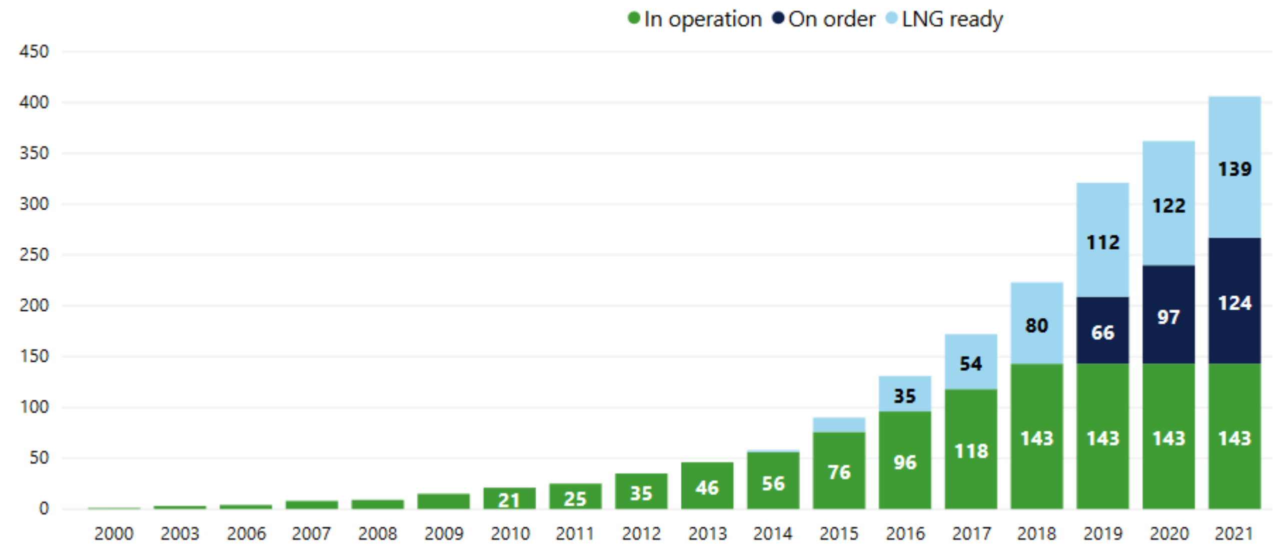

Figure 15. Number of LNG powered marine vessels in the world (2000-2021). Green- In operation, Dark blue- on order, Light blue- LNG ready. The data is updated for 2018. Data for 2019-2021 is partially known (82)

Figure 16. Global infrastructure for LNG bunkering. Global locations for fueling ships with LNG. Green- in operation. Dark blue- under planning or construction. Light blue- under consideration (82, 84)

5.4.2.3 Ship onboard incineration (SOI)

5.4.2.3.1 Technique's description

Oceangoing vessels incinerate waste, instead of disposing it at sea or at port. A US survey found that the average amount of waste that is incinerated per oceangoing vessel is 111 tons per year. 45% of oceangoing vessels have no incinerators at all. The main types of incinerated waste are rags, paper, packing material, and plastics. In this mitigation technique, ship onboard incineration is prohibited within 3 nautical miles of the coast (64)

5.4.2.3.2 General potential of emissions reduction

There is a potential for emission reduction of dioxins, toxic metals and PM for residents living next to the coast.

5.4.2.3.3 Inputs and Costs

For proper monitoring, the vessels must keep an updated waste record book, with information on incinerations dates, vessel position (latitude and longitude), and estimated amount of incinerated garbage.

The vessels must either incinerate their waste away from the shore, or use other approved waste disposal solutions: as disposal at the port, recycling, disposal at sea (of feed waste, etc.).

There can be no economic cost for this technique.

5.4.2.3.4 Cost effectiveness

This technique is not sufficient as a stand-alone technique, yet on its own, is very cost effective- with little or no cost, and with a small health gain. The health gain was calculated to be a reduction of 2 cancer cases per 1 million residents.

5.4.2.3.5 Feasibility

High feasibility, due to the practically non-existent economical cost. Yet, low sufficiency as a stand-alone technique.

5.4.2.4 Oceangoing vessels speed reduction

5.4.2.4.1 Technique's description

Reduction of oceangoing vessels speed from cruise speed to below 15 nautical knots can reduce air pollutants and greenhouse gases emissions. When this technique is applied within 20-40 nautical miles from shore (vessel speed reduction [VSR] zone), a distinct improvement in air quality can be measured onshore (88)

5.4.2.4.2 General potential of emissions reduction

Potentially this technique can reduce CO ,NO_x, $PM_{2.5}$ and SO_x emissions by 60%, 55%, 70% and 70% respectively, in the VSR zone. However in the case of Haifa and Ashdod ports, the potential is estimated to me much lower as most vessels' typical speeds within 20-40 nautical miles are already moderate (lower than 15 knots).

5.4.2.4.3 Inputs and Costs

This technique can reduce the energy costs for vessels, as their fuel consumption per nautical mile improves.

Speed reduction in the VSR zone might mean a time penalty for the vessels, and longer cruise time. However, proper cruise planning can eliminate this time penalty.

5.4.2.4.4 Cost effectiveness

This technique is not sufficient as a stand-alone technique, yet on its own, is very cost effective, as it can reduce costs for vessels, even without taking into account the benefits from an improved air quality. Also, it does not require any costly modifications or improvements in marine vessels or ports.

5.4.2.4.5 Feasibility

This technique has high feasibility, because it requires only a change in habit, no capital investment, no time consuming vessels' or ports' modifications. It is already implemented around the world (for example, in California).

However, based on an assessment we have performed regarding typical speeds of vessels from various distances of both Haifa and Ashdod ports, it is estimated that 80-90% of all the marine vessels within 25-30 nautical miles (~50 km) of the Haifa and Ashdod ports usually sail at less than 15 nautical knots. Therefore, this technique is not expected to significantly reduce the actual marine vessels' emissions.

5.4.2.5 Reduce hotelling time (RHT) and stand by time closer to the port

5.4.2.5.1 Technique's description

Reduction of hotelling time can reduce emissions in ports, in particular if implemented on relatively more polluting vessels.

It can be achieved by limiting hotelling time per vessel, especially more polluting vessels. For example, to fine vessels that stay more than X hours at port.

It can also be achieved by improving cargo handling and monitoring equipment and procedures that will reduce the time a vessel must stay in port to load and\or unload cargo. For example: faster liquid (crude oil, fuel, water) pumping, modern container cranes, and faster passengers boarding in cruise ship.

5.4.2.5.2 General potential of emissions reduction

Highly dependent on many factors, including the congestion at the port and how it is occupied at every moment. It is our estimation that shortening the time of hoteling and stand-by time of more polluting vessels can potentially reduce emissions in range of 10%-25%. One of the more cost-effective ways of achieving such reduction is by allowing relatively more polluting vessels to stand-by at longer distances form the port (at least 5km away from the port).

5.4.2.5.3 Inputs and Costs

Insignificant

5.4.2.5.4 Cost effectiveness

Highly cost-effective

5.4.2.5.5 Feasibility

Highly feasible

5.4.3 SO_x mitigation techniques

SO_x mitigation techniques reduce substantial SO_x and PM emissions. Sometimes they affect other emissions, for better or worse. These techniques are comprised of fueling with low sulfur fuels (MGO, MDO, GTL, on-road diesel), or exhaust gas scrubbing.

5.4.3.1 Low-Sulfur Marine Gas Oil (MGO) Diesel Fuel

5.4.3.1.1 Technique's description

Many vessels use the cheap and "dirty" Heavy Fuel Oil (HFO) diesel fuel that has a 2.8% sulfur content. This high sulfur content is responsible for high SO_x and PM emissions. Replacing the use of HFO, with Low-Sulfur (0.1-0.2%) Marine Gas Oil (MGO) or Marine Distillate Oil (MDO) Diesel Fuels, significantly reduces the mentioned emissions (53, 89). It is possible to permanently switch to a cleaner fuel; or to use the two fuel types in the same vessel: a dirty fuel away from shore and ECAs and a cleaner fuel close to shore and within ECAs. A report estimated that already in 2009 that at least 80% of all vessels have the capacity to use the two fuels without any major modifications to the vessel. Therefore, only the fuel cost is a factor for most vessels (89).

5.4.3.1.2 General potential of emissions reduction

This technique can reduce PM and SO_x emissions by 85% and 90% respectively. However, it does not reduce any other emissions- as NO_x, CO and VOCs (53).

5.4.3.1.3 Inputs and Costs

It costs about $50,000 to clean a vessel's fuel tanks and fuel system and replacing fuel filters etc., before switching to MGO. This is a one-time cost. Besides that, MGO is more expensive than HFO (53, 99).

It is notable that marine fuel must have a flashpoint of at least 60°C to comply with ISO 8217 and 2719, whereas MGO can have a flash point between 57°C and 69°C. Therefore, only MGO with a flashpoint above 60°C should be used (53).

Depending on the engine power and normal operational speed, a newer report calculated the costs for installing the system in a new vessel to be between 34,000-90,000$, or 1.5-8$ per kW. Retrofitting a vessel costs between 45,000-100,000$ per vessel, or 2-10$ per kW (89)

Between 2006-2015, MGO was more expensive than HFO, by an average of 275$ USD per TOE (range of 100-350$ USD), or an average of 60% more expensive (range of 63-82%) (see Figure) (79). This solution is therefore very expensive.

5.4.3.1.4 Cost effectiveness

Switching from HFO to MGO fuel, was found to be cost-effective for all examined vessels even with the relatively low standard externalities calculation on 2004 (53).

5.4.3.1.5 Feasibility

This is one of the easiest techniques to implement. It is relatively not expensive, does not require a significant change is infrastructure and vessels, and can be carried out independently in every vessel independently of other vessels or ports.

In 2015, a designated North-American Emissions Control Area was fully implementing. Within it, only low sulfur marine fuels are allowed. This policy reduced PM emissions from marine vessels by 75% (67)

However, because it is so easy to implement, it is harder to find if a vessel that has actually switched to use MGO instead of HFO. In order to find out, one either needs to test the fuel onboard, or take emission measurements. In other techniques it is much easier to recognize compliance.

5.4.3.2 On-road diesel

5.4.3.3.1 Technique's description

In this technique, HFO or MGO are replaced with cleaner on-road diesel for use in the vessels' auxiliary engines. This fuel has only 0.3% sulfur and lower aromatic organic compounds (53).

5.4.3.3.2 General potential of emissions reduction

Replacing HFO or MGO with on-road diesel would reduce NO_x emissions by 6%, PM by 87% and SO_x by 90% (53).

5.4.3.3.3 Inputs and Costs

Switching to on-road diesel can cause major fuel leakage, and might not comply with injectors.

On-road diesel, that has a flashpoint of 52ºC and 60ºC, is not compliant with ISO standards 8217 and 2719, which require that marine fuel must have a flashpoint of at least 60ºC. Therefore, on-road diesel should be modified before using for hotelling (53).

5.4.3.4.1 Cost effectiveness

Not clear

5.4.3.4.2 Feasibility

Not too difficult to implement from an infrastructure point of view. However, there is a need to modify engines, to modify the fuel and\or ISO standards- before using this fuel on marine vessels (53).

5.4.3.3 Gas to liquid (GTL) fuel

5.4.3.5.1 Technique's description

Gas to liquid is the process of producing a synthetic diesel fuel out of syngas, a mixture of H_2, CO and CO_2- through the Fischer-Tropsch reaction. Syngas itself can be produced from natural gas, coal or biomass or plastic. GTL diesel has no sulfur or aromatic compounds (53)

5.4.3.5.2 General potential of emissions reduction

Compared to HFO and MGO, PM emission reduction is 13% and 87% respectively. There are no SO_x emissions. Compared to on-road diesel, GTL emits 39% less CO and 5% less NO_x and no SO_x (53)

5.4.3.5.3 Inputs and Costs

GTL diesel will be probably more expensive compared to HFO and MGO, with comparable price to that of on-road diesel. The capital cost of a GTL facility is very high, somewhere between $5-20$ billion (91)

It is assumed that switching to GTL fuel will cost $50,000 per vessel to replace seals, pumps, lines, filters and to modify the fuel system.

As with on-road diesel, there are issues with GTL diesel volatility, flammability, engine injector tolerance etc. (53)

5.4.3.5.4 Cost effectiveness

Questionable. Efforts of using GTL are not negligible and yet only sufficiently reduce SO_X, while NO_X must also be addressed.

5.4.3.5.5 Feasibility

As part of the national fuel choices initiative, Israel is considering production of GTL from natural gas. However, GTL production facilities are very rare (less than a handful worldwide), extremely expensive, and with little experience. Also, reduction in emissions onboard, is offset by huge environmental impacts of the GTL facility (92-94). Therefore, until a GTL plant is in operation, this solution is irrelevant.

5.4.3.4 Exhaust gas cleaning systems (EGCS, "scrubbers")

5.4.3.4.1 Technique's description

This technique uses seawater or fresh water to scrub the exhaust gas from SO_x. It can also remove NO_x and PM to some degree. In open-system EGCS, the used water is sometimes filtered, sometimes diluted and sometimes neither, before it is discarded to the sea. This solution is an attractive and viable alternative for replacing high sulfur HFO with low sulfur MGO fuel. There are closed system EGCS that can filter the used water and store the "scrubber sludge" for discharge at port (89, 95)

5.4.3.4.2 General potential of emissions reduction

About 90-99% reduction in SO_x emissions, and some NO_x and PM emissions reduction (53, 95).

A different study found only slight reduction of PM in one case, and even a slight increase in PM in another (96)

5.4.3.4.3 Inputs and Costs

Installing scrubbers might be cheaper than switching from HFO to MGO (29), but others found the opposite (100). The decision should be case based, as there are many factors that dictate the overall cost: fuels cost, scrubbers' technology maturation and reduction in cost over the years, number of years until decommissioning, size of vessel, vessel operation, and percentage of trip spent in ECAs (97)

The cost of scrubber installation is estimated at 4-7$ million USD per vessel (29)

, or 80$/kW for retrofit and 55$/kW for new build[37]. However, an earlier EPA report calculated the cost to be 422,000-1,720,000$ per vessel, depending on the engine power and normal operational speed, or 35-94$/kW (89)

An open-system EGCS used scrubbing water discarded to sea is acidic (pH 3), has high temperature, contains contaminates like heavy metals sulfuric acid and nitrate.

Closed systems must have a dedicated tank to store the "scrubber sludge"- up to 7 cubic meters (m^3) for a 2,700 passengers cruise ship per week (95). Fuel consumption is expected to rise by 1-3% due to the extra effort in pumping the sea water to the scrubber (53, 89)

5.4.3.4.4 Cost effectiveness

The technique is cheaper than switching from HFO to MGO, but open-system EGCS reduces the environmental cost-effectiveness (95)

5.4.3.4.5 Feasibility

High feasibility, and already in wide use (76, 95, 98-99)

5.4.4 NO_x mitigation techniques

NO_x mitigation techniques can substantially reduce NO_x emissions. Sometimes they affect other emissions, for better or worse. The techniques are based on reducing combustion temperature (EDF, DWI, Fumigation, EGR), or exhaust gas scrubbing (SCR), or engine retrofitting or replacement to Tier II-IV standards.

5.4.4.1 Emulsified Diesel Fuel (EDF)

5.4.1.1.1 Technique's description

In this technique, HFO or MGO are replaced in the auxiliary generator by emulsified diesel fuel. Water and stabilizing surfactants are added to diesel fuel, turning it into an emulsion. One option is to emulsify the fuel in advance, and keep it agitated in the tank. A probably more cost-effective option is to emulsify the fuel right before it enters the engine.

The water keeps the combustion temperature lower, and therefore less NO_x is produced. It is theorized that reduction in PM emissions is due to fuel drops shattering when they heat up and the water in them explodes into steam (53)

5.4.1.1.2 General potential of emissions reduction

This technique can reduce 14% NO_x, 63% PM and 25% VOC of emissions (53). A newer report stated that up to 50% of NOx reduction is possible. However, high reduction percentage is possible only during low engine load (89).

5.4.1.1.3 Inputs and Costs

Usually, water comprises 15% of the emulsified fuel. This reduces the energy content of the fuel. It is estimated that emulsified fuel will cost 35-50% more than regular fuel, due to the lower energy content, the fuel production and fuel agitation.

It is assumed that switching to emulsified fuel will cost $50,000 per vessel to replace seals, pumps, lines, filters and to modify the fuel system. If the emulsified fuel is produced onshore, and kept agitated in the vessels tanks, a capital cost of $450,000 is added to account for the service barge or for the on-shore fueling station. Therefore, the maximal total capital cost is about $500,000 per vessel. Sharing a service barge or an on-shore fueling station between more than one vessels reduces the capital cost significantly. Even better, if emulsifying the fuel is prepared onboard only prior to its injection into the engine, the capital cost plummets even further.

Storage of emulsified fuel is difficult and expensive, due to natural separation of fuel and water. There is also uncertainty regarding engine durability and lube oil changes due to the emulsified fuel (53).

Depending on the engine power and normal operational speed, a newer report calculated the cost of installing an emulsifying system to be between 86,000-210,000$ per vessel, or 4-19$ per kW (89)

5.4.1.1.4 Cost effectiveness

Half of the 12 vessels tested for using emulsified fuel are cost-effective with regard to externalities calculation in 2002. This number rises when more than one vessel are sharing a service barge or an on-shore fueling station, or when an on-board emulsifying system is installed (53).

5.4.1.1.5 Feasibility

This is one of the easiest techniques to implement. It is relatively not expensive, does not require a significant change is infrastructure and vessels, and can be carried out in every vessel independently of other vessels or ports. However, because it is so easy to implement, it is hard to find if a vessel has actually switched to use emulsified fuel. In order to find out, one needs to either test the fuel onboard, or take emission measurements. In other techniques it is much easier to recognize compliance.

5.4.4.2 Direct water injection (DWI)

5.4.4.2.1 Technique's description

A combustion modification technology for reducing NO_x emissions. In this technique, fresh water is injected independently into the cylinder to cool down the combustion temperature. This technique is most efficient over 40% engine load (89)

5.4.2.2.2 General potential of emissions reduction

A 0.4-0.7 water/fuel ratio can reduce NO_x emissions by 50-60%.

5.4.2.2.3 Inputs and Costs

The technique requires 20-50% rise in fresh water production from sea water, and appropriate storage facilities. It rises fuel consumption.

Depending on the engine power and normal operational speed, installing DWI costs between 185,000$ and 1,115,000$ per vessel, or 23-41$/kW (53)

5.4.2.2.4 Cost effectiveness

Relatively cost-effective, yet limited in its emission reduction potential.

5.4.2.2.5 Feasibility

This is a mature technology, with some experience in marine vessels. This technique is relatively cheap, simple, does not require a lot of space to additional facilities, and can be shut-down without an impact on the running engine performances. It is easy to install, and can even be installed when the ship is in operation (53).

5.4.2.3 Fumigation

5.4.2.3.1 Technique's description

A combustion modification technology for reducing NO_x emissions. In this technique, water is heated to create vapor\fumes that is added to the air injected to the engine. The extra fumes lower the combustion temperature and reduce NO_x formation. In contrast to SCR, no warm-up time is necessary for proper operation. A variant of this technique can be used with high sulfur fuels (up to 4.5%), in contrast to SCR that can operate only with low sulfur fuels (53).

5.4.2.3.2 General potential of emissions reduction

A 50-80% reduction in NO_x emissions can be achieved, depending on the technique variant (53).

5.4.2.3.3 Inputs and Costs

Depending on the engine power and normal operational speed, installing fumigation costs between 170,000$ and 1,085,000$ per vessel, or 22-42$/kW.

Because the systems uses engine heat to increase the water content in the air for combustion, additional boiler capacity may be needed for other needs. The system uses a 2 to 3 water to fuel ratio. Depending on the technique, either fresh or sea water is used (53).

5.4.2.3.4 Cost effectiveness

Could be more cost-effective in smaller marine vessels and other cases where 70%-80% of emission reduction can be achieved while investment costs are at the lower ends ($200, 000-$400,000 per vessel)

5.4.2.4.5 Feasibility

There is relatively plenty of experience with this technique in small marine vessels (e.g. ferries).

5.4.2.4 Exhaust Gas Recirculation (EGR)

5.4.2.4.1 Technique's description

A mature combustion modification technology for reducing NO_x emissions. In this technique, a part of the exhaust gas is recirculated back into the engine cylinders. The exhaust gas is poor in oxygen and richer with inert gases compared to regular air. This lowers the oxygen concentration in the cylinders, the heat produced and the NO_x emissions. The penalty is in fuel consumption.

The technology is confirmed by engine manufactures to reach Tier III level (100). It is less efficient compared to SCR, with less experience on marine vessels (53).

5.4.2.4.2 General potential of emissions reduction

This technique can reduce NO_x emissions by 70%, reaching Tier III standards (53, 100)

5.4.2.4.3 Inputs and Costs

Compared to SCR, EGR is usually cheaper per vessel and per kW. Indeed, a report by the EPA has calculated the cost (2006 US$) of EGR to be between 86,000$ and 251,000$ per vessel with 4.5 MW to 48MW engine power. The cost per kW, is between 5-19 $/kW, depending on the engine size and on the normal operational speed (53).

5.4.2.4.4 Cost effectiveness

A new report calculated the cost of EGR per kg of NO_x removed to be 0.49-5.49 €/kg NO_x for a new vessel (similar to that of SCR), but with higher uncertainty, due to lack of experience with the technique (101). Another report calculated the cost of implementing EGR and estimated figures between 0.21-1.194 €/kg of reduced NO_x (77). Therefore, if one desires only to comply with Tier III requirements, one should install EGR. However, if one desires to reduce NO_x emissions as much as possible, SCR is more compatible.

5.4.2.4.5 Feasibility

Feasible, but appears to be less preferable compared to SCR.

5.4.2.5 Repowering with US EPA Tier II, III and IV Engines

5.4.2.5.1 Technique's description

Tier 0, I, II, III and IV standards permit a decreased limit of air pollution emissions per kWh, from marine vessels' engines. The higher the Tier, the lower the permitted emissions. Replacing old and\or dirty engines with lower-emitting US EPA Tier II marine engines is widely used in the USA. Even better is to repower vessels with newer and cleaner Tier III and IV (53, 69, 102)

5.4.2.5.2 General potential of emissions reduction

This technique reduces NO_x emissions (and in some cases, also PM). Compared to Tier I, Tier II can reduce NO_x emissions by 15-20%, Tier III by 75-80%, and Tier IV by 90% (see Figure). (53, 96, 102)

5.4.2.5.3 Inputs and Costs

Depending on the engine power and normal operational speed, retrofitting a Tier 0 engine to a Tier I standards, costs between 11,000$ and 36,000$, or 0.6-1.6$/kW.

Minor retrofitting of a Tier I engine to a Tier II standards, costs between 8,000$ and 13,000$, or 0.3-1.8$/kW. Engines with a mechanical fuel injection, must replace it with common rail fuel injection to comply with Tier II standards. This modification costs between 68,000$-260,000$, or 5-17$/kW. Engines with an electronic fuel injection, must replace it with common rail fuel injection to comply with Tier II standards. This modification costs between 26,000$-81,000$, or 2-6$/kW. Minor retrofitting of a Tier II engine to a Tier III standards, costs between 52,000$ and 130,000$, or 3-12$/kW (89). Repowering with US EPA Tier 2 costs $7,500-$310,000 (average $75,000) per vessel to replace an engine (53)

5.4.2.5.4 Cost effectiveness

Depending on the engine power and normal operational speed, retrofitting a Tier 0 engine to a Tier I standards has a cost-effectiveness of 11-24$ SDR/MT NO_x (89).

5.4.2.5.5 Feasibility

This technique is suitable for small marine vessels (tugboats, barges, ferryboats), but not for long distance cargo and cruise vessels (53).

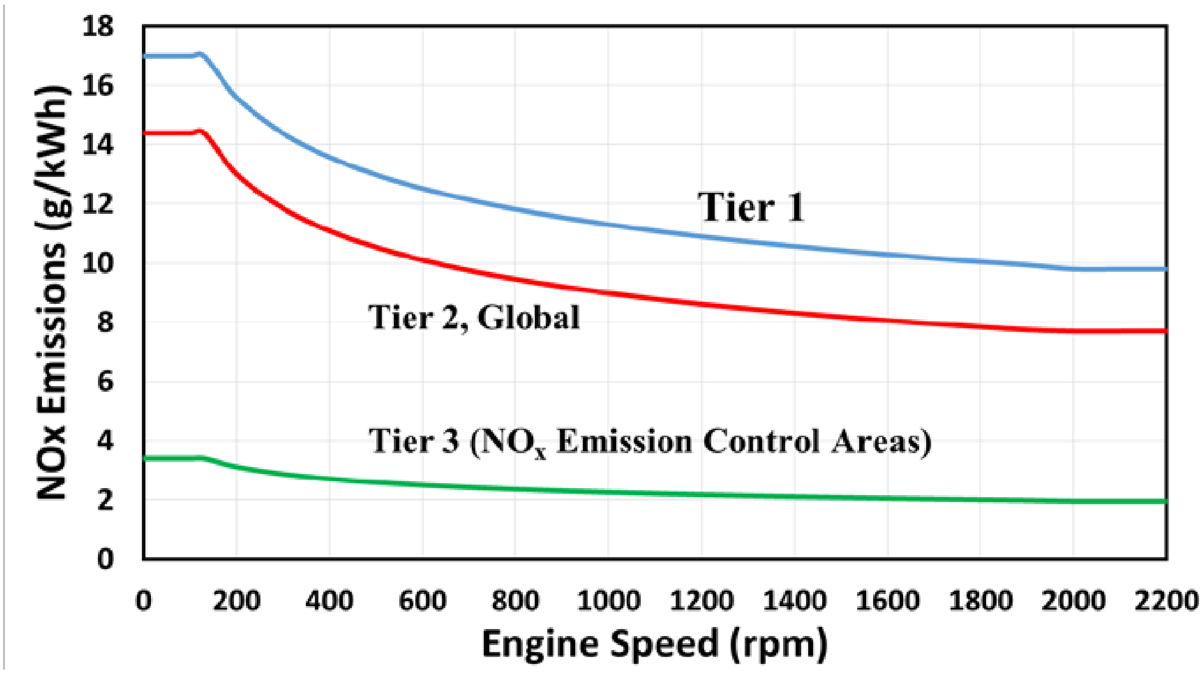

Figure 17. Allowed NOx emissions per Tier I, II and III standards. Y axis is NOx emissions [g/kWh], and the X axis is engine speed [rpm] (96)

5.4.2.6 Selective Catalytic Reduction (SCR)

5.4.2.6.1 Technique's description

A relatively matured after treatment technique for reducing NO_x emissions in marine vessels. NO_2 is reduced to N_2 gas over a catalyst in the exhaust system, by an added reducing agent (urea\ammonia) (100). This technique requires a warm engine in order to operate (210-500°C degrees), and therefore NO_x reduction does not occur upon engine restart. SCR is not suitable for use with sulfur-rich fuels (HFO), as it leads to corrosion and process malfunction (89)

5.4.2.6.2 General potential of emissions reduction

This technique can reduce NO_x levels by 70-98% compared to Tier I engines, to 2-3.5 g/kWh (89, 100) (see figure 17)

5.4.2.6.3 Inputs and Costs

For an average vessel with 13.4 MW engine, that uses 5000 MWh per year, the investment costs are (2010 EU€): 61 €/kW for a SCR in a new vessel, or 89 €/kW for retrofitting an existing vessel with SCR. The total average costs are 711,000 and 1,030,000 € per new and retrofit vessel respectively. The operation and maintenance costs are 2.7 €/MWh (101). The EPA has calculated similar costs (2006 US$), ranging between 390,000 and 2,080,000 $ per vessel with 4.5 MW to 48MW engine power. The cost per kW, is between 39-87 $/kW, depending on the engine size and on the normal operational speed (89).

5.4.2.6.4 Cost effectiveness

The total cost per kg of removed NO_x is between 0.49-5.49 and 1.57-7.82 €/kg NO_x for a new and a retrofitted vessel respectively. The low values are calculated for up to 25 years of operation and\or investment, while the high values are calculated for as low as 5 years of operation and\or investment.

The longer the remainder expected life time of the vessel, the lower the cost per kg of NO_x reduced (101). Another estimation for the cost of implementing SCR is between 0.151-2.025 €/kg of reduced NO_x (77).

Applying this technique to comply with a North and Baltic Seas NECA, has a benefit-cost ratio of 0.99-11.6. Applying this technique to comply with a North and Baltic Seas NECA and a levy on NO_x emissions, has a benefit-cost ratio of 0.97-5.2. Low values are for vessels with a low number of years remaining in operation, and high vales are for vessels with a high number of years remaining in operation (101)

5.4.2.6.5 Feasibility

This technique is not easy to implement. Tier 0 vessels are too old to implement it. Tier I and II vessels will have to pay more than a million € for a retrofit, not to mention at least a few weeks of retrofitting instead of operating. Without specific limit standards, fleets are not expected to adopt this technology. Having said that, this is today the leading NO_x reduction technique in use, with the most experience and range of vessels.

5.4.5 Summary

In the following tables, the different techniques properties are summarized. Lower and higher costs usually reflect new build and retrofitting respectively or size of engine's vessel.

Table 5: Holistic mitigation techniques

Technique name	Emission mitigation potential				Cost (USD)	Sufficiency and relative Cost- effectiveness [$/ton reduced pollutant]	Remarks
	SOx	PM	VOC	NO_x			
ESP- Electric Shore power	100 %	100%	100%	100%	300,000-2,00,000$ per vessel 400,000-5,000,000$ per berth 0-5,000,000$ per elec. Net. 0-600,000$ for O&M (53, 66, 73)	Highly sufficient. Medium to high cost-efficiency.	Eliminate all pollutants during hoteling time (the biggest operation-regime contributor to air pollution from the Haifa and Ashdod ports).
Natural gas\ dual fuel	99%	94%	90%	90%	240,000-4,625,000$ per vessel (184$/kW) (53) LNG price is usually within 15% of HFO price (77, 79) 50,000,000$ per LNG facility (80)	Highly sufficient. Medium to high cost-efficiency.	Emission mitigation applies for all operational regimes (natural gas), or when close to shore (dual fuel). LNG fuel is still not widely available.
SOI- Ship onboard incineration	-	Some		-		Highly cost-effective, but not sufficient as a standalone technique	Does not affect the main emission source (the engine).
VSR- Vessel Speed reduction	70%	70%		55%		Highly cost effective, but not sufficient as a standalone technique	Mitigation is only for sailing. 80-90% of vessels within 25 nautical miles of Israeli ports, usually sail at low speed.
RHT- Reduced Hoteling Time						Highly cost effective, but not sufficient as a standalone technique	Mitigation is only for hoteling time.

Table 6. SO_x mitigation techniques

Technique name	Emission mitigation potential			Cost (USD)	Sufficiency and And relative Cost-effectiveness [$/ton reduced pollutant]	Remarks
	SOx	PM	NO_x			
MGO	90%	85%		New build 34,000-90,000$ (1.5-8$/ kW) Retrofitting 45,000-100,000$ (2-10$/ kW) (89) MGO price is usually 60% more expensive than HFO (79)	Highly sufficient. Medium to high cost-efficiency.	
On-road diesel	90%	87%	6%	Vessel modifications 50,000$ (53) More expensive than MGO.	Highly sufficient. Medium to high cost-efficiency	
GTL	100%	87%	13%	Vessel modifications 50,000$ (53) GTL facility CAPEX is very high: 5-20$ billion USD (81) GTL is more expensive than MGO.	Highly sufficient. low cost-efficiency	The substantial environmental impact of a GTL plant should also be considered
EGCS	80-99%			400,000-7,000,000$ or 35-94$/kW (more expensive for retrofitting) (89, 29)	Highly sufficient. Can be more cost-effective than switching to MGO.	Open systems can cause SO_x & heavy metals sea pollution[42].

Table 7: NO_x mitigation techniques

Technique name	NO_x Emissions Mitigation	Cost (USD) per vessel (or per kW)	Cost- effectiveness ($/ton of reduced NO_x)	Remarks
EDF	10-50%	86,000-210,000$ (4-19$/kW) (89)	Low to medium sufficiency. Low to medium cost-efficiency	Compatible with Tier II.
DWI	50-60%	185,000-1,115,000$ (23-41$/kW) (89)	Medium sufficiency. Low to medium cost-efficiency	Compatible with Tier II.
Fumigation	50-70%	170,000-1,085,000$ (22-42$/kW) (89)	Medium sufficiency. Low to medium cost-efficiency	Compatible with Tier II-III.
EGR	70%	86,000-251,000$ (5-19$/kW) (89)	Medium to high sufficiency. High cost-efficiency	Compatible with Tier III. Some experience in marine vessels.
SCR	70-98%	500,000- 1,300,000$ retrofit (112$/kW) (101) 390,000-2,080,000$ new (39-87$/kW) (89)	Highly sufficient. Medium to high cost-efficiency	Compatible with Tier III-IV. Plenty of experience in marine vessels.
Engine retrofitting from Tier I to II, III.	Tier II 20% Tier III 80% Tier IV 90% [1,43,50] (53, 89, 102)	Retrofitting to Tier II: 8,000-260,000$ (0.3-17$/kW)[36] Replacing to Tier II: 7,500-310,000$ (53) Retrofitting to Tier III: 52,000-130,000$ (3-12$/kW) (not including adding SCR or EGR) (89)	Low to high sufficiency. Medium to high cost-efficiency	Full replacement to Tier III engine is more expensive. New Tier III engines include SCR, EGR or LNG technologies.

Conclusions:

Some of the techniques have benefits beyond the port area. For example: oceangoing vessels speed reduction (energy saving), repowering vessels with newer and cleaner engines and fuels, exhaust gas cleaning systems, etc. It is advised to start with "no-regret" policies that could be implemented easily and fast. For example, to prohibit onboard incineration close to shore and limit vessels speed close to shore and reduce maneuvering and stand-by time close to shore of more polluting vessels (allowing them to stand by at distances of no less than 5 km). These techniques do not require capital investments, or time-consuming vessels'\ports' modifications. However, these techniques will have limited results. We found that most vessels within 25-30 nautical miles from the Haifa and Ashdod ports sail at speeds lower than 15 knots. Also, usually there is a long que to enter the Haifa and Ashdod ports. The Haifa port is in the top 10% percentile of sea ports' container efficiency (but much less efficient for bulk cargo)[51]. Therefore, we assume it will be hard to increase ports efficiencies (reduced hoteling times). Even if reduced hoteling is possible, it seems that no benefit will be achieved through reduced hoteling time, as it will not reduce the number of vessels in the ports at any given time. An exception might be cruise vessels. There are less cruise vessels compared to cargo vessels, and they have a designated terminal. Thus, they might not have ques to Israeli ports and might spend more time than necessary at ports. It is advised to specifically check reduced hoteling for cruise vessels and other relatively more polluting vessels. In addition, it is suggested to start with non-specific solution that can be implemented through a wide range of techniques. For example, to implement a designated emission control area within 12 nautical miles from shore. Each vessel can meet the emission requirements using its preferable technique, while port policy and investments follow and support this process both from the regulatory standpoint as well as by establishing relevant technical means and infrastructure. For example, to introduce electric shore power (ESP) and LNG fueling in the Haifa and Ashdod ports. Introducing these facilities in our ports, will allow shipping companies to consider sending their shore-power ready and\or natural gas fueled vessels. As part of a global trend, it might even convince more of these companies to retrofit or to buy new vessels with these emission reduction solutions.

ESP is a technique that reduces emissions only during hoteling. However, as presented in paragraphs 5.1 and 5.2 , these emissions are the most harmful for the society and for the environment, and they can be completely eliminated (referring to all pollutants: NO_X, SO_X, PM 2.5, CO and VOCs)
On the contrary, the cost-effectiveness of repowering a vessel with LNG is calculated over all of the vessel's voyages and operations. Therefore, the cost of reducing every ton of air pollutant is low. But, if you only consider air-pollution reduction in port, the cost per ton of air pollutant (in the port) is much higher.
Building an LNG bunkering facility in Israeli ports, can also be a strategic step to increase Israel's revenues from natural gas.

It is highly advised to prepare a 10-15 years program that will gradually increase the air emissions reduction demands. This, to give the vessels and the port time to adjust and to properly plan ahead. The program should combine a few complementary techniques, and shouldn't promote only one specific technique. A recent report concluded that the most relevant NO_x emission technique for the EU is SCR. This is due to its efficiency and maturity. EGR is a mature technology and its average NO_x reduction cost per kg NO_x reduced is similar to that of SCR. However, there is less experience with EGR in marine vessels and its costs are less certain. Methanol-fueled ships are too new in the market with high uncertainty, and LNG-fueled ships numbers are also not expected to increase much. However, an LNG increase probability is higher than a methanol one.
SCR, EGR, EGCS and engine replacement techniques are easier to implement, compared to shore power and repowering vessels with LNG. SCR, EGR and EGCS are installed only on vessels and the CAPEX is relatively moderate. Vessels that choose these solutions are independent and are not constrained by port. On the contrary, ESP and LNG require modifications both on vessels and in ports. It is a major constrain on a vessel that is required to reduce emissions on one port using one of the techniques, while at other ports it visits, there are no shore power or LNG bunkering infrastructure . ESP and LNG bunkering require a very high CAPEX. Moreover, countries and port authorities are usually slow to react compared to companies, so big projects like shore power and LNG bunkering take time to be initiated. These solutions also take more time to be installed, as they require special regulations, connecting to shore infrastructure, obtain permits

etc. However, they are holistic, and reduce all emissions. ESP seems to be more common compared to LNG. Also, ESP might be more attractive in Israel than in Europe, due to the current lower electricity prices in Israel.

The long term solution that will reduce most emissions is to restrict NO_X, SO_X, PM 2.5, CO and VOC emissions within 12 nautical miles from Israeli shores (see 5.3), while simultaneously installing LNG bunkering (or other sufficient alternative fuels options) and/or shore power infrastructure at each port. However meanwhile, for 2025 and 2030 recommended mitigation targets, the mitigation plan should include a combination of various optional technical methods with several management, operational and policy methods detailed in the framework presented in paragraph 5.5.

5.5 Recommended mitigation targets framework

5.5.1 General

Israel is a small player is the international maritime sector. Therefore, it is expected to be very difficult to impose its own regulations on international marine vessels. However, there are global regulations already in play, which Israel's policy can go in line with.

- SO_x and PM emissions regulations
- Since 2008, The European Union and North America are imposing strict marine vessels regulations, with only up to 0.1% sulfur fuel or equivalent allowed today. Since 2016, the main ports in China are also restricting SO_x emissions, and starting in 2019, marine vessels within 12 nautical miles of all of China's cost will be prohibited to use more than 0.5% sulfur fuel or equivalent. Furthermore, starting in 2020, all marine vessels globally are prohibited from using more than 0.5% sulfur fuel or equivalent.
- NOx emissions reduction

  North America is imposing strict NO_X emissions regulation.

  It is not sufficient to wait for the global limit of 0.5% sulfur fuel to take effect. That is since it is expected only to reduce marine vessels SOx and PM emissions by 40-60%, without affecting NO_X, VOCs and CO emissions. Therefore, mitigation measures should include all pollutants but especially NO_X, which seems to be the biggest challenge.

5.5.2 Approach

NO_X current and future emissions are very high at both ports and especially at Haifa bay, where these emissions are likely to have a significant impact on the air quality in sensitive receptors. Since more than 50% of these emissions are emitted from vessels at the hoteling stage, an effective mitigation plan, must focus at the hoteling stage but should also include a way of reducing emissions form the other stages (cruising, maneuvering and stand by). The most beneficial way of reducing the hoteling emissions, is by connecting as many vessels as possible to an electric shore power (ESP) infrastructure. A less beneficial but still very effective method would be by relying on SCR or other NO_X abatement techniques (which allow between 60% to 90% of NO_X reduction, but not other emissions). In such case, to achieve similar NO_X reduction results relying entirely on SCR (RMTA1) rather than on ESP (RMTA2), approximately 20%-30% more vessels must be using SCR (or other after treatment techniques) compared to vessels relying on ESP. At present, It is likely that ESP could be more effective at Ashdod port rather than at Haifa port, since at Ashdod, 64% of NO_X emissions are attributed to vessels' hoteling, while at Haifa it is 54%, which is a port that is more congested (with less average hoteling time and a double number of average vessels arriving/departing on a daily basis). This higher marine congestion at Haifa port creates relatively more pollution form cruising, maneuvering and stand by, which NO_X after treatment techniques are effective in reducing while ESP is not. However, the current ratio between congestion-emissions and hoteling-emissions can change in the future[10] with in each port. Therefore, it should not necessarily be a main factor in determining which mitigation technique is potentially more effective at each port. Accordingly, based on these uncertainties and the understanding that each technique has its advantages, we recommend to include in a mitigation plan an implementation of both techniques, knowing that relying on SCR is expected to be less complicated and costly (and perhaps more cost effective in the near future), while ESP is the ultimate solution for reducing all emissions

[10] Any expansion of any port and/or activities within each port to reduce standby time and/or hotelling time and to increase the daily average number of vessels arrivals/departures, can change the ratio of emissions between hoteling, cruising, maneuvering and stand-by operations.

from hoteling, but due to its cost and other complexities, should be more gradually promoted as a long term solution.

We therefore recommend establishing a mitigation plan that will offer vessels to reduce their emissions by any of the available techniques presented in this study. At first, mostly vessels that are Israeli flagged and/or frequently hotel at Haifa and Ashdod ports (for elevating time), can be encouraged to use these technologies. It is assumed that in the beginning it will be relatively easier to reduce the emissions from these vessels. We suspect that at least in the upcoming 5-10 years, transitioning to ESP will go at relatively slow pace and small scale. We suggest that this will be due to four main reasons: 1) as shown in the report, making the required conversion to electric auxiliary engines is quite costly for a ship owner. 2) Investment in such conversion can only be worthy if the ESP infrastructure exist at other related ports. 3) SCR is the currently dominant NO_X mitigation measure. 4) Based on our experience in the field, we argue that emission reduction methods implementation are rather conservative methods by their own, and especially when implemented in conservative driven markets such as the marine transportation. Accordingly, we conclude that for Israel as a relatively small local jurisdiction, it will be very difficult by its own, to encourage growing number of vessels to invest in electric engine auxiliary conversion. Furthermore, for Israel by its own to require or incentivize vessels to invest in SCR (which is currently a less complicated alternative) will also be a highly challenging task. Therefore, we present a framework for establishing an 11-year plan, which will include promoting a number of activities. This framework is ambitious and would first require completing several tasks, which are detailed in paragraph 6. However, we argue that with the right government support, it is feasible to implement this framework and achieve the RMTs presented in this study.

5.5.2 <u>Measures included in the framework</u>

We suggest establishing a gradual mitigation plan that will be extended during a time period of 11 years. Below are the main steps suggested to be followed in such plan:

1. <u>From 2020 and on:</u>

a. Restrict all marine vessels up to 12 nautical miles from the Israeli coastline to use 0.5% sulfur fuel (or equivalent). This will be done in similarity to the IMO regulation. It is better to turn this global regulation also into a local one, to ensure compatibility with the IMO 2020 regulation of all marine vessels in Israel (as was done in the EU, and in China). Also, in case the IMO 2020 regulation might be postponed, Israel will retain this protective regulation. This step is expected to reduce marine vessels SO_x and PM emissions by 40-60%.

b. Restrict all cruise (passenger) vessels up to 12 nautical miles from the Israeli coastline to use 0.1% sulfur fuel (or equivalent). This is assumed to be implemented very easily by cruise vessels, as most of them (if not all), berth at EU ports, where they have been required to use 0.1% fuel (or equivalent) since 2010.

c. Implement a vessel speed reduction [VSR] zone (speed of up to 15 nautical knots per hour) within 12 nautical miles of the Israeli coastline (or an equivalent measure to reduce emissions). Even though this measure can reduce sailing vessels' emissions significantly (as shown above), it is not expected to be the case in the Haifa and Ashdod ports. Based on information we examined (regarding typical speeds in various distances from the ports), we estimate that approximately 80% of the vessels within 10-20 nautical miles in these ports sail bellow 15 nautical knots per hour. However, there is still importance in implementing this measure, as vessels can change their behavior over time.

d. A port policy is implemented that includes enforcement on older polluting vessels to stand by at longer distance away from the port (at least 5 km), reducing their standby time closer to the port by 30%).

e. Explore the possibility of building shore power facilities for marine vessels in the Haifa and Ashdod ports. If a final decision is made by 2021 and the infrastructure is built by 2025, we then suggest that it can be possible to target for 30% of vessels to be using it on a routine basis, so 30% of emissions from hoteling is eliminated from the port. Perhaps it will be worthy to first encourage more polluting Israeli flagged vessels which more frequently hotel at the port.

f. A policy is established and implemented for forcing or incentivizing old vessels at the port to be replaced with either new vessels from 2016 or vessels with retrofitted engines or with SCR/other related after treatment techniques (see paragraph 5.4). Assuming such policy begins during 2022, we suggest that by 2025 it will be possible to have 50% of more older and polluting vessels replaced at any moment at the port with less polluting vessels (forcing fleets/shipping companies "not to send" their more polluting vessels to the Haifa and Ashdod ports).

g. Explore the possibility to compensate vessels\companies that invest in technologies that reduce emissions by: reduced port fees, reduced electricity cost for vessels with ESP, reduced LNG cost for vessels with NG\duel engine, reduced taxes, priority in port services, direct cash compensation.

2. <u>From 2022 and on:</u>
   a. Establish an Israeli DECA: Restrict all marine vessels, up to 11 nautical miles from the Israeli coastline, to use up to 0.1% sulfur fuels (or equivalent).
   b. Apply a 1€/kg NOx emissions levy. The NOx emissions levy revenues will be used to finance ESP infrastructure.

3. <u>From 2025 and on:</u>
   a. Apply a 2€/kg NOx emissions levy. The NOx emissions levy revenues will be used to finance ESP infrastructure.
   b. First ESP infrastructure is operational in the Haifa port.
   c. Extension of ESP infrastructure at Haifa and Ashdod ports, so by 2030, 50% of vessels hoteling the port are using the ESP.
   d. 70% of old vessels at the port are forced or incentivized to be replaced with either new vessels from 2016 or vessels with retrofitted engines or with SCR/other related after treatment techniques.
   e. Standby time closer to the port of more polluting vessels is reduced by 60%.

4. <u>From 2030 and on:</u>

   The mitigation plan is extended with further steps aiming to make Tier III as the standard.

6. Summary and recommendations

The results of this study show that current estimated emissions form the marine sector at both Haifa and Ashdod ports are relatively very high and air polluting. Most of these emissions are emitted during the hoteling stage of the vessel, further to additional high emissions emitted during vessels' maneuvering and stand by activities within short distances from the port's land (0.5-5 km). All these emissions[11] when combined together at each port separately, are similar to a 700 MW and 1,000 MW power plant running exclusively on deiseal fuel oil at Ashdod and Haifa respectively (which is a very polluting fuel being combusted in Israeli power plants only during emergencies). When considering emissions from cruising, the situation is even worse. At Haifa port, it is highly likely that these emissions are strongly affecting the air quality in populated receptors. At Ashdod, it is also possible but requires further investigation. Most concerning emissions that require special attention are SO_X and NO_X. Reducing SO_X emissions will require government efforts, however meeting the RMTs suggested in this report are likely to be much easier compared to NO_X, as in the case of SO_X it will be possible to rely on upcoming international regulations. However, reducing NO_X emissions is expected to be a highly challenging task that is not likely to happen by itself in upcoming 20 years (at least), unless very active government policy and regulatory interventions are applied.

In this study, we presented a framework (chapter 5.5) in which it can be possible to achieve certain RMTs compared to a calculated BAU scenario. This framework requires to be translated into a detailed mitigation plan for an 11-year period starting as soon as possible and achieving first RMT results by 2025. The different components that can be included in the mitigation plan, require further technical, economic and legal analysis. In order to establish such a plan, we recommend completing the following steps:

[11] While NO_X emissions is the pollutant indicator

- Run an air pollution dispersion model to assess the level of impact that the current vessels air pollution (in the port and in the territorial waters) has on populated areas at different distances from the sources of pollution at each port.
- Estimate the damage costs of this pollution.
- Investigate in more detail the technical challenges of the various mitigation alternatives and their costs. We recommend that it should currently focus on SCR, ESP and perhaps other options of alternative fuels.
- Study in more detail different modes of local intervention, including economic incentives that are possible to provide to less polluting vessels versus penalties (fines) to more polluting vessels; and compare the potential effectiveness of each model.
- Assess the levels of economic burden that are possible to impose on polluting vessels and address possible consequences of imposing such penalties.
- Examine legal and economic framework possibilities for declaring NO_X-ECA at Haifa and Ashdod ports.
- Examine if and to what extent it would be possible to require vessels to comply with local emission limits, with different levels of governmental assistance provided as subsidies (if any). Then, estimate, the financial investment that will be needed to support the RMT efforts.
- Detail the exact fundamental steps require to include in an 11-year mitigation plan, including budgets that will require for realizing this plan.

In parallel to these further assessments, we believe that it's important to engage other stakeholders with the results of this study, to point out the extent of the problem as well as challenges facing ahead for coping with current situation. That include local stakeholders in Israel (such as: local management of each port, the port authority, ministry of transportation, ministry of finance, local municipalities) as well as regulatory agencies' officials at other countries belonging to the Mediterranean Sea. If these officials are facing similar challenges, they might be willing to join efforts at regional level, and to coordinate relevant steps with the IMO.

Finally, we emphasize that it is important to consider that the marine sector activity is associated with specific technical, financial, and regulatory[12] characteristics, which make the tackling of this sector a highly challenging task, especially for a local jurisdiction. However, due to the significant environmental impact found to be associated with this sector, special efforts are worthy to be made in order to achieve an effective outcome.

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Appendix 1: Likelihood of Marine pollution reaching populated areas (Haifa port)

As mentioned in the report, we estimate that there is a high chance for the marine emissions (calculated in paragraph 5.1 in the report) reaching various populated areas surrounding the port and affecting the actual air quality in these areas. This conclusion is based on the following analysis.

The potential for air pollutants to be transported to sensitive receptors surrounding the Haifa Bay area (residential, educational institutions, public institutions, hospitals, etc.), is dependent on many factors, including emission source physical parameters (e.g. exhaust gas velocity, gas volumetric flow, gas temperature, etc.) as well as various meteorological and topographical conditions.

The emission sources in this case are characterized by two important elements that are major contributors for a negative outcome (air pollutants reaching the receptors and affecting the air quality of populated areas). First, is the substantial emission rates (see appendix 2). Second, is the relatively low heights of emission-stacks (10-50 m). Other important elements that must be considered are the meteorological and topographical conditions. Based on examining related topographical data from NASA's Shuttle Radar Topography Mission STRM3 (~90 m resolution) and meteorological data from the Haifa Bay area meteorological stations, we point out the following:

- Haifa Bay is characterized by a complex topography (as shown in the topographical map in figure 1 below), so emission sources are located at sea level and sensitive receptors are located only a few dozen meters away from the port, starting at the sea level and up to 500 meters above sea level on Mount Carmel.
- Approximately 60% of winds, are in directions towards any sensitive receptors.
- 20% of winds are likely to transport pollutants towards sensitive receptors, which are at elevated heights relatively to the emission sources (elevated receptors are more likely to receive air pollution from the port).
- The worst air dispersion conditions in this case are "F" and "G" atmospheric stability classes, combined with the relevant wind directions, which are about 10%. It can be assumed that these conditions are causing a significant impact on the air quality of various residential receptors surrounding the Haifa bay area. These receptors are

affected by emissions originating from the port area activities (vessels hoteling and maneuvering) and from vessels cruising at distance of 0-10 kilometers from the port, including waiting vessels "in line".

Another potential contributor to these conditions is when "A" and "B" atmospheric stability classes are taking place, combined with the relevant wind directions. The probability for this case is approximately 7%. It can be assumed that these conditions can cause sensitive receptors to be affected by emissions originating from vessels cruising at distance of 5-20 kilometers from the port (and even more), including waiting vessels "in line".

Meteorological data (annual wind rose) are shown on figure 2 below.

Figure 1: Haifa Bay area topographical map. The figure shows topographical land heights (in meters above sea level) of the sensitive receptors area around the Haifa port. Reference: Topographical data - NASA's Shuttle Radar Topography Mission STRM3, background map - Google's 2018 satellite imagery

When taking into account the all the aforementioned aspects together, it is concluded that there is a high probability for the pollutants emitted from the marine vessels to be transported to various populated receptors. It is estimated that these emissions are increasing air pollutants' ambient concentrations at both substantial amounts and time at these receptors.

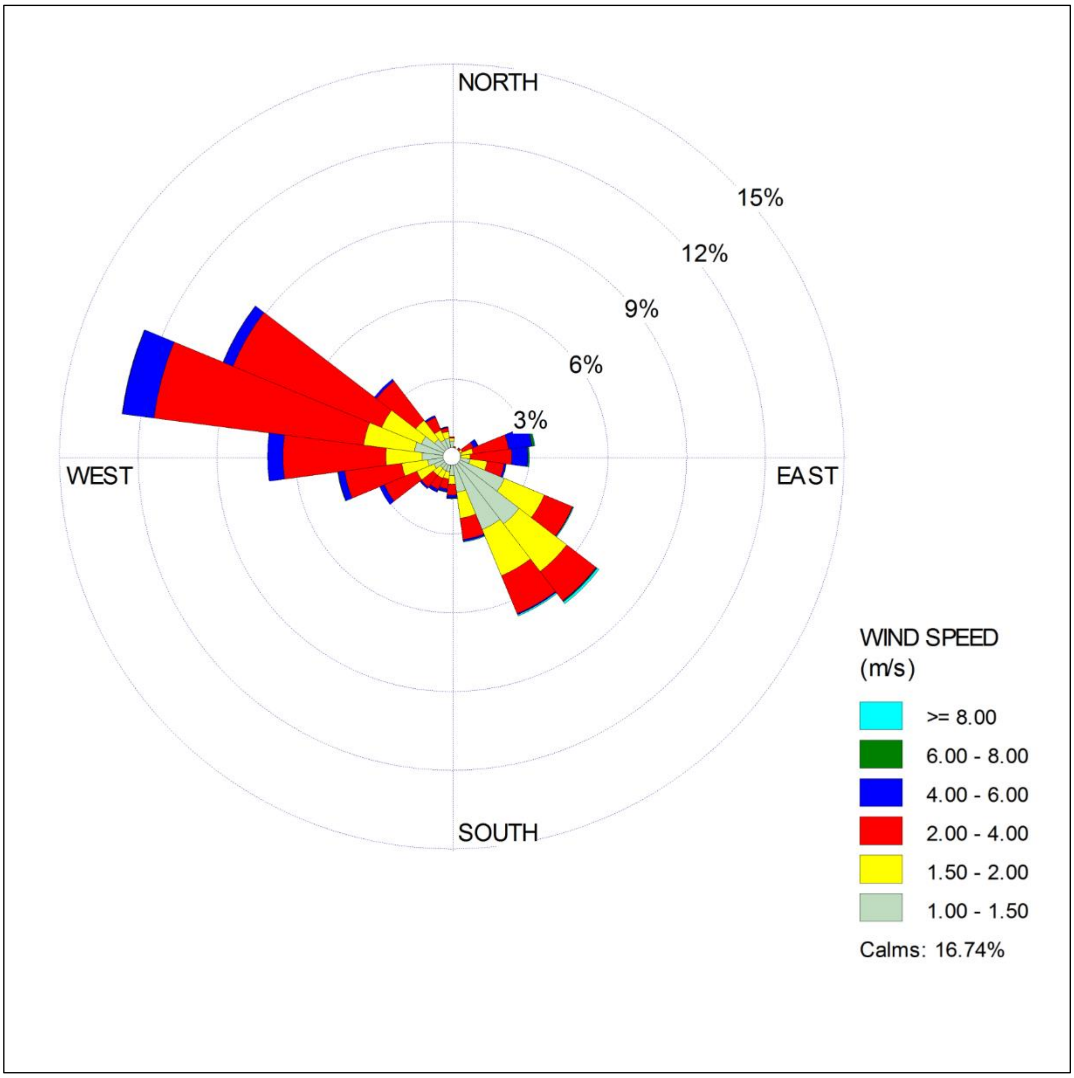

Figure 2: Haifa Bay typical wind rose. The figure shows Haifa bay area winds directions ("blowing from" directions) and velocities (in m/s) distribution on annual average.

Appendix 2
Detailed calculation methodologies and emission results

1.1 Emission sources

Air pollution sources in HAIFA seaport include both marine and land activities. Main sources are the vessels engines, where emissions occur during cruising time (in the territorial waters), maneuvering time (in the port water area) and hoteling time (in the port terminal area). Other significant sources are the land transportation activity in the port, including operating vehicles (trucks, diesel forklifts, diesel cranes and bulldozers) and transportation vehicles (trucks and train locomotives).

Fuel type is one of the most influential factors on the emission volumes for all combustion-based sources. The common fuel types for vessels are BFO (Bunker Fuel Oil), MDO (Marine Diesel Oil) and MGO (Marine Gas Oil). Fuel types for land vehicle are diesel and gasoline. Table 1.1-1 shows the marine emission sources and major mobile sources in HAIFA port.

Table 1.1-1

Source	Engine	Phase	Engine type	Fuel type
Vessels: Cruise, Passenger shuttle, Panamax, Oil tanker, Bunker, General cargo ship, Tugboat, I.N.S, ect.	main	cruise	gas turbine	BFO
				MDO/MGO
			high-speed diesel	BFO
				MDO/MGO
			medium-speed diesel	BFO
				MDO/MGO
			slow-speed diesel	BFO
				MDO/MGO
			steam turbine	BFO

Source	Engine	Phase	Engine type	Fuel type
				MDO/MGO
		manoeuvring / hoteling	gas turbine	BFO
				MDO/MGO
			high-speed diesel	BFO
				MDO/MGO
			medium-speed diesel	BFO
				MDO/MGO
			slow-speed diesel	BFO
				MDO/MGO
			steam turbine	BFO
				MDO/MGO
	auxiliary	cruise / manoeuvring / hoteling	high-speed diesel	BFO
				MDO/MGO
			medium-speed diesel	BFO
				MDO/MGO
Trucks	main	travel	4-stroke gasoline	gasoline
			diesel	diesel
		waiting	4-stroke gasoline	gasoline
			diesel	diesel
Locomotives	main	travel	diesel	diesel
		waiting		
Cranes	main	travel	diesel	diesel
		loading		
Forklifts	main	travel	4-stroke gasoline	gasoline
			diesel	diesel
		loading	4-stroke gasoline	gasoline
			diesel	diesel
Bulldozers	main	travel	diesel	diesel
		loading		

1.2 Emission factors

1.2.1 Vessels

Air emissions produced by vessels are a result of combustion processes occurring in the internal engines. The main pollutants emitted are NOx, CO, VOC and PM2.5. the emission rates are strongly dependent on the engine technology and fueled used.

The total emissions from a vessel can be divided into three phases, during: cruising (in territorial waters ~ 20 km), maneuvering (in the port area) and hoteling (in the port area). Manoeuvring time usually includes also the vessels waiting time in line ("stand by" time) in a distance of 1-10 km from the shore. The emission volume are controlled by the above operation regime/navigation phase, fuel type, engine type and engine duty.

For a single navigation the emissions can be expressed as:

$$E_{vessel} = E_{cruising} + E_{manoeuvring} + E_{hoteling}$$

Fuel types are usually either BFO (Bunker Fuel Oil), MDO (Marine Diesel Oil) and MGO (Marine Gas Oil). In the case where fuel consumption for each operational regime is known, the emissions of pollutant i can be calculate by the following equation:

$$\boldsymbol{E_{vessel,i,e,f}} = \sum_{\boldsymbol{p}}\left(\boldsymbol{FC_{e,f,p}} \times \boldsymbol{EF_{i,e,f,p}}\right)$$

Where:

E_{vessel} = overall emission from a vessel (ton)

FC = feul consumption (ton)

EF_i = emission factor for pollutant i (kg/ton)

i = pollutant (NOx / CO / VOC / PM2.5 / SOx)

f = fuel type (BFO / MDO / MGO)

e = engine type (slow- / medium- / high- speed diesel or gas turbine)

p = phase operational regime (cruise, manoeuvring, hoteling)

Advanced calculation method is applied where fuel consumption per operational regime phase is not known. In this case the emissions can be calculated based on the engine duty (installed power and operation time) in the different phases.

Emissions can be calculated for auxiliary engines, using load factor and total time in hours for each phase by the following equation:

$$\boldsymbol{E_{vessel,i,e,f}} = \sum_{\boldsymbol{p}}\left[\boldsymbol{T} \times \boldsymbol{P} \times \sum_{\boldsymbol{ec}}\left(\boldsymbol{P_{ec}} \times \boldsymbol{LF_{ec}} \times \boldsymbol{EF_{i,ec,e,f,p}}\right)\right]$$

Where:

E_{vessel} = overall emission from a vessel (g)

EF_i = emission factor for pollutant i (g/kWh) see table 1.2.1-1 below

LF = engine load factor (%)

P = engine nominal power (kW)

T = time (hour)

ec = engine category (main / auxiliary)

i = pollutant (NOx / CO / VOC / PM2.5 / SOx)

f = fuel type (BFO / MDO / MGO)

e = engine type (slow- / medium- / high- speed diesel or gas turbine)

p = phase of the navigation (cruise, manoeuvring, hoteling)

Emission factors for pollutants NOx, VOC, PM2.5, CO and SOx, per individual engine and fuel type combinations are displayed in Tables 1.2.1-1 and 1.2.1-2 in units of g pollutant per kWh. The emission factors are categorized according to the vessels manufacturer year. The emission factors were established by the ENTEC report based on a comprehensive emissions inventory for Mediterranean vessels (ENTEC 2007). For vessels manufactured after 2010, the emission factor are equal to the EPA emission standards for NOx and PM2.5, and to the EU emission legislation limits for VOC and CO. SOx emissions are derived from the sulfur content in fuel oil used by vessel engines (Table 1.2.1-3 shows the current legislation in force).

Table 1.2.1-1: Emission factors for NOx

Engine	Phase	Engine type	Fuel type	NOx EF (g/kWh)						
				Entec 2000	Entec 2005	Entec 2010	EPA Standard TIER 1	EPA Standard TIER 2	EPA Standard TIER 3	EPA Standard TIER 4
main	cruise	gas turbine	BFO	6.1	5.9	5.7	$45*N^{-0.20}$	$44*N^{-0.23}$	$9*N^{-0.20}$	1.8
			MDO/MGO	5.7	5.5	5.3				
		high-speed diesel	BFO	12.7	12.3	11.8				
			MDO/MGO	12	11.6	11.2				
		medium-speed diesel	BFO	14	13.5	13				
			MDO/MGO	13.2	12.8	12.3				
		slow-speed diesel	BFO	18.1	17.5	16.9				
			MDO/MGO	17	16.4	15.8				
		steam turbine	BFO	2.1	2	2				
			MDO/MGO	2	1.9	1.9				
	manoeuvring / hoteling	gas turbine	BFO	3.1	3	2.9				
			MDO/MGO	2.9	2.8	2.7				
		high-speed diesel	BFO	10.2	9.9	9.5				
			MDO/MGO	9.6	9.3	8.9				
		medium-speed diesel	BFO	11.2	10.8	10.4				
			MDO/MGO	10.6	10.2	9.9				
		slow-speed diesel	BFO	14.5	14	13.5				
			MDO/MGO	13.6	13.1	12.7				
		steam turbine	BFO	1.7	1.6	1.6				
			MDO/MGO	1.6	1.6	1.5				
auxiliary	cruise / manoeuvring / hoteling	high-speed diesel	BFO	11.6	11.2	10.8				
			MDO/MGO	10.9	10.5	10.2				
		medium-speed diesel	BFO	14.7	14.2	13.7				
			MDO/MGO	13.9	13.5	13				

N = engine rpm

Table 1.2.1-2: Emission factors for VOC, PM2.5, CO and SOx

Engine	Phase	Engine type	Fuel type	VOC EF (g/kWh)		PM2.5 EF (g/kWh)		CO EF (g/kWh)		SOx EF (g/kWh)
				Entec 2000-2010	EU Emission Directive	Entec 2000-2010	EPA Standard	Lloyd's Register	EPA Standard	Lloyd's Register
main	cruise	gas turbine	BFO	0.1	$1.5+2/P^{0.5}$	0.1	0.1-0.8	1.6	5	4.36*S
			MDO/MGO	0.1		0				
		high-speed diesel	BFO	0.2		0.8				
			MDO/MGO	0.2		0.3				
		medium-speed diesel	BFO	0.5		0.8				
			MDO/MGO	0.5		0.3				
		slow-speed diesel	BFO	0.6		1.7				
			MDO/MGO	0.6		0.3				
		steam turbine	BFO	0.1		0.8				
			MDO/MGO	0.1		0.3				
	manoeuvring / hoteling	gas turbine	BFO	0.5		1.5				
			MDO/MGO	0.5		0.5				
		high-speed diesel	BFO	0.6		2.4				
			MDO/MGO	0.6		0.9				
		medium-speed diesel	BFO	1.5		2.4				
			MDO/MGO	1.5		0.9				
		slow-speed diesel	BFO	1.8		2.4				
			MDO/MGO	1.8		0.9				
		steam turbine	BFO	0.3		2.4				
			MDO/MGO	0.3		0.9				
auxiliary	cruise / manoeuvring / hoteling	high-speed diesel	BFO	0.4		0.8				
			MDO/MGO	0.4		0.3				
		medium-speed diesel	BFO	0.4		0.8				
			MDO/MGO	0.4		0.3				

P = engine power (kWh)

S = percentage Sulphur content in fuel (%)

Table 1.2.1-3: Sulfur content in fuel

Regulation		In force from year:	Sulfur content in fuel oil (%)
Marpol Annex VI	SECA	2010	1
		2015	0.1
	Global	**2012**	**3.5**
		2025	**0.5**
EU Directive 2005/33	SECA	2007	1.5
	Global	None	None

Based on table 1.2.1-3 above, the sulfur content in vessels fuel oil determined as 3.5% for the present time (2018) and 0.5% for future time (2025).

Table 1.2.1-4 shows the estimated uncertainties related to the emission factors (ENTEC 2007). Additional operation parameters which were used as the basis for emission calculations are presented in Table 1.2.1-5.

Table 1.2.1-4: Uncertainties of emission factors

Parameter	**Uncertainties of emission factors**		
	Cruising	**Manoeuvring**	**Hoteling**
NOx	±20%	±40%	±30%
SOx	±10%	±30%	±20%
VOC	±25%	±50%	±40%
PM2.5	±25%	±50%	±40%
Fuel Consumption	±10%	±30%	±20%

Table 1.2.1-5: Calculations basis Parameters for 2018

Vessel velocity	10	Knot
	18.5	km/hr
Cruising distance	19.2	km
Cruising time	1	hr
Manoeuvring time	1	hr
Stand by time	3	hr
Hoteling time	84	hr
Specific fuel Consumption	218	g/kWh

The relevant emission factors for each engine and each vessel type were selected according to the specific engine power and revolutions per minute, and multiplied by the operating engines number for each activity phase. The data was adjusted for average parameters of the Mediterranean fleet, based on Lloyd's database (Trozzi 2010).

Emission factors and emission standard tiers were adjusted to the vessels age, regarding three different years (2018, 2025, 2030).

1.3 Emissions

1.3.1 Vessels

Vessels emissions are presented in the following tables with respect to:

Haifa and Ashdod ports, two target years (2025, 2030), business as usual (BAU) scenario and three emission mitigation scenarios (RMTA1, RMTA2, RMT), as described below:

BAU 2025 assumes the following:

- Passive renovation of vessels
- Current global regulation
- Increased vessels congestion
- Reduction of hoteling time
- New "HaMifratz" / "HaDarom" port

RMT A1 2025 assumes the following:

- BAU 2025 with emissions reduction due to:
- Electric shore power for 30% of vessels
- Reduction of stand-by time by 30%

RMT A2 2025 assumes the following:

- BAU 2025 with emissions reduction due to:
- 50% of old vessels are replaced with new ones or with SCR installed
- Reduction of stand by time in 30%

RMT 2025 assumes the following:

- RMT A1 2025 & RMT A2 2025 together

BAU 2030 assumes the following:

- passive renovation of vessels

- Current global regulation
- Increased vessels congestion
- Reduction of hoteling time

RMT A 2030 assumes the following:

- BAU 2030 with emissions reduction due to:
- Electric shore power for 50% of vessels
- Reduction of stand by time in 60%

RMT B 2030 assumes the following:

- BAU 2030 with emissions reduction due to:
- 70% of old vessels are replaced with new ones or with SCR installed
- Reduction of stand by time in 60%

RMT 2030 assumes the following:

- RMTA 1 2030 & RMT A2 2030 together

The calculated instantaneous emissions for typical vessels in 2018 are presented in table 1.3.1-1 with units of gram pollutant per second (g/s). The total yearly vessels emissions calculated for the different scenarios (as described above) are shown in tables 1.3.1-2 – 1.3.1-19 with units of ton pollutant per year (ton/year).

Table 1.3.1-1: Instantaneous emissions from vessels (2018 situation)

Vessel type	Instantaneous emissions (g/s)														
	cruising					manoeuvring					hoteling				
	NOx	PM2.5	VOC	CO	SOx	NOx	PM2.5	VOC	CO	SOx	NOx	PM2.5	VOC	CO	SOx
Large cruise	114.3	6.5	1.6	40.8	124.6	53.4	3.1	1.9	19.2	58.6	26.7	1.54	0.77	9.60	29.3
Passenger vessel	19.1	1.1	0.7	6.8	20.9	6.9	0.4	0.2	2.5	7.5	6.9	0.39	0.20	2.47	7.5
Panamax (containers)	111.7	6.4	1.6	39.9	121.8	38.1	2.4	1.5	14.9	45.5	4.7	0.28	0.14	1.75	5.3
Panamax (grains)	32.1	0.7	0.5	11.5	35.0	0.0	0.0	0.0	0.0	0.0	2.1	0.05	0.06	0.77	2.3
Oil tanker 180m	25.3	0.4	0.4	9.7	29.7	0.0	0.0	0.0	0.0	0.0	1.8	0.03	0.05	0.67	2.0
Chemical tanker 100m	13.3	0.3	0.2	4.8	14.5	0.0	0.0	0.0	0.0	0.0	2.0	0.04	0.06	0.73	2.2
Bunker 120m	6.8	0.1	0.1	2.4	7.4	0.5	0.01	0.02	0.2	0.5	0.5	0.01	0.01	0.17	0.5
General cargo ship 120m	6.8	0.1	0.1	2.4	7.4	0.0	0.0	0.0	0.0	0.0	0.5	0.01	0.01	0.17	0.5
I.N.S	18.5	1.1	0.7	6.8	20.9	6.7	0.4	0.2	2.5	7.5	6.7	0.39	0.20	2.47	7.5
Tugboat	0.0	0.0	0.0	0.0	0.0	4.2	0.1	0.2	1.8	5.4	1.8	0.03	0.05	0.67	2.0

Table 1.3.1-2: Total emissions from vessels (Haifa, 2018)

Pollutant	**Emissions (ton/year)**						
	cruising		**manoeuvring + stand by**		**hoteling**		**total**
NOx	1946	17%	3228	29%	5993	54%	**11167**
PM2.5	156	18%	304	34%	429	48%	**889**
VOC	39	9%	190	43%	214	48%	**444**
CO	312	18%	608	34%	857	48%	**1778**
SO2	460	5%	1891	21%	6526	74%	**8877**

Table 1.3.1-3: Total emissions from vessels (Haifa, BAU 2025)

Pollutant	**Emissions (ton/year)**						
	cruising		**manoeuvring + stand by**		**hoteling**		**total**
NOx	2069	19%	3375	30%	5676	51%	**11119**
PM2.5	120	19%	233	36%	286	45%	**638**
VOC	48	9%	232	46%	229	45%	**509**
CO	383	19%	745	36%	915	45%	**2042**
SO2	113	6%	463	24%	1392	71%	**1968**

Table 1.3.1-4: Total emissions from vessels (Haifa, RMT A1 2025)

Pollutant	Emissions (ton/year)						
	cruising		manoeuvring + stand by		hoteling		total
NOx	2069	24%	2569	30%	4011	46%	**8648**
PM2.5	120	24%	178	36%	202	40%	**499**
VOC	48	12%	177	46%	162	42%	**387**
CO	383	24%	568	36%	647	40%	**1598**
SO2	113	8%	356	25%	984	68%	**1453**

Table 1.3.1-5: Total emissions from vessels (Haifa, RMT A2 2025)

Pollutant	Emissions (ton/year)						
	cruising		manoeuvring + stand by		hoteling		total
NOx	1360	20%	1684	25%	3757	55%	**6801**
PM2.5	120	21%	178	30%	286	49%	**583**
VOC	48	11%	177	39%	229	50%	**454**
CO	383	21%	568	30%	915	49%	**1865**
SO2	113	6%	356	19%	1392	75%	**1861**

Table 1.3.1-6: Total emissions from vessels (Haifa, RMT 2025)

Pollutant	Emissions (ton/year)						
	cruising		manoeuvring + stand by		hoteling		total
NOx	1360	24%	1684	29%	2694	47%	**5738**
PM2.5	120	24%	178	36%	202	40%	**499**
VOC	48	12%	177	46%	162	42%	**387**
CO	383	24%	568	36%	647	40%	**1598**
SO2	113	8%	356	25%	984	68%	**1453**

Table 1.3.1-7: Total emissions from vessels (Haifa, BAU 2030)

Pollutant	Emissions (ton/year)						
	cruising		manoeuvring + stand by		hoteling		total
NOx	2066	19%	3347	31%	5327	50%	**10740**
PM2.5	126	19%	245	38%	280	43%	**650**
VOC	50	10%	244	47%	224	43%	**518**
CO	402	19%	783	38%	896	43%	**2080**
SO2	118	6%	487	25%	1363	69%	**1969**

Table 1.3.1-8: Total emissions from vessels (Haifa, RMT A1 2030)

Pollutant	Emissions (ton/year)						
	cruising		manoeuvring + stand by		hoteling		total
NOx	2066	33%	1909	31%	2192	36%	**6167**
PM2.5	126	33%	140	37%	116	30%	**382**
VOC	50	18%	140	50%	92	33%	**283**
CO	402	33%	449	37%	370	30%	**1221**
SO2	118	12%	284	29%	562	58%	**964**

Table 1.3.1-9: Total emissions from vessels (Haifa, RMT A2 2030)

Pollutant	Emissions (ton/year)						
	cruising		manoeuvring + stand by		hoteling		total
NOx	1088	22%	986	20%	2892	58%	**4966**
PM2.5	126	23%	140	26%	280	51%	**546**
VOC	50	12%	140	34%	224	54%	**414**
CO	402	23%	449	26%	896	51%	**1746**
SO2	118	7%	284	16%	1363	77%	**1766**

Table 1.3.1-10: Total emissions from vessels (Haifa, RMT 2030)

Pollutant	Emissions (ton/year)						
	cruising		manoeuvring + stand by		hoteling		total
NOx	1088	33%	986	30%	1190	36%	**3263**
PM2.5	126	33%	140	37%	116	30%	**382**
VOC	50	18%	140	50%	92	33%	**283**
CO	402	33%	449	37%	370	30%	**1221**
SO2	118	12%	284	29%	562	58%	**964**

Table 1.3.1-11: Total emissions from vessels (Ashdod, 2018)

Pollutant	**Emissions (ton/year)**						
	cruising		**manoeuvring + stand by**		**hoteling**		**total**
NOx	973	13%	1614	22%	4661	64%	**7248**
PM2.5	78	14%	152	27%	333	59%	**564**
VOC	20	7%	95	34%	167	59%	**281**
CO	156	14%	304	27%	667	59%	**1127**
SO2	230	4%	946	15%	5076	81%	**6251**

Table 1.3.1-12: Total emissions from vessels (Ashdod, BAU 2025)

Pollutant	**Emissions (ton/year)**						
	cruising		**manoeuvring + stand by**		**hoteling**		**total**
NOx	1034	14%	1687	23%	4493	62%	**7215**
PM2.5	60	15%	116	29%	226	56%	**402**
VOC	24	7%	116	36%	181	56%	**321**
CO	191	15%	372	29%	724	56%	**1288**
SO2	56	4%	232	17%	1102	79%	**1390**

Table 1.3.1-13: Total emissions from vessels (Ashdod, RMT A1 2025)

Pollutant	Emissions (ton/year)						
	cruising		manoeuvring + stand by		hoteling		total
NOx	1034	19%	1325	24%	3171	57%	**5531**
PM2.5	60	19%	92	29%	160	51%	**311**
VOC	24	10%	91	38%	128	53%	**243**
CO	191	19%	293	29%	512	51%	**996**
SO2	56	6%	183	18%	778	76%	**1018**

Table 1.3.1-14: Total emissions from vessels (Ashdod, RMT A2 2025)

Pollutant	Emissions (ton/year)						
	cruising		manoeuvring + stand by		hoteling		total
NOx	680	15%	869	19%	2974	66%	**4523**
PM2.5	60	16%	92	24%	226	60%	**378**
VOC	24	8%	91	31%	181	61%	**296**
CO	191	16%	293	24%	724	60%	**1208**
SO2	56	4%	183	14%	1102	82%	**1342**

Table 1.3.1-15: Total emissions from vessels (Ashdod, RMT 2025)

Pollutant	Emissions (ton/year)						
	cruising		manoeuvring + stand by		hoteling		total
NOx	680	19%	869	24%	2099	58%	**3648**
PM2.5	60	19%	92	29%	160	51%	**311**
VOC	24	10%	91	38%	128	53%	**243**
CO	191	19%	293	29%	512	51%	**996**
SO2	56	6%	183	18%	778	76%	**1018**

Table 1.3.1-16: Total emissions from vessels (Ashdod, BAU 2030)

Pollutant	**Emissions (ton/year)**						
	cruising		**manoeuvring + stand by**		**hoteling**		**total**
NOx	1043	15%	1690	24%	4194	61%	**6927**
PM2.5	63	16%	123	30%	220	54%	**407**
VOC	25	8%	123	38%	176	54%	**325**
CO	203	16%	395	30%	705	54%	**1303**
SO2	60	4%	246	18%	1073	78%	**1379**

Table 1.3.1-17: Total emissions from vessels (Ashdod, RMT A1 2030)

Pollutant	Emissions (ton/year)						
	cruising		manoeuvring + stand by		hoteling		total
NOx	1043	28%	964	26%	1726	46%	**3733**
PM2.5	63	28%	71	31%	91	40%	**225**
VOC	25	15%	71	42%	73	43%	**169**
CO	203	28%	227	31%	291	40%	**721**
SO2	60	9%	143	22%	442	69%	**646**

Table 1.3.1-18: Total emissions from vessels (Ashdod, RMT A2 2030)

Pollutant	Emissions (ton/year)						
	cruising		manoeuvring + stand by		hoteling		total
NOx	544	17%	502	15%	2209	68%	**3255**
PM2.5	63	18%	71	20%	220	62%	**355**
VOC	25	9%	71	26%	176	65%	**272**
CO	203	18%	227	20%	705	62%	**1135**
SO2	60	5%	143	11%	1073	84%	**1276**

Table 1.3.1-19: Total emissions from vessels (Ashdod, RMT 2030)

Pollutant	Emissions (ton/year)						
	cruising		manoeuvring + stand by		hoteling		total
NOx	544	28%	502	26%	909	46%	**1955**
PM2.5	63	28%	71	31%	91	40%	**225**
VOC	25	15%	71	42%	73	43%	**169**
CO	203	28%	227	31%	291	40%	**721**
SO2	60	9%	143	22%	442	69%	**646**