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Essays on vessel emissions and externality cost in Las Palmas Port

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Essays on vessel emissions and externality costs in Las Palmas Port

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A mis padres Silvia Naranjo y Radko Tichavsky, a mis hermanos Vladislav y Vojtech, a mi tía Cecilia y sobre todo, a Paula Sánchez-Cabezudo con mucho cariño.

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Introducción y resumen general

En los últimos años, los efectos negativos relacionados con las emisiones atmosféricas derivadas del crecimiento del transporte marítimo han generado una preocupación creciente. Se ha reconocido que los buques no sólo contribuyen a los efectos negativos a escala global que se derivan de la elevación de la temperatura (cambio climático), sino que también son responsables de efectos negativos experimentadas en las comunidades locales (Cullinane and Cullinane, 2013). Derivado de esto, los puertos están adoptando de manera creciente, herramientas de gestión para hacer cumplir o fomentar el desarrollo sostenible (Lam y Notteboom , 2014) y la reducción de las emisiones.

Ciertamente, además del incremento en las temperaturas globales causadas por el CO_2, la exposición a gases contaminantes derivados de la combustión de combustibles fósiles, como el NOx, SOx, CO, VOC y partículas volátiles (PM[1]), se relaciona de manera continuada con consecuencias negativas sobre la salud. Estos efectos indeseables se presentan tanto a corto como a largo plazo. Algunos ejemplos son: dolores de cabeza, mareos, náuseas, problemas respiratorios, enfermedades crónicas, ingresos en centros de salud y mortalidad prematura (Corbett et al., 2007).

La necesidad de reducir la contaminación del aire ha sido ampliamente reconocida como una cuestión de política en los puertos. El control de las emisiones requiere como un paso previo imprescindible de la capacidad de cuantificarlas y desarrollar inventarios precisos de las mismas. En efecto, disponer de información sobre las emisiones es necesario para poder evaluar adecuadamente los impactos de proyectos de mejoras portuarias o de crecimiento de la actividad de la flota en el puerto, así como para planificar las estrategias o programas voluntarios de mitigación y, ayudar a los responsables políticos en el desarrollo de requisitos

[1] Las partículas volátiles o suspendidas son una mezcla de compuestos microscópicos o muy pequeños en forma de pequeñas piezas de partículas líquidas y sólidas suspendidas en el aire (por ejemplo hollín, polvo, humo y neblinas). Su composición se define en los estándares internacionales (ISO 8178) de acuerdo con la medida de su diámetro (10 micras o menos y 2.5 micras o menos).

normativos eficaces a nivel nacional e internacional para reducir las emisiones.

Efectivamente, el proceso de combustión vinculado a la operación de los buques en regiones cercanas a la costa y en los puertos, contribuye al incremento en los niveles de exposición de residentes y visitantes de la ciudad portuaria a sustancias peligrosas (Tzannatos, 2010; Miola, 2010;. Castells et al, 2014; Tichavska y Tovar, 2015). Esto se debe principalmente a las operativas de atraque, maniobra (llegada y salida) y navegación dentro del puerto y su canal de aproximación.

En este sentido, el tiempo que permanece el buque atracado puede resultar en una gran contribución a la contaminación del aire. En particular, cuando estos utilizan sus propios generadores para cubrir sus necesidades de electricidad en atraque. Además de esto, las zonas de atraque a menudo se localizan cerca de zonas pobladas por lo que el impacto de las emisiones liberadas durante las operativas de maniobra y atraque pueden resultar, desde una perspectiva local, en una mayor proporción de externalidades negativas de las que resultarían si esas emisiones fuesen liberadas en mar abierto (Goldsworthy y Goldsworthy, 2015).

El reto de identificar los perfiles operativos de los buques atracados, en maniobra y en navegación de crucero (aproximación al puerto), en conjunción con la dependencia de las emisiones que resulta de esos perfiles (la carga real del motor en cada una de ellas), se puede abordar si se dispone de registros de posición de cada buque[2] y de bases de datos complementarias que contienen los detalles técnicos de la nave y de sus motores. Esto garantiza que la ubicación, la velocidad, la ruta, las dimensiones, el tipo de motor y el consumo de combustible de cada buque sea conocido en todo momento; lo que evita la adopción de supuestos acerca de las

[2] Estos pueden obtenerse a través del sistema AIS (Automatic Identification System). Para esta tesis se utilizó información obtenida a través de este sistema. Una unidad AIS consiste en un transceptor de radio VHF capaz de enviar a otros buques y a estaciones receptoras identificadas (terrestres y satelitales), la posición, rumbo, velocidad, eslora, tipo de buque, información de identificación del buque, entre otros. La unidad AIS de a bordo transmite la información de manera automática y sin intervención de la tripulación del buque. Este sistema fue concebido con el objetivo original de ayudar a la navegación en el seguimiento de los buques y la prevención de colisiones en el mar, que con el tiempo, ha evolucionado hasta convertirse en un sistema con una multitud de aplicaciones adicionales, incluyendo la obtención de bases de datos realistas para la estimación de emisiones. Un transceptor AIS transmite regularmente, información estática y también relacionada con la travesía (cada 6 minutos), además de información dinámica con una frecuencia relacionada con la velocidad del buque (2-10 segundos) y estado de navegación (3 min cuando está anclado).

variables anteriores y, además, facilita el beneficio adicional que se deriva de la posibilidad de representar los resultados obtenidos en mapas de alta resolución que reflejen la caracterización geográfica de las emisiones en las áreas de puerto-ciudad. Las metodologías basadas en el sistema de comunicaciones AIS, ya han sido utilizadas para estimar emisiones de buques (Jalkanen et al., 2008) con anterioridad, sin embargo, nunca antes se habían sugerido como un instrumento de apoyo a la formulación de políticas y medidas correctoras dirigidas a un sector específico (pasajeros) o sus subsectores (cruceros y transbordadores) dentro de un contexto insular.

En lo que a esto respecta, el Capítulo 1 titulado "Port-city exhaust emission model: an application to cruise and ferry operations in Las Palmas Port" presenta, por primera vez en la literatura, un inventario de doce meses de emisiones de buques en puerto. Este inventario se ha construido a partir de un modelo *full bottom-up*[3] e información real de tráfico de buques durante 2011 en el puerto de Las Palmas. Esta información ha sido obtenida a través de mensajes transmitidos por el Sistema de Identificación Automática (AIS). El inventario de emisiones se ha realizado con el objetivo de analizar, tanto las emisiones de tráfico marítimo en general como las operaciones de cruceros y ferries en particular. Los resultados se describen por tipo de contaminante (NO_x, SO_x, $PM_{2.5}$, CO, CO_2) y se desagregan atendiendo al tamaño de

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[3] Los enfoques *top-down* y *bottom-up* son ampliamente reconocidos en la literatura de una variedad de temas de investigación (Sabatier, 1986). Estos incluyen la cuantificación de las emisiones al aire (paso necesario para obtener los costes externos) y los costes externos. Un enfoque capta la tecnología del transporte en forma agregada (*top-down*) y el otro en forma desagregada (*bottom-up*) arrojando resultados diferentes debido a complejas interacciones entre efectos, estructura y datos. Tanto en la estimación de emisiones como en la de costes externos, el enfoque *top-down* utiliza variables económicas agregadas mientras que el enfoque *bottom-up* considera información refinada y desglosada, en su mayoría basada en el rendimiento técnico.
La aplicación de uno u otro enfoque varía de acuerdo con el objeto de estudio. Para la estimación de las emisiones, se utiliza un enfoque *top-down*, que se basa en la venta de combustibles, cuando información refinada de tráfico no existe o no está disponible. Sin embargo cuando existe la información de tráfico (obtenida a través seguimiento de buques -*vessel tracks*- o escalas en puerto) y está disponible; se utiliza un enfoque *bottom-up* debido a la precisión de los parámetros de entrada del modelo como, por ejemplo, el tipo de buque, la ubicación, el tamaño y los detalles técnicos. Por último, Miola et al., (2010), hablan de un enfoque *full bottom-up* como el uso de un enfoque *bottom-up* tanto en la cuantificación de las emisiones como en la caracterización geográfica de los resultados. En cuanto a la caracterización geográfica de las emisiones, el nivel de detalle alcanzado también depende del enfoque seguido. Así, con un enfoque, *bottom-up* se tiene en cuenta información individual de los buques y su posición mientras que con un enfoque *top-down* la valoración se realiza sin, o con información parcial, sobre la posición de los buques (es decir, la actividad geográfica del tráfico marítimo se estima con base en una sola ruta de navegación o una célula de actividad geográfica particular, con independencia de que buque lleva a cabo la actividad).

los barcos, al tipo de buque y a la operativa de navegación (atraque, maniobra o navegación de aproximación a puerto). En este capítulo se llega a la conclusión de que el tráfico marítimo en general, y el transporte marítimo de pasajeros en particular, representan una fuente de contaminación del aire en el puerto de Las Palmas. Los mapas de emisiones elaborados con base en los resultados confirman la ubicación de focos de liberación de emisiones en los muelles asignados a operaciones de cruceros y ferries.

Las recomendaciones de política que se derivan de los resultados obtenidos alientan a llevar un control regular de las emisiones con el propósito de orientar el diseño de instrumentos de política ambiental e incentivos basados en el mercado que tengan en cuenta los perfiles de contaminación y de operativa específicos de cada subsector (ferris, cruceros, portacontenedores, graneleros, y otros). Por otro lado, se sugiere se lleven a cabo estudios de viabilidad de proyectos que permitan reducir las emisiones como, por ejemplo, la instalación de sistemas de atraque automático y la provisión a los buques de combustibles alternativos (como el gas licuado, LNG) menos contaminantes. Por último, pero no menos importante, que se analice la viabilidad de instalaciones que permitan el suministro a buques atracados de energía eléctrica desde tierra (evitando así que utilicen sus propios generadores), dando prioridad a su instalación en los muelles de atraque habitual de aquellos sectores o sub-sectores que, tras confirmarse por un estudio de dispersión atmosférica, exposición e impacto, presenten un perfil contaminante con mayores efectos locales.

Los resultados del Capítulo 1 no sólo describen perfiles de contaminantes y operativa en el puerto de Las Palmas si no que, también ponen en valor las metodologías de medición de emisiones basadas en datos AIS. En particular, cuando se acompañan de modelos de calidad del aire, estimaciones de su impacto y de estudios económicos para abordar el diseño de medidas correctivas dirigidas a subsectores específicos en el transporte marítimo (como cruceros y ferries). Los resultados y recomendaciones de política de este estudio pueden ayudar en la adecuación o mejora de la política existente en el puerto de Las Palmas, pudiendo ser también de utilidad a otras ciudades portuarias, sean continentales o insulares, bajo condiciones del tráfico marítimo similares.

Las emisiones de gases contaminantes relacionadas con los puertos, como cualquier externalidad negativa; reflejan un coste real procedente de una actividad económica y dan lugar a un resultado que no es óptimo. De hecho, la población que habita las ciudades portuarias experimenta consecuencias perniciosas derivadas de la degradación en la calidad del aire asociado al tráfico marítimo (Corbett et al., 2007).

Estas emisiones resultan en externalidades negativas que afectan a zonas urbanas y rurales y que pueden ser monetizadas como costes externos. En este sentido, el Capítulo 2 titulado "External costs of vessel emissions at port: A review of the methodological and empirical state of the art" presenta una revisión de las metodologías existentes en la actualidad para estimar el coste de las externalidades (coste externo[4] en adelante) derivado de las emisiones de los buques en puerto como paso previo a la valoración que se realiza en el Capítulo 3. Además, se constata que la literatura empírica que estima emisiones de gases contaminantes derivadas de buques en puerto es reciente. Sus orígenes se encuentran en 2009, año de publicación del primer artículo. De entonces hasta ahora, y según el conocimiento de los autores, solo existen nueve artículos sobre el tema entre los que se cuenta el Capítulo 3 de esta tesis.

Según la revisión efectuada de la literatura relativa a las metodologías existentes para estimar el coste externo de la polución del aire, en la actualidad, es posible estimar e coste externo si bien su estimación es fuente de incertidumbre porque la misma está condicionada, principalmente, por limitaciones metodológicas y lagunas en el conocimiento disponible. El *Impact Pathway Approach* (IPA)[5] es identificado

[4] Son aquellos costes impuestos a la sociedad que, sin actuación o intervención política, no son tenidos en cuenta por los distintos usuarios, en este caso, de los puertos. En esta tesis el interés recae en la componente medio ambiental del coste externo, que incluye los costes relativos a la salud, costes materiales, daños en la biosfera y riesgos a largo plazo.

[5] Esta metodología para evaluar las externalidades ambientales derivadas de los ciclos de combustibles utiliza *la ruta de impacto* (de ahí su nombre) que abarca diferentes etapas, desde la emisión de los contaminantes, dispersión y concentración, el cálculo de los impactos en unidades físicas y la valoración económica.

como la metodología *bottom-up*[6] más completa y la mejor práctica sugerida en el cálculo de costes externos derivados de las emisiones liberadas al aire. Ha sido ampliamente adoptada, entre otros, por los principales estudios Europeos sobre costes externos de transporte (CAFE, BeTa, HEATCO y NEEDS). La complejidad metodológica y los recursos económicos, implícitos en el uso de la metodología *bottom-up* IPA ha resultado en una aceptación generalizada, en la literatura empírica de estimación de coste externo derivado de los barcos en puertos, del enfoque *top-down* y el uso de factores de coste por país o región, obtenidos de los principales estudios europeos (BeTa, CAFE y NEEDS).

El Capítulo 2 concluye que los inventarios de emisiones y los costes externos de los nueve estudios de puertos encontrados en la literatura, y revisados en este capítulo, son significativamente diferentes y difíciles de comparar debido a variaciones metodológicas, supuestos asumidos en las estimaciones, categorías de coste y factores de emisión utilizados, entre otros. Por tanto, se defiende que es de suma importancia revisar estas diferencias para identificar el mejor enfoque y cuáles son los inconvenientes de utilizar la segunda mejor alternativa cuando no existe otra opción. Esto favorece que el mejor enfoque termine imponiéndose lo que no sólo haría más comparables los diferentes estudios sino que, lo que es aún más importante, redundaría en una mayor precisión de las estimaciones algo, por otra parte, de vital importancia si estas estimaciones van a servir, a su vez, de base para la estimación de costes externos. En este sentido, la revisión de literatura efectuada señala que las diferencias de calidad en la información de tráfico que se utiliza para realizar las estimaciones son notables y dignas de mencionar. Ciertamente, los trabajos revisados que utilizan un enfoque *bottom-up*[7] en la estimación de

[6] En la estimación de costes externos también es preferible el enfoque *bottom-up* sobre *el top-down* porque permite una evaluación precisa, basada en información detallada, posibilidades de diferenciación y una mejor precisión en los resultados obtenidos (costes externos marginales). Sin embargo, esta reconocido que el uso de este enfoque impone requisitos costosos y complejos para obtener los costes externos. Por lo tanto, se sugiere, y está ampliamente acepado, el uso de un enfoque *top-down* cuando no se pueden realizar estudios *bottom-up* o no están disponibles. De hecho, como se presenta en el Capítulo 2 de esta tesis, la literatura sobre estimación de costes externos debido a las emisiones de los buques del puerto se basa, exclusivamente, en el uso de factores de coste y variables económicas agregadas (enfoque *top-down*).

[7] Generalmente hablando, en la estimación de emisiones pueden utilizarse dos enfoques principales: *top-down y bottom up*. El primero consiste en estimar las emisiones de modo indirecto a partir de las estadísticas de venta de fuel mientras que el segundo utiliza datos de actividad de la flota de barcos.

emisiones no siempre reconocen, de forma clara, que están utilizando las escalas en puerto como fuente de información de tráfico marítimo, ni describen el nivel de detalle de las posiciones de buques que contienen las bases de datos utilizadas. Por el contrario, normalmente hacen referencia exclusivamente a la elección de un enfoque metodológico *bottom-up* basado en información de tráfico[8].

Por otra parte, la revisión efectuada muestra que el enfoque metodológico representativo para estimar las emisiones de buques en puerto (paso previo para estimar los costes externos), es un enfoque *bottom-up* basado en las escalas en puerto. En este sentido y debido al mayor nivel de precisión que podría obtenerse a través del uso de información de posición de buques (*vessel tracks*) se sugiere su uso; evitando de esta manera la necesidad de utilizar valores promedio (distancia y velocidad) y, de ser posible, que se haga siguiendo un enfoque full *bottom-up*[9].

Por último y en relación con la estimación de los costes externos, todos los artículos revisados siguen un enfoque *top-down*. Esto se atribuye a los requisitos costosos y complejos para obtener costes externos desde un enfoque *bottom-up*. Por otra parte, la falta de estudios que modelen la dispersión atmosférica de emisiones de buques, complica el escenario metodológico resultando, por tanto, en una amplia aceptación del uso de factores de coste por país o región (*top-down*).

Con base en lo anterior, el Capítulo 2 también señala la necesidad de mejoras metodológicas y sugiere la realización de estimaciones más refinadas (tanto de emisiones de buques como de costes externos derivados) ya que esto beneficiaría la calidad de la información necesaria para alimentar a las medidas de política que podrían diseñarse para contribuir a interiorizar los costes externos estimados. Por último, una valoración *bottom-up* (IPA) específica sobre emisiones de buques (aún

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El nivel de precisión de las estimaciones es mayor en el enfoque *bottom-up* por lo que siempre que sea posible es el que debería ser utilizado. Para más detalle, véase nota al pie 3.

[8] Los modelos *bottom-up* para estimar emisiones pueden basarse en datos reales obtenidos a través de AIS o en estadísticas de escalas en puerto. En este segundo caso el investigador no tiene información real de la ruta, velocidad, y otros datos del barco por lo que tiene que hacer un buen número de supuestos que reducen la calidad de la estimación. Para más detalle, véase nota al pie 3.

[9] El enfoque *full bottom-up* utiliza un enfoque *bottom-up* tanto para la cuantificación de las estimaciones como para la caracterización geográfica de los resultados. Para más detalle, véase nota al pie 3.

no llevada a cabo), se sugiere como investigación futura aunque por el momento; los resultados obtenidos utilizando factores de coste de BeTa (único informe disponible, que presenta factores de coste dedicados a las emisiones de buques en puerto) proporcionen una primera aproximación cercana a la magnitud real de costes externos derivados de las emisiones de buques en puerto.

Ya que en el Capítulo 1 se sugiere que, con el fin de permitir la internalización del daño derivado de las emisiones y la consiguiente mejora del bienestar público; la investigación sobre emisiones de buques también debería abordar la valoración de costes externos derivados, esta tesis completa el proceso con el Capítulo 3 titulado "Environmental costs and eco-efficiency from vessel emissions in Las Palmas Port" En este capítulo se extiende la investigación realizada en el Capítulo 1 (inventario de emisiones) a la estimación de los costes externos e indicadores de eco-eficiencia en el puerto de Las Palmas.

En definitiva, en el Capítulo 3, se estiman los costes externos derivados de las emisiones de gases presentadas en el Capítulo 1 de esta tesis que fueron obtenidas a partir de variables desagregadas tanto técnicas como de tráfico. Por tanto, este capítulo contiene el primer trabajo en la literatura que sugiere la estimación y estima los costes externos a partir de un inventario de gases obtenido a través de un enfoque full-bottom up basado en datos AIS[10] cerrando un gap en la literatura y contribuyendo a una mejora metodológica, necesaria para obtener resultados más precisos. Por otra parte, y ya en términos de costes externos, las estimaciones realizadas siguen un enfoque *top-down*, como todos los trabajos existentes en la literatura e identificados en el capítulo anterior, si bien a diferencia de los trabajos publicados hasta ahora las estimaciones recogidas en este Capítulo reflejan todos los posibles umbrales existentes (altos y bajos) de factores de coste disponibles en BeTa, CAFE y NEEDS.

[10] Como ya se ha comentado, el enfoque *bottom-up* basado en datos AIS es el mejor de entre los actualmente disponibles porque elimina la incertidumbre y limitaciones descritas que se derivan de los inventarios de emisiones que siguen un enfoque bottom up basado en las escalas en puerto.

Adicionalmente, en este Capítulo también se calculan indicadores de eco-eficiencia. Estos indicadores son una herramienta valiosa para promover el desarrollo sostenible. Su uso se basa en el concepto de crear más bienes y servicios mediante la reducción del impacto ambiental relacionado con la producción de los mismos. En términos generales, los indicadores de eco-eficiencia se utilizan para medir y gestionar el crecimiento ecológico mediante la comparación del rendimiento medioambiental y económico entre los diferentes sectores económicos, la identificación de políticas susceptibles de mejora y el seguimiento de las tendencias de eco-eficiencia en el tiempo (UN ESCAP 2009).

En la actualidad los puertos, y en relación con las emisiones, tienen el objetivo común de crear mecanismos institucionales para para reducir la contaminación atmosférica y el cambio climático, entre otros, mediante el inicio de estudios, estrategias y acciones para supervisar y mejorar la calidad del aire. Con el propósito de promover la necesidad primaria del desarrollo sostenible, los puertos (como muchas empresas), comienzan a explorar nuevas formas de gestión que permitan la integración de la gestión ambiental en la economía local y la sociedad (Coto-Millán et al. 2010). Entre ellas se encuentran, principalmente, el control de los impactos ambientales a través de estrategias de gestión ambiental; la medición del desempeño (eco-eficiencia) a través de la valoración ambiental (emisiones) en relación con los factores económicos (producción)[11] y, finalmente; apoyando el diseño de instrumentos de política que tengan los indicadores de eco-eficiencia en cuenta.

La eco-eficiencia, como un indicador de rendimiento, proporciona información valiosa al sistema portuario para mejorar su posición competitiva (Coto-Millán et al., 2010). De hecho, el rendimiento financiero de los puertos es clave para convertirse en un importante centro de negocios, pero no es suficiente para garantizar su sostenibilidad. Para asegurar esto último, debe abordarse también el desempeño ambiental y social, entre otros, mediante la recopilación de información sobre los impactos ambientales y el desempeño para reflejar su situación global (Coto-Millán

[11] Los indicadores de eco-eficiencia podrían definirse, como se hace en esta tesis, como la relación entre los impactos del servicio (costes externos) y lo que se ha producido (toneladas, pasajeros, etc.).

et. 2010). Por esta razón, en este Capítulo se obtienen indicadores de eco-eficiencia (coste de emisiones/producción relacionada) tanto para el puerto en su conjunto cómo, y esto es también una novedad en la literatura, por sector de transporte marítimo (buques de contenedores, cruceros, petroleros, entre otros). Estos indicadores de eco-eficiencia definidos por sector se sugieren como posibles indicadores de desempeño ambiental y económico de los distintos sectores que pueden ser útiles en el diseño de políticas portuarias. En síntesis, a través de este caso de estudio, no sólo se cuantifica el coste externo e indicadores de eco-eficiencia asociados a las emisiones de barcos en el puerto de Las Palmas en 2011 sino que también se muestra la utilidad de estas medidas como posibles herramientas de apoyo a otras Autoridades Portuarias y gobiernos locales.

Para concluir, el Capítulo 3 sugiere como investigación futura, la estimación de los costes externos e indicadores de eco-eficiencia siguiendo un enfoque *bottom-up* (IPA) que esté basado entre otras cosas, en información refinada de concentración de gases y partículas contaminantes en la atmósfera y condiciones meteorológicas locales. Esto es de especial interés ya que a pesar de las incertidumbres metodológicas (también existentes en IPA), su esta aceptado en la literatura de estimación de costes externos siendo además considerado como el enfoque metodológico que con un mayor rango de precisión en sus resultados, podría ser utilizado en el diseño de política ambiental de emisiones atmosféricas a pesar de que la metodología IPA no fue originalmente desarrollada con ese propósito. Adicionalmente, y ya que las estimaciones realizadas no incluyen fuentes alternativas de emisiones en el puerto, se sugieren futuras mejoras de los resultados mediante la inclusión de las emisiones generadas en tierra y los efectos derivados en la salud de los marineros y profesionales del mar.

En resumen, esta tesis comprende un enfoque sistemático hacia el análisis de las emisiones atmosféricas y los costes externos generados por el tráfico marítimo en el Puerto de Las Palmas en el año 2011. Los resultados tienen como objetivo reflejar el rendimiento del puerto de Las Palmas teniendo en cuenta preocupaciones sociales, económicas y ambientales. El objetivo de este enfoque es apoyar un modelo de gestión portuaria, que extienda el concepto de gestión portuaria hacia el concepto de gestión sostenible en su más amplia acepción: sostenibilidad económica, social y medio ambiental. Asimismo, los resultados de los indicadores de eco-eficiencia pretenden facilitar futuros análisis coste-beneficio y su posible uso para la valoración de instrumentos de política tendentes a reducir las emisiones derivadas de los buques en Las Palmas, ciudad que acoge una cantidad considerable de residentes y turistas. Finalmente este estudio también contribuye a la literatura reciente de estimación de las emisiones de los buques en puerto, cálculo de los costes de externos derivados y eco-eficiencia describiendo, a través de este caso de estudio, la utilidad de estas medidas como herramientas de apoyo a otras Autoridades Portuarias y los gobiernos locales.

Para finalizar este resumen, cabe señalar que el texto de los tres capítulos de que consta está tesis y que se presentan a continuación, corresponden a trabajos científicos que; o bien se encuentran actualmente en revisión (Capítulo 2 y 3) en revistas de impacto (JCR) o, como es el caso del Capítulo 1, ya han sido publicados (Tichavska, M., Tovar, B., (2015), publicado en Transportation Research Part A: Policy and Practice, 78, 347-360. Abstracted/indexed in: ISI web of knowledge. Impact factor (referido a 2013): 2,525. Revista clasificada en el primer cuartil de las categorías de Economía y Transporte).

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Introduction and summary

In recent years, negative effects related to air emissions derived from the growth of shipping have increasingly raised concern. It has been recognized that operative vessels do not only contribute to negative effects on a global scale -rising temperatures in the climate system- but also to hazardous consequences experienced in local communities (Cullinane and Cullinane, 2013). Indeed, management tools at port are been increasingly addressed to enforce or encourage green development (Lam and Notteboom, 2014) and the abatement of emissions.

In addition to the increase of global temperatures caused by CO_2; the exposure to combustion gases (NOx, SOx, CO, VOC) and Particulate Matter (PM[12]) suspended in the atmosphere are continuously linked to short-term and long-term consequences such as headaches, dizziness, nausea, coughing, laboured breathing, cronical diseases, lung cancer, hospital admissions and premature mortality (Corbett et al., 2007).

The need to abate air pollution is widely recognized as a policy issue in ports and harbours. The control of atmospheric emissions requires the ability to quantify these and to develop accurate emission inventories for ports. Indeed, emission information is necessary to properly assess the impacts of port improvement projects or the growth in shipping activity, as well as to plan mitigation strategies or voluntary programs and to aid policy makers towards the development of effective regulatory requirements at national and international levels.

Fuel combustion from operative vessels also contributes to coastal emissions, at times increasing exposure levels to hazardous substances on residents and visitors (Tzannatos, 2010; Miola, 2010; Castells et al., 2014; Tichavska and Tovar, 2015). This mainly results from hotelling, manoeuvring and cruising operatives of vessels at port.

[12] Particulate Matter (PM) is associated with tiny pieces of solid or liquid particles suspended as atmospheric aerosol. Its composition is defined in international standards (ISO 8178) according to diameter measures (10 micrometres or less, and 2.5 micrometres or less).

In this respect, time spent at anchor may result into a large contribution to air pollution. Particularly when using diesel generators to cover electricity needs. In addition to this, berths are often located near populated areas so the impact of emissions released during hotelling and manoeuvring modes may largely result in local effects than those emissions released at open sea (Goldsworthy and Goldsworthy, 2015).

The challenge of identifying operative profiles of ships at berth (hotelling), manoeuvring and normal cruising navigation in conjunction with the emission dependency on engine load can be addressed with ship position records and databases containing ship technical and engine details, respectively. This guarantees location, speed, route, dimensions, engine and fuel consumption for each ship [13] is always acknowledged, providing the additional benefit of visualizing results through high-resolution maps presenting the geographical characterization of emissions in port-city areas. AIS-based methodologies have been already introduced to estimate vessel emissions (Jalkanen et al., 2008). Nevertheless, they had never been presented as an instrument to assist policy design and corrective measures of a specific shipping sector (passenger) and sub sectors (cruise and ferry) within an island context.

In this respect, Chapter 1 titled "Port-city exhaust emission model: an application to cruise and ferry operations in Las Palmas Port" presents for the first time a twelve-month vessel emissions inventory in port, built from a full bottom-up[14] model and

[13] These parameters (also used in this thesis) can be obtained through the AIS (Automatic Identification System). An AIS unit is equipped with a VHF radio transceiver enabling the transmission of information from/among ships and receiving stations (terrestrial and satellite). The AIS-board automatically unit transmits information without the intervention of the crew such as: position of the vessel, course, speed, dimensions, ship type and some technical details among others. This system was designed with the original aim to assist navigation in the monitoring of ships and the prevention of collisions at sea, which over time, has evolved into a system with a multitude of additional applications, These include, obtaining Realistic base data for estimating emissions.
[14] Top-down and bottom-up approaches are widely recognized in a variety of research subjects over literature (Sabatier, 1986). These include the quantification of air emissions (required step to obtain external costs) and external costs. Each approach captures transportation technology in an aggregated (top-down) or disaggregated form (bottom-up) reflecting differences in results due to complex interplays between purpose, structure and data input. In both emission and external cost estimation, top-down approaches use aggregated economic variables while bottom-up approaches consider refined and disaggregated information, mostly based on technical performance.

AIS ship tracks addressing vessel traffic in general and cruise and ferry operations in particular. Emission assessment is based on a full bottom-up model and messages transmitted by the Automatic Identification System during 2011 in Las Palmas Port. Results are described as a breakdown of NOx, SOx, $PM_{2.5}$, CO and CO_2, according to ship classes, operative type and time. It is generally concluded that vessel traffic in general and passenger shipping in particular are a source of air pollution in Las Palmas Port. Emissions maps confirm location of hot spots in quays assigned for cruise and ferry operations.

Policy recommendations encourage regular monitoring of exhaust emissions and market-based incentives supported by details on polluting and operative profiles. On the other hand, feasibility studies are suggested for automated mooring, LNG bunkering facilities and also shore-side energy services, prioritizing berthing of shipping sectors (or sub-sectors) with the highest share of exhaust emissions once their local effects have been confirmed by a dispersion, exposure and impact assessment.

Results in Chapter 1 do not only provide operative and polluting profiles in Las Palmas Port but also suggest the possible value of AIS based methodologies. Particularly, when accompanied with air quality modelling, impact and economic studies to address the design of corrective measures for specific sub-sectors in shipping, as cruise and ferry. Results and policy recommendations of this study may also support adequacy or improvement of existing policy in Las Palmas Port, being a case transferable to port-city areas and islands under similar traffic conditions.

The application of approaches varies according to the subject of study. For emission estimation, a top-down approach that is based on fuel sales is used when refined traffic information is not available. On the other hand, a bottom-up approach based on traffic information (obtained from vessel tracks or port calls) is used when available, due to the accuracy of input parameters such as ship type, location, size and technical particulars. Finally, a full bottom-up category is described by Miola et al., (2010), as the use of a bottom-up approach for both, the quantification of emissions and the geographical characterization of results.
Regarding the geographical characterization of emissions, the level of detail achieved is also dependent on the approach followed (bottom-up and top-down). Thus, with a bottom-up approach, individual information of vessels and its position are considered while with a top-down approach valuation is based without, or with partial information on the position of vessels (i.e. the geographical activity of shipping is estimated based on a single shipping route or a particular geographic activity cell, no matter which vessel carries out the activity).

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Port-related exhaust emissions, as any negative externality, reflect a real cost accruing from an economic activity and lead to a suboptimal outcome. Indeed, population located in port-cities experience air quality detriments associated to vessel traffic and the atmospheric concentration of air pollution (Corbett et al., 2007).

These result in urban and rural externalities[15] that can be monetised as external costs. In this respect, Chapter 2 titled "External costs of vessel emissions at port: A review of the methodological and empirical state of the art" presents a review of existent methodologies currently used to estimate externality costs[16] from vessel emissions in shipping and in harbours. The empirical literature that estimates external costs from vessel emissions at port is recent and dates back to 2009, when the first related paper was published. From the revised research and to the best of our knowledge, including Chapter 3 of this thesis, only 9 papers were found.

Based on the review, the estimation of externality costs is source of uncertainty. It is conditioned among others, by methodological uncertainties and information gaps on available knowledge. The Impact Pathway Approach (IPA) is considered as the most comprehensive bottom-up[17] methodology and the best practice for calculating external costs derived from air emissions. It has been widely adopted, among others, over major European studies (CAFE, BeTa, HEATCO and NEEDS). Methodological complexity and costly resources are implied in the research pathway of bottom-up studies that address shipping and ports. For this reason, and as a first approximation

[15] Accounted urban externalities include health issues, increased mortality rates and the degradation of built environment. Rural externalities relate to crop damages.

[16] Costs imposed to society that without political action or intervention are not taken into account by the related users, in this case, of ports. In this thesis, the related interest relies in the environmental component of externality costs, which includes the derived costs of mortality, morbidity, the degradation of built environment and the loss of crops.

[17] In the case of external costs a bottom-up approach is also preferred as it enables a refined assessment based on detailed information, differentiation possibilities and an improved precision in derived results (marginal external costs). Nevertheless, costly and complex requirements are also recognized to obtain external costs from a bottom-up approach. Thus, the use of a top-down approach is suggested and widely accepted when bottom-up studies can not be performed or are not available. Indeed, as we present in Section 3, literature on harbour external costs due to vessel emissions is exclusively based on the use of cost factors and aggregated economic variables (top-down approach).

to estimates, it has been widely accepted to follow a top-down approach and use per-unit cost factors obtained mostly from major European studies (BeTa, CAFE, NEEDS).

Chapter 2 concludes that emission inventories and estimated costs from the available harbour studies are significantly different and complicated to compare due to methodological variations, assumptions, cost categories, selected emission factors and others. It is paramount to review these differences to highlight the best approach and the drawback when a second best alternative is applied. In this sense, the review remarks that precision differences on traffic information used for the estimations are noteworthy. Available literature does not always specify port calls as their source of traffic information nor describe the level of detail accounted from ship movements but provide an overall description of activity-based (bottom-up) methodology to estimate emissions. Moreover, our review has shown that the representative approach used to estimate emissions at port (as a previous step to estimate external costs), is a bottom-up approach based on port calls. Due to the refined accuracy of obtained results, we encourage the use of a full bottom-up approach and frequently updated vessel tracks, avoiding in this way the need of using average values (i.e. distance and speed). Finally and regarding the estimation of external costs, every study followed a top-down approach. This is attributed to costly and complex requirements to obtain external costs from a bottom-up approach. Moreover, the lack of dispersion modelling practices not widely undertaken in shipping complicates this methodological scenario. Thus, enabling the wide acceptance of a top-down approach in external cost estimations based on country or region cost factors.

Based on the above, Chapter 2 also suggests methodological improvements and the possible achievement of refined estimations (of vessel emissions and derived external costs) in ports and shipping as these may benefit the quality of input information needed to feed policy measures which contribute to internalize the external cost estimated. Finally, an integrated assessment (IPA) specific to vessel emissions has not been yet addressed in the available studies and is suggested as future research although for now, the obtained results in BeTa provide a meaningful insight to the magnitude of costs associated to vessel emission externalities, specifically because it is the only available report so far, which presents cost factors dedicated to seaports.

Since it is suggested that in order to enable the internalization and improvement of the public welfare, research on vessel emissions should also address the valuation of economic costs derived from vessel emissions shipping, Chapter 3 titled "Environmental costs and eco-efficiency from vessel emissions in Las Palmas Port" extends the vessel emission research in Chapter 1 to the estimation of external costs and the eco-efficiency performance of Las Palmas Port. Firstly, it obtains externality costs of vessel emissions from disaggregated variables as individual vessel tracks and technical details. This approach eliminates the dominant uncertainties reported by previous vessel emission inventories (based on port calls) used to estimate externality costs and fills the gap of methodology improvement, necessary to achieve more accurate results. Secondly, and in terms of externality costs, this harbour study presents the available lower and upper thresholds of top-down estimated costs available in BeTa, CAFE and NEEDS.

Additionally, in this Chapter derived eco-efficiency parameters are obtained. Eco-efficiency indicators are considered as a valuable tool to promote sustainable development. Its use is based on the concept of creating more goods and services by reducing the related environmental impact. Generally speaking, eco-efficiency indicators are used to measure and manage green growth by comparing environmental/economic performance among different economic sectors, by identifying policy areas for improvement in achieving economic benefit and, by tracking eco-efficiency trends over time (UN ESCAP, 2009).

At present, in ports and towards air emissions, its common aim is to create institutional mechanisms to abate air pollution and climate change, among others, by initiating studies, strategies and actions that monitor and improve air quality. To promote the primary need of sustainable development, ports (like many companies), start to explore management phases that enable the integration of environmental management into local economy and society (Coto-Millán et al. 2010). Namely, the control environmental impacts through environmental management strategies; the measurement of eco-efficiency performance by valuating environmental (emissions) with economic factors (production)[18], and at last; support the design of policy instruments that take the later indicators into account.

Eco-efficiency, as a performance indicator, provides port systems with information of value to improve their competitive position when undertaking their activity with business-oriented criteria (Coto-Millán et al. 2010). Indeed, the financial performance of ports is key to becoming an important centre of business but not enough to guarantee their sustainability. To ensure this, environmental and social performance must be addressed among others, by collecting information on environmental impacts and performance to reflect its overall status (Coto-Millán et al. 2010). For the latter reason, in this chapter, eco-efficiency parameters are obtained (environmental/production performance of vessel emissions) in general shipping and also (as a literature novelty) per shipping sub-sector (container, cruise, tankers, among others). These eco-efficiency parameters are suggested, as an indicator of environmental and economic performance to be considered for policy use in port-cities. Summarizing, results respond to the research question of the economic impact and environmental/production performance of vessel emissions in Las Palmas Port, describing through the case study, the utility of these measurements (external cost and eco-efficiency indicators) as support tools to Port Authorities and local governments.

To conclude, Chapter 3 suggests that future research also address these indicators by following an integrated approach based among others, on refined information from pollutant concentration and local meteorological conditions. This is of particular interest since, in despite of methodological uncertainties (also existent in IPA), the use of this approach is accepted in literature for estimating external costs and it remains so far, as the most accurate approach to be used in the design of environmental policy to address atmospheric emissions. Also, and since additional sources of emissions at port were not included in this study we suggest future

[18] That is, eco-efficiency indicators could be measured, as we do in this thesis, as the ratio between the impacts of the service (external costs) and what has been produced (ton, passengers, and so on).

improvements of results by including land-based sources of emissions and the derived effects on sailors and maritime professionals.

In summary, this thesis comprises a systematic approach and analysis of air emissions and externality costs from vessel traffic in Las Palmas Port. Results attempt to indicate performance of Las Palmas port towards social, economic and environmental concerns. Aim of this approach is to support an environmental operation model, which extends value-based management exploring relations of economic and ecological capital efficiency. Also, eco-efficiency results aim to facilitate future cost-benefit analysis used for evaluating abatement policy instruments in Las Palmas, where a large population of residents and visiting tourists are continuously hosted. Finally this study, also contributes to recent literature of vessel emissions, externality costs and eco-efficiency by describing through the case study, the utility of these measurements as support tools to Port Authorities and local governments.

In should be noted that the text from the three main chapters in this thesis are adaptations of scientific papers that have either been already published in JCR journals ranked in the first quartile of the categories of Economy and Transport (Chapter 1, in Transportation Research Part A: Policy and Practice, Tichavska, M., Tovar, B., 2015) or that have been submitted and currently under review (Chapter 2 and 3).

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Chapter 1

Port-city exhaust emission model: An application to cruise and ferry operations in Las Palmas Port

1.1. Introduction

Ferry and cruise, share positive effects and economic benefits in ports and cities. However negative impacts, including air pollution, also relate to engine exhaust emissions while operating at port (Castells et al., 2014; Chang et al., 2014). Shipping activity and the propagation of exhaust gases resulting from the combustion of fuels have a significant impact on air quality in port-city areas. Most importantly, however, harmful ship emissions into the air have been addressed as a risk factor for cardiovascular, respiratory conditions or even human death (Corbett et al., 2007). As a result of this, compliance and enhancement of emission regulation in shipping has been pursued.

Policy makers need the support of methodologies which will reliably inform them on how much, where, how and who releases emissions in order to decide on an effective regulatory framework for the improvement of air quality and the reductions of greenhouse gases emissions. Data scarcity and uncertainty has led to a widespread use of methodologies for estimating the exhaust emissions in shipping. Still, the utilization of new technologies with reliable data retrieving capabilities on vessel traffic question usefulness of the methodologies proposed so far (Miola et al., 2010).

More specifically, AIS-assisted emission inventories can be effectively used to assess the impact of shipping in port areas (Ng et al., 2012). The challenge of identifying operative profiles of ships at berth (hotelling), manoeuvring and normal cruising navigation in conjunction with the emission dependency on engine load can be addressed with ship position records and databases containing ship technical and engine details, respectively. This offers the ability to model the geographical characterization of emissions through high-resolution maps in port-city areas. AIS-based methodologies have been already introduced to estimate shipping emissions (Jalkanen et al., 2008), but they have never been presented as an instrument to assist policy design and corrective measures of a specific shipping sector (passenger) and sub sectors (cruise and ferry) within an island context. Thus, the main contribution of this paper is to present evidence on the application of AIS-based methodologies to assess exhaust emissions of cruise and ferry services according to ship size classes, time and ship activity phases (i.e. hotelling, manoeuvring and cruising).

The results of this study aim at the improvement of the current environmental policy in Las Palmas Port, as well as in other island ports experiencing a similar shipping activity. The structure of this paper is as follows: Section 1.2 provides an overview on regulation and practices for the control of ship exhaust emissions in ports. Section 1.3 describes emission estimation in shipping to then present the full bottom-up Ship Traffic Assessment Model (STEAM) used in this case study. Section 1.4 presents results for emission estimation as a breakdown of ship activity phase, type and time and ship size classes. Also, the geographical characterization of results is described through a selection of high-resolution maps. Discussion and policy implications are presented in section 1.5, followed by conclusions and future research recommendations in section 1.6.

1.2. Regulation and practices for the control of ship exhaust emissions in ports

Current regulation seeks to reduce emissions from ships through the introduction of minimum fuel quality standards and the implementation of new abatement technologies. The International Maritime Organization (IMO) has addressed ship pollution under the MARPOL convention. The regulation of air pollution by ships was defined in MARPOL Annex VI, first adopted in 1997 and enforced in 2005 including a progressive reduction of SOx and NOx and indirectly Particulate Matter

(PM) in Emission Control Areas (ECA). MARPOL Annex VI is the only global regime that clearly addresses the control of air emissions from ships.

The European Union (EU) has also expressed its concerns about the impact of transport on air quality through the Strategy for Sustainable Development published on its White Paper on Transport Policy (Gemeinschaften, 2001), leading to the establishment of stringent sulphur regulation for marine fuels through directives: 2012/33/EU, 2005/33 and 1999/32. According to these, all passenger ships operating on scheduled services to or from any EU port should not exceed 1.5% sulphur limit and all vessels calling at an EU port should use low sulphur fuel (less than 0.1%) or a shore-side electricity facility during port stays longer than two hours. In addition, with the framework of IMO regulations, MARPOL Annex VI sets a maximum 0.1% sulphur for all ship operations in ECAs from 2015, which with regard to European waters are currently limited to the Baltic Sea, the English Channel and the North Sea. It should be also noted that the expressed EU willingness to unilaterally widen the enforcement of sulphur restrictions to all European sea faces compliance constraints in relation to the United Nations Convention on the Law of the Sea 1982 (UNCLOS) to which the EU is signatory. There is currently no legal basis for the EU to exercise extra-territorial jurisdiction and this is likely to give non-EU states and industrial bodies grounds for challenging emissions reduction measures adopted by the EU for maritime transport (Miola et al., 2010).

As ports constitute the nodes of maritime transport where all shipping routes ultimately converge, they are particularly exposed to the burden of ship exhaust emissions. Therefore, in response to this problem and besides the provisions of the IMO and EU framework, they have been collectively or individually active in adopting voluntary measures, which aim at improving the air quality and achieving emission reductions of greenhouse gases (CO_2). These measures either take the form of offering economic incentives (i.e. environmentally differentiated port dues) or the undertaking of infrastructural investments, which encourage ship operators to make use of environment friendly services (i.e. shore-side electricity, LNG bunkering, automated mooring systems, and others). For further information on green ship promotion through major European ports and the use of environmental indices, the reader is referred to Gibbs et al., (2014).

At present, there is no preference for a specific environmentally differentiated port charging system, although it should be noted that the relevant EU proposal (COM/2013/295) in action 8 suggests that "to encourage a more consistent application of environmentally differentiated port infrastructure charges, the Commission will propose principles for environmental charging and promote the exchange of good practices by 2015" in order to abate air emissions and address the technological alternatives available for this.

With regard to infrastructural port facilities, shore-side LNG bunkering[19] is evident in Norway (i.e. Kristiansund, Mongstad, Bergen), Sweden (i.e. Stockholm), the Netherlands (i.e. Rotterdam, Antwerp, Amsterdam) and Belgium (i.e. Zeebruge) whilst the feasibility of providing shore-side electricity services has been studied in various locations (Tzannatos, 2010) and is already offered to ships in the west coast of the USA. In summary, a positive evolution of exhaust emissions related to shipping has certainly led to regulatory stringency and technological development of abatement options. Nevertheless and regardless their existence, adoption feasibility of abatement alternatives by ports and fleet, is often limited by costs, a lack of incentive regulation (Buhaug et al., 2009) and diversified approaches towards air emissions. For instance, in Spain, monitoring and abatement actions addressed by ports towards air emissions have been so far, mostly focused on land-based and not sea-based activities (Puertos del Estado, 2011). Indeed, if existent, diverse approaches can be identified within sustainability reports. On one hand, sea-based emissions from shipping are referred as an externality related to the port community and not to the Port Authority (monitoring only, land-based emissions facing piers or near parking and transit area of trucks); on the other hand, Port Authorities as Port of Cartagena, do aim to reduce sea-based emissions by

[19] World map with LNG bunkering activities in ports is accessible online at http://www.lngbunkering.org/.Website launched in 2014 by the International Association of Ports and Harbours.

monitoring, in line with the present study, three operative scenarios: cruising, manoeuvring, and berthing of vessels.

In this respect, approaches to sea-based emissions by ports might evolve positively over time. Particularly since market value and competitiveness of ports-cities is increasingly strengthened by sustainable contributions in accordance to regulatory framework and retrofitting of global fleet (Merk, 2013; Lee at al., 2014). Indeed, management tools at port are also addressed to enforce or encourage green development (Lam and Notteboom, 2014) and the abatement of emissions. For instance, resolving berth and quay-crane allocation issues considering fuel consumption and speed reduction (Du et al., 2011; Hu et al., 2014) starts to be addressed in literature (Zis et al., 2014). In relation to this, trials carried out by BP and Maersk with tankers showed promising results, with savings up to 27% in fuel consumption for some journeys, and average savings between 12% and 20% (Gibbs et al., 2014).

1.3. Methodology

Over the years, the quantity and geographical characterization of emissions have been considered for valuation in maritime transport. *Bottom-up* (Tzannatos, 2010; Paxian et al., 2010) and top-down (Endresen et al., 2007) methodological approaches have been applied over time, to quantify emissions. A *bottom-up* approach is referred to calculations based on fleet activity. This can be done by using port calls and estimated vessel operative or, through vessel tracks and real time operative. On the other hand, a top-down approach is referred to estimations based on fuel sales statistics[20]. Regarding the geographical characterization of emissions and the level of detail achieved, this is also dependent on the approach followed (*bottom-up* and top-down). Hence, with a *bottom-up* approach, individual information of vessels and its position are taken into consideration while with a top-down approach valuation is based without, or with partial information on the

[20] Tichavska and Tovar (2015) shows that the representative approach in harbour studies is the bottom-up approach although most of them are based on port calls and theoretical operative of vessels. This, despite the accuracy level of detail obtained from vessel tracks (high-definition traffic information that avoids operative assumptions in-port and is based on real and not theoretical operative of vessels).

position of vessels (i.e. the geographical activity of shipping is estimated based on a single shipping route or a particular geographic activity cell, no matter which vessel carries out the activity). Finally, a full *bottom-up* approach, described by Miola et al., (2010), is the use of *bottom-up* approaches both, for emission estimation and the geographical characterization of results.

Data scarcity, and assumptions in literature result in an open debate on adequacy of approaches and contexts analysed so far (Miola et al., 2010). Buhaug et al. (2009) has made an attempt to homogenize results from different studies. Uncertainties when comparing results, confirm the need for the so-called, full *bottom-up* approach[21], by integrating a great extent of traffic data (vessel movements, port calls) and technical characteristics of vessels. Technical information, ship activities and geographical distribution of maritime traffic were, until a few years ago, retrieved from average information (i.e. Du et al., 2011). Today, if not in a total extent, improvements in accuracy can be achieved as a result of the introduction of innovative technologies for vessel monitoring at sea.

AIS-based inventories can be effectively used to assess shipping emissions in port areas. The challenge of identifying operating profiles of ships at berth, manoeuvring and normal cruising navigation and, emission relation to engine load can be addressed with position records and commercial databases containing technical and engine details. This guarantees location, speed, route, dimensions, engine and fuel consumption for each ship is always acknowledged, providing the additional benefit of visualizing results through high-resolution maps presenting the geographical characterization of emissions in port-city areas.

1.3.1. The STEAM and its main components

Emission results in this case study (NOx, SOx, $PM_{2.5}$, CO and CO_2,) are estimated by the STEAM, model specifically designed to assess emissions based on shipping activity and information provided by the Automatic Identification System (AIS)[22].

[21] This is the approach followed by the model used in this case study: the STEAM.

[22] The AIS was conceived as a navigational aid for ship monitoring and collision avoidance at sea. According to the IMO regulation 19.2 of Safety Of Life at Seas (SOLAS), an AIS transceiver shall be

The modelling of emissions is based on basic principles of ship design, including the modelling of the propelling power for each vessel in terms of its speed. The instantaneous velocity is obtained from the AIS signal, which is also used to identify the ship. Also, engine loads during voyages are determined with reasonable accuracy based on the ratio of ship speed and the calculated resistance that the ship is required to overcome at a specified speed (Jalkanen et al., 2009).

The effect of waves on the consumption of fuel and on the emissions to the atmosphere is also modelled. At its current state, the program takes weather effects into account by applying additional power requirements in bad weather areas with high values of significant wave height. The wave height data is obtained from the WAve Model (WAM) further described in Thomen et al., (1994) and Tuomi, (2008). The additional power requirement depends on parameters describing the three-dimensional structure of the hull and the direction of the waves (Jalkanen et al., 2008). Also, shipping routes and speed changes are included specifically and there is no need to guess which routes ships may take during the voyage. The model also includes an enhanced modelling of the power consumption of auxiliary engines, which depend on ship type and its operation mode (Jalkanen et al., 2012).

Model components are presented in Figure 1. Input data and output results are presented in the uppermost and lowest row of rectangles. Arrows describe the information flow of the model, dependency between factors in addition to dotted and solid arrows used for visual clarity. Colours denote variable categories included in the model.

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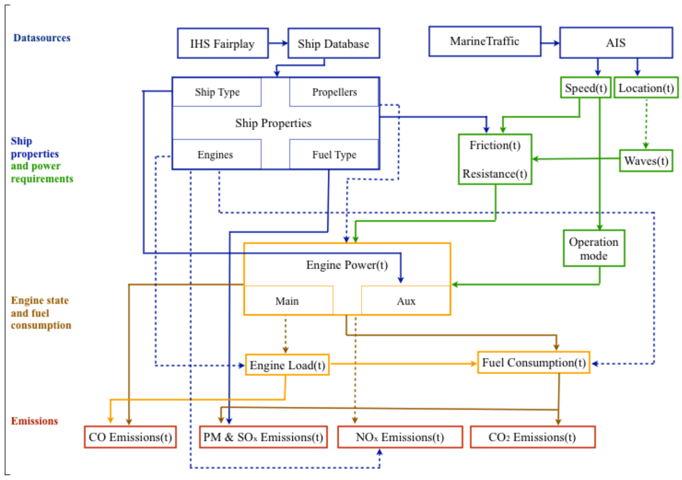
equipped in every sea-going ship larger than 300 gross tons and every passenger vessel irrespective of size. Its system regularly transmits static and voyage-related information every 6 minutes in addition to dynamic information with a frequency related to the vessel´s speed underway (2-10 seconds) and navigational status (3 min. when anchored). For this case study, dynamic information from the AIS was used for the estimations (see section 1.3.2).

Figure 1 – Main components of the STEAM and their inter-relations



Source: adapted from Jalkanen et al. (2012).

1.3.2. Input values

A ship database of over 50,000 vessel particulars (over a third part of the global fleet) and AIS position records define input values for the STEAM.

Ship database considers: physical properties, engine particulars and variables presented on Table 1. Database holds information among others, on experimentally determined emission factors, installed abatement techniques, shaft generators, specific fuel oil consumption, fuel type and sulphur content of fuel for main and auxiliary engines. Information was provided mainly, by: IHS Fairplay ship register, engine manufacturers, local authorities and ship owners.

For this case study, AIS data gathered from coastal stations was provided by MarineTraffic. This results in a data flow of thousands of dynamic information per ship, per year. Longitude, Latitude, a unique nine digit Maritime Mobile Service Identity (MMSI) of vessels, Navigation Status (at anchor, under way using engine, not under command among others), Speed over ground, Course (relative to true north to 0.1°), Heading (0 to 359 degrees) and Timestamp in Coordinated Universal Time (UTC) integrate dynamic fields from AIS data transmitted by passenger vessels during 2011 in Las Palmas Port (area defined by bounding coordinates: LAT from 28° to 28,45 °, LON from -15,60° to 15°)

Table 1- STEAM model regarding the properties of ships

Identification	Physical properties	Main engine properties	Auxiliary engine properties
Ship name	Length	ME, Fuel sulphur content	AE, installed kW
IMO registry number	Breadth	ME, abatement technique	Number of AE
MMSI code	Draught	ME, SFOC	AE, Fuel type
Ship type	Build year	ME, design	AE, Fuel sulphur content
Gross tonnage	Design speed	ME, model	AE, SFOC
Deadweight tonnage	Number of cabins	ME, stroke type	AE, abatement technique
	Hull type	ME, rpm	
		Number of ME	
		ME, installed kW	
		ME, Fuel type1	
		ME, Fuel type2	
		Measured EFs	

Note: MMSI = Mobile Maritime Service Identity, ME=Main engine, AE=Auxiliary engine, rpm=crankshaft revolutions per minute, SFOC=Specific Fuel Oil Consumption, Measured EF = Experimental value for emission factors of NOx, SOx, CO and PM. Source: adapted from Jalkanen et al. (2009). Additional data fields, like the existence of bulbous bow, propeller details and cargo capacity are also used (see Jalkanen et al.,2012).

1.3.3. Model performance and uncertainty considerations

As described in Johansson et al., (2013), the model has been able to predict aggregate annual fuel consumption of a collection of large marine ships with a mean prediction error between 9 and 15%. Still, uncertainties regarding properties of ships and AIS information should be considered as well as limitations for auxiliary power predictions and its relevance for ship emissions occurring in port areas.

For instance, in despite of the consideration of navigation resistance through waves, power prediction during voyages may be also uncertain due to the neglect of additional environmental effects in estimations (e.g. wind, currents, sea ice covers and others). In addition to this, insufficient information on empirical performance of engines and chemical composition of exhaust gases and particulate matter, non-existent in recent literature and not considered in the model should be also taken into consideration.

Ship routes and a high-resolution activity map can be expected from the AIS messages and their location signal transmitted. Still, the temporal and spatial coverage of the AIS will depend on performance of terrestrial receiving stations and equipment installed in vessels (AIS transponder, GPS, and navigation tools). An accurate modelling of engine power usage during hotelling and manoeuvring operations in harbour areas requires a frequent update of data (several times per minute) as the speed of vessels may change constantly. Temporal gaps and a low frequency of messages may be the cause of significant inaccuracies. Also, uncertainties related to the auxiliary engine power usage onboard vessels could be significant. Commercial databases may offer an incomplete representation of installed auxiliary engine power, which must be augmented with data from classification societies, fleet owners or engine manufacturers. This information is often unavailable and must be estimated based on existing knowledge, like extensive vessel boarding programs (Starcrest, 2011). In contrast to the main engine power predictions, there is no accurate, generally available model for auxiliary engine usage of ships as it may vary in accordance to their cargo handling gear, need for heating, cooling, pumping and additional uses of energy. An overview of the STEAM has been presented in this section, for extensive details; the reader is referred to Jalkanen et al., (2009), Jalkanen et al., (2012) and Jalkanen et al., (2013).

1.4. Case Study: Las Palmas Port.

The Canary Islands are one of Spain's seventeen Autonomous Communities and an outermost region of the European Union. Located in the Atlantic Ocean, this collection of seven islands is at 115 kilometres of distance from the northwest African coast at 1,200 kilometres from the nearest mainland port in southern Spain (Cadiz). The Autonomous Community of the Canary Islands is administrated by two provinces, Las Palmas and Santa Cruz de Tenerife. Gran Canaria and Tenerife, both capital islands, are the main transport nodes connecting the archipelago with mainland Spain and other countries. Main ports in the Canary Islands, Las Palmas Port (located in Gran Canaria) and S.C. Tenerife Port (located in Tenerife) are managed by different Port Authorities[23]. In 2011, cargo transported in these ports, summed up to more than 88% of the Canary Islands total freight.

[23] A detailed analysis of the port management model in Spain is beyond the scope of this paper but it could be found in Rodriguez-Álvarez and Tovar (2012).

The advantages of having good port connectivity have accrued to the Canary Islands once one of their ports became an international hub[24] (Tovar et al., 2015). Las Palmas Port is a major logistic platform between Europe, Africa and America and it offers many advantages to ocean-going vessels such as a recognized technical and commercial maritime community and competitiveness in supplies and repair services. Its location between main commercial trade routes makes it a cargo hub (over 19 million tons from loading, unloading and transhipments). Moreover, passenger traffic, with over 908,000 passengers in 2011 is growing steadily over time.

To meet the maritime transportation demand in the Canarian archipelago (passengers or passengers and goods), ferry routes are offered in a daily basis through direct or scaled services. Hub operations are set in both main canaries ports. Direct connections are regularly offered from Gran Canaria, and Tenerife in direction to other Canary Islands: Fuerteventura, Lanzarote, La Gomera and Spanish mainland (Huelva). In addition to the regular ferry services, passenger numbers accounted in cruise operations in the Canary Islands have increased steadily up to 1,600,000 with a major participation of Carnival (49%) and Royal Caribbean cruise lines (23%), (EDEI, 2011). According to EPPE, passenger share of Las Palmas Port increased in over 20% with a total of 1,605,531 passengers in 2013. Sustained market growth increases the need to identify and measure environmental impacts generated by passenger traffic, particularly in locations where actions to mitigate these are not being pursued as it is in many other harbours in the world.

As we stated before, cruise passengers numbers and cruise services deployed in Canarian ports also increase over time. Indeed, Las Palmas Port holds one of the largest shares in continuous growth. For instance, in 2011, 197 port visits, 418,184 cruise passengers (22% from the total share of the archipelago) and up to 57 cruise ships were accounted. In 2013, a growth in numbers can be noticed with the 425,267 cruise passengers reported, while a remarked increase can be noticed

[24] Driven mainly by container operations, the transshipment traffic in Las Palmas Port has reached a rate close to 69% of the total number of handled containers, whereas Tenerife port focus its container traffic merely on the domestic market.

during the first quarter of 2014 with a total of 511,248. This can be attributed to the concentration of ships with hub operations. In fact, further expansion of cruise operations could be expected as recruitment of new vessels and the hosting of new hub services over the year also relate -in addition to what we refer in previous lines- to socio-political stability, currency, infrastructure improvement and recognized quality on land services, attributes acquired and also recognized in this port.

Emissions estimated for passenger traffic are presented in the following section as a breakdown of hotelling, manoeuvring cruising operations and size classes. To follow, geographical characterisation of results will be addressed by a sample of high-resolution maps.

1.4.1. Results

According to terrestrial AIS data received during 2011, 3,183 unique ships entered, navigated and anchored in Las Palmas Port during 2011. From these, 1,228 of them (39%) are classified as cargo, 329 (10%) as container, 612 (19%) as tankers and, seventy-four vessels (2%) as passenger vessels. Engine requirements and operative needs among shipping sectors are diverse, particularly in a port-city context where the speed and load rates of engines will constantly change according to requirements of ports and vessels. Indeed, the energy demand, the engine loads and resulting emissions from different type of vessels may vary. To set an example we may remark how large cruise vessels (with more than a thousand air-conditioned cabins), will most probably demand more energy and contribute with more emissions than a cargo carrier when at port. Also, the regular and tight schedules of ferry vessels may increase the load level of engines during acceleration-deceleration and hence also increase the related emission share (Jalkanen et al., 2009).

In order to better understand these differences, emission results for NOx, SOx, $PM_{2.5}$, CO, CO_2 and operative time spent at hotelling, manoeuvring and cruising are presented in Table 2 for nine different ship types. Ship types and its operative type and time are an automated classification from information transmitted by the AIS[25]. From Table 2, a noticeable share of emissions related to local (NOx, SOx, CO, $PM_{2.5}$) and global effects (CO_2) are seen for passenger, container and tanker vessels while categories as others and unknown (mostly small sized ships) contribute with a minimum amount of emissions in despite the considerable number of hours they spend at port. Shipping sectors identified in this research as the ones with the highest level of emission contribution (passenger, container, and tanker vessels) have been also identified as shipping categories with representative emission shares by other studies as Stipa et al., (2007); De Meyer et al., (2008); Howitt et al., (2010); Eijgelaar et al., (2010); Berechman and Tseng, (2012); Ng et al., (20129; Kalli et al., (2013); Jalkanen et al., (2013); Johansson et al., (2013).

Table 2- Emissions and operative time related to traffic sectors as predicted by the STEAM

		EXHAUST EMISSIONS					OPERATIVE TIME			
	Las Palmas Port (2011)	NOx [Ton]	SOx [Ton]	PM2.5 [Ton]	CO [Ton]	CO2 [Ton]	H [Hours]	M [Hours]	C [Hours]	T [Hours]
Traffic sectors	Passenger	1063	536	113	99	50426	22109	597	4254	26960
	Service	283	72	19	37	14500	26583	338	316	27237
	Cargo	373	112	27	47	17700	59444	2121	3861	65426
	Container	1019	288	73	119	48000	63889	1648	2712	68249
	Tankers	667	186	47	91	33300	65833	2889	3028	71750
	Other	241	52	15	37	13300	78889	4500	2361	85750
	Fishing	296	59	17	33	15100	43611	229	349	44188
	Vehicle Carriers	153	56	13	17	7479	8583	245	699	9528
	Unknown ships	143	58	13	18	8892	90833	3667	5972	100472
	Total	4237	1420	338	497	208697	459776	16233	23551	499560

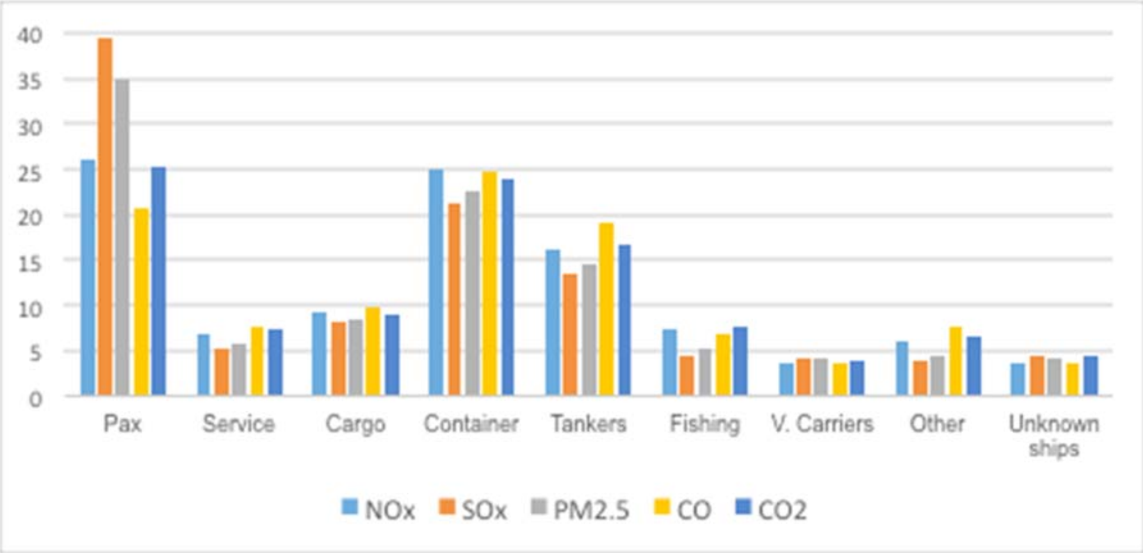
Note: Fuel consumption and emissions released while at berth are included. Compliance of IMO and EU regulatory frameworks for marine fuels is assumed and also included in these estimations. Time spent in Hotelling (H), Manoeuvring (M), Cruising (C) and its Total (T) is expressed in hours

Emission results for all categories are presented as a relative percentage from the totals at port, in Figure 2. This figure better reflects ship emissions contribution at the source and enables the view of remarked shares. Particularly, the passenger sub sectors are identified as the main source of emissions with the exception of CO. In addition to this, major figures of emissions are allocated in container vessels, followed closely by tankers. Moreover, figure 3 shows that over a 35% of SOx and a

[25] Details on codes and category of vessels transmitted by the AIS are referred in the ITU-R, (2010). Unknown category refers to failure cases of identification (no static message received, no connection to national MMSI databases available, small vessels not transmitting a valid IMO registry number).

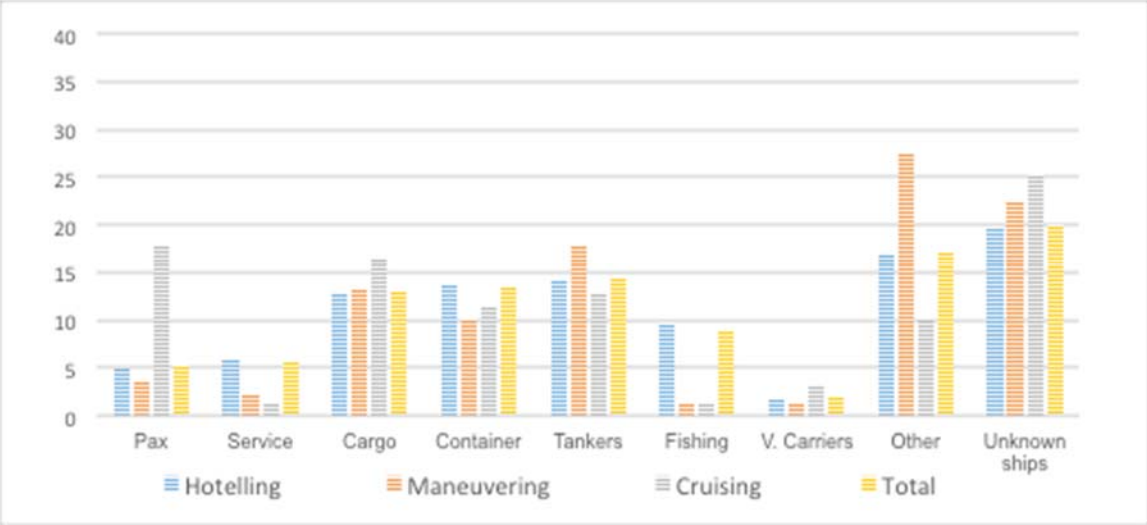
30% of $PM_{2.5}$ result from the passenger sector while almost a 50% of resulting NOx, CO and CO_2 derive both, from passenger and container ships.

Figure 2 – Emission percentage by shipping sector in Las Palmas Port



On the other hand, Figure 3 reflects hours of hotelling, manoeuvring and cruising as a relative percentage of operative time at port. In this regard, and as it was stated before, the activity levels of other and unknown categories are noticeable. Specifically when compared to their relative low emission share. The explanation for this might rely on small sized engines and a low demand of energy from leisure navigation. On the other hand, differences among operative time (5%) comparing passenger vessels to the rest, should be noted. This is significantly low, while cargo, container and tanker categories together represent almost a 45% from the total activity of vessels at port, However, when the profile is observed by type of operative the role of cruising is clearly representative for the passenger sector while cargo, containers and tankers reflect a rather balanced operative profile.

Figure 3 – Operative percentage by shipping sector in Las Palmas Port



According to terrestrial AIS data received during 2011, seventy-four unique passenger ships entered, navigated and anchored in Las Palmas Port during 2011. From these, fifty-seven vessels (75%) are classified as cruise ships and twelve of them (19,7%) as RoPax vessels operating ferry services. Considering polluting and operative differences among shipping sectors, it is also of interest to analyse differences when categorized as the sub-groups that regard this case study (cruise and ferry). In order to address this, Figure 4 and 5 reflect results as a relative percentage of the total emissions and operative time at port. It can be noted that contribution of ferries is significantly large in overall emissions. Particularly SOx, CO and $PM_{2.5}$ (related to severe health consequences) and CO_2 (related to greenhouse gas effects and global warming) while differences on shares of operative time are also noticeable. Ferry vessels reflect a noticeable percentage of cruising, similar to cargo sectors (see Figure 2 and 3) while in the case of cruise vessels, this is not representative.

Figure 4 – Emission percentage of cruise and ferry vessels relative to the total emissions in Las Palmas Port

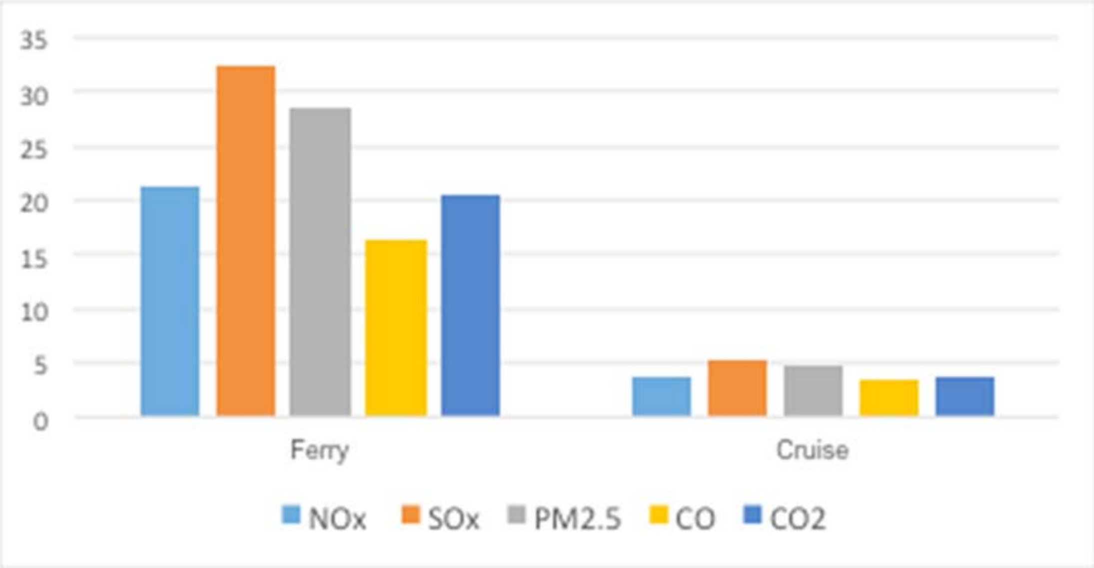
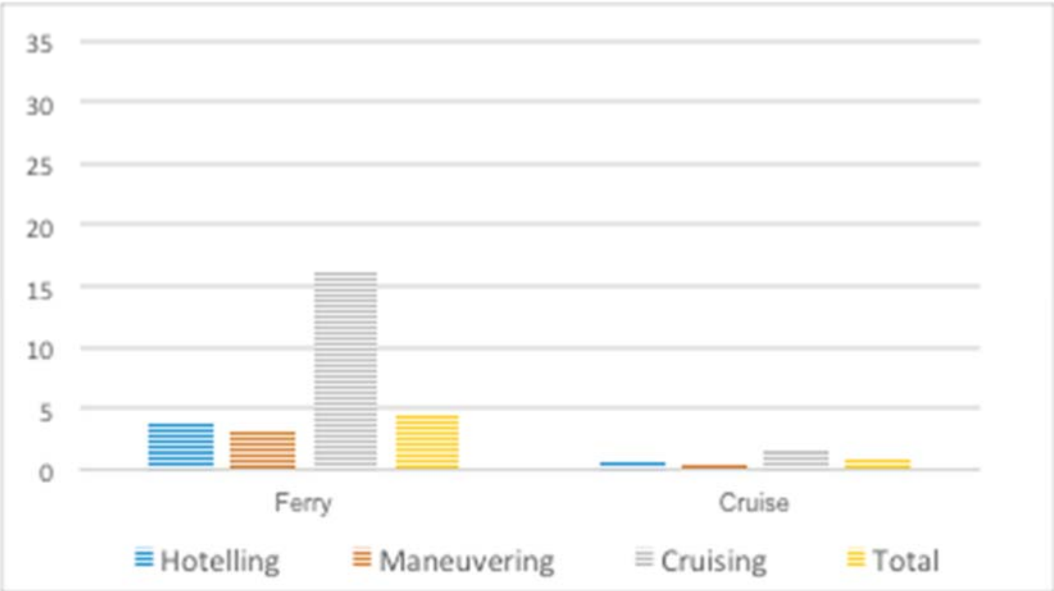


Figure 5 – Operative percentage of cruise and ferry vessels relative to the total operative in Las Palmas Port



Ship size (weight) is also crucial to fuel consumption and emission estimation. Table 3 presents results for cruise and ferry as a total of passenger categories. According to results and in terms of emissions the role of the largest size classes (from 60kt to 80kt) is representative for cruise operations, while for ferry services this is mainly allocated between 10 and 30kt.

In terms of pollutants commonly related to local effects (NOx, SOx and $PM_{2.5}$), the largest share of results is attributed to ferry vessels between 10kt-30kt, and cruise vessels with a GT between 30kt-45kt and over 80kt. On the other hand, emissions related to global effects allocate, mostly, under the largest classes of cruise vessels and ferries between 10 and 30kt.

Regarding operative details, Table 3 also enables a detailed analysis of cruise and ferries. In this respect, although the relative importance of operative types measured in hours, is the same (hotelling, with the largest share of hours followed by cruising and manoeuvring) each subsector has particularities. That is, that cruise vessels spend more time in hotelling (89%) than ferries (81%) being results opposite when referred to cruising (9% for cruise and 17% for ferries). Operative profiles of vessels are consistent with the overall nature of the passenger sub-sectors. This means cruising and hotelling shares derived from loading/unloading operations and waiting in harbour areas while passengers go ashore, in the case of cruise. In the case of ferries, tight schedules, frequent services and a low turnaround time at port.

Table 3- Exhaust emissions and operative time of cruise and ferry vessels according to size classes as predicted by the STEAM

		EXHAUST EMISSIONS					OPERATIVE TIME			
	Las Palmas Port (2011)	NOx [Ton]	SOx [Ton]	PM2.5 [Ton]	CO [Ton]	CO_2 [Ton]	H [Hours]	M [Hours]	C [Hours]	T [Hours]
Cruise	GT Below 4kt	2	1	0	0	96	10	1	3	14
	GT Between 4kt-10kt	9	2	0	1	474	1575	4	17	1596
	GT Between 10kt-20kt	3	1	0	0	133	55	2	10	67
	GT Between 20kt-30kt	7	2	0	1	355	148	6	29	183
	GT Between 30kt-45kt	26	10	2	2	1261	371	13	50	433
	GT Between 45kt-60kt	22	9	2	2	1003	195	9	32	236
	GT Between 60kt-80kt	74	39	8	9	3529	1002	31	179	1212
	GT over 80kt	16	13	3	3	831	301	15	63	379
	Total Cruise	158	75	16	18	7683	3657	79	384	4120
Ferry	GT Below 4kt	0	0	0	0	21	199	1	1	202
	GT Between 4kt-10kt	57	13	3	6	2590	3046	45	593	3685
	GT Between 10kt-20kt	588	316	65	47	27446	10854	329	2433	13616
	GT Between 20kt-30kt	259	132	28	29	12686	4352	143	843	5338
	Total Ferry	905	461	97	81	42744	18452	517	3871	22840
Total Pax		**1063**	**536**	**113**	**99**	**50426**	**22109**	**597**	**4254**	**26960**

Note: Fuel consumption and emissions released while at berth are included. Compliance of IMO and EU regulatory frameworks for marine fuels is assumed and also included in these estimations.

In terms of the temporality of results and following identified seasons of passenger transport (EDEI, 2011) results have been later divided into three periods over time. Emission and operative shares of cruise and ferry are thus aggregated by periods of four months. That is P1 (January, February, March and April), P2 (May, June, July, August) and P3 (September, October, November and December) in Figure 6 and 7 comparing emissions and activity levels (total operative hours at port). When comparing one figure to the other, it is noticeable how the contribution levels of cruise are highest on P1 and P3, consistent with the referred peak season for cruise (EDEI, 2011) while results for ferry vessels and its regular services remain stable over time.

Figure 6 – Seasonal percentage of emissions and operative hours of cruise vessels, relative to the totals accounted in Las Palmas Port.

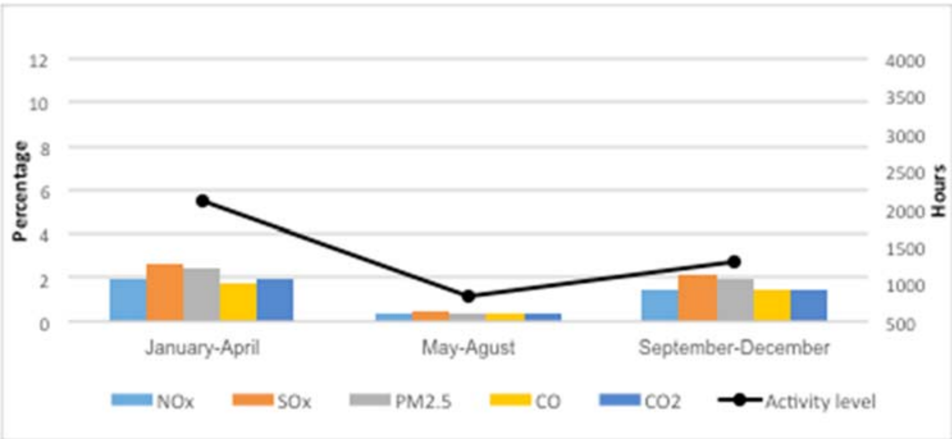
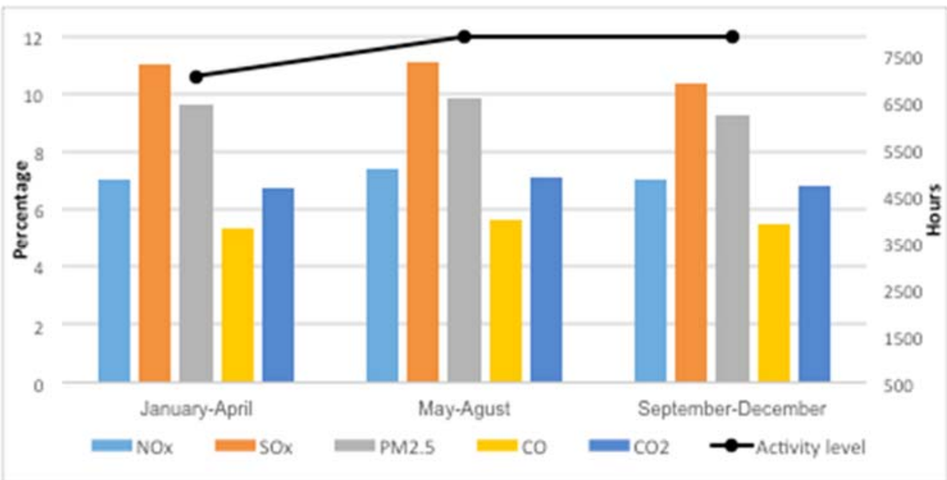


Figure 7 – Seasonal percentage of emissions and operative hours of ferry vessels, relative to the totals accounted in Las Palmas Port.



Results -when combined with in-situ measurements, dispersion modelling, impact valuation and external cost estimation- provide information of value to design market-based instruments founded on emission profiles, which consider the distance sailed and the technical performance of the vessel so as to reflect actual emissions as proposed by Kågeson (2009)[26]. Kågeson (2009) also states that determining emissions from different vessels appears not to be a technical problem since the AIS makes possible to identify vessels and to measure the distance and time that each ship travels within a specific sea area. Thus, its use as a tool for policy design remains open to consideration. Additionally, it is hereby suggested the support of the participation of IMO compliant states is encouraged to motivate all vessels in domestic traffic and state waters to also be subject to AIS measures, being then eligible for charges and discounts to be applied to all vessels regardless of flags.

1.4.2. Geographical characterization of results

The location of berthing areas at port is relevant and this is not only due to their inference in maritime operations (arrival, departure, loading, unloading and berthing) but also to their contribution to air quality as a source of air pollution and global warming. Indeed once they are released from the emission source; pollutants disperse into the atmosphere affecting both, the rise of global temperatures and the local detriment of air quality, human health, infrastructures and crops.

In this respect, it should be noted that the aim and scope of this case study does not relate to the atmospheric dispersion of pollutants or the exposure effects derived from them but to the exclusive application of an emission model to cruise and ferry vessels in Las Palmas Port. Therefore, the aim of the geographical characterization of results exclusively attempts to illustrate the spatial capabilities of the emission modeling, as to locate the release of emissions at source (ship´s funnel) and to note the added value of observing changes in results over time.

[26] Kågeson (2009) in his proposal states: "the Authority would use vessel-specific data from its register and information from participating ports and the AIS system to calculate the charges to be paid by individual ships.The responsibility of participating ports would be limited to controlling each ship's bunker delivery note and asking the ship owner or the operator to sign a statement confirming that he/she accepts responsibility to pay the en-route charge per pollutant based on the ship's latest journey in these waters. Based on this information, the Authority would later bill the company. This could be done on a monthly, quarterly or annual basis"

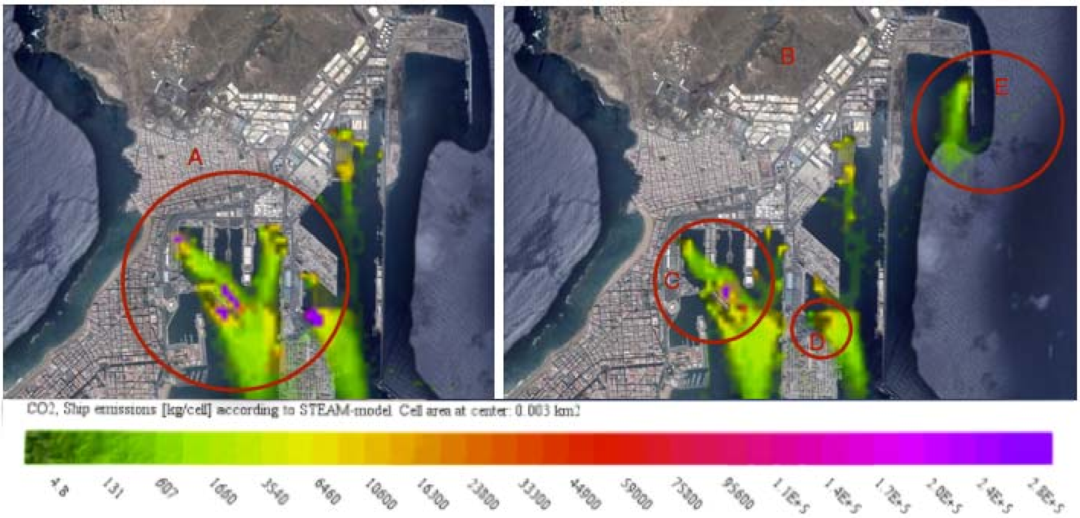
To set one example and based on results from 2011 (see Figure 8, left) emission maps do not only reflect hot spot areas for the modelled release of emissions from its source but operative of cruise and ferry vessels (over hotelling and manoeuvring) is mainly observed in quays located near densely populated areas (left image, A). On the other hand, and if we were to compare these results with a similar map for 2012 (see Figure 8, right), hot spots and operative changes are evident (right image, E) in areas surrounded by a lowest rate of inhabitants.

In this case study, the view of the geographical characterization of modelled emission released at source, enables us to observe preliminary evidence (to be confirmed by in-situ measurements and dispersion modelling) of changes over time that in a context of air emissions, may be induced by the relocation of passenger services. Indeed, the observed change in 2012 relate to the relocation (due to logistical reasons) of one ferry route (Las Palmas – Santa Cruz) to an operative quay located in the forthcoming passenger terminal La Esfinge (right image, E).

Forthcoming passenger terminal to be completed in 2015 is expected to allow significant cost savings by centralizing routes connecting Tenerife, Gran Canaria, Fuerteventura and the Spanish mainland reducing fuel consumed and at least 20 minutes of travel time. Nevertheless, and based on preliminary indications of emission decrease at source (left image, A) near densely populated areas (right image, C and D), suggests that the relocation of ferry services (starting 2012) may not only result in operative improvements but in a positive contribution to air quality in the port-city. In order to prove this, and according to suggested guidelines in Europe (Miola et al., 2009) a detailed assessment including pollution dispersion, the modelling of exposure effects and the valuation of related economic costs is necessary. This becomes particular interest when considering alternatives to potentially reduce the human exposure and effects from a large share of emissions (and PM) that according to this study relate to passenger traffic and ferry services. Since this remains outside the scope of the current research, it is suggested as an action for future research.

As observed in this case study, the geographical characterization of emissions when based on the AIS, also enable modelled results to be compared over time. Additionally, it facilitates to monitor the effects of environmental, operative or political actions that address shipping in general or a sub-sector in particular.

Figure 8– Geographical characterization of estimated CO_2 at source from passenger vessels hotelling and manoeuvring. Left: 2011, right: 2012.



1.5. Discussion and policy implications

In order to maintain a positive relation and support from the local population, the endeavour of maintaining a long-term and sustainable relation between ports and cities has been suggested (Merk, 2013). This might be achieved in a large extent, with the recognition of negative impacts, the design of mitigation actions and self-regulation strategies. Results of this case study reflect that vessel traffic in Las Palmas Port is a source of air pollution and gases commonly related to the acceleration of greenhouse gas effects and global warming. To accordingly measure local detriments and effects derived from these, further steps must be accounted such as dispersion assessment, impact estimation and monetization of damages. Nevertheless, this serves as first indicator to be followed with a line of action and to encourage local authorities pursue those targets.

Gibbs et al., (2014) summarize port actions to abate emissions from ocean-going vessels during their journey and at berth. Actions identified comprise: vessel speed reduction through voluntary programmes and virtual arrival; green ship promotion based on ship fuel consumption profile and technical specifications; on-shore power supply; exhaust gases control for auxiliary engines and automated mooring systems. The two first types of measure require low capital investment and could be applied more easily than the latter three, which require a highest level of capital. In this sense and in line with results (prior dispersion and impact assessment for NOx, SOx and $PM_{2.5}$), we suggest following with detail the evolution and possibilities these systems could offer to environmental performance of Las Palmas Port and its passenger terminal La Esfinge.

On the other hand, evidence on market-based instruments such as environmentally differentiated port fees, have been so far positive but at present without a preferred fee system. Also, the scale factor for current fees due, are based on GT. In this sense and considering the availability of tools to gather related information with further detail, we suggest for innovative fee systems to be explored (e.g. Kågeson, 2009). This, with the aim of creating incentive instruments that consider polluting and operative differences among shipping sectors, when at port or in a regional context (Chen et al., 2014). To this effect, measures presented in this paper are of great value. This may not only prevent non-compliance but it may also promote a fair competition among stakeholders.

Additional enforcement requires cooperation and coordination between the IMO and regional powers but also, actions of shared interest towards the environment should be explored among ports (e.g. European and Spanish) in order to achieve common goals in accordance with international maritime law.

From the measures mentioned above, only green ship promotion through ISO and EMAS certifications has been actively pursued in Las Palmas Port. Still, this should be only considered as a preliminary step in relation to improvements that the participation in voluntary indexes as the ESI or the implementation of previously mentioned alternatives could represent in this port.

Policy recommendations for this case study encourage the regular monitoring of exhaust emissions related to sea-based activities at port. This will provide required information to monitor and support market-based incentives for traffic share in Las Palmas Port. To approach this purpose, we suggest AIS-based methodologies as they enable accuracy, disaggregation of results and the possibility to consider variables previously neglected (i.e. speed, engine loads and vessel particulars) providing high-resolution outputs and information of great interest for regulatory compliance and policy-making. An additional suggestion is to conduct dispersion, impact and economic studies to provide complementary guidance and the necessary information to support port layout (as the relocation of terminals).

Also, we suggest pursuing feasibility studies, to install on-shore technologies as cold ironing or automated mooring in order to address shipping sectors with the highest participation of emissions and CO_2 (e.g. passenger shipping). It has been recognised that on-shore power might represent an advantage for urban ports because of NOx, SOx and PM emission reduction. Moreover, if this power is drawn from a grid fed with low carbon electricity from renewable resources, it can also significantly reduce CO_2 emissions. Vessels offering regional services, docking at regular ports and quays might be best candidates for on-shore power. For this reason we suggest to explore installation of this abatement alternative for the use of passenger sub-sectors (ferry and cruise) once dispersion and impact modelling have supported the convenience of reallocation.

Although the on-shore power also holds a high potential to reduce global effects of greenhouse emissions, it is dependent on the electricity generation mix in the island of Gran Canaria. At present, this mix presents a large dependency on oil and thus, a strong relation with emission contribution. Despite this fact, excellent conditions exist to pursue development of renewable energy[27]. Moreover, due to particular

[27] Gran Canaria hosts the largest wind farms in Spain and many more are being developed The latest investment is an offshore wind turbine at the end of a dyke in the port of Arinaga on Gran Canaria. At 154 metres tall it is credited with being able to supply the annual energy needs of 7,500 homes. The turbine has yet to be certificated and is still officially on trial. If it continues to work as planned then it should begin to contribute to the Spanish electrical grid in March 2014.

characteristics of the Canary Islands, the role of renewable energies and their complementarity with natural gas offers a solid path to reduce costs and to achieve the main energy policy goals of the regional government. These goals are presented in the Strategic Plan of the Canary Islands (PECAN 2006)[28]. This may support the potential use of renewable energy and the diminishment of air pollutants released in the future.

So far, Las Palmas Port has not addressed LNG. Still, it is a leading worldwide bunker trader and it has consolidated a position over the years as bunkering specialist by serving the needs of a wide scope of ships such as merchants vessels, ocean going yachts & cruise ships, oil tankers, military and government vessels as well as many fishing fleets. In relation to this, we suggest to replicate feasibility studies to analyse the potential introduction of LNG infrastructure in Las Palmas Port as the initiative currently driven for the port of Santander. Not only because this would ease the introduction of LNG-fuelled vessels as the ones currently operating in the North and Baltic Seas (e.g. Viking Grace) but also as a potential market opportunity for bunkering in relation to: a regional demand increase expected due to stringent regulation, the availability in neighbouring terminals and a possible demand by maritime stakeholders and corporate actions.

On the other hand, LNG global fleet is so far dominated by ferries navigating in Norway and the Baltic Sea. We suggest following incentive strategies to extend the use of LNG-fuelled crafts for regional services operating regionally from Las Palmas Port.

In addition to this, development and monitoring of fleet performance indicators and berthing allocation strategies (Du et al., 2011), may be of great value as innovative alternatives to reduce fuel consumption and abate exhaust emissions. This may be in confluence with productivity improvements and environmental balance increasingly seeked by the shipping companies (Lai at al., 2013).

[28] Ramos-Real et al. (2007) estimates that the kWh individual cost using gas is some 25% lower than the cost of using petroleum derivatives. In the same way, the combined effect of reaching the PECAN (2006) goals of renewables (30% of electricity mix) and natural gas (40,5%) would reduce cost about 32%, as well as in atmospheric CO_2 emissions about 30% (Marrero and Ramos-Real, 2010).

1.6. Conclusions and future research

Emission estimates presented in this case study suggest shipping in general and passenger shipping in particular as a source of air pollution (NOx, SOx, $PM_{2.5}$, CO, CO_2) in Las Palmas Port. These results are consistent with other studies that also address emission inventories at port. In summary it can be observed from results that the, passenger, container and tanker vessel categories have contributed with the highest share of emissions related to local detriments on air quality (NOx, SOx, $PM_{2.5}$, CO) and global GHG effects caused by exhausts (CO_2). Additional studies[29] to follow with preliminary results of this paper are suggested as future research.

Operative profiles are diverse among shipping sectors and also for passenger sub-sectors where cruise vessels spend more time in hotelling than ferries being results opposite when referred to cruising. Operative profiles of vessels are consistent with the overall nature of the passenger sub-sectors. Temporality of results on the other hand, has been also addressed for cruise and ferries over three quarterly periods. Results are consistent with the cruise industry seasonality, with the highest contributions during the peak seasons from September to April while shares of ferry vessels maintain stable over time due to their regular services.

The role of size classes from passenger sub-sectors (ferry and cruise) is also different being the larger size representative for cruise operations while ferry services are mainly carried out with a smaller size of vessels. The largest share of pollutants related to local effects is attributed to ferry vessels between 10kt-30kt and to cruise vessels between 60kt-80kt. Moreover, pollutants related to global effects mostly allocate under ferry size classes between 10 and 30kt. Emission maps confirm the location of emission hot spots at source (i.e. ship´s funnel). In particular, berthing quays assigned for cruise and ferry operations located near populated areas are distinguished from the rest.

[29] Dispersion and impact modelling followed by the economic valuation of damages.

This paper encourages the collection of emission information, in order to design incentive instruments according to detailed operative and polluting profiles, which can be used to develop policies, for instance through vessel speed reduction and green ship promotion, to mitigate harmful impacts. Moreover, emission information is useful both, to identify hot spots of emissions at shipping sources near densely populated areas and also, to support dispersion and impact studies of air pollution that will allow further assessment on the port layout, relocation decisions (if needed) to quays surrounded by a lowest rate of affected inhabitants as well as improvements in the port related structures (i.e. on-shore power).

Feasibility studies are also suggested for automated mooring, LNG port infrastructure development and also for on-shore energy services, prioritizing berthing of shipping sectors (or sub-sectors) with the highest share of responsibility in exhaust emissions, once the level of contribution is accordingly confirmed by a dispersion, exposure an impact assessment. Cost can be a barrier for the widespread use of on-shore electricity supply. Nevertheless, in the absence of international standards, the installation or retrofitting of electrical power systems on vessels may support the acceptance of ports towards an alternative such as cold ironing.

The main contribution of this paper to literature relates to the application of an AIS-based emission model to shipping sub-sectors (cruise and ferry) at port, presenting results according to size classes, operative type and time. This is also the first time an AIS-based model is used to address exhaust emissions from shipping sub-sectors in an island context. Results have not only provided operative and polluting profiles in Las Palmas Port but suggest the possible value of AIS based methodologies. Particularly, when accompanied with air quality modelling, impact and economic studies to address the design of corrective measures for specific sub-sectors in shipping, as cruise and ferry. Results and policy recommendations of this study may also support adequacy or improvement of existing policy in Las Palmas Port, being also transferable to port-city areas and islands under similar traffic conditions.

Port-related exhaust emissions, as any negative externality, reflect a real cost accruing from an economic activity and lead to a suboptimal outcome. Thus, future research should also focus in the valuation of economic costs derived from exhaust emissions in shipping. Indeed, the inclusion of external costs to the decision-making process will allow internalization and improvement of the public welfare.

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Chapter 2

External costs of vessel emission at port: a review of the methodological and empirical state of the art

2.1. Introduction

In recent years, negative effects related to air emissions derived from the growth of shipping have increasingly raised concern. It has been recognized that operative vessels do not only contribute to negative effects on a global scale -rising temperatures in the climate system- but also to hazardous consequences experienced in local communities -detriment of health, crops and built environment- (Cullinane and Cullinane, 2013). Indeed, management tools at port are been increasingly addressed to enforce or encourage green development (Lam and Notteboom, 2014) and the abatement of emissions.

Negative impacts derived from air pollution[30] can be quantified and monetised as external costs. Nevertheless, its estimation is an inevitable source of uncertainty, mostly conditioned by methodological uncertainties and information gaps on available knowledge. Indeed, this is mainly due to the complex relation between factors involved in air quality valuation and derived costs such as, the overall levels of pollution, the geographical location and height of emission sources, local meteorological conditions, the chemical reaction and dispersion of atmospheric hazardous substances; and the physical harm that this might cause to human health, crops and urban infrastructure.

[30] Primary pollutants are produced from a process, such as a vehicle exhaust, or factories. Secondary pollutants are not emitted directly. Rather, they form in the air when primary pollutants react or interact.

In despite of limitations, it is possible to estimate the external costs of market-based (crops loss and material damages) or non-market-based (human health) negative impacts by applying statistical valuation techniques (Miola et al., 2009). Namely, market prices are used to estimate the yield loss of products in agriculture and material damages while human health is addressed with a willingness-to-pay (WTP), to accept (WTA) or to be compensated (WTC) for the externality in question (i.e. Tabi and del Saz, 2014).

Greenhouse gases remain as a different challenge since these relate to a long term and risk patterns that are hard to anticipate. Therefore it is difficult to make a detailed assessment on the related damage costs of individual countries (Maibach et al., 2008). Alternatively, and although these rely on an emission reduction target or a scope of reduction (Jiang and Kronbak, 2012), an approach to avoidance costs is utilized and considered adequate (Essen et al., 2007; Lee et al., 2010; Bickel et al., 2006).

Detriments on human health are considered as the most important effect in terms of quantifiable costs (mortality and morbidity). For its assessment, either the Value of Statistical Life (VSL) or the Value of the Life-Year (VOLY) can be taken into consideration. Nevertheless, it is difficult to account the exposure to air pollution as a main cause of death. For this, the use of the VOLY and the reduction of life expectancy in terms of Years of Life Lost (YOLL) are widely preferred in literature (i.e. ExternE and CAFE, see Section 2.1). Moreover, two main studies[31] address mortality derived from air pollution in the UK and in Europe although they are criticized due to detrimental effects covered[32].

Top-down and bottom-up approaches are widely recognized in a variety of research subjects over literature (Sabatier, 1986). These include the quantification of air

[31] DEFRA (Turner et al., 2004) carried by the Department for Environmental Food & Rural Affairs Study refers to estimations in the UK and, NewExt, (Friedrich et al., 2004) regards Europe (surveys from Great Britain, France and Italy). Both provide figures in terms of the VSL and VOLY.

[32] It is argued in literature that while the valuation of detrimental effects in adults is covered by specialized literature, the same cannot be said for the valuation of mortality in children (Hoffmann and Krupnick, 2004), or tourists exposed to conditions similar to local population (Miola et al., 2009).

emissions (required step to obtain external costs) and external costs. Each approach captures transportation technology in an aggregated (top-down) or disaggregated form (bottom-up) reflecting differences in results due to complex interplays between purpose, structure and data input. In both emission and external cost estimation, top-down approaches use aggregated economic variables while bottom-up approaches consider refined and disaggregated information, mostly based on technical performance.

The application of approaches varies according to the subject of study. For emission estimation, a top-down approach that is based on fuel sales is used when refined traffic information is not available. On the other hand, a bottom-up approach based on traffic information (obtained from vessel tracks or port calls) is used when available, due to the accuracy of input parameters such as ship type, location, size and technical particulars. Finally, a full bottom-up category is described by Miola et al., (2010), as the use of a bottom-up approach for both, the quantification of emissions and the geographical characterization of results.

Regarding the geographical characterization of emissions, the level of detail achieved is also dependent on the approach followed (bottom-up and top-down). Thus, with a bottom-up approach, individual information of vessels and its position are considered while with a top-down approach valuation is based without, or with partial information on the position of vessels (i.e. the geographical activity of shipping is estimated based on a single shipping route or a particular geographic activity cell, no matter which vessel carries out the activity).

In the case of external costs and according to Jiang and Kronbak (2012), its estimation can be classified in three categories. The first one relates to an external cost comparison between transport modes, the second to cost-benefit analysis on emission reduction technologies and the third one to case studies that exclude the later two. For the three types of case studies, a bottom-up approach is also preferred as it enables a refined assessment based on detailed information, differentiation possibilities and an improved precision in derived results (marginal external costs). Nevertheless, costly and complex requirements are also recognized to obtain external costs from a bottom-up approach. Thus, the use of a top-down approach is suggested and widely accepted when bottom-up studies can not be performed or are not available[33]. Indeed, as we present in Section 3, literature on harbour external costs due to vessel emissions is exclusively based on the use of cost factors and aggregated economic variables (top-down approach).

To summarize, a bottom-up and a top-down approach may be used for the estimation of external costs. Both provide advantages and limitations (Miola et al., 2009). On one hand, a bottom-up approach follows a causal chain of relations that start with the emission of pollutants to finalize with a detailed estimation of the marginal external costs caused by each unit of pollutant. On the other, a top-down approach (i.e. Miola et al., 2010; Tzannatos 2010a; Berechman and Tseng, 2012) estimates the external costs by using cost factors from bottom-up studies (per country or region). This results on average costs derived per pollutant but it will not allow further differentiation (i.e. Tzannatos et al., 2010b; Castells et al., 2014).

As an initial step to methodological improvement specific to vessel emissions at port and with the aim of improving air-quality in port cities, the present study renders a review on the methodological and empirical state of the art on external cost estimation from harbour emissions released by vessels. The structure of this document is described in the following lines. After briefly introducing the subject of study in Section 2.1, Section 2.2 presents a methodological review on the bottom-up approach and its application to external cost estimation in ports and shipping. Section 2.3 follows with an empirical review on the top down approach and the existent harbour studies that measure external costs derived from vessel emissions. To finalize, Section 2.4 presents conclusions and future research.

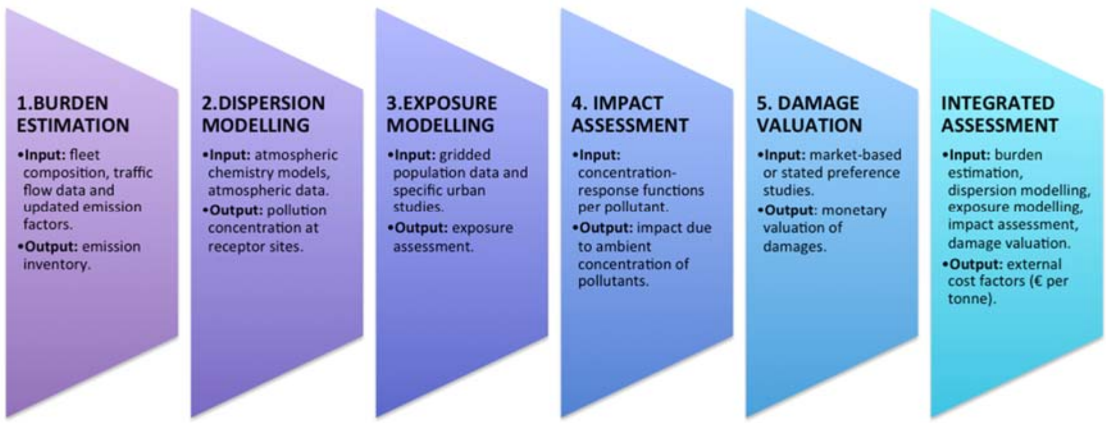
[33] This could be due to the lack of atmospheric dispersion modelling practices not widely undertaken in shipping.

2.2. Methodology: Impact Pathway Approach to air pollution (a bottom-up approach)

Regardless of methodological limitations, the internalization of external costs in transport has been a relevant issue for research and policy development. Indeed, research supported by the European Commission towards a competitive and resource efficient transport system (Commission of the European Communities, 2011), suggest that in order to generate considerable benefits and aim for a fair and efficient pricing in transport, command and control measures and market-based instruments should be defined from marginal cost pricing (Gibson et al., 2014). The estimation of marginal costs is accomplished by using a bottom-up approach. These are more precise and with potential for differentiation but costly and of complicated implementation (Jiang and Kronbak, 2012).

The first attempt to develop a bottom-up approach to address air emissions was integrated in the External Costs of Energy (ExternE) project series (1990-2005) under the ExternE DG Research of the European Commission (European Commission, 1999). Over the ExternE, a bottom-up methodology referred as Impact Pathway Approach (IPA) was conceived, following a pathway process, which requires: emission estimation, dispersion modelling, exposure modelling, impact, and damage valuation

Figure 1. Impact Pathway Approach to air pollution



Source: adapted from the ExternE (Bickel et al., 2005).

The IPA is considered as the most comprehensive and best practice methodology for calculating site-specific external costs[34] derived from air emissions. It has been widely adopted, among others, over major European studies specifically addressed for external cost estimation in transport such as the Benefits Table database (BeTa) (Holland and Watkiss, 2002; NETCEN, 2004); the Harmonised European Approaches for Transport Costing and Project Assessment (HEATCO) (Bickel et al., 2006); the Clean Air for Europe (CAFE) (Holland et al., 2005; Amann et al., 2005) and the New Energy Externalities Development for Sustainability (NEEDS) (Preiss et al., 2007).

Indeed, in a context of ports and shipping, literature addressing external costs mostly rely and accept major bottom-up European studies (BeTa, CAFE and NEEDS) that follow the IPA[35] with methodological variations and differences on input values such as modelling scenarios, emission baseline by country and pollutant, dispersion model used, impact assessment methodology and others.

BeTa (Holland and Watkiss, 2002) was developed for the European Commission and includes the external cost of EU (14 countries) air emissions (SO_2, NOx, VOCs and PM) estimated in 1998. Three scenarios are addressed. Namely emissions from all sources in rural locations for EU countries except Luxemburg, emissions at ground level in cities of different sizes; and emissions from shipping (based on data for urban areas of various sizes). In order to address emissions close to shore, BeTa suggests the use of national urban and rural cost factors. Also, it provides offshore cost factors for countries surrounding sea areas[36] weighted by straight-line length of coast for bordering countries. In BeTa, dispersion and environmental chemistry, exposure of sensitive receptors, impacts (using exposure-response functions) are

[34] External costs related to air pollutants hazardous in a local context are addressed differently than the climate change costs (CO_2). The latter, are estimated as avoidance cost factors according to reduction targets, the application year, the discount rate and equity weights. Thus, a combination of the IPA and avoidance costs is suggested when addressing greenhouse effects (Denisis, 2009).

[35] It should be noted that in despite of the comprehensiveness and policy value provided by the IPA methodology, pollutant chemistry and dispersion outcome in regional studies (i.e. BeTa) may be source of inconsistencies as these were not developed with the original purpose of external cost estimation for wider policy use.

[36] Namely the Eastern Atlantic, the Baltic Sea, the English Channel, the Northern Mediterranean and the North Sea

based on the ExternE/IPA. Finally economic valuation is pursued through a willingness to pay estimation.

On the other hand, CAFE (Amann et al., 2005; Holland et al., 2005) combines information on expected trends in energy consumption, transport, industrial and agricultural activities with validated databases describing the present structure and technical features of the various emissions sources for 25 Member States of the European Union. Air quality issues in CAFE include damages per tonne emission of $PM_{2.5}$, NH3, SO_2, NOx and VOCs from each EU25 Member State (excluding Cyprus) and surrounding areas. The analysis presented builds on the Regional Air Pollution Information and Simulation (RAINS) model[37]. In doing so, the model compiles for all European countries databases with the essential information and links this data in such a way that the implications of alternative assumptions on economic development and emission control strategies can be assessed. Also, the suite of health functions was improved and updated values were included such as rural impacts related to yield loss for: barely, cotton, fruit, grape, millet, maize, oats, olive, potato, pulses, rapeseed, rice, rye, seed cotton, soybean, sugar beet, sunflower seed, tobacco and wheat. Moreover, CAFE considers four different sensitivity scenarios. The variation comes from methodologies used to value mortality (mean or median values to estimate the value of a life year or the value of statistical life). Also, the range of health effects and the cut point for ozone impact assessment also changes in each of the sensitivity scenarios. To examine the robustness of CAFE results against important exogenous assumptions, operative vessels were included as a sensitivity case but no related cost factors were provided. It was found that overall costs would decline if some of the required emission reductions were implemented at seagoing ships.

HEATCO (Bickel et al., 2006) provides harmonised guidelines for infrastructure project appraisal covering environmental costs of air pollution ($PM_{2.5}$, PM_{10}, SO_2 and

[37] RAINS combines information on economic and energy development, emission control potentials and costs, atmospheric dispersion characteristics and environmental sensitivities towards air pollution, which describes the pathways of pollution from the anthropogenic driving forces to the various environmental impacts.

NMOVOC[38]), noise and global warming. Monetary valuation is based on the principles of welfare economics, contributing to the long run consistency with transport costing. Cost factors in euro per tonne of pollutant released in different environments (urban areas, outside built-up areas) are provided for air, bus, car and train contributions in the EU (25 countries). Although external costs related to shipping are not considered in HEATCO, it is suggested that country-specific cost factors are used to address specific locations when no state-of-the-art cost factors (resulting from bottom-up studies) are available.

Finally, it should be noted that after the completion of ExternE in 2005, EU-projects as the NEEDS have used the ExternE resources transferring the model into web-based tools. For instance, the EcoSense model (NEEDS) and its web platform were based on the IPA[39] and support the estimation of external costs in Europe. It was designed for the analysis of single point sources (electricity and heat production) but it can also be used for the analysis of multi emission sources. Information on its suitability to shipping scenarios is not publicly or easily available[40]. For rough estimations[41], the model can be used for free but is limited to a specific number of EcoSense runs and specific scenarios where only power plants can be chosen as emission source, so they are not related to shipping. The single source, multi source, the EcoSense Transport and the EcoSense China are purchasable licenses that are also apparently (since this information could not be confirmed) not specific to shipping. The BelEUROS model for Belgium (VITO, 2010) is applied and compared

[38] Methane, a VOC whose atmospheric concentration has increased tremendously during the last century, contributes to ozone formation but on a global scale rather than in local or regional photochemical smog episodes. In situations where this exclusion of methane from the VOC group of substances is not obvious, the term Non-Methane VOC (NMVOC) is often used.

[39] As stated in their webpage "The EcoSenseWeb and the calculation of external costs follow as far as possible the so called Impact Pathway Approach (IPA)" without explaining what is the meaning of "as far as possible"

[40] In order to obtain Information on its suitability to shipping scenarios the authors have tried to make contact with the EcoSense administrators, over a period of three months and by using the available communication channels but did not receive any response.

[41] Indeed, the users have no information about what is behind the few options that they can choose in order to estimate external costs. Due to difficulties to obtain additional information and request user support, in our opinion this web is a very limited source to estimate external costs. This is a recognizable fact reflected by a thick box the user is asked to mark whose text tells that "to acknowledge that you have understood that the following results are only rough estimates of the order of magnitude that should be replaced by more detailed calculation, if decision is to be based on it."

with the EcoSenseWeb model. The authors claim to have more plausible results, in particular for local effects, because much additional local detail is included in BelEUROS. Due to the local character of the study, results for other countries are not available (Korzhenevych et al. 2014).

The NEEDS project (Preiss et al., 2007) also obtains their externality cost estimations from the EcoSense model. Results cover all major pollutants and all EU Member States, enhancing features of relevance for the purpose of environmental policy application (see Korzhenevych et al., 2014). Firstly, it covers all European sea territories (Baltic Sea, Black Sea, Mediterranean Sea, North Sea and Remaining North-East Atlantic). Secondly, they cover not only health effects, but also quantify the side effects of emitted NOx and SO_2 on materials (e.g. buildings), biodiversity, and crops.

Additionally, the latest update (Korzhenevych et al. 2014) of the handbook on External Costs of Transport (Maibach et al., 2008) presents unit cost values for maritime transport by types of vessel. These are estimated from the corresponding emission factors taken from Delft (2011) and damage cost factors (non-urban) from NEEDS (Preiss et al., 2007). It is important to note that some important vessel categories are not included. For instance, Ro-Ro and container ships due to the lack of comprehensive data, in a consistent format (Korzhenevych et al. 2014).

To summarize, external costs derived from shipping are exclusively addressed in the BeTa, the CAFE and the NEEDS reports. In NEEDS, cost factors per sea areas are presented; In CAFE, shipping results are presented but as a sensitivity case without presenting ton/euro values. On the other hand, and in BeTa cost factors per sea area and per EU country (specific to seaports) are provided, stating that dispersion modelling is not undertaken for shipping due to the lack of modelling practices. Indeed, dispersion modelling from shipping emissions is currently addressed by a limited number of studies mostly based on satellite information transmitted by the AIS[42]. In this respect, latest experiments on emission modelling derived from

[42] The Satellite Monitoring of ship emissions in the Baltic Sea (SAMBA) project was aimed to monitoring Baltic Sea ship emissions via satellite. The SAMBA feasibility study, was carried out in the framework of the "Integrated Applications Promotion (IAP)" program of the European Space Agency,

shipping (Third IMO GHG Study, 2014) reflect precision improvements when additional data sources as terrestrial AIS or the Long-range Identification and Tracking of Ships (LRIT)[43] are parsed with satellite AIS. Thus, the inclusion of vessel traffic information from different data sources may be foreseen and precision improvements may be expected in forthcoming reports that estimate emissions and derived costs. Considering the later, improved precision may also benefit dispersion modelling and impact-related cost results.

To conclude, an integrated assessment (see Figure 1) on shipping emissions has not been directly addressed in the referred studies (BeTa, CAFE and NEEDS) although the obtained results in BeTa provide an insight to the magnitude of associated externalities (Miola et al, 2010; Tzannatos, 2010a).

2.3. Literature review on external costs derived from air emissions in shipping: a top-down approach.

Presently and due to the complexity and costly resources required to generate bottom-up studies on shipping and ports, it has been widely accepted to estimate these based on a top-down approach and per-unit cost factors obtained from major European reports (BeTa, CAFE, NEEDS) and recent literature. Indeed, most studies exclusively address emission estimation making assumptions on vessel operative at port and do not further evaluate the associated external costs. Limited research has been found on the valuation of external costs from shipping emissions at port. From those identified (see Table 1), all followed a top-down approach based on national or regional cost factors presented in bottom-up studies with a predominant reference to BeTa and CAFE.

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called for a combination of earth observation (EO) Instruments, air quality (AQ) and vessel emission modeling based on satellite AIS information.

[43] LRIT is a maritime domain awareness (MDA) initiative to enhance maritime safety, security and protect the marine environment. It allows Member States to receive position reports from vessels operating under their flag, vessels seeking entry to a port within their territory, or vessels operating in proximity to the State's coastline. SOLAS Chapter V, Regulation 19-1, on LRIT refers to the requirement for specified Convention vessels to automatically transmit their identity, position and date/time of the position at 6-hourly intervals, with an ability to increase the rate to intervals of up to once every 15 minutes when requested. The SOLAS amendment came into effect 1 January 2008.

Table 1 presents a summary of available harbour studies on external costs derived from vessel emissions. In the second column, the area, timeframe and shipping sectors addressed are presented. To follow, and in the third column, the methodological approach and emissions estimated are shown. To finalize external costs´ methodological approach and estimated values are described in the last column.

Miola et al. (2009) recalls the main studies that estimate the economic cost of air emissions from shipping and proposes a pathway of steps based on international studies (top-down approach) to address external costs. Emission estimation in the referred case study of the Port of Venice is based on port calls and an estimated operative of vessels (bottom-up approach) After emission estimation, impacts for $PM_{2,5}$, PM_{10}, SOx and PAH are determined and monetised based on Martuzzi et al. (2006) and CAFE which is referred as the most reliable and suitable work for this case-study. Although it is true that the emission exposure of population is considered by CAFE, results imply assumptions of importance related to health affections on people. For instance in cities as touristic as Venice, touristic flows have an order of magnitude that is out of the reach of the city size, although exposure is limited to the period of visit. Results reflect total external costs of 23,951,397 € when using cost factors from CAFE. The range of external costs calculated varies between 2,58 - 5,82 €/passenger and 0,24 – 0,55 €/ ton. In turn, the external cost per vessel corresponds to 2,169 – 4,894 €/ship.

Tzannatos (2010a) presents an emission inventory (NOx, SO_2 and $PM_{2.5}$) for passenger and cruise ships hotelling and manoeuvring in the Port of Piraeus. Emission estimations are based on port calls and estimated vessel operative while at port (bottom-up approach) for a twelve-month period (2008-2009). In despite emission results are not based on position, speed and timestamp details automatically transmitted by vessels with a frequent update (AIS); it should be noted that when compared to available research estimated operative at port; in this research it is attempted to better represent reality of the operative status of vessels by partly obtaining information from port records and in-situ observation. Cost factors are also based on BeTa. Overall, for case studies at port, BeTa is considered as the more appropriate since it accounts air pollutants released from high stacks of ships. Also, it is case specific not only with respect to shipping but also to the operative of ships at port. The external costs associated with the damages ship emissions impose around the passenger port of Piraeus were found to be quite significant. More specifically, the overall externalities were valued at almost 51 million euros, whereas the individual contribution of the pollutants was around 28, 14 and 9 million euros for NOx, SO_2 and $PM_{2.5}$ emissions.

In Tzannatos (2010b), air emissions (NOx, SO_2, PM and CO_2) and its external costs are addressed for domestic and international shipping in Greece (1984 – 2008). For domestic shipping, emission estimations are based on fuel sales (top-down approach) while estimations for international shipping are based on port calls and estimated vessel operative at port (bottom-up approach). In the absence of comprehensive information based on the AIS in the period of time referred, operative and traffic details were also supported by on-site observations. External cost factors for NOx, SO_2 and $PM_{2.5}$ are also based on BeTa. In 2008, the CO_2, NO_X, SO_2 and PM emissions reached 12.9 million tons (of which 12.4 million tons of CO_2) and their externalities were found to be around 3.1 billion euros. The utilization of the fuel-based (fuel sales) analysis for domestic shipping and the activity-based (ship traffic) analysis for international shipping shows that the ship-generated emissions reached 7.4 million tons (of which 7 million tons of CO_2) and their externalities were estimated at 2.95 billion euros. Finally, the internalization of external costs for domestic shipping was found to produce an increase of 12.96 and 2.71 euros per passenger and transported ton, respectively.

Berechman and Tseng (2012) on the other hand, estimate air emissions (NOx, CO, CO_2, PM_{10}, $PM_{2.5}$, SO_2, HC and VOC) and external costs (NOx, CO_2, PM_{10}, $PM_{2.5}$, SO_2, VOC, HC) approaching an inter-modal case study for ships and trucks operating at the port of Kaoshiumg in Taiwan. Emission quantification is based on port calls and estimated vessels operative (bottom-up approach) and also based on traffic intensity of trucks. This work is based on Tzannatos (2010a) and Villalva and Gemechu (2011). For cost estimation factors were used from Lee et al. (2010), Denisis (2009) and Wit et al. (2003). Also, External costs are based on BeTa. By calculating annual ship and truck emissions it was found that the major contributors are tankers, container, bulk ships and trucks. The combined environmental cost of ships and trucks were estimated to be over $123 million per year: the overall environmental costs of ships and trucks were respectively valued at about $119.2 and $4.2 million. In terms of external costs from vessel emissions $2,499,000 were associated to NOx, $153 to CO, $898,000 to CO_2, $45,911,000 to PM_{10}, $61,647,000to $PM_{2.5}$, $8,218,000 to SO_2, $297 to HC and $26,146,000 to VOC. In the case of intercity truck emissions, these reflected minor values with $295,000 derived from NOx, $20 from CO, $11,730 from CO_2, $1,643,000 from PM_{10}, 2,222,000 from $PM_{2.5}$, $24,430 from SO_2, $10 from HC and $5,250 from VOC.

Castells et al. (2014), presents an emission inventory and external costs for hotelling and manoeuvring Ro-Ro, Passenger and Container vessels in Spain during 2009. Emissions estimated at port (NOx, SO_2, VOC and $PM_{2,5}$) are based on port calls and an estimated operative of vessels (bottom-up approach). External cost factors ($PM_{2.5}$, SO_2, NOx and VOC) are then used from BeTa (urban cost factors) and CAFE (rural cost factors). Impact on target harbours per emitted pollutant and year was estimated in four sensitivity scenarios. The average total of costs was of 227,426,765 €. In terms of pollutants, 97,231,633 € were associated to PM2.5, 48,700,862 € to SO_2, 80,962,011 € to NOx and 534,510 € for VOC.

McArthur and Osland (2013) quantify ship emissions at berth (NOx, NMVOC, SO_2, PM10, $PM_{2.5}$, and CO_2) in the Port of Bergen in Norway during 2010 following a bottom-up approach based on port calls and estimated operative of vessels. For external cost estimation, a top-down approach is based on transportation cost factors in Norway (Magnussen et al., 2010), the Coastal Administration (Kystverket, 2007), BeTa and CAFE. Author states that given the lack of knowledge on how much lower the costs related to shipping could be, Magnussen et al. (2010) do not specify separate estimates for modes of transport, and thus their values may be seen to represent an upper limit to the unit costs of emissions from ships. As performed by Tzannatos (2010a) and Tichavska and Tovar (2015) unit cost estimates are taken to prices for the year of interest (using the consumer price index). The lowest estimate is obtained using cost factors from CAFE resulting in 38.02 million NOx per year. The highest estimate is obtained using the values from Magnussen et al. (2010), which estimates costs at 172.20 million NOx per year. On average the cost per person living in Bergen is around 660 NOx per year. Additional results indicate the cost per cruise passenger of between €6.79 and €14.63, using (Kystverket, 2007), and (Magnussen et al., 2010) values.

Song (2014) on the other hand, estimates air emissions for vessel traffic in the Port of Yangshan in China during 2009 to later determine the external costs of the environmental impacts. Emission calculation (CO_2, CH_4, N_2O, PM_{10}, $PM_{2.5}$, NOx, SOx, CO and HC) is based on port calls and estimated vessel operative while at port (bottom-up approach). External costs of $PM_{2.5}$, SO_2, NOx, VOC, CO_2, CH_4, N_2O, PM_{10}, $PM_{2.5}$, NOx, SOx, CO and HC are calculated using a weighted average of cost factors, which were determined through a series of expert judgement/survey[44] (Delphi process). Higher weights (over 70%) were given to the studies which were conducted for China or Chinese cities; while lower weights were for the studies of other countries and worldwide. Results reflect a contribution of 578,444 tons from vessel emissions in Yangshan port area with a total external cost of $287 million. From the latter, $16,485,649 were associated to CO_2, $8,432 to CH_4, 242,748 to N_2O, $114,974,587 to NOx, $69,324,202 to SOx, $1,301,601 to CO, $1,549,119 to HC and $82,862,158 to PM_{10} from which $73,656,489 relate to $PM_{2.5}$.

Maragkogiannani and Papaefthimiou (2015) follow a bottom-up approach based on port calls and estimated operative of vessels creating a NOx, SO_2 and $PM_{2.5}$ emissions inventory from cruise ships approaching ports of Piraeus, Santorini, Mykonos, Corfu and Katakolo, in 2013. The total in-port inventory of cruise shipping accounted to 2742.7 tons: with NOx being dominant (1887.5 tons), followed by SO2 and PM2.5 (760.9 and 94.3 tons respectively). For the estimation of external costs a top-down approach from CAFE was used, followed by results from NEEDS (Korzhenevych et al. 2014). The lowest estimates result from the application of CAFE (12.4 million €) while by using the EcoSense model, the anticipated total external cost reaches €24.3

[44] From several international studies: Funk and Rabi, (1999); USEPA, (2002); Gallagher, (2005); Sirikijpanichkul et al., (2006); IPCC, (2006); USEPA, (2010); World Bank, (2010); Marten and Newbold, (2012); Muller and Mendelsohn, (2007); Yuan and Cheng, (2011); Berechman and Tseng, (2012); VTPI, (2012); Yang et al., (2013).

million. The average cost for all ports per cruise passenger is €5.3 and €2.5 for CAFE and the EcoSense (NEEDS) respectively.

Tichavska and Tovar (2015) estimate external costs and eco-efficiency parameters associated to exhaust emissions in Las Palmas Port. Emission assessment is based on a vessel emissions inventory obtained from the full bottom-up Ship Traffic Emission Assessment Model and messages transmitted by the Automatic Identification System over 2011. The overall economic costs for NOx, SOx, VOC and $PM_{2.5}$ when using urban and rural values provided by BeTa derive in 174,288,076 € while using urban cost factors from BeTa and rural cost factors from CAFE results in an average (including four sensitivity scenarios) of 180,930,427 €. Moreover, results derived using rural cost factors in CAFE results in a variation of 18.7% depending on the sensitivity scenario chosen. Summarizing, the overall cost totals of NOx, SOX, and PM2.5 reflect the dominant shares, accounting respectively for a 22%, 29% and 33% from the total sum being GHG, (CO2 High) responsible for the remaining 15% from the totals at port. In the case of NEEDS and when compared to top-down estimations with BETA methodology (only BeTa and BeTa combined with CAFE) figures are considerably lower with 21,750,913 € from for NOx; 11,567,621 € from SO_2, 87,901 € from and VOC and 68,186, 804 € from $PM_{2.5}$. Therefore, from all the observed variation, the importance of reaching a consensus to assess external costs in shipping and ports has been concluded. In terms of externality costs, Tichavska and Tovar, (2015) presents the available lower and upper thresholds of top-down estimated costs (from BeTa, CAFE and NEEDS). Additionally, derived eco-efficiency parameters (in general) and per shipping sector (in particular) are defined and suggested, as an indicator of environmental and economic performance to be considered for policy use in port-cities.

At last, and to complete our literature review, in 2014 the School of Production Engineering and Management of Technical University of Crete, in Greece, in collaboration with the Research Centre of Energy Management of ESCP Europe Business School have completed an assessment of external cost due to air emissions in European ports. Specifically, the survey focused on the external costs caused by maritime air pollution (NO_x, SO_x and PM), during hoteling, manoeuvring and berthing operative of vessels. Cost factors were obtained from BeTa, CAFE and HEATCO. Results reflect that, as expected, the busiest commercial ports exhibit the highest rate of external costs. The port of Antwerp, for instance, recorded a total external cost that ranges from 475 to 1850 million euros depending on the cost factors considered from literature. In the case of the Port of Rotterdam, cost range over 80-215 million euros. As regards the largest passenger port in the EU, Piraeus estimates ranged from 3-33 million euros. The case of the port of Piraeus is of great interest as due to a high population density (16,000 inhabitants per km^2) and the large amount of air emissions, impacts on planned health and the total cost of compensation per capita is estimated to be extremely high. For less active ports in terms of cargo and passenger transport, case studies have also been addressed. For instance, Copenhagen and Aberdeen recorded 2-4 million euros. Of all the ports in the EU, the lowest external costs were estimated at the port of Koge (Denmark) with less than 300,000 euros per year. So far, results and general details of the referred study have been exclusively published in a note of press[45]. For this reason details have not been accordingly included in Table 1.

Table1. - Top-down external cost estimation derived from air emissions in shipping

Paper	Study	Emission estimation	External cost estimation
Miola,et al. (2009)	**Area:** Port of Venice, Italy. **Timeframe**: 2006 **Shipping sector:** passenger and cargo	**Methodological approach:** BOTTOM-UP (based on port calls) and estimated vessel operative at port **Emissions estimated:** NOx, SO_2, CO_2, CO, HC, PM.	**Methodological approach:** TOP-DOWN based on CAFE and Martuzzi et al., (2006). **External cost estimated for:** PM_{10}, $PM_{2,5}$, SOx and PAH. **Total external costs (CAFE) =** 23million € **Total external costs (Martuzzi et al., 2006) =** 10 million €
Tzannatos (2010a)	**Area:** Port of Piraeus, Greece. **Timeframe:** 12 month period (2008-2009) **Shipping sector:** passenger and cruise ships	**Methodological approach:** BOTTOM-UP (based on port calls) and estimated vessel operative at port **Emissions estimated:** NOX, SO_2 and $PM_{2.5}$	**Methodological approach:** TOP-DOWN, based on BeTa **External cost estimated for:** NOx, SO_2, and $PM_{2.5}$ **Total external costs =** 51 million €

45 http://www.rcem.eu/posts/2014/april/22/assessment-of-external-social-cost-due-to-air-emissions-in-european-ports.aspx

Paper	Study	Emission estimation	External cost estimation
Tzannatos (2010b)	**Area:** Greece **Timeframe:** 1984-2008 **Shipping sector:** domestic and international shipping	**Methodological approach:** TOP-DOWN for domestic shipping, based on fuel consumption statistics BOTTOM-UP (based on port calls) and estimated vessel operative at port **Emissions estimated:** NO_X, SO_2, PM. and CO_2	**Methodological approach:** TOP-DOWN, based on BeTa **External cost estimated for:** NOx, SO_2, and $PM_{2.5.}$ **Total external costs =** 31 billion €
Berechman and Tseng (2012)	**Area:** Port of Kaoshiung, Taiwan. **Timeframe**: 2010 **Shipping sector:** bulk, container, general cargo, barges, tankers, fishing ships, work boats and tugboats.	**Methodological approach:** BOTTOM-UP based on port calls and estimated vessel operative at port **Emissions estimated:** NOx, CO, CO_2, PM_{10}, $PM_{2.5}$, SO_2, HC and VOC.	**Methodological approach:** TOP-DOWN mainly based on BeTa **External cost estimated for:** NOx, CO_2, PM_{10}, $PM_{2.5}$, SO_2, VOC and HC. **Total external costs =** 31 billion €
Castells et al (2014)	**Area:** Spain **Timeframe**: 2009 **Shipping sector:** Ro-Ro, passenger, and container ships.	**Methodological approach:** BOTTOM-UP (based on port calls) and estimated vessel operative at port TOP-DOWN for regional results **Emissions estimated:** NOx, SO_2, VOC and, $PM_{2,5}$	**Methodological approach:** TOP-DOWN, based on BeTa and CAFE **External cost estimated for:** $PM_{2.5}$, SO_2, NOx and VOC. **Total external costs SC1 =** 179 million € **Total external costs SC2 =** 207 million € **Total external costs SC3 =** 238 million € **Total external costs SC3 =** 285 million €
McArthur and Osland (2013)	**Area:** Port of Bergen, Norway. **Timeframe:** 2010 **Shipping sector:** entire fleet at berth	**Methodological approach:** BOTTOM-UP (based on port calls) and estimated vessel operative at port **Emissions estimated:**NOx, NMVOC, SO2, PM_{10}, $PM_{2.5}$ and CO_2	**Methodological approach:** TOP-DOWN based on BeTa, CAFE and several studies **External cost estimated for:** NOx, SO_2, PM, NMVOC, and $CO_{2.}$ **Total eternal costs (CAFE)** = 38.02 million NOK **Total eternal costs (Magnussen et al., 2010)**= 172.20 million NOK
Song (2014)	**Area:** Port of Yangshan, China. **Timeframe:** 2009 **Shipping sector:**entire fleet	**Methodological approach:** BOTTOM-UP based on port calls and estimated vessel operative at port **Emissions estimated:** CO_2, CH_4, N_2O, PM_{10}, $PM_{2.5}$, NO_X, SO_X, CO, and HC.	**Methodological approach:** TOP-DOWN based on several studies **External cost estimated for:** $PM_{2.5}$, SO_2, NOx and VOC. **Total external cost** **=** $287 million

Paper	Study	Emission estimation	External cost estimation
Maragkogiannani and Papaefthimiou (2015)	**Area:** Port of Piraeus, Santorini, Mykonos, Corfu and Katakolo **Timeframe:** 2013 **Shipping sector:** cruise	**Methodological approach:** BOTTOM-UP based on port calls and estimated vessel operative at port **Emissions estimated:** NOx, SO_2 and $PM_{2.5}$	**Methodological approach:** TOP-DOWN based on CAFE and NEEDS (**Korzhenevych et al, 2014**). **External cost estimated for:** NOx, SO_2, and $PM_{2.5}$ **Total External costs (CAFE):** 12.4 million € **Total External costs (EcoSense model):** 24.3 million €
Tichavska and Tovar (2015)	**Area:** Port of Las Palmas, Spain. **Timeframe:** 2011 **Shipping sector:** entire fleet	**Methodological approach:** FULL BOTTOM-UP based on vessel tracks and AIS-transmitted operative in port **Emissions estimated:** NOx, SOx, VOC, EC, Ash, SO_4, $PM_{2.5}$, CO and CO_2.	**Methodological approach:** TOP-DOWN, based on BeTa, CAFE and NEEDS. **External cost estimated for:** $PM_{2.5}$ NOx, SOx, VOC, CO and CO_2 **Total external costs SC1 =** 104 million € **Total external costs SC2 =** 112 million € **Total external costs SC3 =** 121 million € **Total external costs SC3 =** 136 million € **Total external costs of CO_2=** range between 5 and 69 million €.

2.4. Conclusion and future research

As an initial step to methodological improvement and with the aim of improving air quality in port cities, the present study renders a review on the methodological and empirical state of the art on external cost estimation from harbour emissions estimated from vessels. According to the observed information, the application of approaches varies according to the subject of study.

For emission estimation, a top-down approach that is based on fuel sales is used when refined traffic information is not available. On the other hand, a bottom-up approach based on traffic information (obtained from vessel tracks or port calls) is used when available, due to the accuracy of input parameters such as ship type, location, size and technical particulars. Although a full bottom-up approach it is rarely used its application should be encouraged due to it its capability of accounting measurements with greater detail.

In the case of external costs a bottom-up approach is also preferred as it enables a refined assessment based on detailed information, differentiation possibilities and an improved precision in derived results (marginal external costs). Nevertheless, costly and complex requirements are also recognized to obtain external costs from a bottom-up approach. Thus, the use of a top-down approach is suggested and widely accepted when bottom-up studies can not be performed or are not available.

The IPA is considered as the most comprehensive bottom-up methodology and the best practice for calculating site-specific external costs derived from air emissions. It has been widely adopted, among others, over major European studies (CAFE, BeTa, NEEDS and HEATCO). Due to the complexity and costly resources required to generate bottom-up studies on shipping and ports, it has been widely accepted to estimate these based on a top-down approach and per-unit cost factors obtained from major European reports (BeTa, CAFE, NEEDS). The ExternE resources have been also transferred into web-based tools, although none of them yet seems to have been designed for shipping. This could be due among others, to the lack of atmospheric dispersion modelling practices not widely undertaken in shipping.

Nowadays, literature regarding the valuation of external costs from vessel emissions at port is in its early steps, as is easily deducted by the fact that the first paper appeared in 2009. However, there are enough papers to extract some interesting conclusions, which could be useful to improve future studies. From those identified, all followed a top-down approach based on national or regional cost factors presented in bottom-up studies with a predominant reference to BeTa and CAFE.

The representative approach used to estimate emissions at port, is a bottom-up approach either based on port calls and an approximation to vessel operative at port or on vessel tracks. In regional studies, bottom-up and top-down approaches have been used (Castells et al., 2014; Tzannatos, 2010b). All address gases and particles related to negative effects in coastal communities but only four from the nine studies found, estimate CO_2 (Miola., 2009; Tzannatos, 2010b; Berechman and Tseng., 2012 and Tichavska and Tovar, 2015).

When estimating external costs, every study followed a top-down approach based on cost factors from BeTa (Berechman and Tseng, 2012); CAFE (Miola, 2009); BeTa and CAFE (McArthur and Osland, 2013; Castells et al., 2014); BETA and HEATCO (Tzannatos, 2010ab) NEEDS and CAFE (Maragkogiannani and Papaefthimiou, 2015) or, BeTa CAFE and NEEDS (Tichavska and Tovar, 2015). In addition to this, Song (2014) obtained cost totals from weighted average cost factors through a series of expert judgement/survey.

Summarizing, we conclude that results for emission inventories and estimated costs are significantly different and complicated to compare due to methodological variations and assumptions. For this reason, it is paramount to review these differences in order to highlight the best approach to follow or identify the drawback when a second best alternative needs to be applied. From the review, we conclude that precision differences on traffic information are noteworthy. Available literature does not always specify port calls as their source of traffic information nor describe the level of detail accounted from ship movements but provide an overall description of activity-based (bottom-up) methodology to estimate emissions. Moreover, our review has shown that the representative approach used to estimate emissions at port (as a previous step to estimate external costs), is a bottom-up approach, but we only found one study that is based on a frequent update of vessel tracks, avoiding in this way the need of using average values (i.e. distance and speed). Moreover, the latter study is also the only one which follows a bottom-up approach for the geographical characterization of emissions (full bottom-up approach), Due to the refined accuracy of obtained results, we encourage the use of this latter approach. Finally and regarding the estimation of external costs, the literature review has also shown that every study followed a top-down approach. This is probably due to costly and complex requirements to obtain external costs from a bottom-up approach. Moreover, the lack of dispersion modelling practices not widely undertaken in shipping complicates this methodological scenario. Thus, enabling the wide acceptance of a top-down approach in estimations.

Based on the above, methodological improvements and the possible achievement of refined estimations (of vessel emissions and derived external costs) in ports and shipping are strongly suggested as these may benefit the quality of input information needed to feed policy measures which contribute to internalize the external cost estimated. Finally, an integrated assessment (IPA) specific to vessel emissions has not been yet addressed in the available studies and this could be addressed in future research although for now, the obtained results in BeTa provide a meaningful insight to the magnitude of costs associated to vessel emission externalities, specifically because it is the only available report so far, which presents cost factors dedicated to seaports.

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Chapter 3

Environmental costs and eco-efficiency from vessel emissions in Las Palmas Port

3.1. Introduction

Exhaust emissions from shipping are a major concern towards environmental and human health protection. Impact of hazardous pollutants released into the air negatively affects communities located near the coastlines and the built environment of port-city areas. Mitigation strategies contribute to the overall picture of the issue. Yet, the contribution and the economic impact of air emissions released by vessels operating in port remains in many cases as unknown or uncertain.

Emissions released at port and by operating vessels in harbour contribute with a small percentage when compared to the total amount released by shipping. Nevertheless, they inevitably constitute a source of pollution concentration in the air. In addition to GHG, the urban character of ports and their populated surroundings are a main focus of the negative effects of exhaust pollutants (NOx. SOx, VOC, CO and PM) associated to local impacts on human health and built environment.

The need to abate air pollution is widely acknowledged as a policy issue in ports and harbours. Emission control requires the ability to quantify emissions and to develop accurate emission inventories for ports. Indeed, emission information is necessary to properly assess the impacts of port improvement projects or growth in shipping activity, as well as to plan mitigation strategies or voluntary programs and to aid policy makers towards the development of effective regulatory requirements at national and international levels.

In order to be reliable, it is suggested that port emission inventories, should be based on real vessel traffic information, ship engine ratings and operative times corresponding to each vessel tracked. In despite of this, assumptions in port traffic are regularly made and bias emission inventories may be produced with the use of a top-down approach; or a bottom-up approach[46] based on port calls (Tzannatos, 2010a). According to recent quality control analysis performed on the Third IMO GHG Study (2014), quality advantages for the bottom-up activity-based inventories relate to the use of calculations for individual vessels, performed either with port calls or vessel tracks. Nevertheless, by maximising vessel-specific activity characterisation using AIS data sources (as it happens with vessel tracks), estimations account the variability among vessels within a type and size category. This eliminates the dominant uncertainties reported by previous vessel emission inventories at port.

The external cost of air emissions released at port, by ships, starts to be addressed in literature (i.e. Miola et al., 2009; Tzannatos et al., 2010b; Castells et al., 2014; Song, 2014, Maragkogianni and Papaefthimiou, 2015). Yet, scientific evidence on externalities and costs directly related to vessels is still at an initial stage, and improvement requires of sufficient and refined information. Indeed information quality is key and of particular interest to cost-benefit analysis when compared with the economic benefits, the costs estimated attempt to support burden-reduction measures (Tzannatos, 2010a). The analysis of external cost is achieved in two stages that first involve the quantification of air emissions. In this respect, a substantial amount of research investigating ship emissions has been addressed using methodologies that are either based on marine fuel sale statistics (Jiang and Kronbak, 2012) or on vessel traffic information. It should be noted that data input to estimate the activity of vessels entail differences based on its source[47], type (ports of call or vessel tracks) and the precision level provided by the information. Indeed, while the ports of call indicate the origin and destination of the vessel route

[46] A bottom-up approach is referred to calculations based on fleet activity. This can be done by using port calls and estimated vessel operative or, through vessel tracks and real time operative of vessels. On the other hand, a top-down approach is referred to estimations based on fuel sales statistics.

[47] Fleet activity information may be acquired either from public authorities (port call records) or from automatic transmission of data fields from individual. The latter possibility was originated by the vessels mandatory communication protocols regulated by the IMO.

excluding operative details; the AIS[48]-transmitted vessel tracks regularly updates the unique identification of the vessel, its position, course and speed with a rate that may go from two seconds to six minutes according to the vessel status and to the communication system´s protocol (ITU-R, 2010).

Integrating high-definition traffic information avoids operative assumptions of vessels and estimations are enabled with a greater precision based on the most reliable information presently available. In addition to this, geographical characterization of pollutants may be accounted due to the speed and route of ships being known. Recent research on ship emissions based on high-definition traffic information (vessel tracks with an update rate of one minute) has been pursued in Las Palmas Port (Tichavska and Tovar, 2015a).

Located in the Atlantic Ocean, Las Palmas Port is the fourth largest port within the Spanish system and a major logistic platform between Europe, Africa and America. Its location between main commercial trade routes makes it a cargo hub[49] with over 19 million tons from loading, unloading and transhipments; and also a leading worldwide bunker trader. Ferry routes are offered in a daily basis with hub operations set in the main Canarian ports[50]. In addition to the regular ferry services, cruise operations in the Canary Islands increase steadily (EDEI, 2011). According to Las Palmas Port Authority, passenger share of Las Palmas Port increased in over 20% with a total of 1,605,531 passengers in 2013. A sustained market growth increases the need to identify and measure environmental impacts generated by shipping traffic. Particularly with the aim of reducing related externalities as generally pursued in many other harbours in Europe.

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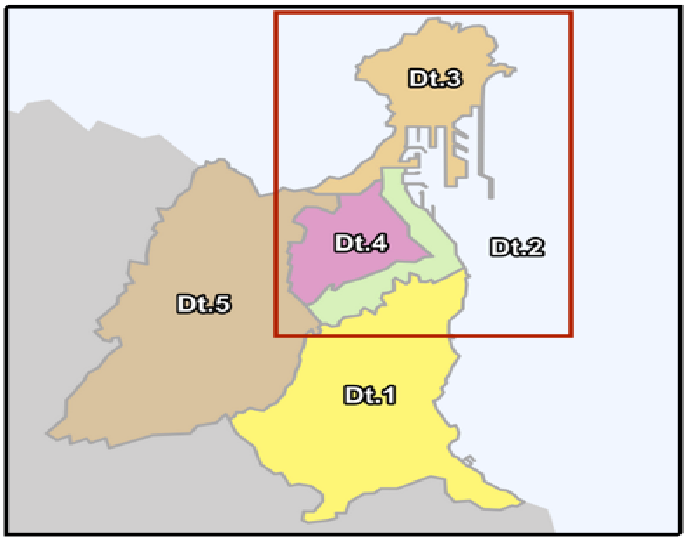
[48] Starting 2002, the protocol transmitted by the AIS includes vessel tracks (Lon, Lat, Status, Speed, Course, heading and Timestamp) and particulars (unique identification number, vessel name, type, dimensions, flag and others) in its messages.

[49] Regarding transhipment, the international hub in the Canary Islands is located in Las Palmas port (Tovar et al., 2015). Driven mainly by container operations, the transshipment traffic in Las Palmas Port has reached a rate close to 69%, whereas Tenerife port focus its container traffic merely on the domestic market.

[50] The seven Canary Islands are situated 115 kilometres from the northwest African coast. The Canary Islands main ports are Las Palmas Port (located in Gran Canaria) and S.C. Tenerife Port (located in Tenerife). They are managed by different Port Authorities. A detailed analysis of the port management model in Spain is beyond the scope of this paper but it can be found in Rodriguez-Álvarez and Tovar (2012) and Tovar and Wall (2014).

Las Palmas de Gran Canaria is the most populated municipality and capital of Gran Canaria Island, and the ninth largest city in Spain with a population of 383,343 inhabitants in the period of study (2011). It is divided into five administrative districts and sub-districts (see Figure 1). The most populated are namely: (D1) Vegueta, Cono Sur y Tafira, (D2) Center, (D3) La Isleta-Puerto-Canteras and (D4) Ciudad Alta; all located near operative quays of Las Palmas Port, the main city beaches, and commercial areas. The great economic engine of the island is tourism. Nevertheless, commercial activity is also noteworthy, particularly in the vicinities of the port area, located in the capital. There is a small industrial sector, primarily focused on food production, light manufacturing and cement. In addition to this, agriculture remains as an economic activity of relevance in rural counties, but this is experienced in a minor extent when compared with past years.

Figure 1– Neighbour districts of Las Palmas Port



The present study extends the vessel emission research in Tichavska and Tovar, (2015a); to the estimation of external costs and the eco-efficiency performance of Las Palmas Port. This has been firstly motivated by the identified contribution of vessel emissions in harbour and, by the need to address its economic impact and derived eco-efficiency performance of vessel emissions. Results attempt to indicate performance of Las Palmas port towards social, economic and environmental concerns. Aim of this approach is to support an environmental operation model, which extends value-based management exploring relations of economic and ecological capital efficiency. Also, eco-efficiency results aim to facilitate future cost-benefit analysis used for evaluating abatement policy instruments in Las Palmas, where a large population of residents and visiting tourists are continuously hosted. Finally this study, also contributes to recent literature of vessel emissions, externality costs and eco-efficiency by describing through the case study, the utility of these measurements as support tools to Port Authorities and local governments. The structure of this document is described below.

After presenting an introduction to the subject of research and the case study in Section 3.1; Section 3.2 presents a brief review on the bottom-up and top-down approaches applied to estimate external costs from vessels at ports and in shipping. Section 3.3, follows with a breakdown of emission results and external cost valuation for tanker, bulk, general cargo, container, service, fishing, vehicle carriers, cruise, ferries and other vessels operative at port. After this, external costs are combined with port operations profiles to estimate the eco-efficiency performance of Las Palmas Port. To finalize, Section 3.4 presents conclusions and future research.

3.2. External Cost Estimation: Methodological Aspects and Literature Review

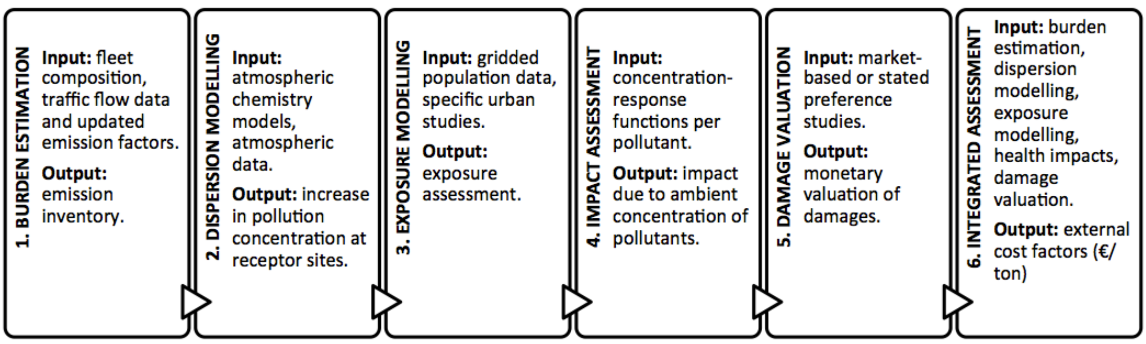
Negative impacts derived from air pollution can be quantified and monetised as external costs. Nevertheless, its estimation is an inevitable source of uncertainties, mostly conditioned by methodological limitations and information gaps on available knowledge due to the complex relation between factors involved in air quality valuation and derived costs. These factors comprise the overall levels of pollution, the geographical location and height of emission sources, local meteorological conditions, the chemical reaction and dispersion of atmospheric hazardous substances; and the physical harm that this might cause to human health, crops or urban infrastructure.

A bottom-up and a top-down approach may be used for the estimation of external costs. Both provide advantages and limitations (Miola et al., 2009). On one hand, a bottom-up approach follows a causal chain of relations that start with the emission of pollutants to finalize with a detailed estimation of the marginal external costs caused by each unit of pollutant. On the other, a top-down approach (i.e. Miola et al., 2010; Tzannatos 2010a; Berechman and Tseng, 2012) estimates the external costs by using cost factors from bottom-up studies (per country or region). This results on average costs derived per pollutant but it will not allow further differentiation (i.e. Tzannatos et al., 2010b; Castells et al., 2014).

The first comprehensive attempt to develop a bottom-up approach related to air emissions was integrated in the External Costs of Energy (ExternE) project series (1990-2005) under the ExternE DG Research of the European Commission (European Commission, 1999). Over the ExternE, a bottom-up methodology referred as Impact Pathway Approach (IPA) was conceived, following a pathway process, which requires: emission estimation, dispersion modelling, exposure modelling, impact, and damage valuation (see Figure 2).

The IPA is considered as the most elaborated and best practice methodology for calculating site-specific external costs derived from air emissions. It has been widely adopted, among others, over major European studies specifically addressed for external cost estimation in transport such as the Benefits Table database (BeTa) (Holland and Watkiss, 2002; Netcen, 2004); the Harmonised European Approaches for Transport Costing and Project Assessment (HEATCO) (Bickel et al., 2006); the Clean Air for Europe (CAFE) (Holland et al., 2005; Amann et al., 2005) and the New Energy Externalities Development for Sustainability (NEEDS) (Preiss et al., 2007).

Figure 2 – Impact Pathway Approach to air pollution



Source: adapted from the ExternE (Bickel et al., 2005).

External costs derived from shipping are exclusively addressed in reports from the BeTa, the CAFE and the NEEDS projects. In BeTa, cost factors (ton/euro) per sea area and per EU country (specific to seaports) are provided. In CAFE, shipping results are also included but as a sensitivity case and without presenting ton/euro figures. Finally, in NEEDS, cost factors per sea areas and country (although not specific to seaports) are presented. Although it is widely known that the BeTa provides a straightforward process for estimating external costs (by putting together urban and rural externalities); it has been also stated that its rural cost figures underestimate real costs. Specifically once the rural cost factors under the CAFE programme had been published (see Castells et al. 2014). For this reason, harbour studies that maintain the estimation approach of BeTa (add urban and rural costs) but taking updated rural costs from CAFE can be also seen in literature (Castells et al. 2014 and the present study). Moreover, other studies (Tzannatos, 2010b) additionally as sensitivity range, results from cost factors not specific to seaports or shipping, such as the ones the HEATCO[51] report (Bickel, 2006).

An integrated assessment (IPA) on shipping emissions in general and, seaports in particular, has not been directly addressed in the referred studies (BeTa, CAFE, HEATCO and NEEDS). Nevertheless, it is widely considered that the obtained results in BeTa provide an insight to the magnitude of associated externalities from vessel emissions in port (Miola et al, 2010; Tzannatos, 2010ab). In this respect, it should be noted that externality costs from hazardous effects in a local context (NOx, SOx, PM, VOC and CO) are addressed differently than the climate change costs (CO_2). The latter, are estimated as avoidance cost factors according to reduction targets, the application year, the discount rate and equity weights. Thus, a combination of the IPA and avoidance costs is suggested when addressing greenhouse effects (Denisis, 2009).

At present, and due to the complexity and high cost of generating bottom-up external cost studies on shipping and ports, estimations based on a top-down

[51] The HEATCO provides harmonised guidelines for externality cost estimation (air and road transport). While HEATCO refers to road transport with the release of emissions in the street canyon, BeTa accounts for the release of air pollutants from the high stacks of ships. Thus, it is considered by some authors (Tzannatos, 2010ab) that cost factors from BeTa are more appropriate for the estimation of the examined externalities, since they are case specific to the activity of ships within the port. Others suggest that more recent and updated cost factors better represent reality and thus, should be addressed (Castells et al. 2014; Maragkogiannani and Papaefthimiou, 2015).

approach (and per-unit cost factors) derived from major European reports (BeTa, CAFE, NEEDS) and recent literature have been widely accepted. Indeed, most studies exclusively present emissions inventories with assumptions on vessel operative at port and do not further evaluate the associated external costs. Limited research was found on the valuation of external costs from shipping emissions. From those identified, all followed a top-down approach based on national or regional cost factors presented in bottom-up studies as BeTa, CAFE, NEEDS and HEATCO. Table 1 presents a summary of available studies on external costs estimated at port.

Top-down and bottom-up approaches are widely recognized in a variety of research subjects over literature (Sabatier, 1986). As Table 1 reflects, these include air emissions and its quantification (required step to obtain external costs). Each approach captures transportation technology in an aggregated (top-down) or disaggregated form (bottom-up) reflecting differences in results due to complex interplays between purpose, structure and data input. In both, emission and external cost estimation, top-down approaches are performed by using aggregated economic variables whereas bottom-up approaches consider refined and disaggregated information for valuation, mostly from an engineering perspective (technical performance).

Suggestions and acceptance of the application of approaches vary according to the subject of study. For emission estimation, a top-down approach (based on fuel sales) is used when refined traffic information is not available. On the other hand, a bottom-up approach based on traffic information (obtained from vessel tracks or port calls) is suggested by recent literature due to the accuracy of input parameters such as ship type, location, size and technical particulars. For the estimation of air emissions, cost and complexity variables are not recognized in literature as a limitation when performing a bottom-up approach; particularly when traffic information is built based on vessel tracks (AIS). Finally, a full bottom-up category is described as the use of a bottom-up approach for both, the quantification of emissions and the geographical characterization[52] of results (Miola et al., 2010).

In the case of external cost estimation, a bottom-up approach is also preferred as it enables a refined assessment based on detailed information, differentiation possibilities and an improved precision in derived results (marginal external costs). Nevertheless, costly and complex requirements are also recognized to obtain external costs from a bottom-up approach. Thus, the use of a top-down approach is suggested and widely accepted when bottom-up studies can not be performed or are not available[53]. Indeed, as seen in Table 1, literature on derived costs from air emissions in shipping is exclusively based on the use of cost factors and aggregated economic variables (top-down approach).

Available research on external costs from air emissions in harbours is representative in regional (US, Greece and Spain) and harbour case studies (Venice, Piraeus, Bergen, Kaoshiung, Yangshan and Las Palmas). Most, with the exception of Tzannatos (2010b), based on a twelve-month timeframe of analysis.

For emission estimation, the representative approach in harbour studies was a bottom-up approach either based on port calls and approximation to vessel operative at port (all) or on vessel tracks (only the present study). In regional studies, bottom-up and top-down approaches have been used (Castells et al., 2014; Tzannatos, 2010b). All address gases and particles associated to negative effects in coastal communities but only some estimate CO_2 (Miola, 2009; Tzannatos, 2010b; Berechman and Tseng, 2012 and the present study).

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[52] Regarding the geographical characterization of emissions and the level of detail achieved, this is also dependent on the approach followed (bottom-up and top-down). Hence, with a bottom-up approach, individual information of vessels and its position are taken into consideration while with a top-down approach valuation is based without, or with partial information on the position of vessels (i.e. the geographical activity of shipping is estimated based on a single shipping route or a particular geographic activity cell, no matter which vessel carries out the activity).

[53] This may be due, among others, to the lack of dispersion modelling practices not widely undertaken in shipping.

Table 1 – Summary of previous papers on measuring external cost derived from vessel emissions at port

Authors	Area/Timeframe	Shipping sector	Methodological approach	
			Emission estimation	External cost estimation
Miola et al. (2009)	Port of Venice, Italy. 2006	Passenger and cargo	BOTTOM-UP (based on port calls) and estimated vessel operative at port	TOP-DOWN based on CAFE and Martuzzi et al., (2006).
Tzannatos (2010a)	Port of Piraeus, Greece. 12 month period (2008-2009)	Passenger and cruise ships	BOTTOM-UP (based on port calls) and estimated vessel operative at port	TOP-DOWN, based on BeTa
Tzannatos (2010b)	Greece 1984-2008	Domestic and international shipping	TOP-DOWN for domestic shipping, based on fuel consumption statistics BOTTOM-UP (based on port calls) and estimated vessel operative at port	TOP-DOWN, based on BeTa
Berechman and Tseng (2012)	Port of Kaoshiung, Taiwan. 2010	Bulk, container, general cargo, barges, tankers, fishing ships, work boats and tugboats.	BOTTOM-UP based on port calls and estimated vessel operative at port	TOP-DOWN mainly based on BeTa
Castells et al. (2014)	Spain 2009	Ro-Ro, passenger, and container ships.	BOTTOM-UP (based on port calls) and estimated vessel operative at port TOP-DOWN for regional results	TOP-DOWN, based on BeTa and CAFE
McArthur and Osland (2013)	Port of Bergen, Norway. 2010	Entire fleet at berth	BOTTOM-UP (based on port calls) and estimated vessel operative at port	TOP-DOWN based on BeTa, CAFE and several studies
Song (2014)	Port of Yangshan, China. 2009	Entire fleet	BOTTOM-UP based on port calls and estimated vessel operative at port	TOP-DOWN based on several studies
Maragkogiannani and Papaefthimiou (2015)	Port of Piraeus, Santorini, Mykonos, Corfu and Katakolo, Greece. 2013	Cruise vessels	BOTTOM-UP based on port calls and estimated vessel operative at port	TOP-DOWN based on CAFE and NEEDS
Present study	Port of Las Palmas, Spain. 2011	Entire fleet	FULL BOTTOM-UP based on vessel tracks and AIS-transmitted operative in port	TOP-DOWN, based on BeTa, CAFE and NEEDS.

Note: For emission estimation, a bottom-up approach refers to emission quantification based on fleet activity (vessel tracks or port calls). On the other hand, a top-down approach refers to estimations based on fuel sales statistics. Additionally, a full bottom-up approach is referred as the use of the suggested bottom-up both, for emissions quantification and the geographical characterization of results. For external cost estimation, a top-down approach refers to the use of cost factors obtained from IPA results published in technical reports.

When estimating external costs, every study followed a top-down approach based on cost factors from BeTa (Berechman and Tseng, 2012); CAFE (Miola, 2009); BeTa and CAFE (McArthur and Osland, 2013; Castells et al., 2014); BeTa and HEATCO (Tzannatos, 2010ab) NEEDS and CAFE (Maragkogiannani and Papaefthimiou, 2015) or, BeTa CAFE and NEEDS (the present study). In addition to this Song (2014) weighted average cost factors, which were determined from international studies[54] and through a series of expert judgement/survey (Delphi process).

Results of emission inventories and estimated costs are significantly different and complicated to compare due, to methodological variations, assumptions, cost categories, emission factors and unit values. Nevertheless, precision differences on traffic information are noteworthy, and commonly not described with detail over literature. Indeed, available literature on external costs derived from vessel emissions in harbours, do not always specify port calls as their source of traffic information nor describe the level of detail accounted from ship movements but provide an overall description of activity-based (bottom-up) methodology to estimate emissions.

The present case study is based on refined traffic information and vessel operative transmitted in real-time. Moreover, and in terms of externality costs, results are estimated through the use of cost factors from BeTa, CAFE, and NEEDS. This provides an overall comparative picture, coverage of an adequate time-scale of research (from early to recent) and the use of widely accepted reports that either present cost factors partly dedicated to seaports (BeTa, see page 14 of NETCEN, 2004), present updated rural cost factors (CAFE, see Castells et al. 2014) or reflect the most recently updated cost factors which are specific to maritime areas but not to seaports (NEEDS, Korzhenevych et al, 2014).

Indeed, although total costs have been estimated by using euro per ton factors from BeTa, CAFE and NEEDS; only BeTa and CAFE have been further used to reflect the temporal variation and eco-efficiency from results. This relates to the fact that BeTa is, so far, the only report that makes specific reference to damage from shipping-related air pollution in seaports and; that the use of its urban cost factors and further addition to updated rural cost factors from CAFE (as a better approximation to

[54] From several international studies: Funk and Rabi, (1999); USEPA, (2002); Gallagher, (2005); Sirikijpanichkul et al., (2006); IPCC, (2006); USEPA, (2010); World Bank, (2010); Marten and Newbold, (2012); Muller and Mendelsohn, (2007); Yuan and Cheng, (2011); Berechman and Tseng, (2012); VTPI, (2012); Yang et al., (2013).

seaport reality) is also considered within literature (see Castells et al. 2014).

Moreover, the more recent and updated cost factors from NEEDS (Korzhenevych et al, 2014) have also been cited as appropriate for correctly calculating the external costs of maritime transport (within sea regions) and harbour case studies (Maragkogiannani and Papaefthimiou, 2015). For this reason, and in order to guarantee completeness of this work cost factors for Spain (Table 15 from Korzhenevych et al, 2014) have been used to reflect and integrate results from NEEDS.

3.3. Results and Discussion

3.3.1 External cost estimation

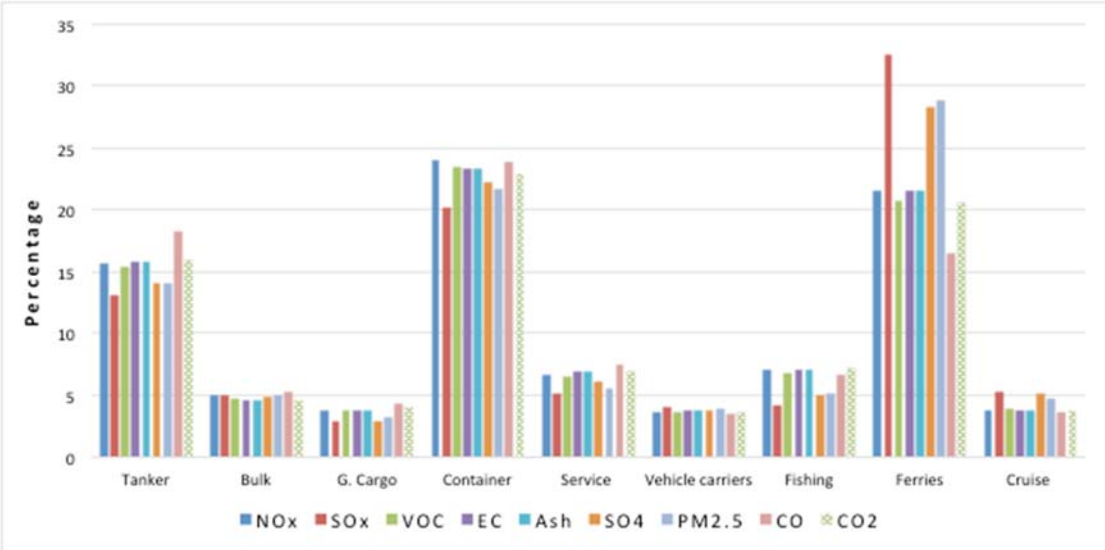
The emission inventory presented in this research is based on the full bottom-up Ship Traffic Emission Assessment Model (STEAM) and messages transmitted by the AIS (with at least a 2 min. update) over a twelve-month period (2011). A ship database of over 50,000 vessel particulars (over a third part of the global fleet) and AIS position records define input values for the STEAM. Database holds information on among others, the latest emission factors, installed abatement techniques, shaft generators, specific fuel oil consumption, fuel type and sulphur content used for main and auxiliary engines. Information was obtained, mainly from IHS Fairplay ship register, engine manufacturers, local authorities and ship owners. For this case study, AIS vessel tracks were provided by MarineTraffic resulting in a data flow of thousands of input records per ship, per year. For extensive details on the model, performance and uncertainty considerations, the reader is referred to Jalkanen et al. (2009), Jalkanen et al. (2012) and Jalkanen et al. (2014). For extensive details on the application of the STEAM to vessel traffic in Las Palmas Port, the reader is referred to Tichavska and Tovar (2015a).

Results reflect a total of 215,867 tons of exhaust emissions derived from vessel traffic in Las Palmas Port (2011). From these, 4,246 tons are associated to NOx, 1,422 tons to SOx, 75 tons to VOC, 29 tons to EC, 21 tons to Ash, 168 tons to SO_4, 338 tons to $PM_{2.5}$, 498 tons to CO and 209,070 tons to CO_2.. Although in line with previous studies (Stipa et al., 2007; De Meyer et al., 2008; Howitt et al., 2010; Eijgelaar et al., 2010; Berechman and Tseng, 2012; Ng et al., 2012; Kalli et al., 2013; Jalkanen et al., 2014; Johansson et al., 2013) that also suggest ferry, tanker and container vessels as the largest contributors of air emissions affecting local (NOx, SOx, PM, CO) and global (CO_2) environments; differences may arise. Castells et al. (2014) for instance, presents emissions derived from vessel traffic for 14 Spanish harbours in 2009. Results include Las Palmas, for which, 59 tons of PM, 131 tons of SO_2, 1,501 tons of NOx and 87.5 tons of VOC have been reported. A largest share of results per gas can be identified when comparing 2011 figures (present study) with emission results in Castells et al. (2014). Based on the number of vessels and population considered in both, we suspect differences are mainly due, to estimations based on Las Palmas Port Authority, which runs the main ports in this province[55] although referred as Las Palmas (Castells et al, 2014) while estimations in the present study exclusively relate to Las Palmas Port.

On the other hand, this may also be a consequence of vessel traffic increase in the harbours of study and methodological differences as assuming key inputs of speed, distance, operative and engine load (i.e. Castells et al., 2014) instead of using real operative as the present study. To facilitate a better understanding of emission results, Figure 3 presents the relative percentage of emissions by shipping sector based on the total numbers at port. It is noticeable that apart from tanker, container and ferry vessels, the rest of the fleet represents an overall that does not exceed a 7% from the total share at port.

[55] The Port Authority of Las Palmas manages Las Palmas Port and the four remaining ports of general interest of the State in the province of Las Palmas.

Figure 3– Share of emissions by shipping sector in Las Palmas Port



For external cost estimation and after conducting a literature review, urban and rural cost factors for NOx, VOC and $PM_{2.5}$ have been selected from BeTa, CAFE and NEEDS reports (NETCEN, 2004; Holland et al., 2005; Korzhenevych et al, 2014). On the other hand, cost factors that are not included in BeTa, CAFE and NEEDS (CO and CO_2) are obtained from Denisis (2009) and Delft and Infras (2011), cost factors also previously applied to vessel traffic at port and in shipping (see Tzannatos, 2010a,b; Berechman and Tseng, 2010 and Heinbach, 2012).

Due to the global effect and damages caused by global warming, there is no difference on how and where in Europe the emissions of greenhouse gases take place. For this reason the same cost factors are commonly applied in all countries although these are dependent on time since emissions released in future years will have greater impacts than emissions today and have to be addressed separately. Based on transport studies that include two different CO_2 prices concerning climate change costs, we also present a lower value and an upper value. These suppose a high and a low scenario chosen according to the avoidance target scenario addressed.[56]

[56] According to CE/INFRAS/ISI (2008) the variance when addressing avoidance cost estimates is large, particularly for the long term. With the very high uncertainties in climate costs, it would be misleading to give a single cost estimate. It is generally assumed that climate cost increase over time. Thus, and following Delft and Infras (2011) our lower cost estimate is based on the avoidance factor

Finally, external costs for EC and Ash, have not been included due to the lack of cost figures in bottom-up studies. Thus, urban and rural cost factors used in this research (NOx, SO_x VOC, $PM_{2.5}$, CO and CO_2) are summarized in Table 2. It should be noted that cost factors in Table 2 reflect non-updated year prices. For this reason, and in order to bring these in line with the year under study the CPI for Spain was utilized.

Table 2 – External cost factors used in this case study

Bottom-up studies	Year prices	External cost factors (€/Ton)						
		Local					Global	
		NOx	SO_x	VOC	$PM_{2.5}$	CO	CO_2 Low	CO_2 High
BeTa urban (Spain)	2000	4,700	23,040	880	126,720	n/a	n/a	n/a
BeTa rural (Spain)	2000	4,700	3,700	880	7,900	n/a	n/a	n/a
CAFE rural (Sensitivity case 1, Spain)	2010	2,600	4,300	380	19,000	n/a	n/a	n/a
CAFE rural (Sensitivity case 2, Spain)	2010	3,800	6,600	510	29,000	n/a	n/a	n/a
CAFE rural (Sensitivity case 3, Spain)	2010	5,200	8,400	920	37,000	n/a	n/a	n/a
CAFE rural (Sensitivity case 4, Spain)	2010	7,200	12,000	1,100	54,000	n/a	n/a	n/a
NEEDS (Korzhenevych et al, 2014)	2010	4,964	7,052	1,135	195,252	n/a	n/a	n/a
Denisis (2009)	2003	n/a	n/a	n/a	n/a	3	n/a	n/a
Delft and Infras (2011)	2008	n/a	n/a	n/a	n/a	n/a	25	146

The external costs associated to the damages that vessel emissions contribute upon human health and the built environment surrounding the port of Las Palmas were found to be significant. Table 3 presents the estimated total costs for the port-city. These include external costs exclusively estimated from BeTa, from NEEDS; and also from the addition of urban cost factors from BeTa and rural cost factors from CAFE within four sensitivity scenarios[57].

calculated for meeting the EU GHG reduction target for 2020. These are calculated to be at least 25 € per ton of CO_2. On the other hand, the higher climate cost factor (146 € per ton of CO_2) is based on the cost for meeting the long term target of keeping CO_2 below 450 ppm in the atmosphere and maintaining global temperature rise below 2 centigrades.

[57]Four combinations of sensitivity have been considered in the estimation of total damages from each of the 5 pollutants considered in CAFE. As stated in Holland et al., 2005, "The range takes account of variation in the method used to value mortality, reflecting the use of the median and mean estimates of the value of a life year (VOLY) from NewExt (2004) (€50,000 and €120,000 respectively), and the use of the median and mean estimates of the value of statistical life (VSL), also from NewExt (€980,000 and €2,000,000 respectively). The overall range shown also includes sensitivity to the range of effects included, and to the use of a zero cut-point for assessment of ozone impacts (the core analysis is based on use of a cut-point of 35 ppb for ozone impacts. No cut-point is

Table 3 – Estimated external costs (€)

Bottom-up studies	External costs (2011 prices)						
	Local					Global	
	NOx	SO_x	VOC	$PM_{2.5}$	CO	CO_2 Low	CO_2 High
BeTa urban + BeTa rural (Spain)	54,301,272	57,828,205	179,699	61,979,900	n/a	n/a	n/a
BeTa urban + CAFE rural (Sensitivity case 1, Spain)	38,543,136	56,879,155	119,279	64,977,958	n/a	n/a	n/a
BeTa urban + CAFE rural (Sensitivity case 2, Spain)	43,801,213	60,651,941	129,347	68,470,204	n/a	n/a	n/a
BeTa urban + CAFE rural (Sensitivity case 3, Spain)	49,935,637	63,604,556	161,099	70,863,440	n/a	n/a	n/a
BeTa urban + CAFE rural (Sensitivity case 4, Spain)	58,699,099	69,509,787	175,040	77,200,819	n/a	n/a	n/a
NEEDS	21,750,913	11,567,621	87,901	68,186,804	n/a	n/a	n/a
Denisis., (2009)	n/a	n/a	n/a	n/a	1,846	n/a	n/a
Delft and Infras, (2011)	n/a	n/a	n/a	n/a	n/a	5,478,784	31,500,803

Note: when following BeTa (NETCEN, 2004), external costs from vessel emissions at port have been estimated by adding urban results (for the city of the same size as the port city) and the rural cost factors for the country in question.

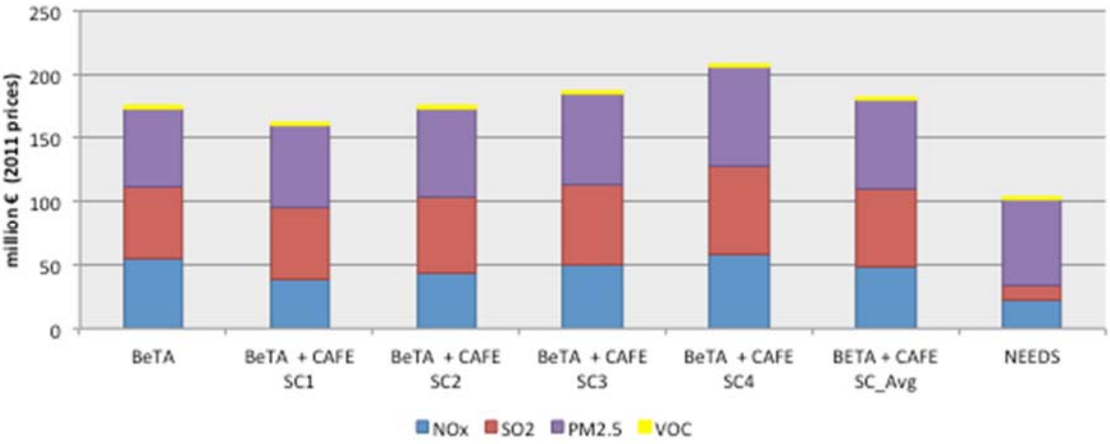
To be specific, the overall economic costs from NO_x, SO_x, VOC and $PM_{2.5}$ when using urban and rural cost values provided by BeTa (for Spain) derive in a total of 174,288,076 €. On the other hand, and when using urban cost factors from BeTa and rural cost factors from CAFE the four sensitivity scenarios results reflect 160,519,527 € for SC1, 173,052,705 € for SC2, 184,564,732 € for SC3 and, 205,584,744 € for SC4. These reflect a variation of a -8% (SC1), -1% (SC2), a +6% (SC3) and a +18% (SC4) with respect to results when using urban and rural factors exclusively from BeTa.The variation in results (within CAFE SC scenarios) derives mostly from mortality valuation (mean or median values). Moreover, from the range of health effects and the cut point for ozone impact assessment also changes in each of the sensitivity scenarios[58]. In the case of NEEDS, figures are considerably lower. Specifically and from NO_x, results reflect 21,750,913 €; 11,567,621 € from SO_2; 87,901 € from VOC and 68,186,804 € from $PM_{2.5}$. This is probably due mainly to methodological differences when estimating results from the BeTa and NEEDS

used for assessment of PM2.5 effects)". For additional information on these scenarios readers are referred to Holland et al., (2005).

[58] See previous footnote.

reports[59]To facilitate the comparison of results, Figure 4 reflects the estimated total costs in million euros per gas.

Figure 4 – Estimated local external costs (€)



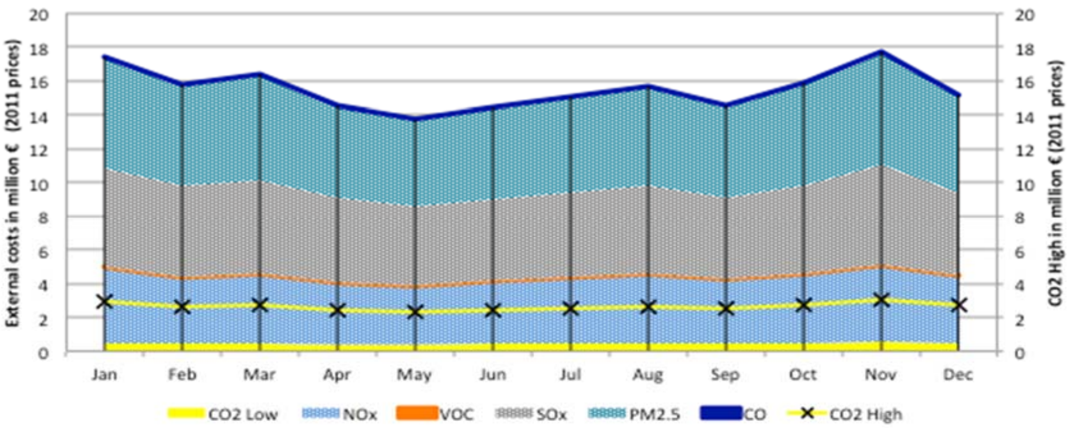
In addition to this, derived costs for CO sum a total of 1,846 € while 5,478,784 € and 31,500,803 € respectively reflect the low and high estimates for CO_2. On average, the approximate cost per person living in the port-city has been estimated at 554 €. The external costs include acute and chronic effects of $PM_{2.5}$, SO_2 and NOx on mortality and morbidity; the effects caused by acidity of SO_2 on materials used in buildings and structures (excluding those of cultural value) and the effects of NO_x on arable crop yield.

In terms of temporality, Figure 5 shows that the external costs throughout the twelve months of 2011 are relatively stable but with a major cost derived from NO_x, SO_X, VOC and $PM_{2.5}$. Although results have been obtained throughout four sensitivity scenarios based in CAFE, to summarize and to avoid selecting one of them, results reflect the average figures obtained from the four sensitivity scenarios described in Table 3. It should also be noted that both, the highest and the lowest value of external cost for CO_2 have been included in the plot. Nevertheless and in order to facilitate its understanding "CO_2 High" is represented in the secondary axis making possible both, to include "CO_2 Low" in the cumulative sum of the plot and to visually

[59] It should be noted that the present study follows the methodology described in BeTa (by adding urban and rural cost factors) in 5 out of the 6 estimated results of NO_x, SO_2, VOC and $PM_{2.5}$, (this means, in all cases except when using NEEDS).

compare differences in contribution shares where the highest exceeds the lowest with an approximate of over one million euros every month. Also, certain peaks are noticeable due to the increase of vessel calls mostly on January, March and November.

Figure 5. - Monthly external costs from vessel emissions in Las Palmas Port



3.3.2. Eco-efficiency indicators

Eco-efficiency[60] indicators are considered as a valuable tool to promote sustainable development. Its use is based on the concept of creating more goods and services by reducing the related environmental impact. It can be measured as the ratio between the impacts of the products or service (externality costs) and the added value of what has been produced (such as port profiles). This way, results add more value to products/services generating less pollution through environmental, economically efficient procedures. Generally speaking, eco-efficiency indicators are used to measure and manage green growth by comparing environmental/economic performance among different economic sectors, by identifying policy areas for improvement in achieving economic benefit and, by tracking eco-efficiency trends over time (UN ESCAP, 2009).

In ports and towards air emissions, its common aim is to create institutional mechanisms to abate air pollution and climate change, among others, by initiating

[60] Eco-efficiency is defined as the character that can create more goods and services while using less resource and generating less waste and pollution (WBCSD, 1992). On the other hand, the "emission efficiency", defined in the basis of the concept of the "eco-efficiency", is "the product or service value per environmental influence" Tahara et al., 2005 in Song (2014).

studies, strategies and actions that monitor and improve air quality. Indeed, and in addition to the environmental committee created by the International Association of Ports and Harbours (IAPH) and starting 2011; EcoPorts Foundation integrated within the structure of the European Sea Ports Organisation (ESPO) enabling port authorities to support and address solutions towards environmental management and five selected issues: air quality, energy conservation, noise management, waste management and water management.

To promote the primary need of sustainable development, ports (like many companies), start to explore management phases that enable the integration of environmental management into local economy and society (Coto-Millán et al. 2010). Namely, the control environmental impacts through environmental management strategies; the measurement of eco-efficiency performance by valuating environmental (emissions) with economic factors (production), and at last; support the design of policy instruments that take the later indicators into account. Indeed, at present and in Spain, institutional mechanisms (Law 33/2010) enable the access to a 15% discount port fees to land and sea operators that either comply with environmental certifications as the ISO14001:2004[61], the European Eco-Management and Audit Scheme (EMAS), or with a best practice agreement signed with the Port Authority according to environmental guidelines authorized by State Owned Enterprise of National Ports (Ente Público Puertos del Estado, EPPE)[62]. Nevertheless, and in addition to this incentive instrument, tools to internalize environmental, economic and production performance need to be further explored. For this reason, and as an attempt to indicate performance of Las Palmas port towards economic and environmental concerns, this research estimates eco-efficiency indicators from port performance.

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[61] Requirements of the ISO 14001:2004 intend to be incorporated into any environmental management system to address air emissions, spills, soil pollution, natural resource management, energy use, energy emission –heat, radiation, vibration, and others. The extent of the application will depend on factors such as environmental policies, products, services and location of the organization.

[62] The Spanish state-owned port system comprises 46 general interest ports, which are managed by 28 port authorities. Coordination of these port authorities is the responsibility of the public organism EntePúblicoPuertos del Estado (EPPE). The EPPE, which has comprehensive responsibilities for the whole port system, is in charge of executing the government's port policies Tovar and Wall (2014).

Eco-efficiency, as a performance indicator, provides port systems with information of value to improve their competitive position when undertaking their activity with business-oriented criteria (Coto-Millán et al. 2010). Particularly within a public management model where, as it happens with state-owned Las Palmas Port[63], the port authority acts as a supplier of land and infrastructure, regulating the use of the public domain while private suppliers provide port services. Indeed, the financial performance of ports is key to becoming an important centre of business but not enough to guarantee their sustainability. To ensure this, environmental and social performance must be addressed among others, by collecting information on environmental impacts and performance to reflect its overall status (Coto-Millán et al. 2010).

The present study estimates eco-efficiency indicators (port totals and by shipping sub-sector) with the aim to provide organizations (ports, firms and governments) with a practical tool to measure their performance in the context of eco-efficiency (Liu et al., 2015). Results are presented in Table 4 and Table 5. These are based on externality costs[64] and the port performance profile during the year under study.

Results on Table 4 describe external costs per passenger, per tons of cargo, ship calls and port revenue. Obtained totals within results of local associated impacts (NO_x, SO_2, VOC, $PM_{2.5}$ and CO) reflect 48 € per passenger; 4,960 € per 1,000 tons of cargo; 19,822 € per ship call and 3,656,463 € per million euros of port revenue. On the other hand, totals including local and global (CO_2 high) associated impacts reflect 54.2 € per passenger; 5,931 € per 1,000 tons of cargo; 23,273 € per ship call and 4,293,063 € per million euros of port revenue.

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63 See previous footnote.

64 Total external costs for NOx, SO_X, VOC, $PM_{2.5}$ and CO have accordingly been included in Table 4. In terms of CO_2 only the highest value has been taken into consideration in the total sum of eco-efficiency parameters. Results from the lowest value of CO_2 derive in 247 € per passenger; 4,224 € per 1,000 tons of the total traffic of cargo; 600 € per ship call and; 110,721 € per million euros of port revenue.

Table 4 – Overall port eco-efficiency performance

		ECO-EFFICIENCY PERFORMANCE			
Exhaust Emissions	**Total External Costs**	**Emission external cost per passenger (€/ pax)**	**Emission external cost per tons of cargo (€/1,000 tons)**	**Emission external cost per ship call (€/call)**	**Emission external cost per port revenue (€/million euros)**
NOx	47,744,771	9.8	1,453	5,231	964,875
SO_2	62,661,360	19.1	1,597	6,865	1,266,324
VOC	146,191	0.029	4.	16	2,954
$PM_{2.5}$	70,378,105	19.2	1,905	7,710	1,422,272
CO	1,877	0.0003	0.06	0.206	38
CO_2 High	31,500,803	6.2	971	3,451	636,600
Total (local only)	212,433,107	48	4,960	19,822	3,656,463
Total (local and global*)	212,433,107	54.2	5,931	23,273	4,293,063

*Note: externality cost figures used in this table have been obtained from the average results from the addition of BeTa and the four sensitivity scenarios in CAFE (see Table 3). In terms of CO_2, only the highest bound has been taken into consideration in the total sum of eco-efficiency parameters.

In Table 5, results per gas, per shipping sub-sector are described according to the local (NO_x, SO_2, VOC, $PM_{2.5}$ and CO) and the global (CO_2) context of associated impacts. Parameters considered are, external costs per passenger (for cruise and ferry), per throughput (euros per TEUs handled in port) and per tons of cargo (tanker, bulk, general cargo, container[65], fishing, and the rest of categories). Totals within results of local associated impacts reflect 63 € per ferry passenger, 20 € per cruise passenger, 31 € per TEU handled in port, 8,025 € per 1,000 tons of liquid cargo, 21,986 € per 1,000 tons of dry cargo, 2,422 € per 1,000 tons of general cargo, 2,876 € per 1,000 tons of containerized cargo and 17,656 € per 1,000 tons of fishing cargo. Similar patterns can be observed among sub-sectors when local and global figures are added.

[65] It should be noted that in Table 5 we have included two eco-efficiency indicators in the case of containers: one expressed in TEUs and other in tons, respectively.

Table 5 – Port eco-efficiency performance per shipping sector

ECO-EFFICIENCY PORT PERFORMANCE									
Exhaust emissions	Emission external cost per passenger (€/Pax)		Emission external cost per TEU (€/ TEU)	Emission external cost per tons of cargo (€/ 1,000 tons)					
	Ferry	Cruise	Container	Tanker	Bulk	General Cargo	Container	Fishing	Rest
NOx	13	4	8.92	2,351	5,816	752	833	6,154	2,161
SO_2	25	8	9.97	2,584	7,603	751	931	4,911	2,487
VOC	0.04	0,01	0.03	7	17	2	2	18	7
$PM_{2.5}$	25	8	11.88	3,083	8,549	916	1,110	6,573	2,912
CO	0.0004	0.0002	0.0003	0.106	0.234	0.032	0.032	0.224	0.094
CO2 low	1	0	0.98	274	601	91	91	730	271
CO2 High	8	3	5.62	1,574	3,456	522	525	4,199	1,560
Total (only local)	63	20	31	8,025	21,986	2,422	2,876	17,656	7,567
Total (local and global) low	65	20	32	8,299	22,587	2,513	2,967	18,386	7,839
Total (local and global) high	72	22	36	9,599	25,442	2,944	3,401	21,855	9,128

Note: externality cost figures used in this table have been obtained from the average results from the addition of BeTa and the four sensitivity scenarios in CAFE (see Table 3). In terms of CO_2 and in order to avoid bias results, only the highest bound has been taken into consideration in the total sum of eco-efficiency parameters.

Although results in Table 4 follow the efforts of studies that similarly aim to support environmental policy in ports by exploring relations of economic, operational and ecological capital efficiency[66]; aggregated indicators may not be a proper reflection of what happens in each subsector and important differences may be obscured. To set an example, and taking into account only local effect pollutants (NO_x, SO_2, VOC, $PM_{2.5}$ and CO), results reflect that with respect to local external costs from the passenger sub-sectors, a 76% relate to ferries and the remaining 23% to cruise. With respect to cargo categories, the local external cost per 1000 tons of cargo is in decreasing order: bulk (36.2%), fishing (29.2%) tanker (13.3%), rest (12.5%), container (4.8%), general cargo (4%).

Since our eco-efficiency indicators are measured as the ratio between the impacts

[66] Song, (2014) estimated parameters to assess eco-efficiency in the Yangshang port area. Results reflect for 2009, a total of $36,528 per 1,000 TEU throughput, $43,993 per ship call, and $44 million per billion US$ of port revenue.

of the service (externality costs) and what has been produced (ton, passengers, and so on) the greater the indicator the less environmental efficient the subsector analysed. From the above figures derive that within the passenger sector, the subsector that generates the most external costs is the ferry over the cruise sector. Indeed, the eco-indicators calculated for local effects reflect a higher external cost of 43 € when related to a ferry passenger. In terms of cargo categories, eco-indicators also allow us to identify the least efficient environmental sectors per manipulated ton. Again and when considering only local costs, the most efficient category is general cargo with a cost of 2,422 € per 1,000 tons. The calculated indicators reflect that the rest of the presented sub-sectors present (with respect to general cargo) an external extra-cost per 1000 tons of: 454, 5,145, 5,604, 15,234 and 19,564 euros from the container, rest, tanker, fishing and bulk categories, respectively.

3.4. Conclusions and Future Research

One of the challengers that European ports will have to confront to ensure their future competitiveness will be sustainability. One way of achieving this is to monitor (eco-efficiency performance) and improve port actions to control air emissions. Among these port actions, to begin the quantification and management of emission inventories, creating structures and reporting mechanisms to internalise emission self-assessment and control through reduction targets.

This research presents a brief review of external cost estimation applied to shipping and ports. This is followed by the emission estimation of vessel traffic in Las Palmas Port (2011), derived costs (based on BeTa, CAFE and NEEDS) and port eco-efficiency performance (cost per passenger, per tons of cargo per ship call, and per port revenue). Moreover, eco-efficiency indicators are further described per shipping sector (per type of passenger, TEUs and 1000 tons of cargo) at port. Namely, eco-efficiency indicators from ferry, cruise, container, bulk, general cargo, container, fishing and other shipping sub-sectors are addressed.

Emission assessment is based on a vessel emissions inventory obtained from the full bottom-up Ship Traffic Emission Assessment Model and messages transmitted by the Automatic Identification System over a twelve-month period (2011). Results reflect a total of 215,867 tons of exhaust emissions derived from vessel traffic in Las Palmas Port (2011). It is noticeable that apart from tanker, container and ferry vessels, the rest of the fleet represents an overall that does not exceed a 7% from the total share at port. Although in line with previous studies that also suggest ferry, tanker and container vessels as the largest contributors of air emissions affecting local (NO_x, SOx, PM, CO) and global (CO_2) environments; differences may arise due to assumptions on key inputs such as speed, distance, operative and engine load. When compared to literature, the use of vessel tracks from the AIS, and the STEAM support the accuracy of the emission inventory. To the best of our knowledge, the present paper is the first to combine port emissions inventory obtained through a full bottom-up approach with external cost and eco-efficiency indicators derived from them. This eliminates the dominant uncertainties reported by harbour studies whose results are based on vessel emission inventories at port.

The estimated external costs associated with the damages that vessel emissions contribute upon human health and the built environment surrounded the port of Las Palmas were found to be significant. To be specific, the overall economic costs for NO_x, SO_2, VOC and $PM_{2.5}$ when using urban and rural values provided by BeTa (for Spain) derive in 174,288,076 € while using urban cost factors from BeTa and rural cost factors from CAFE results in an average (including four sensitivity scenarios) of 180,930,427 €. Moreover, results derived using rural cost factors in CAFE results in a variation of 18.7% depending on the sensitivity scenario chosen, establishing a confidence interval for estimates made, and most importantly; highlighting the importance of assumptions chosen when making similar calculations and the need to conduct studies that result in cost factors and scenarios increasingly more refined. In the case of NEEDS and when compared to top-down estimations with BeTa methodology (only BeTa and BeTa combined with CAFE) figures are considerably lower with 21,750,913 € from for NO_x; 11,567,621 € from SO_2, 87,901 € from and VOC and 68,186, 804 € from $PM_{2.5}$. Therefore, from all the observed variation, the importance of reaching a consensus to assess external costs in shipping and ports can be concluded.

Summarizing, and from the costs totals obtained from the average of BeTa + CAFE (SC1, SC2, SC3 and SC4); NO_x, SO_X, and $PM_{2.5}$ reflect the dominant shares, accounting respectively for a 22%, 29% and 33% from the total sum being GHG, (CO_2 High) responsible for the remaining 15% from the totals at port. Moreover, the temporal evolution of external costs throughout a twelve-month period (2011) is relatively stable, with a major cost derived from NO_x and $PM_{2.5}$. Also, peaks are noticeable due to the increase of vessel calls, mostly on January, March and November. An average, the approximate cost per person living in the port-city has been estimated at 554 €.

On the other hand, the present study suggests eco-efficiency indicators as a practical tool to measure performance within the context of ports. The financial performance of ports is key to becoming an important centre of business but not enough to guarantee their sustainability. To ensure this, environmental, social and economic performance must be addressed by collecting environmental impacts and performance.

In order to create or improve port actions to control air emissions in Las Palmas Port the present study estimates eco-efficiency indicators from externality costs of vessel emissions. In this case study, overall results of port eco-efficiency performance describe external costs per passenger, per tons of cargo, ship calls and port revenue. Obtained totals within local associated impacts reflect 48 € per passenger; 4,960 € per 1,000 tons of cargo; 19,822 € per ship call and 3,656,463 € per million euros of port revenue. On the other hand, the latter result of 48 € per passenger represent higher or lower figures than when performing similar estimations by sub-sectors which reflect 63 € per passenger of ferries and 20 € per passenger of cruise. Similarly the previous result of 4,960 € per 1,000 tons of cargo represent a higher or lower value than when estimating the eco-efficiency indicators by tanker (8,025 €/1,000 tons), bulk (21,986 €/1,000 tons), general cargo (2,422 €/1,000 tons), container (2,876 €/1,000 tons), fishing (17,656 €/1,000 tons) and the rest of vessels (7,567 €/1,000 tons).

As it has been shown, aggregated indicators may not be a suitable reflection of what happens in each subsector and important differences may be obscured. For instance, from the passenger sub-sectors, the ferry reflects the highest figures over cruise. In terms of cargo categories, eco-indicators also allow us to identify the least efficient environmental sectors per manipulated ton. Again and when considering only local costs, the most efficient category is general cargo, followed by container, rest, tanker, fishing and bulk categories, respectively.

For the later reason, eco-efficiency indicators by subsector are suggested to be the ones to be considered by authorities to apply corrective measures since these better reflect what the real responsibility of each subsector is, in the external cost generated. In this way, one of the core principles of sustainable development *Polluter Pays Principle* could be better applied whether port authorities decide dealing with the polluters by imposing them 'eco-taxes'. In this way, it internalizes the cost of pollutant into the cost of the service and the "polluters" receive an incentive to ensure that best environmental practice is followed. It should be noted that the potential of this measures to improve port environmental situation is high because corrective effect may be generated just for the fact of being published, especially if the evolution and reduction efforts of shipping sectors/companies are monitored. Beneficial effects may also arrive through public pressure from informed citizens and as a result of firms attempting to avoid the possible threat of being charged based on their polluting profile if doing nothing for improvement.

To summarize, the contribution of this paper to the available literature relates to the following. Firstly, it obtains externality costs of vessel emissions from disaggregated variables as individual vessel tracks and technical details. This approach eliminates the dominant uncertainties reported by previous vessel emission inventories at port (based on port calls) used to estimate externality costs (see Table 1) and fills the gap of methodology improvement, necessary to achieve more accurate results. Secondly, and in terms of externality costs; this harbour study presents the available lower and upper thresholds of top-down estimated costs (from BeTa, CAFE and NEEDS). Additionally, derived eco-efficiency parameters (in general) and per shipping sector (in particular) are defined and suggested, as an indicator of environmental and economic performance to be considered for policy use in port-cities. At last, results respond to the research question of the economic impact and environmental/economic performance of vessel emissions in Las Palmas Port, describing through the case study, the utility of these measurements as support tools to Port Authorities and local governments.

Cost results associated to damages that vessel emissions contribute upon human health and the built environment in Las Palmas de Gran Canaria (and in available literature) follow a top-down approach. Thus, and although assumptions are valid as a first insight into derived costs and eco-efficiency from vessel emissions; we suggest that future research also address these indicators by following an integrated approach based among others, on refined information from pollutant concentration and local meteorological conditions. This is of particular interest considering that policy value provided by the use of the IPA methodology in regional studies (i.e. BeTa) may be source of inconsistencies, as these were not developed with the original purpose of external cost estimation for wider policy use. Also, and since additional sources of emissions at port were not included in this study we suggest future improvements of results by including land-based sources of emissions and the derived effects on sailors and maritime professionals.

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