Liquefied Natural Gas as an Alternative Fuel: a Regional-Level Social Cost-Benefit Appraisal

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Abstract
The impact from traditional marine fuels has the potential of causing health and non-health damages and contributes to climate change. Here, the introduction of Liquefied Natural Gas (LNG) as an energy end-use fuel for marine purposes is analysed. The aim of this study is to verify LNG's policy implementation feasibility as a step-change for a low carbon perspective for shipping by means of developing a social cost-benefit analysis on a regional basis. Emissions from the Portuguese merchant fleet, weighted by their contribution to the National Inventory, were used to quantify and monetise climate, health and non-health externalities compared with benefits from LNG as a substitute fuel. Benefits from the policy implementation are those related to the reduction of external environmental, health and non-health impacts. Costs are those that nationals are willing to pay for. In this sense, to estimate the value of the atmospheric air - a non-market commodity - people were asked about the price they hypothetically are willing to pay by responding to a specific questionnaire. The present study, based on a social cost-benefit analysis, indicates that benefits are almost 8 times superior to the costs and is consistent with real world efficiency gains. Although it addresses Portuguese particularities, this methodology should be applied elsewhere.

Keywords: Environmental, health and non-health impacts; Liquefied Natural Gas; Contingent valuation; Social Cost-benefit Analysis; Portuguese merchant fleet

JEL classification: H5; N7; R4

Introduction

For a coastal country like Portugal, although marine emissions occur mostly far from shore (Corbett, Fischbeck, Pandis, 1999) depending on

Moreira P.P., Caetano F. 2017. Liquefied Natural Gas as an Alternative Fuel: a Regional-Level Social Cost-Benefit Appraisal. *Eastern European Business and Economics Journal* **3(2)**: 122-161.

the prevailing wind directions pollutants can spread for over hundreds of kilometres with clear implications for the air quality in regions far away from the coastline. LNG fuelled ships comply with all current and anticipated environmental legislation targets for nitrogen oxide (NO_x), sulphur oxide (SO_x), particulate matter (PM) and carbon dioxide (CO_2) reduction (Kolwzan, Narewski, 2012; Chryssakis, Balland, Tvete, Brandsaeter, 2014; Wurster, Weindorf, Zittel, Schmidt, Heidt, Lambrecht, Lischke, Müller, 2014) and is considered, at present time, as the most promising alternative fuel in the maritime sector. Therefore, the driving forces behind the LNG as an alternative marine fuel are environmental, health and non-health considerations relative to residual and distillate fuels. Following the recommendations from the European Commission (DIRECTIVE 2012/33/EU; DIRECTIVE 2014/94/EU) and in line with the findings and solutions embedded in the 2015 report commissioned by Det Norske Veritas–Germanischer Lloyd providing recommendations to the EC for the adoption of LNG as a marine fuel in Europe, this study addresses airborne emissions emitted by the Portuguese merchant fleet.

Contributions to climate change and impacts on populations' health, crops and materials and the benefits obtained from the introduction of a less damaging substitute fuel are therefore addressed at a regional scale. This is achieved through means of quantifying and monetising costs and benefits as they come from a comparative analysis between traditional marine fuels and the LNG as a substitute fuel. Non-health benefits include reduced damages and costs over crops and materials, comprising infrastructures, buildings, cultural monuments and damages over ecosystems. Yet, the present study does not address noxious effects of eutrophication and acidification over vulnerable marine and terrestrial ecosystems due to the difficulty to gather accurate data. The Portuguese domestic fleet uses mostly high sulphur fuel content and there is a lack in detailed knowledge about the effects on climate and over exposed population at country level scale. Such perverse effects in terms of public health and climate change are not being monitored and the topic is regretfully absent from the academic literature; likewise, the benefits arising from a switch to a less polluting marine fuel for crops and cultural heritage are not subjected to any broad evaluation at national level. Our aim is therefore to fill in these important gaps and to propose a more ambitious reduction target for the maritime transport sector outside the EU Emissions Trading Scheme. The contribution of this study for the field of final energy consumption and mitigation measures can have a threefold use: first, it gives the rationale to evaluate overall costs of emissions by energy sector; second, by comparing benefits from mitigation strategies, it provides to public agents an important tool for responsible energy consumption related policies, this when Lisbon, Portugal's capital, is becoming an important port of call for cruise ships burning essentially hard fuel oil; third, it contributes to people's awareness and knowledge about environmental and health issues related with the use of oil-based fuels in the transport sector. The emissions quantification and the negative externalities associated to each fuel show that after externalities from the different fuels are internalised at society level, LNG is a feasible option. Although the adoption of LNG as a marine fuel addresses only domestic navigation, the outcome should be possible to be replicated being the results proportional to the size of the fleets. The structure of this article is as it follows: it starts by providing an overview of the Portuguese marine airborne emissions and how to assess climate, health and non-health impacts. Next, the social cost-benefit framework is detailed and the theoretical foundation of Contingent Valuation technique method used in this research as "contingent" on the features of the surveys' scenario is described. Then, it is demonstrated how was made possible to elicit people's willingness to pay (WTP) by means of a pre-test that was used to delimitate the upper and lower money bounds for the online survey from where the WTP was calculated. The next section displays the data sources and methodology to estimate costs and benefits arising from the policy implementation, i.e., the feasibility of the adoption of LNG as a substitute fuel by the Portuguese merchant fleet and what is the net present value from such policy implementation. A brief overview about the absence of ongoing policies in place and how the present study can be useful for the design and implementation of future marine fuel policies is discussed in the next section. After, a discussion section highlights the adoption of LNG as a cost-effective solution in the context of "value for society" instead of "value for money" consistent with real-world efficiency gains. Finally, the last section points out some study limitations also referring suggestions for future research.

Moreira P.P., Caetano F. 2017. Liquefied Natural Gas as an Alternative Fuel: a Regional-Level Social Cost-Benefit Appraisal. *Eastern European Business and Economics Journal* **3(2)**: 122-161.

Measuring noxious effects from marine airborne emissions

Although Portugal is allowed to emit 1% more GHGs in the horizon 2020 than it did in 2005 (Decision n. 406/2009/EC), however, "*the number of episodes of tropospheric ozone pollution and of fine particles pollution [remains] higher than the long-term target established*" (European Environment Agency, 2015) urging for a deep understanding at sectoral level, namely within the transport sector which includes domestic shipping. Marine airborne pollution contributes for climate change through greenhouse gas (GHG) emissions and impacts human health, crops and materials. These environmental externalities are not borne by transport operators, consumers or users, but by society as a whole. With respect to exposure, and conversely to what is appointed to mobile sources, there is not an important difference between local pollutants for which population exposure in port's vicinity largely determines the health impact. Thus, the impact assessment does not take account of the population density variation between near port areas and areas farther away.

Emissions produced in the land side of maritime operations are extremely low if we compare with those emitted at sea because auxiliary engines run mostly on marine gas oil (MGO) while ships are loading/unloading at port. Emissions from hard fuel oils (HFOs) at sea mode are long-range pollutants disseminated all over the coastline and thus the link to population densities is not clear or at least, difficult to establish and to model. As such, we do consider that pollutants around the source – port areas and emissions while on route - are dispersed evenly throughout the national territory. Our study begins by calculating the share of emissions by pollutant from domestic shipping and ends by quantifying potential monetary benefits resulting from the reduction of the pollutants as depicted in the next subsections.

Assessing climate change impacts

Shipping emissions from traditional marine fuels contribute to climate change due to GHG emissions, namely carbon dioxide. Portugal is among the most vulnerable European countries when it comes to the impacts of climate change (European Environment Agency, 2015). The use of LNG lead to representative reductions of greenhouse gases by 12-27% (Lowell, Wang,, Lutsey, 2013), or 10-20% (Chryssakis, Balland, Tvete and Brandsaeter, 2014; Wurster, Weindorf, Zittel, Schmidt, Heidt, Lambrecht, Lischke and Müller, 2014), compared with conventional oil based fuels including the emissions of non-burnt methane (EMSA, 2010). More substantial GHG reductions are possible if fossil LNG is substituted with biomethane (Wurster, Weindorf, Zittel, Schmidt, Heidt, Lambrecht, Lischke and Müller, 2014), in both well-to-tank and tank-to-propeller leakages. Based in values from literature review we consider a reduction of 20% in CO_2 emissions from domestic shipping. Carbon is priced at €96.5 per tonne as it comes from Korzhenevych, Dehnen, Bröcker, Holtkamp, Meier, Gibson, Varma and Cox, 2014) updated to 2014 prices using the Eurozone CPI deflector.

Assessing health impacts

The emissions of fine particles, nitrogen oxides and tropospheric ozone (O_3) are currently the two most important pollutants in Europe, representing a serious risk to human health and the environment (Fowler, Brunekreef, Fuzzi, Monks, Sutton, Brasseur, Friedrich and Mingo, 2013) affecting the quality of life and reducing life expectancy. NO_x acts as a precursor in the formation of ground-level ozone, a threat to the health of humans and for the environment. The majority of ozone formation occurs when NO_x and volatile organic compounds (VOCs) react in the atmosphere in the presence of sunlight. For this reason are called ozone precursors. Although these precursors often originate in the vicinity of port areas, winds can carry NO_x hundreds of kilometres, causing ozone formation to occur in less populated regions as well (Evtyugina, Pio, Nunes, Pinho and Costa, 2007). Owing to its highly reactive chemical properties, ozone is harmful to vegetation, materials and human health leading to a wide range of health problems (Amman, Derwent Forsberg, Hänninen, Hurley, Krzyzanowski, de Leeuw, Liu, Mandin, Schneider, Schwarze and Simpson, 2008). Moreover, nitrogen oxides present in nitrate aerosols damages forests and arable lands leading to crop losses.
Particulate matter are ultra fine particles that may cause important respiratory problems; the smaller the particles, the more likely to penetrate deep into the respiratory system and greater the risk of inducing adverse effects. These particles can remain in the atmosphere from days to weeks and travel through the atmosphere hundreds to thousands of kilometres. Adding to this, sulphur dioxide from combustion exhaust gases during the process of oxidation in the atmosphere forms sulphate aerosols being harmful to health and is a precursor of acid rains in the form of sulphur oxide (SO_x). Since LNG reduces emissions of NO_x by

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90% and SO_2 and PM at practically 100% (Corbett, Thomson and Winebrake, 2014; Rahman and Mashud, 2015) human health risk to air pollution will fall to lower ranges. For the health impact assessment, account is taken from aggregated health damages over Portuguese territory population in year 2014, based on Holland's report (2014).

Assessing non-health impacts

To perform a non-health impact analysis, detailed quantification of effects on ozone damage to crops and acid damage to buildings would be necessary requiring additional pollutant metrics and a very strong effort to collect data. Such information 'is not available at the national level, which implies to follow the same approach as used for health impacts calculation: the share from domestic shipping for total emissions multiplied by net benefits resulting from its reduction. As previously cited, damage to other non-health receptors, notably ecosystems has not been quantified. Such assessment limitations incur against benefits which, if taken into account, will positively impact the final outcome. For the effects on crops and materials we use the data available for the year 2014 for each type of impact quantified (NO_x as ozone precursor and SO_x as acid rain precursor), based on Holland and Watkiss (2002) damages cost after values have been adjusted to year 2014.

Social Cost-benefit Analysis (SCBA) framework

Social cost-benefit analysis is an extension of a project (or policy) assessment adjusted to take into account the full spectrum of costs and benefits including social and environmental effects borne by society as a whole as a result of an intervention. SCBA for the purpose of analysing public policy accounts for more than just financial costs and benefits in order to evaluate the net effect of a policy on overall social well-being (Kotchen, 2010). An appraisal or evaluation decision then could be made by ranking activities using net present values or benefit/cost ratios. The framework also gives systematic insights into choice of techniques and the assignment of distributional weights (Cameron, Hunter, Jagals and Pond, 2011). The development of a SCBA requires the metric of "monetising" the benefits even when societal values are not necessarily a field where the main objective should be "efficiency maximisation", as it happens with environmental nonmarket assets such as the atmospheric air we breathe.

Moreira P.P., Caetano F. 2017. Liquefied Natural Gas as an Alternative Fuel: a Regional-Level Social Cost-Benefit Appraisal. *Eastern European Business and Economics Journal* **3(2)**: 122-161.

Our SCBA study estimates the value of a non-market commodity resulting from the price people are willing to pay providing the accuracy and relevance for an empirical economic study to assess the economic desirability of such a change. The SCBA ponders costs and social benefits of a project or policy in order to determine the Total Economic Value (TEV) attributable to environmental assets in question. Usually, total value is decomposed into direct use value and passive use value. Atmospheric air has indeed a direct use value thought it requires that the agent physically experiences the commodity. The Rule of the Net Present Value (NPV) transmits to the analyst whether the policy should be implemented according to the following formula: NPV = PV (B) – PV (C), NPV> 0, where PV (B): current gross value of the benefits; PV (C): current gross value of the costs.

In the case of a policy that improves the scale or intensity of an environmental asset: Benefit = + ΔTEV (the variation – in this case the improvement – implies accounting the benefits with reduced emissions). Estimation of non-market commodities requires the use of hypothetical markets, in which a method known as contingent valuation directly questions people through surveys about their economic value.

Methods

Contingent Valuation technique and Willingness to Pay (WTP)

Contingent Valuation (CV) is a technique which uses surveys to value public goods, built on the idea of a hypothetical market scenario where a public good is transacted, by asking questions to reveal the monetary trade-off each person would make concerning the value of goods or services (Cameron, Hunter, Jagals and Pond, 2011; Carson, 2012). The term “contingent” refers to the estimated values obtained using the data collected being contingent on the features of the survey’s scenario, or constructed market (Carson and Louviere, 2010). For what follows, we assume the term “contingent valuation” applied to a particular elicitation method: stated preference or SP. SP questions follow a standardized questionnaire to elicit the price people are willing to pay for public goods (in our case environmental and health) in order to avoid polluted air. Therefore our online questionnaire asks respondents about simple direct questions to obtain information for economic empirical valuation purposes on a non-tradable asset. Care was taken to avoid potential non-responses: a comprehensive preamble to the questionnaire and the

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introduction of a third possible choice, which therefore can be viewed as a triple-bounded dichotomous choice. To what it concerns the good to be valuated - the atmospheric air - and to the best of our knowledge, this is the first time this topic is subjected to people's elicitation.

The pre-test/pilot study

Before the final survey was drawn up a pre-test/pilot study was administered under field conditions, i.e., by means of in-person interviews to help to identify questions that make less sense to participants, or problems with the questionnaire that might lead to biased answers. The pre-test/pilot was used to:

i) provide adequate power to test the hypotheses of interest; and,
ii) to delimitate the upper and lower bound people are willing to pay for the improvement in the good.

Some key issues were addressed during this phase. First, enough information was provided to respondents to help them making an informed decision but without overwhelming them with information. Also the formulation of the scenario in which the good is to be improved was set. A second issue concerns to the payment vehicle; the way, how much and whether it is a one-time *lump sum* or a recurrent payment people will pay for the good. Another underpinned preoccupation was to respondents feel comfortable with making either a "favour" or "oppose" decision. In-person interviews were made containing ancillary visual aids (paper slides) depicting the harmful effects of marine traditional fuels over people's health and the environment emphasising its expected increase in the decades ahead. Extreme care was also taken for persons realise implicitly the high level risk for people's health if the atmospheric air is not improved. The inherent problem here was to make people perceive they are not dealing with a low-level risk as suggested by Carson, Flores and Meade, (2000), also because some of them, at least, could have the motivation to consider it as a "bequest value" and might want to preserve it for their children and grandchildren (A "bequest value" concept means that some people's concern to future generations' would like to pay for. Even if they see it as something they cannot control, they care about and thus, it enters their utility function). As such, the risk problem was communicated during the survey.

Both the pre-test/pilot survey and the questionnaire require a description of how the air is going to be improved (the *mechanism*). The *payment vehicle*, a three year tax which seems an appropriate period of time – not long enough to create fear of a camouflaged fiscal burden but neither too short, in a way to make it be likely to comply with it according to a payback period time of 2 - 4 years. Respondents will face the *hypothetical* situation to pay a *one time* amount once a year for air quality improvement in that given period of time even though knowing that the results will last for a much longer period. Notwithstanding the mere question to pay a tax for an universal good supported by exposed population seems to be not righteous, eventually, if national/European funds are allocate to the adoption of LNG as a marine fuel, the nature of those funds come in fact from taxpayers. By the other hand, if ship-owners have to support the retrofitting and/or new orders costs by themselves, due to a more stringent regulation, for example, amortization costs will assume the form of higher freight rates and ultimately it will be reflected in the final price goods will exhibit in the supermarket shelves. In one way or another, people have to support those costs anyway. If this is what actually happens in the real world, thus is consistent with standard neoclassical economic theory.

In-person interviews were performed by the authors themselves around the Greater Lisbon area, thus including part of the Centre and in the Setúbal area, which in fact belongs to the South division of the country, and by two volunteers located one at North (Porto-Braga areas) and another at South (Faro-Portimão-Lagos areas), not limited to shore near areas, after interviewers have been trained about the face-to-face method. To what matters about the location in this stage and different from what was later decided with the online survey, a sensitive question was to know at what distance from the ocean respondents live as a means to measure its sensitivity to the proposed solution as a function of its geographical location. Special attention was given to provide interviewers with an insight about the delicacy of the subject of asking people if they are “willing to pay” for an asset people assume as universal and free of charge provided, and that challenges can be magnified when gathering such kind of information among some portions of the population (i.e., the elderly and less educated strata, for instance but not restricted to).

This action was performed during the second half of April and beginning of May 2016 and the responses to a normalised paper

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questionnaire were filled out by the interviewees themselves in the presence of the interviewer. The target population was set as an equally distributed sample of men and women aged 18-69 living or not in the specific areas where they were interviewed and participants were randomly assigned once they fulfil those previous conditions. People were approached in public places like cafeterias, markets and shopping malls. Of course, in-person interview surveys are more time-consuming and considerably expensive especially when there is a need to travel and meet the respondents at different locations. In face of such constraints a considerable part of the territory was obviously left out. Further studies should be carrying on in the future to partially eliminating this gap. However, knowing that about 70% of the Portuguese population is located in the so-called littoral stripe - about 500 km long and 50 km wide belt - such asymmetric distribution is not as deep as one initially might think.

Post-interview follow up assessments to verify that respondents understood the questions were not conducted *per se*; instead during the interviews, to ensure that the core questions were broadly understandable and perceived as consequential, people were asked about their perception about what was at stake, their doubts or less clear questions. This procedure has had also the intent to avoid potential protest bids that could therefore bias willingness to pay results. Each interview could easily surpass the 30 minutes long.

At the end of the pre-test a simply direct question was asked: if the respondent is willing to pay and, in the case he/she respond “yes”, how much is the amount that best represent his/her WTP. Then, the upper and lower bounds delimitated by the first and the third quartiles (the interquartile range) were used to obtain the initial and second elicitation amounts for the online questionnaire questions since the true value people are willing to pay for, lies somewhere between the two. Figure 1 presents some conclusions from the pre-test/piloting survey analysis.

Fig. 1. Demographic characteristics.

Demographic Characteristics (pre-pilot)				
Division		Frequency (N=68)*	Percentage (100%)	Mean (€uro)
Gender	Male**	32	47.1%	9.0
	Female***	36	52.9%	8.5
Age	18-34	10	14.7%	7.5
	35-54	41	60.3%	9.4
	55-69	17	25.0%	6.4
Academic Background	Basic education (up to 9th degree)	15	22.1%	4.6
	Secondary (9 to 12th degree)	25	36.8%	7.5
	University	28	41.2%	11.3
Gross monthly Income (euro)	500-1000	29	42.6%	6.4
	1000-2000	35	51.5%	10.2
	>2000	4	5.9%	9.5
Geographical location (km from ocean)	0-30km	55	80.9%	8.2
	30-60km	8	11.8%	10.1
	>60km	5	7.4%	5.5

* Not including three "no" responses
** Not including one "no" response
*** Not including two "no" responses
Note: We follow the Portuguese educational system (https://en.wikipedia.org/wiki/Education_in_Portugal#Secondary_education)

Roughly around 300 persons have been invited to respond to the pre-test survey. From those, a total of 71 acceded. Three (3) of the interviewees have decided to respond “no” to any amount at all. Here, the assumption wasn’t that those who have not responded do prefer to breathe a bad air or not prevent climate change; rather they are not willing to pay for the improvement. Age does not seem to have a negative effect from what we have gathered from this in-person survey. Conversely, the respondents’ level of academic qualifications, geographical location and higher income appear as the major contributors for high WTP, presenting a positive effect, even though in the two latter cases, the respondent’s number within the higher income class (> €2,000) and farther away from the coastline (> 60km), were minimal. In this study a completely nonparametric approach was adopted, letting the data speak for itself without imposing any assumptions about the nature of the data generating process. Although the price people would be willing to pay ranks from 1 single Euro to 30 maximum no extremely high responses (outliers) were registered. Figure 2 summarises descriptive statistics from the pre-pilot test.

Moreira P.P., Caetano F. 2017. Liquefied Natural Gas as an Alternative Fuel: a Regional-Level Social Cost-Benefit Appraisal. *Eastern European Business and Economics Journal* **3(2)**: 122-161.

Fig. 2. Descriptive statistics for willingness to pay for a better air quality (pre-pilot).

Descriptive statistics for willingness to pay for a better air quality (pre-pilot)	
N (number of observations)	68
Mean	8.45
Std. Deviation	7.25
Variance	52.52
Maximum	30
Minimum	1
Upper quartile	10
Median	5
Lower quartile	3

€1: 7	€3: 5	€6: 2	€10: 11	€20: 3
€2: 5	€4: 1	€7: 2	€12: 1	€25: 5
€2.5: 1	€5: 18	€8: 1	€15: 5	€30: 1

As it was expected, the main problematic issue to transpose was the initial unease people demonstrate when asked about their WTP a given exact amount. For that large majority who were willing to pay, defining an exact amount became a defying exercise with their inner conscience. It was not provided any kind of help from the interviewers in the sense to avoid any type of interference in delimiting the values even when some of them request a "reference" value to be provided. From the 68 valid responses, lower and upper quartiles have been set, for both lower and upper money bounds, respectively, as it follows: lower: €3; upper: €10, which will consist in the questionnaire's first and second questions. The third question, the minimum amount, was set as €1 (one) single Euro. Next subsection provides the rationale in which our questionnaire is based upon and gives people the full insight of what is at stake.

The questionnaire's framework

The survey asked people to elicit WTP to avoid climate change consequences, a lower health status, changes in life expectancy and risk of premature death by means of improving the atmospheric air, a non-marketed good, through the adoption of LNG as a marine fuel, as opposed to those traditionally burned by vessel's engines. The main features in the construct of the survey include: i) a preamble section which helps set the general context for the decision to be made: noxious emissions derived from traditional marine fuels in comparison with less harmful emissions from LNG and the consequences of a doing nothing scenario; ii) a description of the good to be improved; iii) the manner in which the good will be paid for; and, iv) the collection of a set of respondent characteristics (personal data and demographic information). In this research we assume that people truthfully answered the questions that were asked about. A critical feature one needs to be aware is that people prefer undoubtedly to breathe a better air and, as such, increases the likelihood for the agent to accept to pay to obtain the good (Carson, Flores and Meade, 2000). Data was collected using a convenience sampling to whom a link for an online survey was sent. Portugal was roughly divided into three large areas: North, Centre and South. The Azores and Madeira archipelagos were considered as to belong to South region. Yet, an "other" location was also included to allow those who were living abroad the possibility to respond. Main preoccupation was to ensure that the core questions were broadly understandable and perceived as consequential. The questionnaire has received a total of 261 responses. Data analysis of the survey results was conducted using Excel spreadsheet statistical functions.

As mentioned before, the questionnaire was elaborated following the triple-bounded dichotomous choice, bounded by a lower and upper value people are willing to pay rather than simply responding to a single presumably exact value. Usually, in a *double-bounded* questionnaire the lower and upper bound questions asked respondents who said yes to the initial amount whether they would pay the second higher amount or not, since the true value is assumed to lie somewhere between. The response reduces the length of the interval in which the respondent's WTP lay and decreases the confidence interval introducing a second choice set without changing any attribute of the good other than cost (Carson and Czajkowski, 2012*)*. However, the format we choose is an extension of double-bounded choice: for those who are not willing to pay for the lower bound, a third question is asked: are they willing to pay for a *lower* bid amount used in the first question? In this case, the minimum value is considered to be one single Euro. This "triple bound" format was considered by Bateman, Langford, Jones and Kerr, (2001). In this case, with three valuation questions, the response probability model is given by four possible response outcomes: (no, no); (no, yes); (yes, no) and (yes, yes). The Euro amount in the initial valuation question is denoted by A. If the response to that question is no, it is followed up using a lower

Moreira P.P., Caetano F. 2017. Liquefied Natural Gas as an Alternative Fuel: a Regional-Level Social Cost-Benefit Appraisal. *Eastern European Business and Economics Journal* **3(2)**: 122-161.

amount A_L, if yes (to A), this is followed by a second valuation question using a higher amount A_U, as depicted in Figure 3.

Fig. 3.
Possible response outcomes.

A	A_U	A_L
€ 3.00	€ 10.00	€ 1.00
NO	-	NO
NO	-	YES
YES	NO	-
YES	YES	-

Accordingly, the general formula for the various response probabilities is:
Pr (Response is no/no) = Pr ($A_L \geq C$) $\equiv G_C$ (A_L),
Pr (Response is no/yes) = Pr ($A \geq C \geq A_L$) $\equiv G_C$ (A) $-$ G_C (A_L),
Pr (Response is yes/no) = Pr ($A_U \geq C \geq A$) $\equiv G_C$ (A_U) $-$ G_C (A),
Pr (Response is yes/yes) = Pr ($C \geq A_U$) $\equiv 1 - G_C$ (A_U).

C denotes the compensation variation measuring the individuals' maximum WTP for the change and G_C is the WTP cumulative distribution function for a given individual, specifying the probability that the individual's WTP is less than the given amount.

The main features in the construct of the survey include: i) a preamble section which helps set the general context for the decision to be made - noxious emissions derived from traditional marine fuels in comparison with less harmful emissions from LNG and the consequences of a doing nothing scenario; ii) a description of the good to be improved; iii) the manner in which the good will be paid for; and, iv) the collection of a set of respondent characteristics (personal data and demographic information).

Population and sample representativeness

The population was set to be those aged between 18-69 years (in accordance to the legal voting age in Portugal and the age when digital divide grows substantially; only 11.8% of the Portuguese population aged 65 and over are Internet users (Rebelo, 2016), which represents around 82% of the Portuguese population aged 18-85 and above living in Portugal, including the Atlantic archipelagos of Azores and Madeira, roughly divided into three large rectangles: North, Centre and South. The Azores and Madeira archipelagos were considered as to belong to South division. An “other” location was also included to allow those who are living abroad the possibility to respond. Following this method, the respondents’ city of residence question also foresees the proximity to some major coastal Portuguese cities distributed from north to south of the country, including its hinterland. North: between Viana do Castelo and Coimbra (including major cities as Braga and Oporto), Centre: between Coimbra and Lisbon, a densely populated region, and South: between Lisbon and Faro (excluding the former), comprehending all the regions from Setúbal unto the southern littoral.

Given the size of the population and inherent physical constraints to set an appropriate random sample, the sample chosen was not a probability-based sampling but instead a convenience sampling or, by other words, a nonprobability sampling. A convenience sample consists of a group of individuals who are available at the time of the investigation. This procedure allows conveniently for time and resources savings and is an example of a self-selected sample. The sample to be collected through an online survey was determined to collect a minimum of 250 valid responses. After the number of responses equalised this number, the sample was then divided into male and female constituents to verify if sex ratio among the sample was representative of the same ratio for the population (M-48%; F-52%). Since this was not achieved, and that male contributors were over represented, the following procedure was to collect female only responses until the ratio was achieved. According to Griskevicius, Tybur, Ackerman, Delton, Robertson and White, (2012) this ratio is an important parameter because: “*sex ratio [also] has pervasive effects in humans, such as by influencing economic decisions*” (according to this study: “(…) *sex ratio influences saving, borrowing, and spending. Findings show that male-biased sex ratios (an abundance of men) lead men to discount the future and desire immediate rewards. Male-biased sex ratios decreased men’s desire to save for the future and increased their willingness to incur debt for immediate expenditures*”). This do not mean the others (age, income, occupation and geographical location) are not. It was simply a choice that was to be made in accordance with obvious time-consuming restrictions. In face of this dilemma, it was necessary to continue with the collection until the true ratio was matched or nearly equalled. As such, the sample format is likely to be similar to a quota sampling

Moreira P.P., Caetano F. 2017. Liquefied Natural Gas as an Alternative Fuel: a Regional-Level Social Cost-Benefit Appraisal. *Eastern European Business and Economics Journal* **3(2)**: 122-161.

method, a non-probabilistic version of stratified sampling. The Portuguese sex ratio is the quotient of males versus females in the Portuguese population as from the PORDATA database as of December 31st 2015. Nevertheless, after data have been processed, some other socio-economic ratios display a somewhat proximity with those from real world. This method of achieving equal sex ratio representation led to a final sample of 261 collected responses (Figure 4).

Fig. 4. Socio-economic ratios from the sample vs. population.

		Sample (%)		PORDATA (%)
Gender	Male	47.9%	Male	48.0%
	Female	52.1%	Female	52.0%
		n= 261		*N= 7016000*
Age	18-34	23.8%	18-34	28,3%
	36-54	43.3%	36-54	44.0%
	55-69	33.0%	55-69	27,6%
Education	Incomplet.	20.3%	Incomplet.	20.4%
	Compl.	23.0%	Compl.	20.4%
	Grad.	38.7%	Grad.	10.5%
	MSc/PhD	18.0%	MSc/PhD	6.0%
Occupation	Student	13.0%	Student	7.4%
	Unempl.	8.0%	Unempl.	10.0%
	Employed	67.4%	Employed	70.0%
	Retired	11.5%	Retired	9.4%
Income*	500-1000	26.8%	500-1000	39.0%
	1000-2000	33.7%	1000-2000	26.0%
	>2000	25.3%	>2000	11.1%
Location	North	25.7%	North	35.6%
	Center	39.5%	Center	41.2%
	South	29.1%	South	23.2%
	Other	-	Other	-

* 37 of the respondents (14%) didn't answered this question.
Therefore it is not possible to ascertain the true values.

Indeed, we are well aware that due to the "opportunistic" character of the sample this sample may not be representative of the population. Yet, in spite of its scientific fragility, this type of sampling can be used successfully in situations where grasping general ideas and identifying critical aspects may be more important than scientific objectivity as it was the case. In view of this, and if this particular Web survey is to be judged as less inappropriate, we recall the words of Couper (2000: 465-466): "*Any critique of a particular Web survey approach must be done in the context of its intended purpose and the claims it makes. Glorifying or condemning an entire approach to survey data collection should not be done on the basis of a single implementation, nor should all Web surveys be treated as equal*".

Similarly to the pre-test major preoccupation of the online questionnaire was to ensure that the core questions were broadly understandable and perceived as consequential. In this research we assume that people truthfully answered the questions that were asked about, albeit Carson, Groves (2011) argue that in general, this assumption is likely to be false if the survey question is consequential and the respondent is acting like a rational economic agent. Indeed, Carson, Groves (2011) divide questions into two types: consequential and inconsequential. For a question to be consequential, survey respondents need to believe, at least probabilistically, that their responses to the survey may influence some decision they care about. The key question is how to interpret such information and the nature of the deviations from truthful preference revelation that were likely to be observed in particular instances (Carson, Groves, 2011). Finally, and to ensure respondents provide thoughtful responses to the questions, was explicit written in the questionnaires' preamble that the information they provide will remain anonymously and for this sole purpose.

Foreword of the questionnaire

Since the results of this questionnaire will be later used within the Doctoral thesis: "Shipping and Sustainability - Liquefied Natural Gas as an Alternative Marine Fuel: Evidence from Portugal", which is currently under development, a bilingual online survey was posted at Survey Monkey, (exception was made to the preamble text due to word count limitations) but also a Portuguese language one, posted at Survio to reach those potential respondents who could be adverse to a bilingual survey. The English translated preamble text, which gives the rationale and the aiming, is at it follows:

"*Emissions from traditional shipping fuels are an invisible killer that cause lung cancer, heart disease, atmospheric ozone, damage heritage and crops and ecosystems, and contribute to the greenhouse effect. The costs of the harmful effects associated with these energy options are borne by society as a whole and tend to be exacerbated in the near future.*

Moreira P.P., Caetano F. 2017. Liquefied Natural Gas as an Alternative Fuel: a Regional-Level Social Cost-Benefit Appraisal. *Eastern European Business and Economics Journal* **3(2)**: 122-161.

For example, if another type of less polluting fuel is adopted about 60,000 premature deaths per year in Europe can be avoided. The viability of Liquefied Natural Gas (LNG) as an alternative fuel for maritime transport is the case under study; a gas that eliminates 100% of sulphur dioxide (SO2) and microparticles and nitrogen oxide (NOX) by about 90%. LNG is assumed to be a bridge fuel applied to the maritime industry because there is NO global available fuel at short-term for this industry that replaces traditional fuels while fulfilling three fundamental assumptions: being abundant, cheap and whose technology is proven. A transition fuel because, although it contributes to a 25% reduction in carbon dioxide (CO2) emissions, it is a fossil fuel. However, with the introduction of LNG there is a non-negligible reduction of Greenhouse Gas emissions and an extreme improvement in the air we breathe - a public and universal good - to which it is possible to ascribe an "economic value". However, as such a market does not exist it is through this questionnaire that an approximate value can be determined. This research follows a contingent evaluation approach; a technique based on the idea of a hypothetical market where a public good is traded. The good to be valued by members of the hypothetical market (the atmospheric air therefore) conveys the approximate value of their willingness to pay for the good. The value of the statistical mean will then be used as a metric in the development of a Social Cost-Benefit Analysis for the purpose of analysing the economic feasibility of adopting LNG at the national level. Note that "willingness to pay" does not mean that a hypothetically adopted policy should be paid by the taxpayers. It is simply intended to attribute a price to an asset for which there is no market. All contributions will remain anonymous".

Analysis and discussion of the survey results

A total of 261 responses have been collected an acceptable number, nevertheless if one takes into account the difficulty to reach people and make them respond to this type of inquiries. Sent emails were those provided from authors' private, professional and academic contact lists. Also social networks were used to send invitations to access the survey platforms. A particular strategy adopted can be viewed as emulating "snowball" sampling, a technique where existing study subjects recruit future subjects from among their acquaintances resending the survey link to their contacts lists. It is thought that around 600 emails were sent at total.

From the 261 collected responses, 19 (9M; 10F) assume their willingness not to pay any amount at all or about 7.3% of the respondents. The mean WTP was calculated in €6.8 after been rounded up to the nearest decimal being female, in the number of 136, those who are willing to pay the most in average: €7.2 against €6.6 average from their 125 male counterparts.

As already said, women present a higher tendency to value more the asset in question, in average, with more than 66% bidding €10, while 58.4% of the men does it. The distribution based on age shows that about 44% of the respondents are situated in the 35-54 years age group. To what matters about the average willingness to pay, the age has a positive effect, being the 35-54 and 55-69 groups components those who are willing to pay more (€6.7 and €6.4). However, the difference between those and the younger group (€5.4) may be due to the fact that, as "opened" rank groups, it may, and it will, include considerably wealthy strata individuals within. In this case, the probability that WTP could fall with age is not a priori discarded (see, e.g. Bleichrodt, Crainich, Eeckhoudt, 2002; Itaoka, Krupnick, Akai, Alberini, Cropper, Simon, 2005).

As for the academic background, 38.7% of the respondents have, at least, a complete graduate level education. To what matters about the average willingness to pay based on academic background, linearity was not found since those who hold an MSc or a PhD are willing to pay "only" €6.6 in contrast with those belonging to the graduate level (€7). The complete secondary and incomplete secondary group's mean is €6.1 and €3.3, respectively, in accordance with results from related studies on environmental improvements (Belhaj, 2003; Wang, Zhang, 2009; Wang, Wu, Wang, Yang, Chen, Maddock, Lu, 2015).

The distribution based on the occupation shows that 67.4% of the respondents are employed and from the statistical analysis they are also those who want to pay more for a better air quality: €6.8. Students, i.e. those who are, in theory at least, younger, more educated towards environmental challenges and more prone to react in conformity, are willing to pay only €4.9, which in fact is in accordance with their expenditure capacity, disposable income or lack of it. Indeed, income levels display higher mean WTP's: the amount increases as wealth's increases too and, in accordance with other similar surveys (Wang, Whittington, 2000; Wang, Zhang, 2009; Baumgärtner, Drupp, Munz, Meya, Quaas, 2011; Wang, Wu, Wang, Yang, Chen, Maddock, Lu,

Moreira P.P., Caetano F. 2017. Liquefied Natural Gas as an Alternative Fuel: a Regional-Level Social Cost-Benefit Appraisal. *Eastern European Business and Economics Journal* **3(2)**: 122-161.

2015), this was expected to happen even tough income is different from wealth for it captures monetary influx but not existing cash reserves or fixed expenditures. Hence, the >2,000 income strata average is €7 followed by the 1,000-2,000 (€6.8) and by those earning 500-1,000 (€3.8). 37 of the respondents have opted not to answer the income question and if this number would be accounted for it could have produced distinct outcomes.

According to the health status, those 45 who positively have responded suffering from air-related diseases show a lower propensity to pay: €5.6 whereas those who declared not to suffer would pay €6.4. This apparently surprising result is nonetheless in accordance with the results from surveys pertaining to air pollution-related respiratory disease and WTP (e.g. Wang, Zhang, 2009:5). In reality, being those who address to respiratory problems the exception, very few studies reporting that people with respiratory symptoms are more willing to pay for air quality improvement than those who had no symptoms do exist.

From the fifteen respondents located abroad (for this study purposes those who are living in the islands of Madeira (2) and Azores (2) were considered as from located in the South region) the respondent's distribution is as it follows: Brazil: 3; France: 2; Germany: 3; Luxemburg: 1; Netherlands: 1; Switzerland: 2; UK: 2; and U.S.: 1.

Figure 5 presents a weighted distribution according to the independent variables.

Moreira P.P., Caetano F. 2017. Liquefied Natural Gas as an Alternative Fuel: a Regional-Level Social Cost-Benefit Appraisal. *Eastern European Business and Economics Journal* **3(2)**: 122-161.

Fig. 5. Weighted distribution according to the independent variables.

		No amount		€ 1.00		€ 3.00		€ 10.00			
		n	%	*n*	%	*n*	%	*n*	%	Σ	Mean (€)
Gender	Male	9	7.2%	17	13.6%	26	20.8%	73	58.4%	125	6.6
	Female	10	7.4%	12	8.8%	24	17.6%	90	66.2%	136	7.2
									Sample (n) =	*261*	**6.750**
Age	18-34	3	4.8%	15	24.2%	17	27.4%	27	43.5%	62	5.4
	35-54	12	10.6%	4	3.5%	31	27.4%	66	58.4%	113	6.7
	55-69	4	4.7%	10	11.6%	26	30.2%	46	53.5%	86	6.4
Education	Incomplet.	5	9.4%	23	43.4%	14	26.4%	11	20.8%	53	3.3
	Compl.	3	5.0%	11	18.3%	15	25.0%	31	51.7%	60	6.1
	Grad.	6	5.9%	4	4.0%	30	29.7%	61	60.4%	101	7.0
	MSc/PhD	5	10.6%	3	6.4%	12	25.5%	27	57.4%	47	6.6
Occupation	Student	3	8.8%	8	23.5%	10	29.4%	13	38.2%	34	4.9
	Unempl.	2	9.5%	8	38.1%	6	28.6%	5	23.8%	21	3.6
	Employed	12	6.8%	15	8.5%	43	24.4%	106	60.2%	176	6.8
	Retired	2	6.7%	5	16.7%	13	43.3%	10	33.3%	30	4.8
Income*	500-1000	3	7.1%	23	54.8%	28	66.7%	16	38.1%	70	3.8
	1000-2000	7	8.6%	5	6.2%	24	29.6%	52	64.2%	88	6.8
	>2000	2	3.3%	3	5.0%	22	36.7%	39	65.0%	66	7.0
Location	North	5	14.7%	11	32.4%	28	82.4%	23	67.6%	67	4.9
	Center	8	9.1%	9	10.2%	28	31.8%	58	65.9%	103	6.5
	South	6	7.6%	7	8.9%	15	19.0%	48	60.8%	76	7.0
	Other	0	0.0%	0	0.0%	3	15.8%	12	63.2%	15	8.6
Health	Yes	4	11.1%	8	22.2%	12	33.3%	21	58.3%	45	5.6
	No	17	9.2%	23	12.5%	58	31.5%	118	64.1%	216	6.4

* 37 of the respondents (14%) didn't answered this question.

To what concerns to a potential value transfer application from this study to other locations or countries one should note that, as some authors claim, (e.g. Barbier, Czajkowski, Hanley, 2015), the WTP for environmental improvement variation with respect to income are often based on the assumption that the income elasticity of these WTP values must be constant. If this elasticity varies significantly with income levels, then assuming a constant elasticity will lead to significant errors in the WTP estimates based on these value transfers. As so, the best way to proceed is by estimating local/national income elasticities of the WTP for environmental improvement, to ensure that the correct functional form of the WTP-income elasticity relationship is estimated.

Theoretical construct validity and predictive power

Theoretical construct validity is assessed by considering the relationship between the CV result and other variables that theory suggests are related to it in some particular way. It often refers to how well the measurement is predicted by factors that one would expect to be predictive a priori, providing an equation that relates some indicators of the respondent's

Moreira P.P., Caetano F. 2017. Liquefied Natural Gas as an Alternative Fuel: a Regional-Level Social Cost-Benefit Appraisal. *Eastern European Business and Economics Journal* **3(2)**: 122-161.

WTP to the respondent's characteristics and to characteristics of the good. For the air we all breathe, environmental attitudes that come specifically from the sample should have a significant impact in respondents' willingness to pay. Of course, even if it has predictive power, this does not necessarily mean it will have ex ante predictive power (e.g. Perman, McGilvray, Common, 2003).

Indeed, questionnaires' construct validity was demonstrated by the agreement level with other measures as predicted by theory. For example, income has a positive effect on WTP; the upper monthly gross revenue range presents a higher WTP compared with the previous ranges. Conversely, in CV theory and in the case of use values, age has a negative effect, differently from our results: in fact, people aged 36-54 evidence a superior WTP in contrast with younger people. Geographic proximity usually has a positive effect. In our study this issue is not such relevant since the capacity of pollutants to spread within long distances from the point they occur was due stressed, and, by another hand, people who live near or nearby the littoral are not necessarily aware of the problem: maritime pollution is almost produced at high seas and not near the coast, nor the intensity of traffic at Portuguese ports imparts such impression. Nevertheless respondent's location displays an interesting outcome. Those outside the Portuguese territory are willing to pay more (€8.6) than any other located elsewhere. North (€4.9) presents a somewhat discrepancy in comparison with other parts of the Portuguese territory: Centre (€6.5) and South (€7.0). Also variables related to the unsuccessful of the program to provide the good or that the payment vehicle is not appropriate tend to be very negatively associated with WTP (Carson, Flores, Meade, 2000). In our specific case this was, even admitting partially, assumed by those who have responded no to any bidding amount.

Estimating costs and benefits: data sources and methodology

Despite Portuguese domestic emissions from shipping account for a small percentage of national emissions when compared with those produced by international navigation, given the fact that the Iberian coast is not an Emission Control Area (ECA region) ships are still allowed to burn marine heavy fuel oil with a sulphur content up to 3.5% (Moreira, 2016). As major emissions occur far from coast people are not aware as they should be about the reality upon which our study was based: that they are exposed to a silent killer in the form of noxious marine emissions. Concomitantly, they are very slightly aware of the contribution for climate change and completely unaware about the non-health damages from shipping emissions. These assumptions are underpinned from the in-person interviews. Despite the small size of the national merchant fleet in 2014 and according to the Portuguese Environmental Agency (APA) Inventory Report, domestic navigation was responsible for the following emissions (in kt): 3.1 of NO_x; 1.7 of SO_2 and 0.6 of PM considering both $PM_{2.5}$ and PM_{10}. Those emissions to national inventory contribute are, respectively: 1.9%; 4.9% and 1.2%, being sulphur emissions those to keep in mind.

Pollutant emissions indicators

Pollutant emissions indicators were collected from the national inventory as it stands from the Portuguese Environment Agency 2016 National Inventory Report on GHGs (NIR) which fuel consumption in 2014 estimates follow a sector-specific category bottom-up approach (Tier II) combined with a top-down approach for calibration (for CO_2 emissions). The GHG emission inventory is the official annual accounting of all anthropogenic emissions and removals of greenhouse gases in Portugal. The inventory measures Portugal's progress against obligations under the United Nations Framework Convention on Climate Change (UNFCCC), the Kyoto Protocol and the European Union agreements. Final emissions presented by pollutant substance type were defined according to the data given by the national inventory for the year 2014. Monetised climate benefits are those obtained from reduced climate change-induced damages embedded in carbon prices which reflect expected uncertainties about real-world climate change related problems in the future and the costs incurred with adaptation measures. Monetised health benefits are those from the aggregated health damages reduction (saved human lives from premature death and other health benefits) in accordance to Holland's (2014) methodology, using the scenario envisaged for year 2014. Non-health benefits are those arisen from net benefits to crops from ozone reduction and benefits to materials from a reduction in SO_2 levels. Costs are those incurred with the implementation of mitigation measures and by which people are willing to pay for, deduced from the survey's results.

Marginal costs for pollutant from maritime transport damages were those from EcoSense model as it is used in Korzhenevych, Dehnen,

Moreira P.P., Caetano F. 2017. Liquefied Natural Gas as an Alternative Fuel: a Regional-Level Social Cost-Benefit Appraisal. *Eastern European Business and Economics Journal* **3(2)**: 122-161.

Bröcker, Holtkamp, Meier, Gibson, Varma, Cox (2014) for sea areas costs per pollutant together with those from Holland, Watkiss (2002) for rural areas values. CO_2 was valued at €96.5/tonne mean assuming a 20% reduction or 33.6kt net emissions. Further to this, it is here assumed that the effects quantified for NO_x as ozone precursor was estimated to account for 20% of total ozone damages whilst materials damage accounts for around 10% of SO_2 externalities (non-health damages), following what is suggested by Holland, Watkiss (2002). The present study does not take into consideration effects on productivity losses and healthcare costs. Pollutant emissions emitted by ships will be derived by considering the total concentration of this pollutant at national level and by determining which part of the total concentration is attributable to domestic shipping, according to the same methodology used by Miola, Paccagnan, Mannino, Massarutto, Perujo, Turvani (2008), for the SO_x emitted by ships. Figure 6 represents the emissions share from domestic shipping for the national inventory after data been collected from the APA's NIR on GHGs, 2014.

Fig. 6. Emissions share from domestic shipping for the national inventory.

Pollutant	NOx	SO_2	PM	CO_2
National shipping emissions (kt)	3.1	1.7	0.6	168
% Reduction from LNG vs. HFO (%)	90	100	98	20
Net emissions (kt)	2.79	1.7	0.6	33.6
National inventory (kt)*	159.6	34.8	99	47,215
National contribution	1.9%	4.9%	0.6%	0.4%
Effects on	Health (nitrate aerosols); Crops (O_3)	Health (sulphate aerosols); Materials (acidity)	Health ($PM_{2.5}$ and PM_{10})	Climate change
Weighted % for damage reduction on:	Health: 100%; Crops: 20%	Health: 100%; Materials: 10%	Health: 100%	GHGs: 20%

* Without land-use, land-use change and forestry (LULUCF).

As stated before, annual value of damage costs were based in Holland (2014) report prepared under contract to assess and to inform the revision of the EU's Thematic Strategy on Air Pollution for $PM_{2.5}$ and O_3 considering the anticipated development of emissions and their effects over the period to 2025 and 2030, featuring several expected scenarios.

Moreira P.P., Caetano F. 2017. Liquefied Natural Gas as an Alternative Fuel: a Regional-Level Social Cost-Benefit Appraisal. *Eastern European Business and Economics Journal* **3(2)**: 122-161.

Critical values for inputs are those calculated from Holland's year 2014. This year's values, even though are not discriminated in Holland's time series, were chosen to compare with the same year's data from the Portuguese National Inventory. Therefore, all the following values respecting the year 2014 were estimated according with an interpolation established between years with available data: 2010 and 2015. Following the percentage in the specific emissions as it arises from literature review (EMSA, 2010; Kolwzan, Narewski, 2012) national quotas for health damages from domestic shipping is as it follows: Ozone: for NO_x was considered a reduction in 90% as ozone precursor; 100% for SO_x, 98% reduction for PM (health) and a reduction of 20% for CO_2. Figure 7 displays the percentages based on the expert estimates.

Fig. 7. Emission reduction with LNG as fuel.

Emission component	Emission reduction with LNG as fuel	Source
CO_2	25% 12-27% 20-25%	Winnes et al. 2015 Lowell et al. 2013 Laugen, 2013
SOx	100% 100% 100%	DNV-GL, 2015 Deal, 2013 Jónsdóttir, 2013
NOx	85% 85-90% 85-90% 85-90%	DNV-GL, 2015 Laugen, 2013 Herdzik, 2011 Jónsdóttir, 2013
PM	95-100% 100% 98-100%	DNV-GL, 2015 Laugen, 2013 Deal, 2013
VOC	100% 100% 98-100%	Wärtsilä, 2016 Laugen, 2013 Deal, 2013

Although NO_x also contribute for the formation of acid rain, causing damages in infrastructures, forests and crops, it was not considered in the non-health benefits assessment. Similarly, volatile organic compounds (VOCs) are not addressed as ozone precursors because those emissions are more than an order of magnitude smaller than NO_x contribution from domestic navigation: about 0.1%. Holland (2014:9), have considered not including quantification of impacts against functions for NO_2 and SO_2 because under The Clean Air for Europe (CAFE) Programme "*separate inclusion of functions for these pollutants would incur at least some*

Moreira P.P., Caetano F. 2017. Liquefied Natural Gas as an Alternative Fuel: a Regional-Level Social Cost-Benefit Appraisal. *Eastern European Business and Economics Journal* **3(2)**: 122-161.

double counting". Diversely of that report however, our analysis include the quantification of those pollutants since the purpose is to estimate the overall effect of air pollution on the exposed population. In fact the Health Risks of Air Pollution in Europe – HRAPIE project of the World Health Organization (WHO, 2013) indicates that NO_2 effects should be quantified and added. As such, NO_x was included as ozone precursor while the SO_2 was considered a secondary PM precursor in a way to achieve a broad completeness. As previously said, CO_2 was priced at the value of €96.5/t after updated to 2014 prices using the Eurozone CPI deflector.

Estimated health benefits
According to Holland (2014), data from Portugal show a decrease in people's years of life due to chronic PM exposure in the year 2014 to reach a total sum for the population of about 58,000 years being some 3,190 attributed to 5.4% domestic PM shipping contribution (including SOx as a precursor). For the same year, deaths from chronic PM exposure should affect some 5,825 individuals, being the death toll of 320 individuals attributable to shipping, using the same methodology. Deaths from short-term O_3 exposure in 2014 were estimated in 512 being 10 provoked by 2% contribution for ozone formation from shipping. All aggregated damage costs are quantified in a total of €4610M according to year 2014 for Portugal (Table A.3.6 – Aggregated Health Damages in the aforementioned study). Based in the aggregated health damage costs, the following health benefits from a reduction in marine airborne pollutants with the introduction of LNG as an alternative fuel have been collected:

<u>Monetised health benefits</u> (using VOLY – value of life year)
According to year 2014 and in line with our inferences, PM emissions from shipping are responsible for 0.6% of the national inventory, SOx for ~5% and ~2% for O_3. Health benefits attributable to shipping emissions reduction are valued in (the values have been rounded up to the nearest unit) and according to the following equation:

Moreira P.P., Caetano F. 2017. Liquefied Natural Gas as an Alternative Fuel: a Regional-Level Social Cost-Benefit Appraisal. *Eastern European Business and Economics Journal* **3(2)**: 122-161.

$$NB = \sum \left[V_P \cdot Ra \right]$$

Where:
NB is net health benefits;
V_P is the aggregated health damage for Portugal, year 2014;
R is the pollutant (NO_x, SO_x, PM);
a = as % of domestic shipping emission*.

(*Note: To make this calculation reasonable, it is assumed that % of domestic emissions contributes exactly the same % of the aggregated damage costs for Portugal).

Figure 8 below summarises monetised benefits from avoided health problems.

Fig. 8. Monetised benefits from avoided health problems.

O_3 (as NO_x)
4610 * 0.02 = €92M/year = €276M for the three years policy
SO_x (as SO_2)
4610 * 0.05 = €231M/year = €693M for the three years policy
PM (PM_{10} and $PM_{2.5}$)
4610 * 0.006 = €28M/year = €84M for the three years policy

Summed up, equals €1,053M, being the first benefit from avoided damages, in this case respecting health status.

Estimated climate and non-health benefits
Monetised climate benefits
Domestic shipping was responsible for 0.4% CO_2 emissions in the year 2014, or some 168 kt. We do consider a reduction of 20% in those emissions from the adoption of the LNG as a substitute fuel (Laugen,

Moreira P.P., Caetano F. 2017. Liquefied Natural Gas as an Alternative Fuel: a Regional-Level Social Cost-Benefit Appraisal. *Eastern European Business and Economics Journal* **3(2)**: 122-161.

2013; Lowell, Wang, Lutsey, 2013; Winnes, Styhre, Fridell, 2015). Therefore, 33.6kt reduction represents an annual value of €3.24M or ~€9.70M benefit for the three year policy timetable.

Monetised non-health benefits

Non-health benefits were much more complicated to estimate; unfortunately Holland's study do not address marginal external costs for ozone and PM reduction – it only depicts yearly benefits arising from the compliance of several scenarios compared with 2010 baseline year drawing on past €/tonne estimates. Thus, we took hand from Korzhenevych, Dehnen, Bröcker, Holtkamp, Meier, Gibson, Varma, Cox (2014) Report for the European Commission 2014, the RICARDO – AEA Update of the Handbook on External Costs of Transport, which settle damages costs of main pollutants in sea areas referring to year 2010. After adjusting remaining North-East Atlantic (referring to Bay of Biscay and Iberian Coast) values to CPI year 2014 European average damage, costs are depicted in Figure 9.

Fig. 9. Maritime transport: damage costs of main pollutants in sea areas, in €/ tonne.

Sea Region	NOx	$PM_{2.5}$	SO_2
Baltic Sea	4700	13800	5250
Black Sea	4200	22550	7950
Mediterranean Sea	1850	18500	6700
North Sea	5950	25800	7600
Remaining North-East Atlantic	2379	5869	3067

This data could be used directly as inputs due to its nature of damage costs borne by maritime transport in European waters. In this case we proceed by calculate emissions average costs from offshore emissions and rural emissions values as it follows: Portugal (remaining North-East Atlantic): O_3 marginal external costs of emissions in rural areas, adjusted to CPI year 2014 European mean prices, results in: NO_x: €5315/t.

Next step is to calculate the mean value of costs between sea and rural areas for these two pollutants: NO_x: 2379 + 5315/2 = €3847/tonne. For SO_2 as PM precursor is not necessary to perform this exercise. CO_2 damage costs as those from Korzhenevych, Dehnen, Bröcker, Holtkamp, Meier, Gibson, Varma, Cox (2014) updated to Eurozone CPI deflector as previously cited. Finally we can proceed with calculations to quantify

Moreira P.P., Caetano F. 2017. Liquefied Natural Gas as an Alternative Fuel: a Regional-Level Social Cost-Benefit Appraisal. *Eastern European Business and Economics Journal* **3(2)**: 122-161.

climate change reduction benefits and ozone and PM precursors following Holland, Watkiss (2002) methodology in which O_3 damage to crops is estimated to account for a little over 20% of total O_3 damages, whilst materials damage accounts for around 10% of SO_2 externalities. Figure 10 shows climate change, ozone and PM precursor's reduction benefits.

Fig. 10.
Net health, climate, materials and crops benefits for Portugal in a 3y period.

CO_2 (Climate Change)	NO_x (O_3 precursor)	SO_2 (PM precursor)
33,600t x €96.5/t = €3.24M x 3 = €9.7M	2,800t x €3847/t = €10M x 3 = €30M (20% = €6M)	1,700t x €3067/t = €5.2M x 3 = €15,6M (10% = €1,56M)
Net benefits for climate change mitigation: 9.7M€	Net benefits to crops from Ozone reduction: 6.5M€	Net benefits to materials from SO_2 reduction: 1.56M€

Summed up, equals ~€53M for the three years policy, being the second and third benefits arising from our analysis. Last benefits have shown to be very small in comparison to those quantified for health.

Estimated costs

Mean WTP reveals the cost to avoid a certain level of pollution. Estimating individual's willingness to pay as it comes from the survey results the value of €6.8 was set as defining the maximum amount that can be subtracted from an individual's income to keep his/her expected utility unchanged. To estimate society's willingness to pay that value was multiplied by the resident population to obtain the first benefit attributable to the environmental asset in question. For that purpose, the Portuguese Database of PORDATA (http://www.pordata.pt) was consulted in order to determine the number of residents in the Portuguese territory comprising the Atlantic islands of Madeira and Azores as of 2015. Thus, the number of ~7,016,000 individuals aged between 18 and 69 years was multiplied by the WTP obtained from the sample giving a total of €47,7M/year which multiplied by the three years' time project/policy gives the sum of €143M, that is, the theoretical amount that around 83% of Portuguese nationals would be willing to pay in the period of three years to improve the quality of the air in the terms presented by the survey's rationale. To put in another way, this sum

Moreira P.P., Caetano F. 2017. Liquefied Natural Gas as an Alternative Fuel: a Regional-Level Social Cost-Benefit Appraisal. *Eastern European Business and Economics Journal* **3(2)**: 122-161.

represents both the value that people attach to this non-market asset and the amount national government could hypothetically collect through taxes, or equivalent, to spend in order to achieve a better air quality by introducing financial aid allocated to ship-owners to invest in vessel's LNG retrofitting and/or in new orders, including public aid to upgrade existing facilities or to new ones or to help to establish an LNG supply chain. Following this reasoning, this also implies that the European Commission or other governmental body or country organisation can achieve similar findings assuming that the inherent results can be replicated elsewhere. Summarising, we have:

a) Health benefits: 1,053M€
b) Climate 9.7M€
c) Non-health benefits: 8M€
d) Costs: 143M€

Figure 11 gives a general overview of costs and benefits and the resulting Net Present Value (NPV) of the implemented policy.

Fig. 11.
Costs and benefits and the resulting Net Present Value (NPV) of the implemented policy

Costs		Totals
	From Willingness To Pay €143M	
Net costs		€143M
Benefits		
Mortality reduction (health benefits)		
	From Ozone	€276M
	From SOx	€693M
	From $PM_{2.5}$	€83M
Climate		
	In reduced CO_2 as a GHG	€9.7M
Materials		
	In avoided damages	€1.56M
Crops		
	From reduced losses	€6.5M
Net benefits		~€1,070M
Net Present Value: €927**M**		

According to the Net Present Value equation, NPV is positive in €927M being net benefits 7.5 times superior to costs, the same is to say the benefit-cost ratio is almost 8. To further increase the robustness of this value one should bear in mind that direct benefits are specific to the

Portuguese population but the actions proposed also brings benefits to third party countries through the transboundary decrease of pollutants because others who suffer but live in a different country should count. This outcome also does not take into account the effects from the reduction of acid rains on forests nor ecosystems eutrophication which will positively impact the general assessment and the final result benefits'. By another hand, if we have used the Value of Statistical Life (VSL) instead of VOLY, for the calculation of net benefits for human health, the final value will surpass at least in two thirds (Holland, 2014:27) which will strengthen the conclusions drawn here. Finally, we should consider that whilst costs are to be incurred in a time span of three years, the benefits, that is, air quality improvement, and reduced risks from a changing climate will last for long.

The present analysis shows that beneficial results are undoubtedly superior to costs, even assuming some uncertainties from external costs quantification, benefit-cost ratios of such order of magnitude are bullet-proof. The SCBA final outcome is not intended to make this analysis as doctrine but make it compatible with other in their differences in order to obtain, by the multiplicity of looks, a broader view.

Policy implication for the society as a whole

Human health and environmental concerns are the underlying support to discuss and evaluate LNG as an alternative fuel to ships' engines based on the rules and principles for progressive decarbonisation for maritime transport. Since all industrial sectors need to contribute with their share for energy transition, the ultimate objective of this study was to verify to what extent the substitution of oil-based fuels by natural gas – until feasible technically and economically renewable energy sources are available -, can reduce GHG emissions, contribute for the phasing out of oil dependency and provides better air quality, taking into account social negative externalities. In fact, under the scenario of a widely decarbonised transport sector fossil gas can merely represent a bridge technology – to renewable energy sources must be given preference as quick as possible. Yet, for marine applications, there is no immediate alternative to the LNG to ensure the transition to a more sustainable fleet. Some of the toughest challenges faced while elaborating the survey study was to override the difficulty for message-passing be effectively apprehended by people about what do we mean with "willingness to pay"

Moreira P.P., Caetano F. 2017. Liquefied Natural Gas as an Alternative Fuel: a Regional-Level Social Cost-Benefit Appraisal. *Eastern European Business and Economics Journal* **3(2)**: 122-161.

for a non-market asset. Some have thought they were asked to pay from their own pockets to repair something they were not directly responsible for damaging. While we sympathetically recognise their feelings, after all no one can discard its part of responsibility due to the simple fact that all of us belong to the society and society is driven by our wishes and consuming preferences; we are all self-interested *homo œconomicus*. Ethical consumers hoping to minimize their carbon footprint should be able to ask about not only the provenance of, - saying - his/her new pair of sneakers, but also should be able to capture the process in which it was produced. At the end we need to take into account the life cycle of economic goods and products, from the raw material extracted, the manufacturing stages and usage until its final disposal on a landfill as by-product (or worst, in the Oceans, while keeping the intention, whenever possible, that this waste can be recovered, reused or recycled). Those considerations were already present at the time the pilot-study was conducted and it was relatively simple to explain to the interviewee what those concepts and questions meant. Inversely to personal interviews, the online survey does not allow the detailed description of what is at risk, despite the effort spent to accomplish that task.

The present study demonstrates that LNG can be an efficient end-use fuel to assure that transition to reduce emissions of polluting gases thus promoting people's health and minimising shipping footprint. For consumers, the LNG inasmuch as it produces less negative externalities will improve their utility function regarding this option, an option that can also winning consumers by accentuating desirable climate, health and non-health qualities. People are mindful and willing to pay for to breathe a better air when confronted with the challenge of the upcoming environmental and climate-related damages. Both pre-study and the online questionnaire had the merit to make them aware of. The price people, and hence, the society, are willing to pay provides the accuracy and relevance of an empirical study to fully assess the economic desirability of an environmental change.

Discussion

The policy section above should effectively highlight the relevance of the contributions of this study in the context of current marine fuel structure in Portugal. As already noted, both the domestic fleet and foreign ships on route within Portuguese waters burn essentially residual fuels. Several studies do exist in which the fuel switch from traditional marine fuels to the LNG is analysed. Yet, and as far as we know, this is the first time that a study about the shift from traditional fuels to LNG is made on the basis of a social cost-benefit analysis in which people were directly asked about their willingness to pay and it is in this peculiarity that lies the strength of the present study as a novelty in academic terms. Unfortunately, since national and international literature does not exist for the sake of comparing the results obtained in this research, the outcomes cannot be confirmed or excluded. The approach to calculate pollutant emissions from shipping based on NIR indicators relies basically, by one hand, in the degree of certainty embedded in the national inventories and by another hand, in the method itself. Indeed, we are well aware that this process of quantification involves uncertainties and some gaps. Since we assume national data values as trustfully accurate major uncertainties are thus relegated to the process of calculate benefits from climate change impacts, health aggregated costs and non-health damage costs and this can be seen as a limitation. Yet, the quantification process should be seen as a proxy and this means that the outcome described here is not one monolithic value describing external costs with high certainty but rather displays a close proximity range in which true value lies with. Despite these uncertainties, this method is seen to be useful as the knowledge of an order of magnitude on health, crops and materials benefits and is obviously better for policy decisions than having no quantitative information at all since important parameters that cause costs and how these costs can be mitigated resulting in benefits were identified. Moreover, uncertainties about overall benefits mostly reflect the uncertainties in our knowledge about the true impacts from a reduction in atmospheric pollution. This is correct and not a deficiency of methodology; a scientific method cannot transfer uncertainty into certainty (Bickel, Friedrich, 2001). Knowledge gaps are assumed where information about monetary valuation is lacking (e.g. GHG reduction effect, the impact of noxious substances over the ecosystems, i.e. acidification and eutrophication and cultural heritage, the macroeconomic effects of reduced crop yield, altruistic effects of impacts and other unknown effects), so that benefits estimates cannot be provided.

Moreira P.P., Caetano F. 2017. Liquefied Natural Gas as an Alternative Fuel: a Regional-Level Social Cost-Benefit Appraisal. *Eastern European Business and Economics Journal* **3(2)**: 122-161.

Recently a study for the implementation of a LNG supply chain in the Iberian Peninsula, including new and the expansion of existing facilities was launched with financial aid from the European Commission in the amount of €33.3M. Among the project's partners one cannot find any of the five main continental Portuguese ports even though the port of Sines, in the Atlantic façade, being the one hosting the only Portugal's LNG terminal. By the other hand, maritime-based policies to counteract maritime noxious emissions are none so no measures are planned to be adopted in the near future. Therefore, as this subject is apparently marginal within the scope of the broad national energy agenda, to what concern to health improvement and climate change mitigation policies, we assume that decisionmakers are in need to fully understand the consequences of a doing nothing scenario. In this sense this study can help draw future marine fuel policies by highlighting to the subject of LNG as a marine transition fuel, the visibility it merits. By identifying issues of risks to health and to environment from marine-borne air pollution, this will help to fill gaps in stakeholders' and policy-makers' knowledge. The adoption of LNG as an alternative fuel is a cost-effective solution in the context of "value for society" instead of "value for money" and is consistent with real-world efficiency gains. The applied research method used here seeks to find a solution for an immediate problem the society is facing and, although assuming Portuguese particularities, aims that findings can be reproduced and applied elsewhere. In fact, by means of using the same methodologies here depicted, at first hand, people in other locations should be inquired about their WTP and, at second, that particular country-level studies to evaluate benefits shall be performed. Of course the outcomes will vary as different are people's preferences and perceptions and country's particulars.

Future studies and research

First of all, both the pre-test and survey's samples should be augmented to further represent the population. As already cited, such in-person interview surveys are very time-consuming and cost money especially when there is a need to travel and meet the respondents at different locations. Thus, to undertake such a task some funding process scheme should be put in place. With the allocated monetary resources it will be possible to deepen the research and ultimately to compare results. We also could refer to future research studies those who can potentially cover the linkage between marine air pollution and its impact on ecosystems and cultural heritage, not forgetting that the statues and monuments have their own intrinsic value and the cost of replace them is priceless. The methane slippage and the radiative forcing effect from methane emissions from LNG fuelled ships is a controversial question that deserves much more attention. A study that incorporates the slippage along the natural gas supply chain both from the so-called Algerian pipeline and from gas carriers unloading at Portuguese ports should contribute for a holistic approach on this subject.

One efficient approach for the field study could be to assess to which degree the imposition of an internationally harmonized tax levy on the carbon content can provide market incentives for a quick fuel switch by means of innovative technologies and processes to replace the current generation of oil-based fuels and associated technologies. Because it seems reasonable that by raising the price of fuels by a carbon tax can provide strong incentives to reduce carbon emissions (e.g. by signaling ship-owners about which fuels use more carbon, thereby inducing them to move to low-carbon alternatives). A carbon tax raises fuel market price by the tax, times the carbon content of fossil fuels making ship-owners pay for the social cost of their decisions. To what extent a carbon tax would improve economic efficiency because it would correct for an implicit subsidy not paying for the costs of their activities from the use of carbon fuels is a topic worth to study.

Another envisaged possibility is to apply this social approach as a benchmark to study other transport modes. By attaching all negative externalities to fuel consumption one can explicitly be aware of the spillover effect of a particular transport vis-à-vis inefficiency to allocated resources. By doing so, there might happen that a market anomaly is taking place which provides the justification for government intervention in the public interest.

Moreira P.P., Caetano F. 2017. Liquefied Natural Gas as an Alternative Fuel: a Regional-Level Social Cost-Benefit Appraisal. *Eastern European Business and Economics Journal* **3(2)**: 122-161.

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