

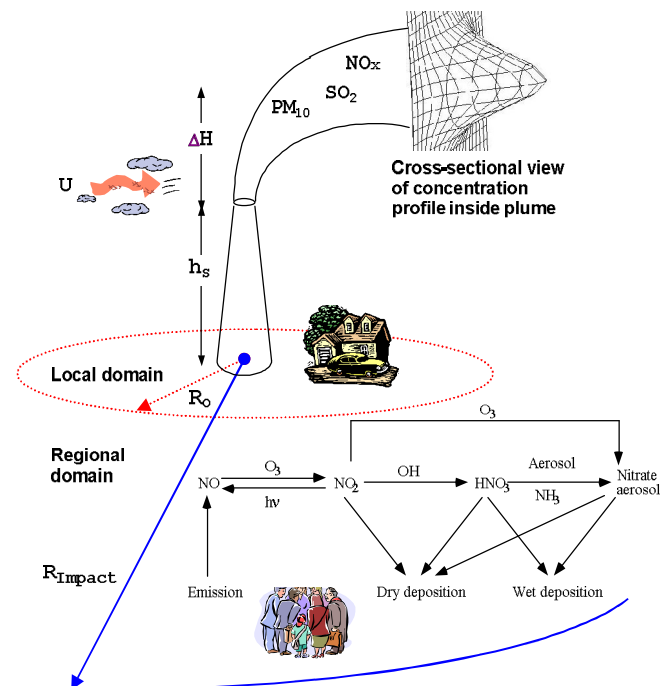


NATIONAL TECHNICAL UNIVERSITY OF ATHENS
School of Naval Architecture and Marine Engineering
Division of Ship Design & Maritime Transport

Estimation of Annual External Health Cost of Air Pollution From Ships In The Port of Piraeus Using The Impact Pathway Approach

DIPLOMA THESIS

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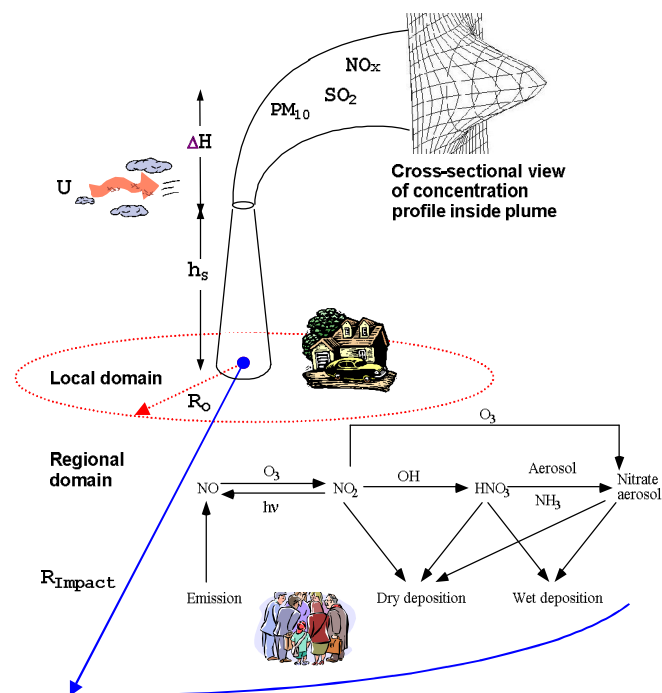


ΕΘΝΙΚΟ ΜΕΤΣΟΒΙΟ ΠΟΛΥΤΕΧΝΕΙΟ
ΣΧΟΛΗ ΝΑΥΠΗΓΩΝ ΜΗΧΑΝΟΛΟΓΩΝ ΜΗΧΑΝΙΚΩΝ
ΤΟΜΕΑΣ ΜΕΛΕΤΗΣ ΠΛΟΙΟΥ ΚΑΙ ΘΑΛΑΣΣΙΩΝ
ΜΕΤΑΦΟΡΩΝ

Εκτίμηση Ετήσιου Εξωτερικού Κόστους Στην Υγεία Από Αέριες Εκπομπές Πλοίων Στο Λιμάνι Του Πειραιά Με Την Μεθοδολογία Impact Pathway Approach

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Contents

Περίληψη.....	8
Abstract	13
Introduction.....	15
Chapter 1: Ship air emissions	20
1.1 The problem of air pollution from ships.....	20
1.2 Quantities of total air emissions from ships and comparison with other transport modes.....	20
1.3 Categories of air emissions.....	27
1.4 Origin and impact of each air pollutant	27
1.4.1 Particulate matter (PM).....	27
1.4.2 Carbon monoxide (CO)	29
1.4.3 Carbon dioxide (CO ₂)	30
1.4.4 Nitrogen oxides (NO _x).....	30
1.4.5 Sulfur dioxide (SO ₂).....	31
1.4.6 Volatile organic compounds (VOC).....	32
1.4.7 Ozone (O ₃)	32
References of Chapter 1.....	36
Chapter 2: External Costs of Maritime Shipping	40
2.1 Externalities and external cost.....	40
2.1.1 Discharges into the sea.....	40
2.1.2 Solid and liquid waste.....	41
2.1.3 Shipping resources and chemicals consumptions.....	42
2.1.4 Ship recycling.....	42
2.2 Bottom-up and top-down approaches for estimating the external cost.....	42
2.3 Studies on external costs of air emissions from maritime shipping.....	43
References of Chapter 2.....	44
Chapter 3: Methodology	46
3.1 The impact pathway approach.....	46
3.1.1 Source emission.....	47
3.1.2 Atmospheric depression.....	47
3.1.3 Impacts	48

3.1.4 Quantification of impact's cost	50
3.2 Uncertainties	51
3.3 IPA applications in shipping.....	52
References of Chapter 3	53
Chapter 4: Software	57
4.1 RiskPoll and the Simple Uniform World Model (SUWM).....	57
4.2 Available models	59
4.2.1 QUERI (Basic, Intermediate and Best estimate)	59
4.2.2 RUWM (Intermediate and Best estimate).....	59
4.2.3 URBAN (Best estimate).....	59
4.2.4 AGRIMAT	60
4.3 RiskPoll models VS Detailed assessment (EcoSense model).....	60
4.4 The QUERI model.....	62
4.4.1 Atmospheric dispersion.....	62
4.4.2 Damage cost equation.....	65
4.4.3 Uncertainties of economic valuation	67
References of Chapter 4.....	69
Chapter 5: Case study.....	71
5.1 Description of case study	71
5.1.1 The port of Piraeus.....	71
5.2 Assumptions	73
5.3 Input data	73
5.3.1 Meteo	73
5.3.2 Pollutant	75
5.3.3 Stack parameters.....	76
5.3.4 Receptor	77
5.3.5 Exposure Response Functions (ERF) and Monetary Values	79
References of Chapter 5	81
Chapter 6: Results	82
6.1 Results presentation.....	82
6.1.1 QUERI Model Results.....	82
6.2 Sample of the results per pollutant (Mortality)	89
6.2.1 PM _{2.5} - Mortality YOLL [Pope 2002]	89
6.2.2 PM ₁₀ - Mortality YOLL [Pope 2002]	90

6.2.3 Sulfates - Mortality YOLL [Pope 2002].....	91
6.2.4 Nitrates - Mortality YOLL [Pope 2002]	91
6.2.5 SO ₂ - Mortality YOLL [Anderson/Toulomi 1996].....	92
6.3 Damage costs per pollutant and damage cost per kg of pollutant.....	93
6.4 Local Concentration Profiles.....	94
6.4.1 PM ₁₀ Concentration Profile	94
6.4.2 SO ₂ Concentration Profile.....	94
6.4.3 NO _x Concentration Profile	94
6.4.4 PM _{2.5} Concentration Profile.....	95
6.5 Concentration Contours	95
6.5.1 Comparison with the air limit values (LV)	99
References of Chapter 6.....	101
Chapter 7: Analysis of case study results	103
7.1 Overall external cost.....	103
7.2 External cost of primary and secondary pollutants.....	103
7.3 Mortality vs Morbidity.....	106
7.4 Local vs Regional impact.....	107
7.5 External cost per tonne of pollutant	107
7.6 External cost per person.....	108
7.7 Point of maximum concentrations.....	110
7.8 Comparison with Tzannatos study	110
References of Chapter 7	111
Chapter 8: Case study 2 (at ship level)	112
8.1 Description of the study	112
8.2 Assumptions and input data.....	112
8.3 Results presentation.....	113
8.4 Sample of the results per pollutant (Mortality)	118
8.4.1 PM _{2.5} - Mortality YOLL [Pope 2002]	118
8.4.2 PM ₁₀ - Mortality YOLL [Pope 2002]]	119
8.4.3 Sulfates - Mortality YOLL [Pope 2002].....	120
8.4.4 Nitrates - Mortality YOLL [Pope 2002]	120
8.4.5 SO ₂ - Mortality YOLL [Anderson/Toulomi 1996].....	121
8.5 Damage costs per pollutant and damage costs per kg of pollutant.....	122
8.6 Local Concentration Profiles.....	123

8.6.1 PM ₁₀ Concentration Profile	123
8.6.2 SO ₂ Concentration Profile.....	123
8.6.3 NO _x Concentration Profile	123
8.6.4 PM _{2.5} Concentration Profile.....	124
Chapter 9: Analysis of case study 2 results	125
9.1 Overall external cost.....	125
9.2 External cost of primary and secondary pollutants.....	125
9.3 Mortality vs Morbidity.....	126
9.4 Local vs Regional impact.....	126
9.5 External cost per tonne of pollutant	127
Chapter 10: Comparison with other sectors.....	128
10.1 Comparison with the industrial sector.....	128
10.2 Comparison with the road transport sector.....	129
10.3 Comments	130
References of Chapter 10.....	131
Chapter 11: Conclusion-Discussion	132
11.1 Conclusion	132
11.2 Discussion.....	132
Annex 1: Tables which are used to find various parameters of the three dimensional Gaussian concentration field $C(x, y, z)$	134
Annex 2: Sample of meteo input data (Faliro meteo station).....	138
Annex 3: General Arrangement of Blue Star Belos	146
Annex 4: Population distribution (local scale).....	147
Annex 5: ERF and monetary values.....	148
Annex 6: Case study results file.....	151
Annex 7: Case study detailed review of impact assessment results.....	153

List of Tables

Table 1: CO ₂ emissions - Comparison of different transport modes (source: IEA, 2005).....	25
Table 2: Effects of air pollutants on human health, the environment and the climate (source: EEA, 2013).....	34
Table 3: Input requirements for each model (source: Sparado, 2004).....	60
Table 4: The number of ships involved by type and their seasonal and overall number of calls (or departures) at the port of Piraeus (source: Tzannatos, 2010b)	72
Table 5: Values of deposition velocity (k) for Europe (source: Spadaro, 2003).....	76
Table 6: Explanation of site index integer (source: Spadaro, 2003).....	77
Table 7: QUERI model results.....	86
Table 8: The air limit values (LV) for the pollutants under examination (source: Ministry Of Environment & Climate Change, 2013).....	100
Table 9: The emission factors for fuel consumption that were used.....	112
Table 10: QUERI model results.....	115
Table 11: The industrial activities that were taken into account (source: IERSD, 2007)	128
Table 12: Formulae for predicting plume rise under buoyancy driven conditions (source: Spadaro, 2002; Brode and Wang, 1992)	134
Table 13: Lateral σ_y and vertical σ_z diffusion coefficients for Gaussian plume model (source: Spadaro, 2002; Zannetti, 1990).....	135
Table 14: Pasquill dispersion classes (source: Zannetti, 1990; Dobbins, 1979; Pasquill, 1974)	135
Table 15: Classification of atmospheric stability (source: Zannetti, 1990; DeMarrais, 1978; Best et al., 1986; Hanna, 1989)	136
Table 16: Classification of atmospheric stability (source: Zannetti, 1990; U.S. EPA, 1986; Irwin, 1980)	136
Table 17: Classification of atmospheric stability (source: Zannetti, 1990; U.S. EPA, 1986; Irwin, 1980)	137

List of Figures

Figure 1: Ship's Resources Consumptions and Pollution Sources (source: Maffii et al., 2007)	20
Figure 2: Studies comparison of global emissions of CO ₂ from Shipping	22
Figure 3: Studies comparison of global emissions of SO ₂ from Shipping	23
Figure 4: Studies comparison of global emissions of NO _x from Shipping	23
Figure 5: Studies comparison of global emissions of PM from Shipping	24
Figure 6: Studies comparison of global emissions of HC from Shipping	24
Figure 7: Emissions of CO ₂ from shipping and other transport modes given in presentence of total emissions (source: Buhaug, Ø et al, 2009)	25
Figure 8: Percentage contribution of transport and not transport sector to total emission of air pollutants in EEA32 (source: http://www.eea.europa.eu/data-and-maps/figures/the-contribution-of-the-transport-1)	26
Figure 9: Illustration of PM ₁₀ and PM _{2.5} particle size (source: EPA, 2010)	29
Figure 10: Formation of ground-level O ₃ (source: Jenkin & Hayman, 1999)	33
Figure 11: Health impacts of air pollution (source: EEA, 2013f)	33
Figure 12: The steps of IPA (source: ExternE, 2005)	46
Figure 13: Different types of Exposure Response Functions (source: Friedrich & Bickel, 2001)	48
Figure 14: Different types of Exposure Response Functions (source: ExternE, 2005)	57
Figure 15: Estimates of mortality impacts for different sites in Europe following the Impact Pathways Approach (source: Spadaro, 2002)	58
Figure 16: Comparison of mortality estimates between the RiskPoll models and the EcoSense model for Paris (France) (source: Spadaro, 2003)	61
Figure 17: Comparison of mortality estimates between the RiskPoll models and the EcoSense model for Stuttgart (Germany) (source: Spadaro, 2003)	61
Figure 18: Comparison between a detailed analysis and the Best estimate of QUERI (source: Spadaro, 2002)	62
Figure 19: The Gaussian plume (source: Zannetti, 1990)	63
Figure 20: Overhead and side view of a Gaussian plume (source: Spadaro, 2002)	64
Figure 21: Graphical depiction of modeling task (source: Spadaro, 2004)	66
Figure 22: Example of lognormal distribution for economic valuation (source: Rabl, A. & J.V. Spadaro, 1999)	68
Figure 23: Photo of the main (passenger) port of Piraeus	71
Figure 24: The berth layout at the passenger port of Piraeus (source: Tzannatos, 2010b)	72
Figure 25: Emissions of 124 cruise and 59 coastal passenger ships for the passenger port of Piraeus during a twelve-month period in 2008-2009 (source: Tzannatos, 2010b)	73
Figure 26: Meteo input data screen	74
Figure 27: Example of a meteo input file (source: Spadaro, 2003)	75
Figure 28: Pollutant input data screen	75
Figure 29: Stack Parameters input data screen	76

Figure 30: Receptor input data screen.....	78
Figure 31: Example of a population input file (source: Spadaro, 2003).....	78
Figure 32: The ERF Values input data screen	79
Figure 33: The Monetary Values input data screen	80
Figure 34: View results screen.....	82
Figure 35: Damage costs per pollutant	93
Figure 36: Damage cost per kg of pollutant.....	93
Figure 37: PM ₁₀ concentration profile.....	94
Figure 38: SO ₂ concentration profile	94
Figure 39: NO _x concentration profile.....	95
Figure 40: PM _{2.5} concentration profile	95
Figure 41: PM ₁₀ concentration contour.....	96
Figure 42: PM ₁₀ concentration contour (with zoom).....	96
Figure 43: NO _x concentration contour.....	97
Figure 44: NO _x concentration contour (with zoom)	97
Figure 45: PM _{2.5} concentration contour	98
Figure 46: PM _{2.5} concentration contour (with zoom).....	98
Figure 47: SO ₂ concentration contour	99
Figure 48: SO ₂ concentration contour (with zoom).....	99
Figure 49: Estimation of RiskPoll's best algorithm QUERI.....	103
Figure 50: The course of formation of secondary pollutants.....	104
Figure 51: External cost in health of each pollutant for the year 2008-2009	105
Figure 52: Presentence of each pollutant's contribution in the overall external cost.....	106
Figure 53: External cost per tonne of pollutant for the year 2008-2009	107
Figure 54: External cost per person (total-Greece) for the year 2008-2009.....	108
Figure 55: External cost per person (local-Athens) for the year 2008-2009	109
Figure 56: External cost per person (regional-Greece) for the year 2008-2009	109
Figure 57: View Results Screen.....	114
Figure 58: Graph of damage costs per pollutant.....	122
Figure 59: Graph of damage costs per kg of pollutant.....	122
Figure 60: PM ₁₀ concentration profile.....	123
Figure 61: SO ₂ concentration profile.....	123
Figure 62: NO _x concentration profile.....	124
Figure 63: PM _{2.5} concentration profile	124
Figure 64: External cost in health of each pollutant for the year 2013-2014	125
Figure 65: Presentence of each pollutant's contribution in the overall external cost.....	126
Figure 66: External cost per tonne of pollutant for the year 2013-2014.....	127
Figure 67: Comparison between the industrial and the shipping sectors costs per person in Athens.....	130
Figure 68: Comparison between the road and the shipping sectors costs per person in Athens.....	130

Περίληψη

Σκοπός της παρούσας διπλωματικής εργασίας είναι η εκτίμηση του εξωτερικού κόστους στην υγεία των ανθρώπων που προκύπτει από τις αέριες εκπομπές πλοίων. Η μέθοδος που προτιμήθηκε ήταν η Impact Pathway Assessment (IPA), η οποία έχει χρησιμοποιηθεί και από το ExternE, μια σειρά από ερευνητικά προγράμματα χρηματοδοτούμενα από την Ευρωπαϊκή Επιτροπή (Γενική Διεύθυνση Έρευνας) για την εκτίμηση των εξωτερικών κοστών που προέρχονται και συσχετίζονται με την παραγωγή ενέργειας. Η IPA είναι μια αναλυτική μέθοδος “από κάτω προς τα πάνω”, η οποία ξεκινά από την μικροδομή του ρυπαντή και φτάνει μέχρι τους επηρεαζόμενους υποδοχείς. Αν και αρκετά πολύπλοκη η μέθοδος αυτή προσφέρει αυξημένη αξιοπιστία και ακρίβεια στα αποτελέσματα σε σχέση με τις πιο συχνά χρησιμοποιούμενες μεθόδους (top down).

Η περίπτωση που εξετάστηκε είναι αυτή των ακτοπλοϊκών γραμμών και κρουαζιερόπλοιων τα οποία προσεγγίζουν το λιμάνι του Πειραιά για το έτος 2008-2009. Οι αέριες εκπομπές στο λιμάνι του Πειραιά έχουν μεγάλο ενδιαφέρον δεδομένου ότι το λιμάνι βρίσκεται εντός της μητροπολιτικής περιοχής των Αθηνών και έχει την πρώτη θέση στην κίνηση επιβατών στην Ευρώπη και την τρίτη στον κόσμο. Ήταν επομένως απαραίτητο να υπάρξει μια αναλυτική μελέτη για το εξωτερικό κόστος των ρύπων που προκαλούνται από τη ναυτιλία στο λιμάνι του Πειραιά. Η συγκεκριμένη διπλωματική καλύπτει αυτό το κενό και ταυτόχρονα δίνει το έναυσμα για περαιτέρω έρευνα στο μέλλον.

Στην εργασία αυτή κύριο ρόλο είχε το πρόγραμμα RiskPoll το οποίο στην πραγματικότητα είναι μια σειρά προγραμμάτων σχεδιασμένη για την εκτίμηση -με χρήση της IPA- επιπτώσεων στην υγεία από τοξικά μέταλλα (As, Cd, Cr, Hg, Ni and Pb) και αέριες εκπομπές των ακόλουθων ρυπαντών: μονοξείδιο του άνθρακα (CO), αιωρούμενα σωματίδια (PM), οξείδια του αζώτου (NO_x), διοξείδιο του θείου (SO_2) και δευτερεύοντα είδη όπως νιτρικά και θειικά αερολύματα. Η εύρεση ωριαίων μετεωρολογικών δεδομένων ενός χρόνου καθώς και η δημιουργία αναλυτικών τοπικών δεδομένων πληθυσμού για την περίπτωση του Πειραιά έκαναν δυνατή την χρήση του πιο εξελιγμένου αλγορίθμου που μπορεί να προσφέρει το RiskPoll (QUERI) αυξάνοντας έτσι την ακρίβεια και αξιοπιστία των αποτελεσμάτων.

Η ανάλυση των αποτελεσμάτων έδειξε ότι το εξωτερικό κόστος στην υγεία των ατόμων από όλους τους ρυπαντές, φτάνει τα 26 εκατομμύρια ευρώ για την περίοδο 2008-2009 με κυριότερο συνεισφέρων ρυπαντή τα αιωρούμενα σωματίδια. Είναι σημαντικό εδώ να αναφερθεί ότι το ετήσιο εξωτερικό κόστος στην υγεία από τα σωματίδια είναι μεγαλύτερο στην τοπική κλίμακα και πιο συγκεκριμένα στην περιοχή τη Αθήνας. Ωστόσο, το ετήσιο εξωτερικό κόστος στην υγεία ανά άτομο που μένει στην Αθήνα από τα σωματίδια είναι πολύ μικρότερο συγκρινόμενο με το αντίστοιχο εξωτερικό κόστος που προκαλούν οι τομείς της βιομηχανίας και των οδικών μεταφορών.

Επιπλέον, γίνεται η εκτίμηση του εξωτερικού κόστους στην υγεία που προκαλείται από τους αέριους ρύπους ενός πλοίου της ακτοπλοϊκής γραμμής όταν αυτό βρίσκεται στον Πειραιά για το έτος 2013-2014, το οποίο βρέθηκε ίσο με 850 χιλιάδες ευρώ. Για το σκοπό αυτό χρησιμοποιήθηκαν οι ώρες παραμονής στο λιμάνι (παραμονής και εισόδου/εξόδου), η λειτουργία των μηχανών κατά την παραμονή και είσοδο/έξοδο από το λιμάνι και τα χαρακτηριστικά του πλοίου.

Τέλος, για την καλύτερη κατανόηση των αποτελεσμάτων γίνονται δυο συγκρίσεις: μια του ετήσιου εξωτερικού κόστους ανά κάτοικο στην Αθήνα προκαλούμενο από τα σωματίδια (διαμέτρου 10 μ m) που εκπέμπουν τα πλοία ακτοπλοϊκών γραμμών και τα κρουαζιερόπλοια που προσεγγίζουν τον Πειραιά με το ετήσιο εξωτερικό κόστος ανά κάτοικο στην Αθήνα προκαλούμενο από τα σωματίδια (διαμέτρου 10 μ m) που εκπέμπουν οι βιομηχανίες στην περιοχή της Αθήνας και μια του ετήσιου εξωτερικού κόστους ανά κάτοικο στην Αθήνα προκαλούμενο από τα σωματίδια (διαμέτρου 2.5 μ m) που εκπέμπουν τα πλοία ακτοπλοϊκών γραμμών και τα κρουαζιερόπλοια που προσεγγίζουν τον Πειραιά με το ετήσιο εξωτερικό κόστος ανά κάτοικο στην Αθήνα προκαλούμενο από τα σωματίδια (διαμέτρου 2.5 μ m) που εκπέμπουν οι οδικές μεταφορές αυτή τη φορά. Για τις βιομηχανίες το ετήσιο κόστος στην υγεία ανά αθηναίο είναι 24.6 € ενώ των πλοίων του Πειραιά 1.4 € και για τις οδικές μεταφορές 25.9 € ενώ των πλοίων του Πειραιά 2.2 €.

Η δομή της ακόλουθης διπλωματικής εργασίας είναι η εξής:

1^ο Κεφάλαιο

Στο πρώτο κεφάλαιο υπάρχει η βιβλιογραφική επισκόπηση όσον αφορά το πρόβλημα των αερίων εκπομπών από πλοία. Αρχικά παρουσιάζεται επιγραμματικά το χρονικό

του προβλήματος και οι μέχρι τώρα ενέργειες για περιορισμό του. Στη συνέχεια σημειώνεται ο διαχωρισμός των αερίων εκπομπών σε αυτές που προκαλούν ρύπανση και αυτές που προκαλούν κλιματικές αλλαγές παραθέτοντας παράλληλα εκτιμήσεις διαφόρων εργασιών για τις εκπομπές αυτών παγκοσμίως από την ναυτιλία. Επίσης, γίνεται σύγκριση με τις εκπομπές αερίων άλλων μεταφορικών μέσων και βιομηχανιών για καλύτερη αντίληψη του μεγέθους του προβλήματος. Τέλος, επισημαίνονται οι κύριοι και δευτερεύον αέριοι ρυπαντές στη ναυτιλία καθώς και η προέλευση τους και οι επιπτώσεις που προκαλούν στην υγεία και το περιβάλλον.

2^ο Κεφάλαιο

Στο δεύτερο κεφάλαιο γίνεται μια πρώτη αναφορά στους οικονομικούς όρους “εξωτερικότητες” και “εξωτερικά κόστη” οι οποίες είναι βασικές για την βαθύτερη κατανόηση του προβλήματος των αερίων ρύπων. Στη συνέχεια απαριθμούνται οι πηγές προέλευσης των εξωτερικών κοστών στη ναυτιλία και ακολουθεί μια σύντομη ανάλυση τους. Επιπλέον, παρουσιάζονται και συγκρίνονται οι δυο προσεγγίσεις εκτίμησης του εξωτερικού κόστους, οι “από κάτω προς τα πάνω” και “από πάνω προς τα κάτω”. Τελειώνοντας, γίνεται μια επισκόπηση των μελετών με θέμα το εξωτερικό κόστος των αερίων εκπομπών στη ναυτιλία.

3^ο Κεφάλαιο

Στο κεφάλαιο 3 παρουσιάζεται η μέθοδος Impact Pathway Assessment (IPA) και αναλύονται τα τέσσερα βήματα για την εφαρμογή της: πηγή εκπομπής, ατμοσφαιρική διασπορά, επιπτώσεις και ποσοτικοποίηση του κόστους των επιπτώσεων. Έπειτα, γίνεται αναφορά στις αβεβαιότητες της μεθόδου και περιγραφή των μέχρι τώρα εφαρμογών της στη ναυτιλία.

4^ο Κεφάλαιο

Το τέταρτο κεφάλαιο αναφέρεται στο πρόγραμμα που χρησιμοποιήθηκε το RiskPoll. Αρχικά, γίνεται μια αναφορά στο Απλό Ενιαίο Παγκόσμιο Μοντέλο και πως αυτό ενσωματώνεται μέσα στο RiskPoll. Στη συνέχεια παρουσιάζονται τα διαθέσιμα απλοποιημένα μοντέλα που περιέχονται στο πρόγραμμα και γίνεται μια σύγκριση αυτών με άλλα πιο λεπτομερή μοντέλα. Τέλος, γίνεται ανάλυση του μοντέλου που προτιμήθηκε (QUERI): γκαουσιανό μοντέλο θυσάνου, εξίσωση του κόστους των ζημιών και νομισματοποίηση αυτού του κόστους.

5^ο Κεφάλαιο

Στο 5 κεφάλαιο γίνεται περιγραφή της περίπτωσης που μελετάται: η εκτίμηση του εξωτερικού κόστους στην υγεία των ανθρώπων από τους κύριους αέριους ρυπαντές ($PM_{2.5}$, PM_{10} , SO_2 και NO_x) και δευτερέων ρυπαντές (νιτρικά και θειικά αερολύματα) που εκπέμπονται από τα πλοία ακτοπλοϊκών γραμμών και κρουαζιερόπλοιων που προσεγγίζουν το λιμάνι του Πειραιά για ένα χρόνο (2008-2009). Στη συνέχεια παρουσιάζεται η μελέτη από όπου θα χρησιμοποιηθούν οι ποσότητες των αερίων ρυπαντών που εκπέμπονται από τα πλοία στο λιμάνι του Πειραιά. Επιπλέον, αναφέρονται οι υποθέσεις που έγιναν για την μελέτη της διπλωματικής, τα δεδομένα εισόδου που δέχεται το RiskPoll καθώς και τα δεδομένα που χρησιμοποιήθηκαν.

6^ο Κεφάλαιο

Στο κεφάλαιο 6 παρουσιάζονται τα αποτελέσματα του προγράμματος για την κύρια περίπτωση μελέτης: οθόνη προβολής αποτελεσμάτων, αναλυτικά αποτελέσματα του αλγορίθμου, γράφημα του κόστους ζημιών, προφίλ συγκέντρωσης των κυρίων ρυπαντών και γραφήματα συγκέντρωσης των κυρίων ρυπαντών.

7^ο Κεφάλαιο

Στο έβδομο κεφάλαιο γίνεται μια ανάλυση των αποτελεσμάτων με τα ακόλουθα γραφήματα και σχολιασμό του καθενός: γράφημα εξωτερικού κόστους όλων των ρυπαντών, γράφημα ποσοστού συμμετοχής κάθε κύριου ρυπαντή στα εξωτερικά κόστη, γράφημα ποσοστού συμμετοχής κάθε δευτερεύον ρυπαντή στα εξωτερικά κόστη, γράφημα ποσοστού συμμετοχής κάθε ρυπαντή στα εξωτερικά κόστη, ποσοστό τοπικών και περιφερειακών επιπτώσεων στα εξωτερικά κόστη κάθε ρυπαντή, ποσοστό κόστους προερχόμενο από θνησιμότητα και νοσηρότητα στο εξωτερικό κόστος κάθε ρυπαντή, γράφημα κόστους/τόννου κάθε ρυπαντή και γράφημα εξωτερικού κόστους ανά κάτοικο (σε όλη την Ελλάδα, την Αθήνα και στις περιοχές εκτός Αθήνας). Τέλος, επισημάνεται το σημείο μέγιστων συγκεντρώσεων των ρυπαντών στο χάρτη.

8^ο Κεφάλαιο

Το κεφάλαιο 8 αναφέρεται στην εκτίμηση του εξωτερικού κόστους στην υγεία που προκαλείται από ένα πλοίο ακτοπλοϊκής γραμμής στο λιμάνι του Πειραιά για το έτος 2013-2014. Αφού αποκτήθηκε το βιβλίο ταξιδιού του εν λόγω караβιού υπολογίστηκε η μέση ώρα παραμονής του στο λιμάνι καθώς και η ώρα ελιγμού

εισόδου και εξόδου. Έπειτα, οι ώρες αυτές σε συνδυασμό με την χρήση συντελεστών εκπομπής καθώς και με γνωστά την ισχύ της κυρίας μηχανής και της ηλεκτρογεννήτριας σε λειτουργία σε κάθε περίπτωση, βρέθηκαν οι τόνοι εκπομπής των καυσαερίων που μας ενδιαφέρουν για ένα χρόνο. Τέλος, με χρήση του προγράμματος RiskPoll εκτιμήθηκε το εξωτερικό κόστος στην υγεία με ταυτόχρονη παρουσίαση των αποτελεσμάτων: οθόνη προβολής αποτελεσμάτων, αναλυτικά αποτελέσματα του αλγορίθμου, γράφημα του κόστους ζημιών, προφίλ συγκέντρωσης των κυρίων ρυπαντών και γραφήματα συγκέντρωσης των κυρίων ρυπαντών.

9^ο Κεφάλαιο

Στο κεφάλαιο εννέα γίνεται η ανάλυση των αποτελεσμάτων για την περίπτωση του ενός πλοίου με ταυτόχρονη παράθεση των ακόλουθων γραφημάτων και σχολιασμό του καθενός: γράφημα εξωτερικού κόστους όλων των ρυπαντών, γράφημα ποσοστού συμμετοχής κάθε κύριου ρυπαντή στα εξωτερικά κόστη, γράφημα ποσοστού συμμετοχής κάθε δευτερεύον ρυπαντή στα εξωτερικά κόστη, γράφημα ποσοστού συμμετοχής κάθε ρυπαντή στα εξωτερικά κόστη, ποσοστό τοπικών και περιφερειακών επιπτώσεων στα εξωτερικά κόστη κάθε ρυπαντή, ποσοστό κόστους προερχόμενο από θνησιμότητα και νοσηρότητα στο εξωτερικό κόστος κάθε ρυπαντή και γράφημα κόστους/τόννου κάθε ρυπαντή.

10^ο Κεφάλαιο

Το κεφάλαιο 10 περιέχει δυο συγκρίσεις: μια του ετήσιου εξωτερικού κόστους ανά κάτοικο στην Αθήνα προκαλούμενο από τα σωματίδια (διαμέτρου 10 μ m) που εκπέμπουν τα πλοία ακτοπλοϊκών γραμμών και τα κρουαζιερόπλοια που προσεγγίζουν τον Πειραιά με το ετήσιο εξωτερικό κόστος ανά κάτοικο στην Αθήνα προκαλούμενο από τα σωματίδια (διαμέτρου 10 μ m) που εκπέμπουν οι βιομηχανίες στην περιοχή της Αθήνας και μια του ετήσιου εξωτερικού κόστους ανά κάτοικο στην Αθήνα προκαλούμενο από τα σωματίδια (διαμέτρου 2.5 μ m) που εκπέμπουν τα πλοία ακτοπλοϊκών γραμμών και τα κρουαζιερόπλοια που προσεγγίζουν τον Πειραιά με το ετήσιο εξωτερικό κόστος ανά κάτοικο στην Αθήνα προκαλούμενο από τα σωματίδια (διαμέτρου 2.5 μ m) που εκπέμπουν οι οδικές μεταφορές αυτή τη φορά.

11^ο Κεφάλαιο

Είναι το κεφάλαιο στο οποίο περιλαμβάνονται το τελικό συμπέρασμα αλλά και προτάσεις βελτίωσης ανάλογων εργασιών στο μέλλον.

Abstract

The purpose of this thesis is the estimation of the external cost in health resulting from air pollutants emitted by coastal passenger ships and cruise ships approaching the port of Piraeus for the year 2008-2009. The preferred method was the Impact Pathway Assessment (IPA) which has been used by the ExternE, a number of research projects funded by the European Commission, Directorate-General (DG) Research for the assessment of external costs derived and correlated with the energy. The IPA is an analytical "bottom up" method starting from the micro-structure of the pollutant and going all the way up to the affected receptors. Although is a fairly complex method it offers increased reliability and accuracy in the results compared with the more commonly used methods.

The case of Piraeus it's of a high interest since it is the port with the highest passenger traffic in Europe and the third highest in the world. It was therefore necessary to have a detailed study on the external costs of air pollution caused by shipping in the port of Piraeus. This thesis fills this gap and simultaneously provides a starting point for further investigation in the future.

A major role in this work had the RiskPoll program which is actually a suit of programs designed to assess –with the use of IPA- impacts on health and the environment caused by toxic metals (As, Cd, Cr, Hg, Ni and Pb) and air emissions of the following pollutants: carbon monoxide (CO), particulate matter (PM), nitrogen oxides (NO_x), sulfur dioxide (SO_2) and secondary species such as nitrate and sulfate aerosols. Finding hourly meteorological data for one year as well as creating detailed local population data for the case of Piraeus made possible the use of the most sophisticated algorithm that RiskPoll can provide (QUERI), thus increasing the accuracy and reliability of results.

The analysis of the results showed that the external health cost of all the pollutants reaches a total of € 26 million for the period of one year with main contributor pollutant being the particles. This external cost-that undoubtedly leads to concerns-it is hoped to mobilize direct and indirect parties in order to create as soon as possible a framework to protect the most important thing of all, the human health, as well as to take the necessary measures to reduce this cost.

Moreover, an estimation of the yearly external cost in health caused by one coastal passenger ship in Piraeus is taken place which was found to be 850 thousand €. For this purpose they were used the hours of operation in the port (docking time and maneuvering in and out of the port time), the operation of the machines in the dock as well as while in maneuvering and ship characteristics.

Finally, two comparisons were made: one between the annual external cost in health per person living in Athens caused by particles (with diameter $10\mu\text{m}$) that are emitted from the coastal passenger ships and cruise ships approaching the port of Piraeus for one year with the external cost per person living in Athens caused by particles (with diameter $10\mu\text{m}$) that are emitted from the industries in greater Athens is taken place and one between the annual external cost in health per person living in Athens caused by particles (with diameter $2.5\mu\text{m}$) that are emitted from the coastal passenger ships and cruise ships approaching the port of Piraeus for one year with the external cost per person living in Athens caused by particles (with diameter $2.5\mu\text{m}$) that are emitted from the road transport sector this time.

Introduction

What is the goal of this study?

This study has as a goal the estimation of the external cost in health caused from air pollutants emitted by coastal passenger ships and cruise ships approaching the port of Piraeus for the year 2008-2009.

What makes the case of Piraeus so interesting?

The case of Piraeus it's of a high interest since it is the port with the highest passenger traffic in Europe and the third highest in the world. It was therefore necessary to have a detailed study on the external costs of air pollution caused by shipping in the port of Piraeus. This thesis fills this gap and simultaneously provides a starting point for further investigation in the future

Why is this study different from other studies concerning the external cost of shipping's air emissions for Piraeus?

The difference lies in the preferred method, the Impact Pathway Assessment (IPA), which has been used by the ExternE, a number of research projects funded by the European Commission, Directorate-General (DG) Research for the assessment of external costs derived and correlated with the energy.

What is the Impact Pathway Assessment (IPA)?

The IPA is an analytical "bottom up" method starting from the micro-structure of the pollutant and going all the way up to the affected receptors. Although is a fairly complex method it offers increased reliability and accuracy in the results compared with the more commonly used methods.

How was the IPA implemented in this study?

The IPA was implemented with the help of the RiskPoll program which is actually a suit of programs designed to assess –with the use of IPA- impacts on health and the environment caused by toxic metals (As, Cd, Cr, Hg, Ni and Pb) and air emissions of the following pollutants: carbon monoxide (CO), particulate matter (PM), nitrogen oxides (NO_x), sulfur dioxide (SO_2) and secondary species such as nitrate and sulfate aerosols.

What algorithm of RiskPoll was used and is it accurate?

Finding hourly meteorological data for one year as well as creating detailed local population data for the case of Piraeus made possible the use of the most sophisticated algorithm that RiskPoll can provide (QUERI), thus increasing the accuracy and reliability of results.

What are the results show and how they affect shipping?

The analysis of the results showed that the external health cost of all the pollutants reaches a total of 26 million € for the year 2008-2009 with main contributor pollutant being the particles. This external cost-that undoubtedly leads to concerns-it is hoped to mobilize direct and indirect parties in order to create as soon as possible a framework to protect the most important thing of all, the human health, as well as to take the necessary measures to reduce this cost.

What about the yearly external cost in health caused by one ship?

An estimation of the external cost in health caused by one coastal passenger ship in Piraeus for the year 2013-2014 was found to be 850 thousand €.

How is this compared to the main case study?

The main case study gave us 26 million € of external cost in health for 183 ships (124 cruise ships and 54 coastal passenger ships) but that doesn't mean that one ship's external cost will be $183/26$ because every ship has different port times (especially cruise ships), different emissions as well as different features (stack height, diameter, etc)

What is the share of the external cost in health from coastal passenger ships and cruise ships compared to other sectors?

In Chapter 10 there is a comparison between the annual external cost in health per people living in Athens caused by particles (with diameter $10\mu\text{m}$) that are emitted from the coastal passenger ships and cruise ships approaching the port of Piraeus for one year with the external cost per receptor living in Athens caused by particles (with diameter $10\mu\text{m}$) that are emitted from the industries in greater Athens as well as one between the annual external cost in health per person living in Athens caused by particles (with diameter $2.5\mu\text{m}$) that are emitted from the coastal passenger ships and cruise ships approaching the port of Piraeus for one year with the external cost per

person living in Athens caused by particles (with diameter $2.5\mu\text{m}$) that are emitted from the road transport sector this time.

The structure of this thesis is as follows:

1st Chapter

The first chapter is a literature overview on the problem of air emissions from shipping. Initially, it is presented a briefly timeline of the problem and the actions taken so far to constrain it. Then it is noted the separation of air emissions in those that are causing pollution and those that are causing climate change while listing estimates from various studies of global emissions from shipping. Also, a comparison with the air emissions of other vehicles and industries is presented for the better understanding of the magnitude of the problem. Finally, the main and secondary air pollutants in shipping, their origin and their effects on human health and environment are highlighted.

2nd Chapter

In the second chapter a first report on economic terms "externalities" and "external costs", which are essential for a deeper understanding of the problem of air pollution, is presented. Then, the sources of external costs in shipping are listed followed by a brief analysis of them. Moreover, two approaches of estimating external costs are presented and compared, the "bottom-up" and "top-down". Finally, an overview of some studies on the external costs of air emissions in shipping is given.

3rd Chapter

Chapter 3 presents the Impact Pathway Assessment (IPA) methodology and analyzes the four steps for its implementation: source emission, atmospheric dispersion, impact and quantification of impact cost. Then, the uncertainties of the method are analyzed followed by a description of studies that used the IPA in shipping until now.

4th Chapter

The fourth chapter describes the program RiskPoll that was used. Initially, there is a reference to the Simple Uniform World Model and how it is incorporated into the RiskPoll. In addition, the available simplified models contained in the program and comparisons of these with other more detailed models are presented. Finally, an

analysis of the algorithm that was preferred (QUERI) is taken place: Gaussian plume model, equation of damage costs and monetization of these costs.

5th Chapter

Chapter 5 is a description of the case study: the estimation of external cost in health from the main air pollutants ($PM_{2.5}$, PM_{10} , SO_2 and NO_x) and secondary air pollutants (nitrates and sulphates aerosols) emitted by coastal passenger ships and cruise ships approaching the port of Piraeus for the year 2008-2009. Then, it is presented the study from which will be used quantities of the air pollutants emitted from ships in the port of Piraeus. Furthermore, the assumptions made for this study; the input data that accepts RiskPoll and the input data that were used are discussed.

6th Chapter

Chapter 6 presents the results of the program for the case studied: screen results, analytical results of the algorithm, the graph of damage cost, concentration profiles of the main pollutants and graphics concentration of the main pollutants.

7th Chapter

The seventh chapter is an analysis of the results with graphics and commentary. The graphs that were used are: graph of external costs of all pollutants, graph of participation presentence of each main pollutant in the external costs, graph of participation presentence of each secondary pollutant in the external costs, graph of participation presentence of each pollutant in the external costs, percentage of local and regional impacts in the external costs of each pollutant, presentence of costs derived from mortality and morbidity in the external costs of each pollutant and a cost / tone graph comparison of each pollutant. Also, it includes a comparison with the study of Tzannatos.

8th Chapter

Chapter 8 deals with the estimation of the external health cost caused by a coastal passenger ship to the port of Piraeus for the year 2013-2014. After acquiring the travel book then it was calculated the average time that the ship stays in the port and the time of entry and exit maneuver. Then these hours in conjunction with the use of emission factors and the power of the main engine and generator in operation in each

case, found the tones emitted of the pollutants under consideration for one year. Finally, using the program RiskPoll it was estimated the external cost in health while presenting the results: screen results, analytical results of the algorithm, the graph of the damage cost, concentration profiles of the main pollutants and graphics concentration of the main pollutants.

9th Chapter

The seventh chapter is an analysis of the results for the one ship case with graphics and commentary. The graphs that were used are: graph of external costs of all pollutants, graph of participation presentence of each main pollutant in the external costs, graph of participation presentence of each secondary pollutant in the external costs, graph of participation presentence of each pollutant in the external costs, percentage of local and regional impacts in the external costs of each pollutant, presentence of costs derived from mortality and morbidity in the external costs of each pollutant and a cost / tone graph comparison of each pollutant.

10th Chapter

Chapter 10 contains two comparisons: one between the annual external cost in health per person living in Athens caused by particles (with diameter 10 μ m) that are emitted from the coastal passenger ships and cruise ships approaching the port of Piraeus for one year with the external cost per person living in Athens caused by particles (with diameter 10 μ m) that are emitted from the industries in greater Athens is taken place and one between the annual external cost in health per person living in Athens caused by particles (with diameter 2.5 μ m) that are emitted from the coastal passenger ships and cruise ships approaching the port of Piraeus for one year with the external cost per person living in Athens caused by particles (with diameter 2.5 μ m) that are emitted from the road transport sector this time.

11th Chapter

It is the Chapter that contains the final conclusion and recommendations for future improvement work.

Chapter 1: Ship air emissions

1.1 The problem of air pollution from ships

Ships contribution to air pollution first started with the use of steam engines and later internal combustion engines in marine transportation. The IMO (International Maritime Organization) adopted the MARPOL convention on 2 November 1973 for the prevention of marine pollution since the impact of marine pollution is more direct than air pollution. Annex VI for the prevention of air pollution from shipping entered into force on 19 May 2005, almost a century after the problem first started and because of that, a certain culture was developed throughout the years before in favor of more polluting technologies and practices.

1.2 Quantities of total air emissions from ships and comparison with other transport modes

Figure 1 shows the different sources of pollution in a ship. For air emissions it is interesting to note that they are divided into emissions that result in air pollution and emissions that result in climate change.

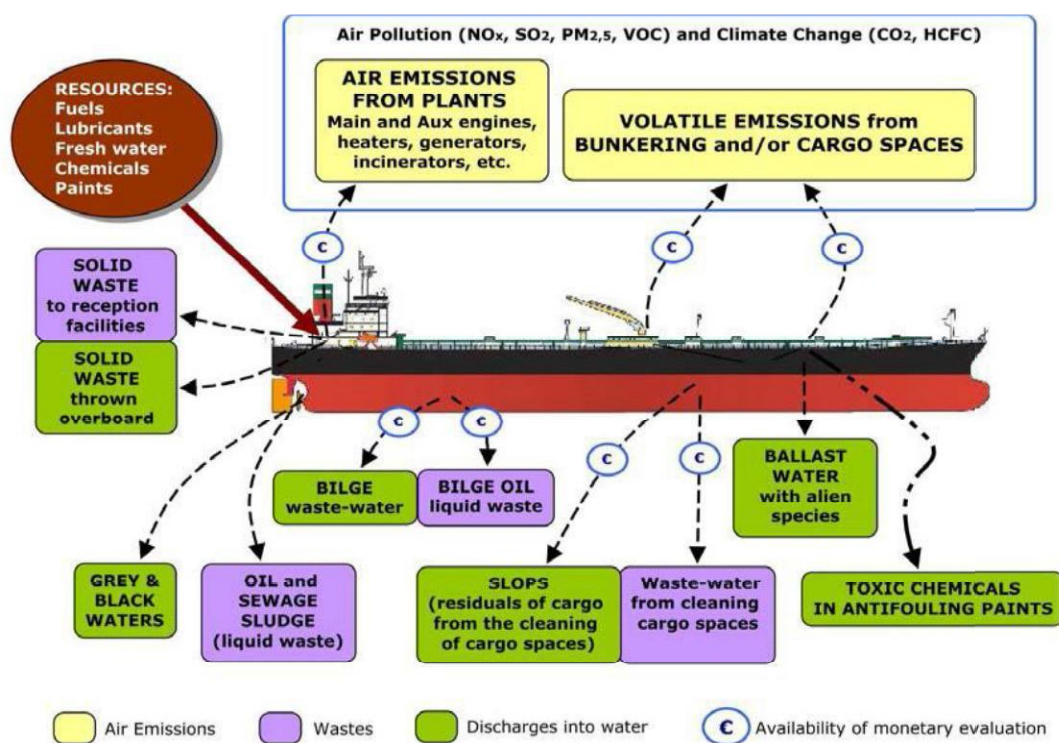


Figure 1: Ship's Resources Consumptions and Pollution Sources (source: Maffii et al., 2007)

Maffii et al. (2007) estimated for the year of 2006 the ship GHG (Green House Gas) emissions (CO_2 , HCFC). Specifically CO_2 emissions for the EU fleet found to be 225.2 Mtonnes/y and for the world fleet 1003 Mtonnes/y. In addition, for the HCFC releases in the atmosphere due to losses of refrigerant gases from air conditioning systems and on-board freezers the results were 1550.8 tonnes/y for the EU fleet and 6402.8 tonnes/y for the world fleet. According to these results world shipping CO_2 emissions account for 3.34% of the global CO_2 emissions from fuel combustion (about 30 billion tonnes, IEA, 2012); the EU fleet for 0.75%. In a geographical perspective, 178 million tonnes of CO_2 were released from ships in the five European sea areas of the EMEP (NE Atlantic & Black & Mediterranean Seas) domain in 2005 according to the reference data of the IIASA-Entec-MET.NO study (2006). Other studies have found similar results (Cofala et al., 2007; Whall et al., 2002; Concawe, 2007). Psaraftis&Kontovas (2009) using the Lloyds-Fairplay world ship database for 2007 calculated a total of 942.44 Mtonnes/y CO_2 emissions from the world fleet. Similar results ranging mostly between 713 and 1046 million tons CO_2 per year were presented also by other studies (Eyring et al., 2005a); (Corbett and Kohler 2003); (Corbett et al., 1999), (Buhaug et al., 2008) (Buhaug et al., 2009), (IEA, 2007).

Maffii et al. (2007) also estimated for the year 2006, the air quality emissions (SO_2 , NO_x , $PM_{2.5}$ and VOC (including HC)). The SO_2 emissions for the EU fleet were found to be 3.48 million tonnes/y and for the world fleet 16.54 million tonnes/y, the NO_x emissions for the EU fleet 5.41 million tonnes/y and for the world fleet 24.29 million tonnes/y, the $PM_{2.5}$ emissions for the EU fleet 0.42 million tonnes/y and for the world fleet 1.91 million tonnes/y and the HC emissions for the EU fleet 1.85 million tonnes/y and for the world fleet 0.83 million tonnes/y. Overall VOC emissions estimated to be 1.2 Mtonnes/y, 368,000 tonnes from oil tanker cargo loading and 46,000 tonnes from ship's bunkering. Also in the EMEP area according to the reference data of the IIASA-Entec-MET.NO study (2006) the SO_2 emissions were 2.96 million tonnes/y, the NO_x emissions 4.1 million tonnes/y, the $PM_{2.5}$ emissions 3.24 million tonnes/y and the HC emissions 1.45 million tonnes/y. Other studies have found comparable results (Cofala et al., 2007; Whall et al., 2002; Endresen et al., 2005; Concawe, 2007). As for the global emissions similar results were presented in previous papers (Eyring et al., 2005b; Corbett and Kohler, 2003; Corbett et al., 1999; Buhaug et al., 2008; Vestreng et al., 2007).

In Figure 2 estimations for global emissions of CO_2 from different studies are displayed all together. Corbett & Kohler (2003) and Corbet et al. (1999) emissions are in million tons of Carbon.

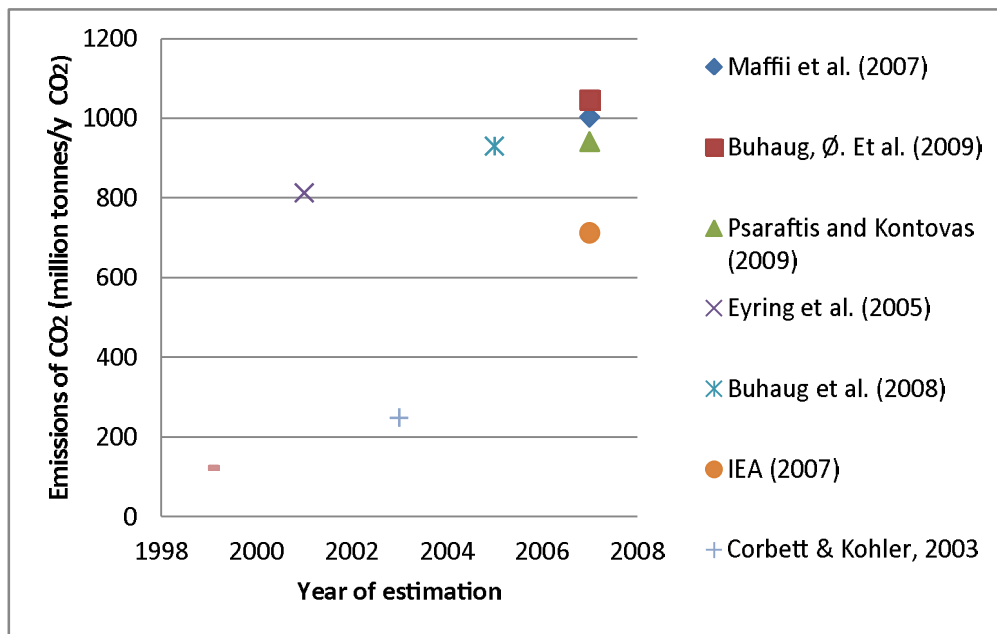


Figure 2: Studies comparison of global emissions of CO_2 from Shipping

Figure 3-6 shows estimations of global emissions of SO_2 , NO_x , PM and HC from different studies. Corbett & Kohler (2003) and Corbet et al. (1999) emissions are in million tones S, Corbett & Kohler (2003) and Corbet et al. (1999) emissions are in million tones N, Maffii et al. (2007) estimates PM_{2.5} where the other studies PM₁₀ and Corbett & Kohler (2003) and Corbet et al. (1999) emissions are in million tones CH₄.

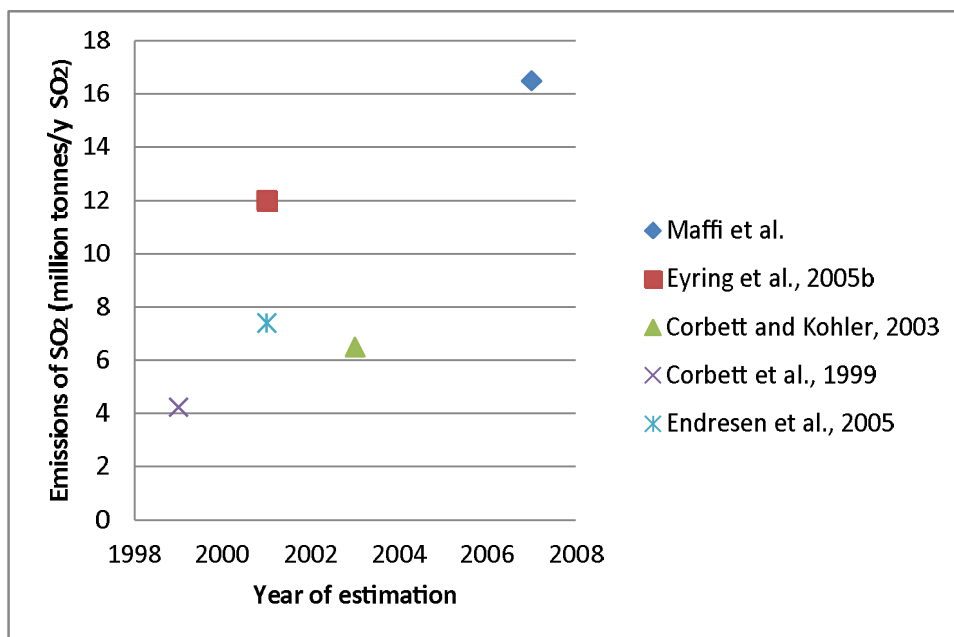


Figure 3: Studies comparison of global emissions of SO₂ from Shipping

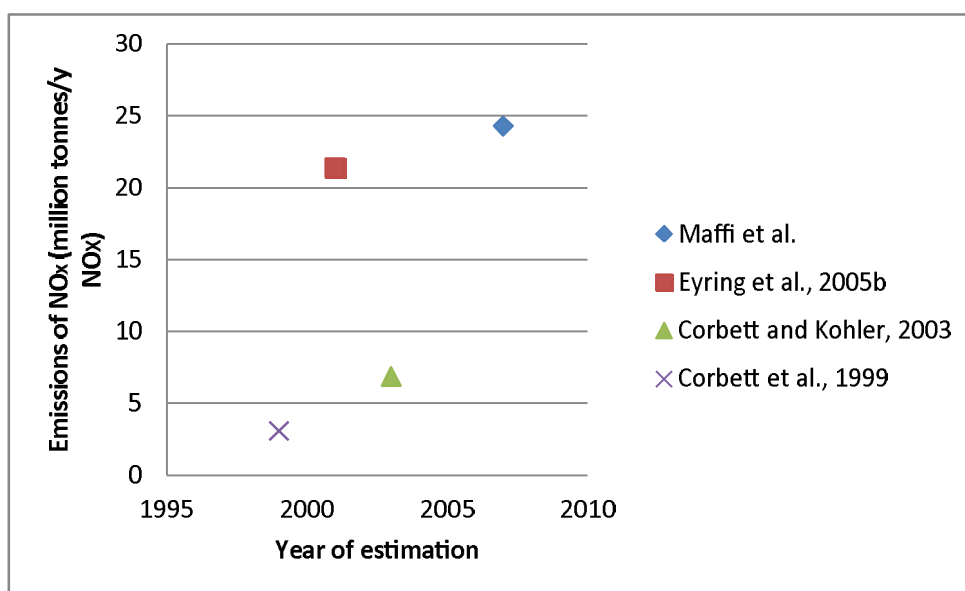


Figure 4: Studies comparison of global emissions of NO_x from Shipping

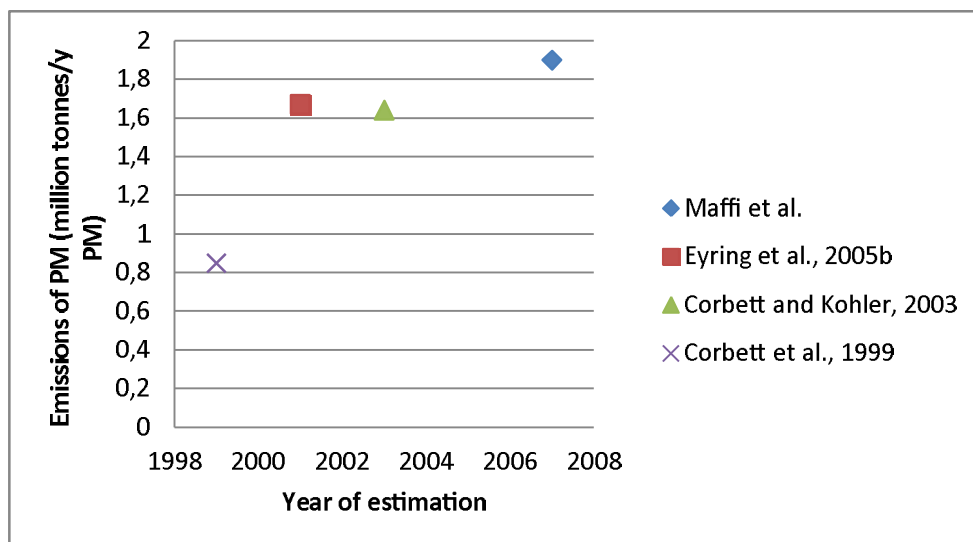


Figure 5: Studies comparison of global emissions of *PM* from Shipping

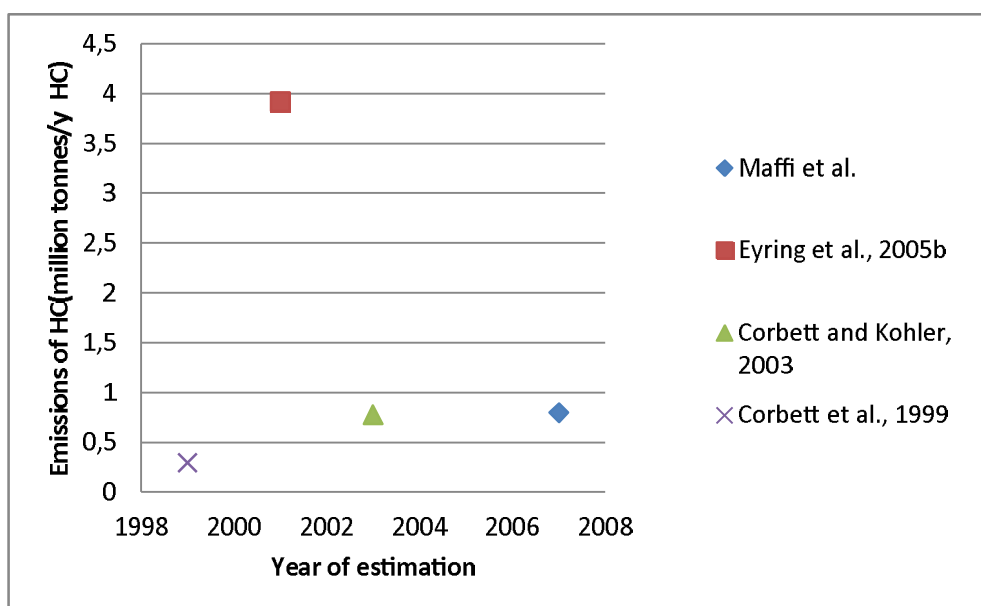


Figure 6: Studies comparison of global emissions of HC from Shipping

A comparison between ship emissions and emissions from other transport modes provides an insight of maritime transport's contribution to global air pollution and climate change. In the study of Buhaug et al. (2008), total shipping emissions of CO_2 were calculated as a sum of international shipping and domestic/fishing and found to be 931 million tonnes while CO_2 emissions from rail, road diesel and aviation are 133,4757 and 735 million tonnes respectively (these estimations are from IEA, 2005). In Table 1 we summarize the above results.

Table 1: CO₂ emissions - Comparison of different transport modes (source: IEA, 2005)

Transport mode	Source	CO ₂ emissions (million tonnes, 2005)
Rail	IEA (2005)	133
Road diesel	IEA (2005)	4757
Aviation	IEA (2005)	735
International shipping	Buhaug et al. (2008)	774
Domestic/fishing	Buhaug et al. (2008)	157

In the Second IMO GHG Study (Buhaug, Ø et al, 2009) the emissions of CO₂ from shipping and other transport modes were given in presentence of total emissions. This way the reader has a clearer picture of the contribution of each transport mode. Figure 7 shows these results.

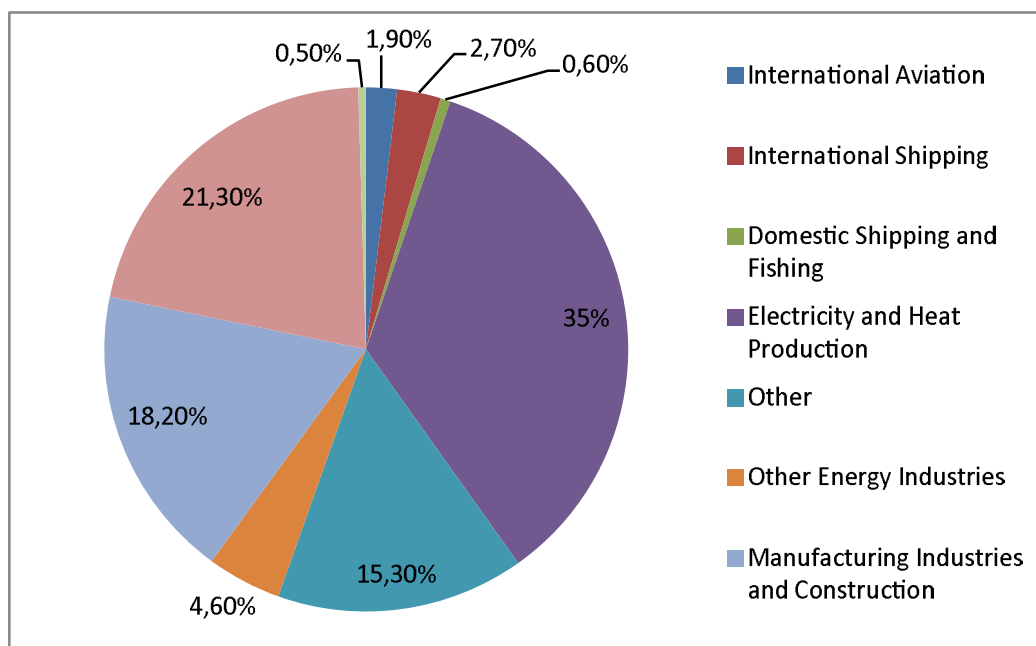


Figure 7: Emissions of CO₂ from shipping and other transport modes given in presentence of total emissions (source: Buhaug, Ø et al, 2009)

Combining the two studies we can conclude that total CO₂ emissions from shipping surpass those from rail and aviation reaching a total of 3.3% of the global emissions. Electricity and heat production are the main contributors to the global CO₂ emissions closely followed by road emissions. However shipping should take imminent action to reduce its future emissions since according to future scenarios (given in the recent IMO GHG Study, (Buhaug, Ø et al, 2009) shipping's contribution will be increased in 2050 (between 12% and 18% of global emissions) while other modes of transport are

expected to reduce their contribution. As for the air pollution, emissions of SO_2 , NO_x , $PM_{2.5}$, PM_{10} , CO and NMVOC have been reported to the Convention on Long-range Transboundary Air Pollution (LRTAP Convention) in EEA32 (European Environment Agency-33 member states). Figure 8 summarizes these results. The graphs report the percentage contribution of transport and not transport sector to total emission of air pollutants in EEA32. Transport sector includes road transport, shipping, aviation and railways.

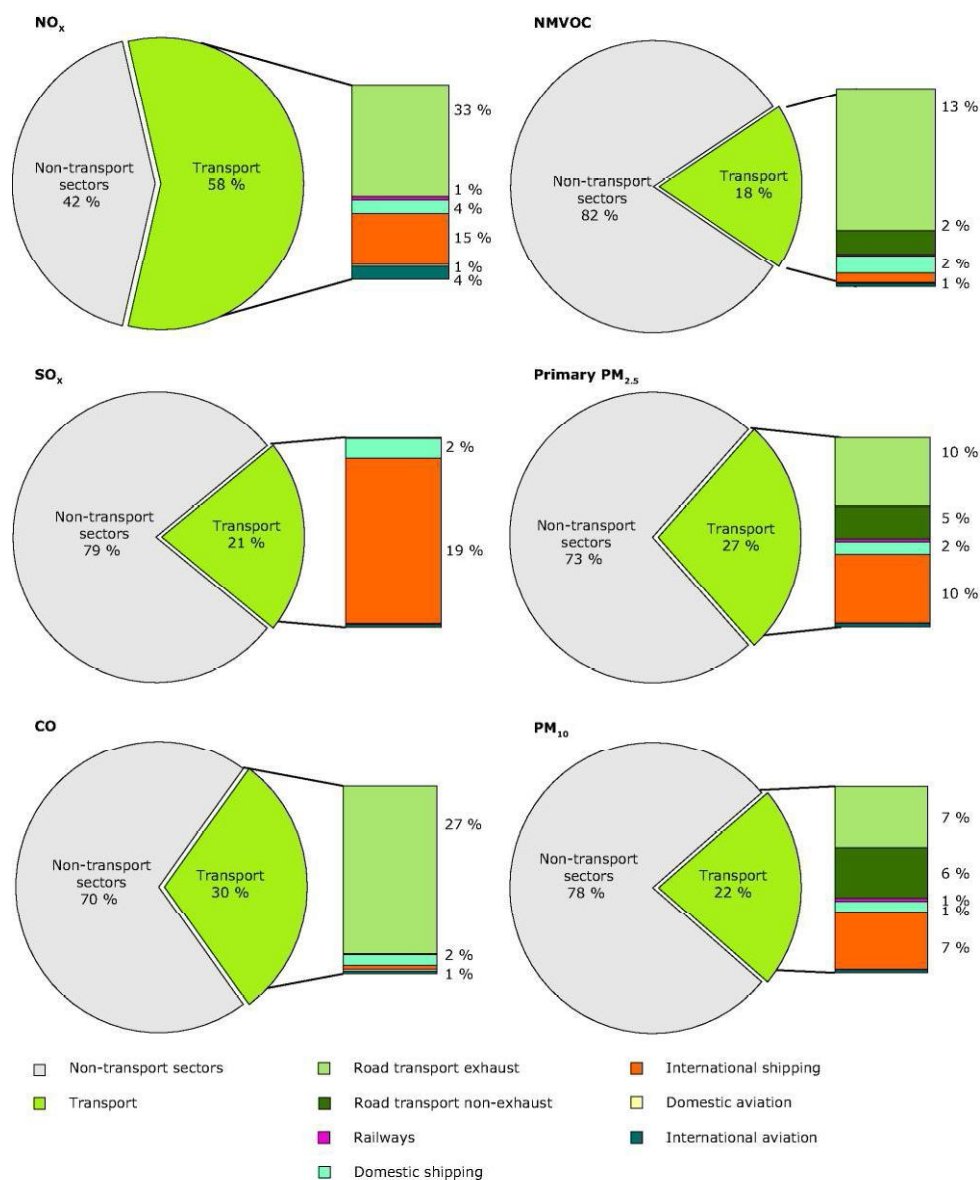


Figure 8: Percentage contribution of transport and not transport sector to total emission of air pollutants in EEA32 (source: <http://www.eea.europa.eu/data-and-maps/figures/the-contribution-of-the-transport-1>)

According to Figure 8, for the transport sector, the contributing emissions of air pollutants from the whole sector of shipping (domestic and international) are: SO_x (21 %), NO_x (19%), PM_{10} (12 %), $PM_{2.5}$ (8%), NMVOC (3 %) and CO (3 %). However it

should be noted that this does not mean that, for example, SO_x emissions are more dangerous than PM emissions, it's just a quantitative comparison of different air pollutants and not a risk analysis.

1.3 Categories of air emissions

Air emissions may be grouped, subject to their general impact, to: emissions causing air pollution and emissions contributing to the climate change phenomenon. In the first category belong the emissions of SO_x , NO_x , PM, CO and VOC and in the second the emissions of CO_2 , HCFC, and CH_4 . Air pollutants can further categorized into main and secondary pollutants. The secondary pollutants are not emitted directly by any emission source (like the main pollutants) but they are formed later in approximately 50 km from the source when chemical reactions are taking place between main air pollutants and the environment. The secondary pollutants in shipping are: O_3 (ozone), sulfates and nitrates.

1.4 Origin and impact of each air pollutant

1.4.1 Particulate matter (PM)

Origin: PM is an ill defined mixture of pollutants, from acids (such as nitrates and sulfates) to organic chemicals, metals, soil, dust particles or generally anything, solid or liquid that accumulates in a particle detector (Rabl A., 2001). It can be categorized in particles with less than 10 micrometers diameter (the “coarse” fraction) and particles with less than 2.5 micrometers diameter (the “fine” fraction) called PM_{10} and $PM_{2.5}$ (Café, 2005). Figure 9 shows an Illustration of PM_{10} and $PM_{2.5}$ particle size. In the atmosphere, PM can either originate from primary particles emitted directly or ‘secondary’ particles from chemical reactions between PM-forming (precursor) gases like SO_2 , NO_x , NH_3 and non-methane volatile organic compounds (NMVOC) (EEA, 2013). Specifically for the ‘secondary’ particles, SO_2 , NO_x , NH_3 form sulfate, nitrate and ammonium compounds which then condense into liquid form and produce new particles in the air, called secondary inorganic aerosols (SIA) (EEA, 2013). Secondary organic aerosols (SOA) are formed from the oxidation of VOC to less volatile compounds (EEA, 2013). The main chemical compounds of an aerosol (Black carbon (BC), nitrate (NO_3^-), ammonium (NH_4^+), organic matter concentrations (OM), non-sea-salt sulfate ($nssSO_4^{2-}$), sea salt and mineral dust)

account for about 70% or more of the PM_{10} and $PM_{2.5}$ mass when the rest 30% is thought to be due to the presence of water or to the underestimation of the molecular mass to carbon mass ratio when calculating organic matter concentrations (Putaud et al., 2004). In shipping, primary particles are emitted directly from the funnel due to incomplete combustion and secondary particles are formed from SO_2 , NO_x and VOC emissions.

Impacts: The most consistent results, worldwide, have been found for PM and multi-pollutant analyses have usually found them to be the most significant source of damage costs (Rabl A., 2001). Numerous studies have found a link between particle levels and hospital admissions and emergency room visits, even death from heart or lung diseases (Denissis, 2009). WHO (2013) (World Health Organization) concluded that “the evidence for a causal link between $PM_{2.5}$ and adverse health outcomes in humans have been confirmed and strengthened and, thus, clearly remain valid. As the evidence base for the association between PM and short-term, as well as long-term, health effects have become much larger and broader it is important to update the current WHO Guidelines for PM”. Also for black carbon, secondary organic aerosols (SOA), and secondary inorganic aerosols (SOA) there is substantial exposure and health research finding associations and effects (WHO, 2013). New evidence links black carbon particles with cardiovascular health effects and premature mortality for both short-term (24 hours) and long-term (annual) exposures where epidemiological studies continue to report associations between sulfates or nitrates and human health (WHO, 2013). What’s more disturbing is that center investigators identified the brain and the autonomic nervous system as new targets for adverse effects of PM (Breysse et al., 2013). Long-term exposures of PM have been associated with reduced lung function, chronic bronchitis and premature death. Short-term exposures can aggravate lung disease, causing asthma attacks, acute bronchitis and increase susceptibility to respiratory infections (Denissis, 2009). The size of particles is crucial to their potential for causing health problems and thus the impact of shipping activity increases with decreasing particle size (EEA, 2013). In fact PM_{10} and $PM_{2.5}$ pose the greatest danger because they can penetrate the lungs and get into the bloodstream (Denissis, 2009). In Café (2005) it’s been estimated that over 300, 000 premature deaths equivalent a year in 2000 are the effects on life expectancy of exposure to particulates. Corbett et al. (2007) modeled ambient PM concentrations from

ocean-going ships and found that PM emissions are responsible for approximately 60,000 cardiopulmonary and lung cancer deaths annually, with most deaths occurring near coastlines in East Asia, Europe and South Asia. Another analysis by WHO (2006b) indicates that PM (and especially $PM_{2.5}$) affects the most of Europe population leading to a wide range of acute and chronic health problems as well as to a reduction in life expectancy of 8.6 months on average in the 25 countries of the European Union (EU). Finally, PM_{10} emissions are closely associated with diesel engines which are 30 to 70 times higher than from gasoline engines (Denissis, 2009).

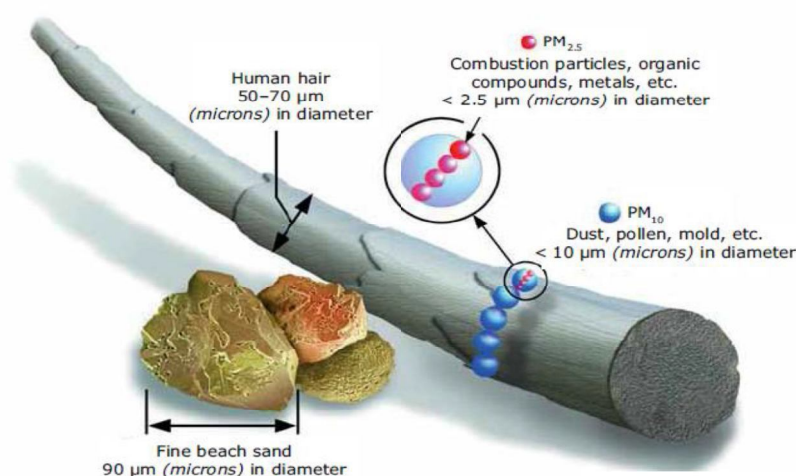


Figure 9: Illustration of PM_{10} and $PM_{2.5}$ particle size (source: EPA, 2010)

1.4.2 Carbon monoxide (CO)

Origin: CO is a gas emitted from incomplete combustion of fossil fuels and biofuels (EEA, 2013) and therefore it is emitted directly from the funnel of the ship. In the atmosphere CO has a lifetime span of three months or so because it slowly oxidizes into CO_2 forming O_3 during the process (EEA, 2013).

Impacts: CO is hazardous for humans and impossible to be detected from them as it is colorless and odorless. It affects not only the sensitive parts of a society like individuals with respiratory diseases, infants and elderly persons but also healthy individuals (Denissis, 2009). CO enters the body through the lungs and is strongly bound to haemoglobin and therefore reduces the amount of oxygen that it can be transferred to the body's organ and tissues (EEA, 2013). People that suffer from cardiovascular disease are the most sensitive because further reduction of oxygen to the heart can cause myocardial ischemia (EEA, 2013). High concentrations of CO can

cause asphyxia and eventually death even to a healthy person. Some of the most common effects of a small increase in the level of carbon monoxide are impairing exercise capacity, learning functions, ability to perform complex tasks, affected coordination, difficult concentrating and damaged visual perception (Denissis, 2009). There is also epidemiological evidence which suggests that direct impacts of CO also appear to be statistically significant. However the resulting damage costs are low, even for the transport sector (Rabl A., 2001). In many studies CO is not examined as a possibly causative pollutant where in other studies it is considered but they fail to find a CO-related effect (Rainer Friedrich & Peter Bickel, 2001).

1.4.3 Carbon dioxide (CO₂)

Origin: CO₂ is naturally part of the atmosphere but it can also be produced from incomplete combustion of fossil fuels and like CO it is also emitted directly from the ship's funnel.

Impacts: CO₂ is a greenhouse gas which means that in large quantities can cause global warming. Global warming is the phenomenon where increasing concentrations of greenhouse gases cause a continuing rise in the average temperature of Earth's climate system (Stocker et al, 2013).

1.4.4 Nitrogen oxides (NO_x)

Origin: Emissions of NO_x are produced from the combustion of fuels under high pressure and temperature (Denissis, 2009). More specifically, high air temperatures activate oxidation of nitrogen in the air passing through the engine as well as the potential formation of NO_x from nitrogen in the fuel result in emissions of NO_x (Concawe, 2007). Most NO_x are emitted in the form of NO which is rapidly oxidized in the atmosphere to NO₂ and then to nitric acid and other nitrates. A small part of NO_x emissions is directly emitted as NO₂, called NO₂ fraction (f- NO₂). F-NO₂ is less than 5% for petrol fuelled vehicles, whereas in diesel vehicles (like most ships) is higher at around 10–12% (Grice et al., 2009).

Impacts: As it was previously noted most NO_x are emitted in the form of NO which is rapidly oxidized in the atmosphere to NO₂ and then to nitric acid and other nitrates. NO is usually considered harmless as it is a reducing and not an oxidizing agent (Rabl A., 2001). NO₂'s toxicity generally is attributed to its oxidative capabilities although it is less reactive as an oxidant than O₃ (Rabl A., 2001). NO₂ primary affects the

respiratory system (EEA, 2013). Short-term exposure to NO_2 can change the lung function in sensitive population groups and long-term exposure can lead to more serious effects such as increased susceptibility to respiratory infection (EEA, 2013). Epidemiological studies have shown that long-term exposure to NO_2 is possibly associated with an increase of symptoms of bronchitis in asthmatic children (EEA, 2013). Bascom et al (1996) concluded that "meta analysis indicates that a long term increase in exposure to NO_2 of 15 ppb is associated with an increase in illness odds of approximately 20% in children but not in adults" (Rabl A., 2001). NO_2 is highly correlated with other pollutants (especially PM), so it is difficult to distinguish the effects of NO_2 from those of other pollutants (EEA, 2013). There isn't sustainable evidence for direct health impacts of NO_2 except maybe for morbidity of children and therefore it seems that the main damage of NO_x is the result of its second pollutants, O_3 and nitrates (Rabl A., 2001). Nitrate particles can be transported long distances by winds and inhaled deep into people's lungs increasing illness and premature death from heart and lung disorders, such as asthma and bronchitis. In addition, NO_2 can have adverse effects on ecosystems. Even though in normal concentration it is an important nutrient, excess deposition of reactive nitrogen can lead to a surplus of nitrogen in ecosystems, causing eutrophication (nutrient oversupply) in terrestrial and aquatic ecosystems (EEA, 2013).

1.4.5 Sulfur dioxide (SO_2)

Origin: Outcome of the combustion process in diesel engines. The main fuel used in international shipping is HFO (Heavy Fuel Oil-used in 87 % of ships in 2010) which contains sulfur (EEA, 2013) and the combustion of sulfur-containing fuels leads to SO_2 emissions.

Impacts: Further oxidation of SO_2 create acidic deposition (Holleman, A. F.; Wiberg, E., 2001) called acid rain, causing adverse effects on aquatic ecosystems in rivers and lakes, damage to forests, and acidification of soils (EEA, 2013). Also, sulfate particles (secondary pollutants of SO_2) can be transported long distances by winds and inhaled deep into people's lungs increasing illness and premature death from heart and lung disorders, such as asthma and bronchitis. SO_2 itself contributes to respiratory problems, particular in children and elderly, and aggravates existing heart and lung

diseases (Denissis, 2009). According to epidemiological studies SO_2 can affect the respiratory system and lung functions, and causes irritation of the eyes (EEA, 2013).

1.4.6 Volatile organic compounds (VOC)

Origin: VOC (which include HC) are produced from incomplete combustion and fuel evaporation and they play an important role in creating ground level-ozone when they chemically react with NO_x (Denissis, 2009).

Impacts: In addition, VOC contain Hydrocarbons (HC), some of which are carcinogenic. For example, prolong exposure to benzene (C_6H_6) can cause damage to genetic material of cells (EEA, 2013) which lead to cancer. Also, chronic exposure to C_6H_6 can damage bone marrow and cause haematological effects such as decreased red and white blood cell counts (EEA, 2013). Other harmful components of VOC are the polycyclic aromatic hydrocarbons (PAHs) which are ubiquitously distributed human mutagens and carcinogen (Choi, 2006).

1.4.7 Ozone (O_3)

Origin: Ground-level (tropospheric) O_3 unlike primary air pollutants is not directly emitted into the atmosphere; instead it is formed from complex chemical reactions following emissions of precursor gases such as NO_x and non-methane VOCs (EEA, 2013). Figure 10 shows these photochemical reactions. Also at continental scale methane (CH_4) and carbon monoxide (CO) play a role in O_3 formation (EEA, 2013).

Impacts: Ozone is a highly oxidative compound and because of that is harmful to vegetation, materials and human health (WHO, 2008). Respiratory health problems, such as breathing problems, asthma, reduced lung function, and other lung diseases can be caused by high concentrations of O_3 (EEA, 2013). Recent epidemiological studies have strengthened the evidence that daily exposures to ozone increase mortality and respiratory morbidity rates and as for long-term exposures, new epidemiological evidence indicate inflammatory responses, lung damage and persistent structural airway and lung tissue changes early in life (however these results are not conclusive and future studies must confirm them) (WHO, 2008). Ozone can also damage buildings by increasing the rate of degradation and reduce agriculture crop yields by impairing reproduction and growth of plants (EEA, 2013). In addition, O_3 is a short lived (unlike CO_2) greenhouse gas, so its contribution to global warming is limited.

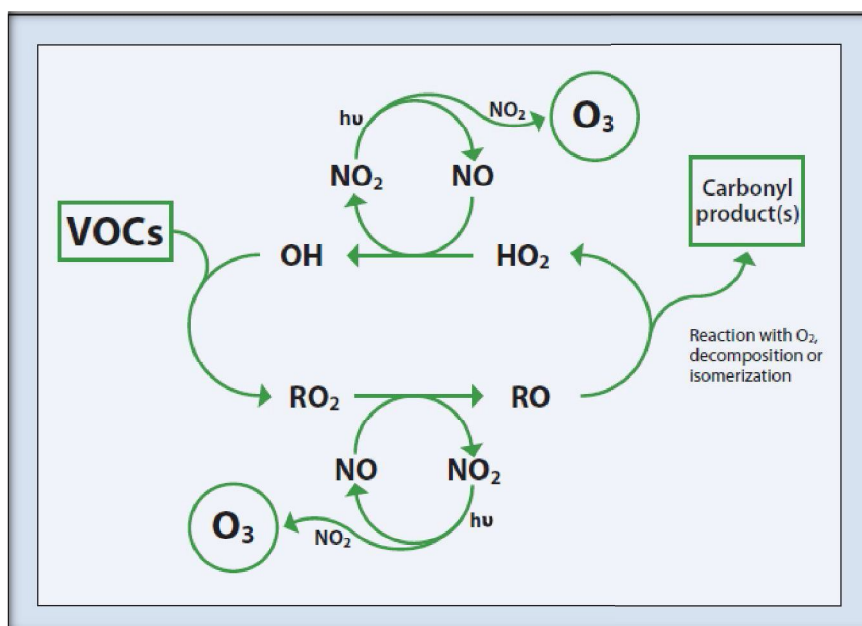


Figure 10: Formation of ground-level O_3 (source: Jenkin & Hayman, 1999)

To summarize all the above, Figure 11 and Table 2 are given below.

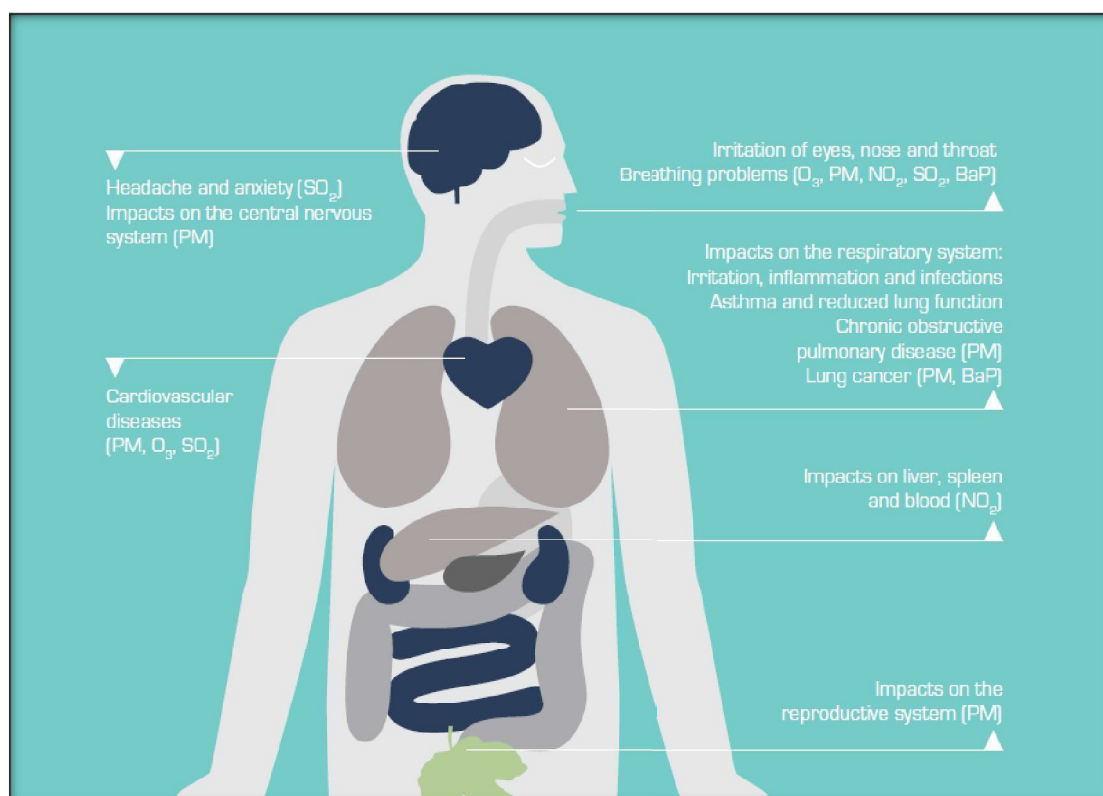


Figure 11: Health impacts of air pollution (source: EEA, 2013f)

Table 2: Effects of air pollutants on human health, the environment and the climate (source: EEA, 2013)

Pollutant	Health effects	Environmental effects	Climate effects
Particulate matter (PM)	Can cause or aggravate cardiovascular and lung diseases, heart attacks and arrhythmias, affect the central nervous system, the reproductive system and cause cancer. The outcome can be premature death.	Can affect animals in the same way as humans. Affects plant growth and ecosystem processes. Can cause damage and soiling of buildings. Reduced visibility.	Climate effect varies depending on particle size and composition: some lead to net cooling, while others lead to warming. Can lead to changed rainfall patterns. Deposition can lead to changes in surface albedo (the ability of the earth to reflect radiation from sunlight).
Ozone (O3)	Can decrease lung function; aggravate asthma and other lung diseases. Can lead to premature mortality.	Damages vegetation, impairing plant reproduction and growth, and decreasing crop yields. Can alter ecosystem structure, reduce biodiversity and decrease plant uptake of CO2.	Ozone is a greenhouse gas contributing to warming of the atmosphere.
Nitrogen oxides (NOX)	NO2 can affect the liver, lung, spleen and blood. Can aggravate lung diseases leading to respiratory symptoms and increased susceptibility to respiratory infection.	Contributes to the acidification and eutrophication of soil and water, leading to changes in species diversity. Acts as a precursor of ozone and particulate matter, with associated environmental effects. Can lead to damage to buildings.	Contributes to the formation of ozone and particulate matter, with associated climate effects.
Sulphur oxides (SOX)	Aggravates asthma and can reduce lung function and inflame the respiratory tract. Can cause headache, general discomfort and anxiety.	Contributes to the acidification of soil and surface water. Causes injury to vegetation and local species losses in aquatic and terrestrial systems. Contributes to the formation of particulate matter with associated environmental effects. Damages buildings.	Contributes to the formation of sulphate particles, cooling the atmosphere.

Carbon monoxide (CO)	Can lead to heart disease and damage to the nervous system; can also cause headache, dizziness and fatigue.	May affect animals in the same way as humans. Acts as a precursor of ozone.	Contributes to the formation of greenhouse gases such as CO ₂ and ozone.
Benzene (C₆H₆)	A human carcinogen, which can cause leukaemia and birth defects. Can affect the central nervous system and normal blood production, and can harm the immune system.	Has an acute toxic effect on aquatic life. It bioaccumulates, especially in invertebrates. Leads to reproductive problems and changes in appearance or behavior. It can damage leaves of agricultural crops and cause death in plants.	Benzene is a greenhouse gas contributing to the warming of the atmosphere as it contributes to the formation of ozone and secondary organic aerosols, which can act as climate forcers.
PAHs, in particular Benzo-a-pyrene (BaP)	Carcinogenic. Other effects may be irritation of the eyes, nose, throat and bronchial tubes.	Is toxic to aquatic life and birds. Bioaccumulates, especially in invertebrates.	No specific effects.

References of Chapter 1

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Chapter 2: External Costs of Maritime Shipping

2.1 Externalities and external cost

An externality, in economics, is the cost or benefit that affects a party who did not choose to incur that cost or benefit (Buchanan, James; Wm. Craig Stubblebine, 1962). The above definition suggests that externalities can either be negative or positive. This study addresses the negative externalities or external costs of ship air emissions. The external cost occurs when the activities of one group of persons have an impact (which is not fully accounted or compensated for) on another group (ExternE, 2005). Monetary estimates for the corresponding external costs are required for the final results. The importance of external cost in the case of shipping lies in the assessment of health and environmental impacts of the pollutants (ExternE, 2005)

External costs of shipping derive from:

1. Discharges into the sea (marine pollution)
2. Solid and liquid waste
3. Resources consumption
4. Ship recycling
5. Air emissions

A detailed description of the sources of air emissions costs has already be given in Chapter 1 and a brief analysis of the other three is given below.

2.1.1 Discharges into the sea

Ships are accountable for five sources of marine pollution: wastewater discharges from bilge separators, accidental oil spills due to operational activities (bunkering; oil cargo loading – relevant only for tankers), wastewater discharges from cargo tanks cleaning with seawater-based process, grey (laundries, kitchen, showers) and black (sewage) wastewater discharges and ballast water discharges (Maffii et al., 2007). Wastewater discharges from bilge separators can either be oil discharges or chemical substances in the engine room bilge wastewater (Maffii et al., 2007). The former are controlled by the Marpol Annex I (and therefore are at very low level <15 ppm) where the later are not controlled under IMO regulation (Maffii et al., 2007). Maritime transport activities release 62 million tonnes of bilge wastewater, containing

893 tonnes of oils in drops and other dangerous chemical substances, into the sea (Maffii et al., 2007).

Accidental oil spills (due to operational activities like bunkering; oil cargo loading – relevant only for tankers) in contrast to accidental oil spills due to non risk-specific activities are not caused by collision, groundings, fire or explosion (Maffii et al., 2007). It is estimated that about 142 tonnes oil are accidentally released in bunkering and cargo loading operational activities by tankers where 52 more tonnes/year are caused by non-tanker bunkering spills giving a total of 194 tonnes/y (Maffii et al., 2007).

Wastewater discharges from cargo tanks cleaning with seawater-based process are mainly related to chemical tankers; these discharges are subject to Marpol Annex II (Maffii et al., 2007). It is estimated that chemical tankers discharge 7 million tonnes wastewater from tank cleaning, with about 1500 tonnes/y legal discharges of oil (<15 ppm).

Grey water (laundries, kitchen, showers) and black water (sewage) discharges are regulated by Marpol Annex IV and are estimated to be more than 250 million tonnes globally from which 46000 tonnes/y are of organic matter (BOD- Biochemical oxygen demand) and about 9000 tonnes are of nitrogen substances and phosphorous legal discharges (Maffii et al., 2007).

World ballast water discharges from shipping estimated to be 12 billion tonnes in EEA (2006) causing the intrusion of non-native species around the world (Maffii et al., 2007). IMO adopted on 2004 an International Convention for the Control and Management of Ships' Ballast Water and Sediments (covering not only alien species but also pathogens carried by ballast water) which is not yet in force since it has not reached the ratification limit by member countries.

2.1.2 Solid and liquid waste

Liquid wastes are regulated by Marpol annex I, V and IV were solid wastes on board are regulated mainly by Marpol Annex V (Maffii et al., 2007). The main liquid waste is sludge produced by sewage treatment plants and oil sludge from centrifuges (Maffii et al., 2007). Global shipping produced 2.8 and 0.6 million tonnes respectively in 2006. to The solid waste produced on board can be comminuted paper, glass, metals, etc. in order to save holding spaces, food waste and plastic (Maffii et al., 2007). It is

estimated that for the year 2006 10.5 millions m^3 of solid waste have been produced by the world fleet (Maffii et al., 2007).

2.1.3 Shipping resources and chemicals consumptions

The main shipping resources and chemical consumptions are: fresh water, fossils (such as fuels and lubricants), paints, cleaning products used in the machinery spaces and deck rooms, refrigerant gases and chemical substances used in sewage treatment processes (Maffii et al., 2007). It is estimated for 2006 that international maritime transport consumes 316 million tons/year of fuels and 3.6 million tons of lubricants, 315 million tons/year of fresh water, used for cleaning, cooling, in showers, kitchens, toilets and other on-board services, 600000 tons of paints/year, 124000 tons of cleansing agents/year, 11000 tons of chemical substances for sewage treatment and 10000 tons of HCFC annual consumption (Maffii et al., 2007).

2.1.4 Ship recycling

Ship recycling can be very dangerous, if not done in specific facilities with specialized personnel, because of the numerous hazardous materials of which a ship is consisted. MEPC (Marine Environment Protection Committee) at its sixty-third session adopted the 2012 Guidelines for Safe and Environmentally Sound Ship Recycling and the 2012 Guidelines for the Authorization of Ship Recycling Facilities (UNCTAD, 2012). In addition MEPC at its sixty-two session adopted the 2011 Guidelines for the Development of the Inventory of Hazardous Materials and the 2011 Guidelines for the Development of the Ship Recycling Plan, and combined with the 2012 guidelines provide assist to ship-recycling facilities and shipping companies to begin introducing voluntary improvements to meet the requirements of the Hong Kong Convention which had been adopted in May 2009 (UNCTAD, 2012).

2.2 Bottom-up and top-down approaches for estimating the external cost

There are generally two ways to calculate the external costs i.e. the bottom-up and top-down approaches (Jiang L. & Kronbak J., 2012). In the bottom-up approach the starting point is at the source of emission where at micro-level the basic elements are first specified in details and then linked together to form a complete system (Jiang L. & Kronbak J., 2012). With other words, the passage from the origin of a pollutant to the affected receptors (population, crops, forests, buildings, etc.) is being traced

(ExternE, 2005). The top-down approach is essentially the breaking down of a system starting from the macro-level and then moving to the sources (Jiang L. & Kronbak J., 2012). An example of this approach is the evaluation of the external costs of the transport system within a country and then the division by the total amount of transportation leading to the average external costs (Jiang L. & Kronbak J., 2012). As for the comparison of the two methods, the bottom up approach is more precise and accurate, with potential for differentiation but it is costly (due to the complexity) and usually results are difficult to grouped (Miola et al., 2008). On the other hand the top-down approach is cheaper (since it is simpler) and easier to use-manipulate but fails to incorporate specific details (Jiang L. & Kronbak J., 2012).

2.3 Studies on external costs of air emissions from maritime shipping

Tzannatos (2010) found that air emissions from shipping in Greece generate an external cost of 2.95 billion euro for the year 2008. In external cost estimation for a specific case of a container ship sailing between Rotterdam and Gothenburg, Lee et al. (2010) estimated that the round trip would create 399,498 euro of air pollution external costs and 23,618 euro of climate change external costs, reaching a total external cost of 423,116 euro. Nash et al. (2008) calculated the air pollution costs of inland water transport for two selected trajectories on the Rhine and the Danube and found that environmental costs range between 0.17 and 0.41 cent per tkm. For the inland waterway transport from Basel to Rotterdam, Schmid et al. (2001) estimated for a vessel carrying 200 TEU the external costs of air pollution and global warming depending the upstream-downstream shipping and the results are for air pollution downstream: 18.54 €₁₉₉₉/LU (loading unit), upstream: 4.95 €₁₉₉₉/LU and for global warming downstream: 7.3 €₁₉₉₉/LU, upstream: 1.8 €₁₉₉₉/LU. Gallagher (2005) analyzed the total emissions and the economic costs of shipping emissions in the United States from 1993 to 2001 and found that the economic costs of SO₂ pollution range from \$697 million to \$3.9 billion and the costs from NO_x emissions are \$3.7 billion. Berechman and Tseng (2012) estimated the costs of key exhaust pollutants from shipping in the port of Kaohsiung in Taiwan to be 119.2 million \$. Finally, Tervonen et al. (2002) calculated the total marginal cost of emission impacts for the trip from Helsinki to Tallinn to be €1622.

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Chapter 3: Methodology

3.1 The impact pathway approach

The impact pathway approach (IPA) is a method for calculating the external costs of air pollutants and it was adopted by the ExternE, a series of research projects financed by the European Commission, Directorate-General (DG) Research for the assessment of external impacts and associated costs resulting from the supply and use of energy (Friedrich & Bickel, 2001). The steps of the methodology (also shown in Figure 12) applied in a pollutant are:

- 1) Source emission
- 2) Atmospheric dispersion
- 3) Impact
- 4) Quantification of impact cost

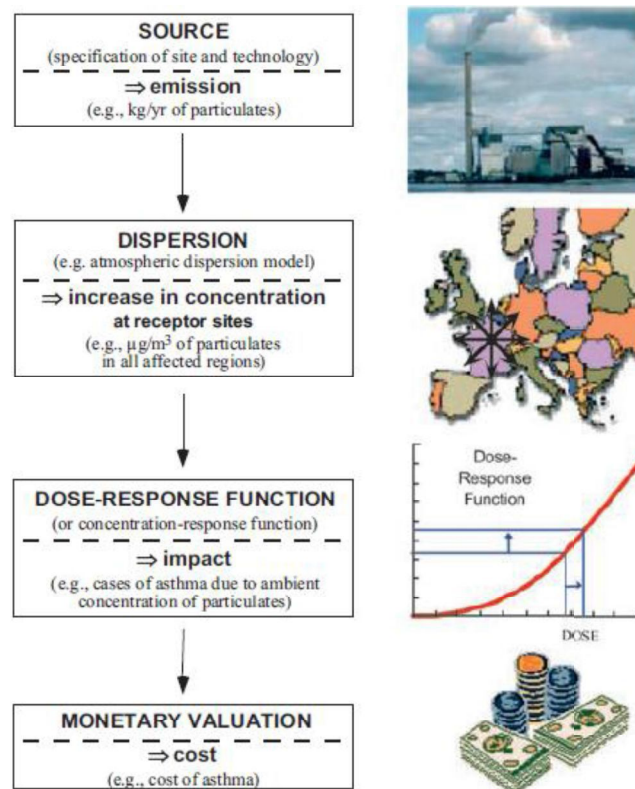


Figure 12: The steps of IPA (source: ExternE, 2005)

An analysis of each step is given in the following paragraphs.

3.1.1 Source emission

In the first stage of the method there must be a specification of the site (e.g. urban or rural surroundings) and the technology used as well as an identification of the pollutant-s (ExternE, 2005). For example a ship in a port emitting x tons/hour of PM_{10} .

3.1.2 Atmospheric depression

In the second stage, a calculation of increased pollutant concentrations in all affected regions is taking place (ExternE, 2005). This calculation is divided into local scale and regional scale analysis.

The local scale analysis usually uses Gaussian plume models for the calculation of primary pollutants concentrations due to low computing time combined with relatively accurate results (Friedrich & Bickel, 2001). The Gaussian plume models ‘‘Industrial Source Complex, ISC’’ (Brode and Wang, 1992) are preferred for point sources and the ROADPOL (International Road Policing Organization) model (Vossiniotis *et al.*, 1996) for lines sources (ExternE, 2005). The chemical conversion of secondary pollutants and aerosols is generally negligible in the local scale analysis (Spadaro, 2002).

For the regional scale analysis, the atmospheric turbulence makes the plume spread vertically and horizontally. In most cases it is assumed that the pollutants have been mixed vertically throughout the height of the mixing layer of the atmosphere (Friedrich & Bickel, 2001). Chemical reactions and deposition due to gravitational settling and precipitation cannot be neglected (Spadaro, 2002). That essentially means that secondary pollutants and aerosols begin to contribute to air pollution. The concentrations of the pollutants can be found using either Eulerian or Lagrangian trajectory models (Spadaro, 2002). For example the EMEP MSC-W (Meteorological Synthesizing Centre – West) uses a Lagrangian Ozone model (Sandness, 1993; Simpson, 1992, 1993; Simpson and Eliassen, 1997) in order to calculate the effects of reducing NO_x and VOC emissions (ExternE, 2005). Also, the ExternE study of the European Commission developed the EcoSense program which uses the Windrose Trajectory Model (WTM) (Krewitt *et al.*, 1995) to estimate the concentration and deposition of acid species on a regional scale (ExternE, 2005).

3.1.3 Impacts

Dose-Response functions (DRF) also known as Exposure-Response functions (ERF) or Concentration-Response functions (CRF) are used for the quantification of impacts (Spadaro, 2002). ERF relate the quantity of a pollutant that affects a receptor to the physical impact on this receptor (ExternE, 2005). However, what the term ERF really means is the response to a given exposure of a pollutant in terms of atmospheric concentration, rather than an ingested dose (Friedrich & Bickel, 2001). The reason for this is that the personal dose is correlated with other factors such as indoor/outdoor concentration ratio, physical activity level, the amount of time a person spends outdoors, proximity to the emission source and chemistry making difficult to be estimated (Spadaro, 2002). It is obvious that quantification of damage requires the corresponding ERF to be known, thus the ERF are central ingredients in the impact pathway analysis (ExternE, 2005).

Exposure response functions can be linear or non-linear and contain thresholds (critical loads) or not as illustrated in Figure 13.

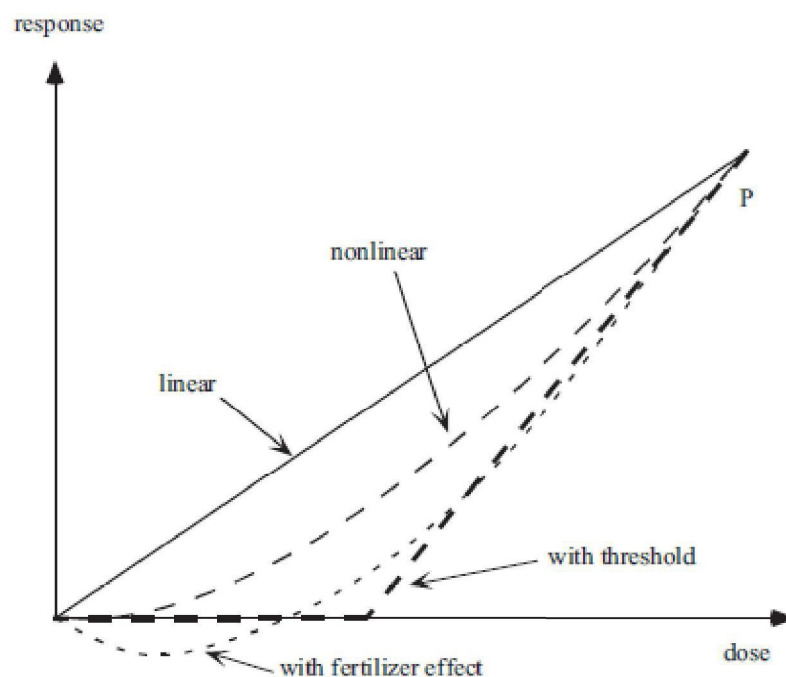


Figure 13: Different types of Exposure Response Functions (source: Friedrich & Bickel, 2001)

The point P refers to the lowest dose at which a response has been measured (ExternE, 2005). The linear model (i.e. a straight line from the origin through the observed point P) appears to be appropriate for many cases, in particular for many

cancers (ExternE, 2005). The straight line down to some threshold, and zero effect below that threshold is called the ‘‘hockey-stick’’ (ExternE, 2005). It is important to note that if the background concentration is everywhere above this threshold there is no difference between the linear and the hockey stick function (with the same slope) for the calculation of incremental damage costs (ExternE, 2005). In most countries the background for particles, NO_x , SO_2 , O_3 and CO is above the level where effects are known to occur so for those pollutants the precise form of the ER function at extremely low doses is irrelevant (ExternE, 2005). The fertilizer effect is referred to the effects of air pollutants with the potential to act as fertilizers like those containing sulphur and nitrogen (Friedrich & Bickel, 2001). Epidemiological studies (e.g. Aunan, 1996; Brunekreef, 1997; ExternE, 1998; Leksel & Rabl, 2001 and Rabl, 2001) help scientists to study the human health and its related illnesses, ultimately leading to the formation of the DRF (Spadaro, 2002).

Epidemiological studies have also the advantage of studying response under realistic conditions, assessing the effects of pollutants on real populations of people, crops, etc where laboratory studies have the disadvantage of exposing study populations to extremely high levels of pollutants even greater than they would be exposed in the field (Friedrich & Bickel, 2001). Most studies to date are focused in finding the short term or acute effects of air pollution mainly because these relations are the easiest to establish as they require few data parameters and are not directly affected by changes in the background pollution level (Spadaro, 2002). On the other hand, long term or chronic cumulative effects of air pollution are correlated with many factors including population life style, personal habits (smoking exercise, diet), age distribution and level of background pollution (Spadaro, 2002). In Pope et al. (1995) study half a million (550000) people from 151 metropolitan communities throughout the United States were followed for 7 years making it the largest study of its kind and a key point of reference for today studies (Spadaro, 2002).

The question here is: Is it valid to assume that these results can be used in Europe? In most cases experts suggest that the transference of the functions should be preferred from ignoring particular types of impact altogether- nevertheless both options have uncertainties (Friedrich & Bickel, 2001).

3.1.4 Quantification of impact's cost

The monetary valuation step has the goal to account for all costs, market and non-market (ExternE, 2005). For the health impacts the market costs include the cost of medical treatment for the illness, wage and productivity losses where the non-market costs take into account one's willingness-to-pay (WTP) to avoid the risk of pain and suffering (Spadaro, 2002).

Air pollution damage costs are dominated by non-market goods, especially mortality (ExternE, 2005). In the last years, the preferred method for valuing non-market goods has become the contingent valuation (CV) (Mitchell and Carson, 1989) in which the WTP is obtained by asking individuals how much money they are willing to pay to achieve a benefit (Spadaro, 2002). With other words, CV involves setting up a hypothetical market (e.g. by questionnaire) to elicit the preferences of those interviewed (Friedrich & Bickel, 2001). Krupnick *et al.* (2002) led the way by developed a questionnaire specifically for the CV of air pollution mortality and used it in Canada, Japan and USA and recently has been used in France (Desaigues *et al.*, 2004), Italy and the UK (ExternE, 2005). However, there are also other valuation methods that can be used in addition or complementarily with CV (ExternE, 2005). The cost of mortality is evaluated by the determination of Value of a Life Year Lost (VLYL), which in turn is based on the Value of Statistical Life (VSL) often called value of a prevented fatality (VPF) (Spadaro, 2002). The real meaning of VSL is the "willingness-to-pay (WTP) to avoid the risk of an anonymous premature death" (ExternE, 2005). Even though most people think that a value of a human life is infinite, VSL is limited and the most used values are in the range of €1-5 million (ExternE, 2005).

European Commission, (1999a-d) and ExternE (2000) had used an average of the VPF studies that had been carried out in Europe around €3 million where ExternE (2004) lowered the value to €1 million with a new CV study. Miola *et al.* (2009) estimate central VSL values of €980,000 (from the study median) and €2 million (from the study mean) both expressed for price year 2000.

For the evaluation of life expectancy (LE) the value of a life year (VOLY) or VSL is needed. Both approaches VSL or VOLY have their own advantages: VOLY approach links more naturally to the quantified health impact but lacks the strong empirical base developed by VSL estimates made over many years (Hurley *et al.*, 2005). Hurley

et al. (2005) followed the recommendation of the peer review team and used both techniques but clearly suggest using VOLY instead of VSL (Miola et al., 2009). Also, Rabl (2003) showed the difficulty to determine the total number of premature deaths due to air pollution making the VSL not appropriate for air pollution mortality but for accidental deaths (ExternE, 2005).

ExternE (2005) used a VOLY of €50,000 where Miola et al. (2009) used central VOLY values of €52,000 (from the study median) and €120,000 (from the study mean). Finally, to find the total economic loss the VOLY is multiplied with the years of lost life (YOLL).

3.2 Uncertainties

The uncertainties in the evaluation of the environmental costs are known to be rather large (Rabl & Spadaro, 1999; ExternE, 2005) due to gaps in present working knowledge (Spadaro, 2002). The good news is that the science behind the IPA is constantly evolving and hopefully the uncertainties will become smaller but for now large uncertainties are still better than no study at all (ExternE, 2005). Furthermore, in many cases the costs are so large that the conjecture for a decision is clear even in the face of uncertainty and it has been shown that the extra social cost incurred because of uncertain damage costs is very small (ExternE, 2005; Rabl, Spadaro & van der Zwaan, 2005). So, although the large uncertainties, the results can still be used for deriving conclusions (Rabl; Spadaro; Desaignes, 1998). The weakest link, regarding the uncertainties, is perhaps the ERF (Spadaro, 2002) but as stated by Friedrich & Bickel (2001) uncertainty arises also from:

- lack of detailed information with respect to human behaviour and preferences;
- assumptions regarding threshold conditions;
- the variability inherent in any set of data;
- political and ethical issues, such as the selection of discount rate;
- the fact that some types of damage cannot be quantified at all.
- extrapolation of data from the laboratory to the field;
- extrapolation of exposure-response data from one geographical location to another;
- the need to assume some scenario of the future for any long term impacts

If the uncertainty is coming from those effects that cannot be described quantitatively a sensitivity analysis could be carried out (e.g. Holland et al. , 2005) where if the

effects can be quantified statistical techniques could be used to address uncertainty (Miola et al., 2009).

3.3 IPA applications in shipping

Miola et al. (2009) calculated with the IPA the effects of $PM_{2.5}$, PM_{10} , SO_x and PAH emitted by maritime activities in the port of Venice. Furthermore, Friedrich & Bickel (2001) used the impact pathway methodology for estimating marginal environmental external costs (including costs caused by air pollution) of different transport technologies (road, rail, air and ship transport) being operated at different locations in Europe. The European intermodal transportation projects RECOEDIT (Real Cost Reduction of Door-to-door Intermodal Transport) and REALISE-SSS (Regional Action for Logistical Integration of Shipping across Europe) estimated the external costs across the range of surface transport modes (including maritime) using the IPA method.

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Chapter 4: Software

4.1 RiskPoll and the Simple Uniform World Model (SUWM)

For the calculation of damage costs the RiskPoll program is used. RiskPoll is a suite of impact assessment programs designed to estimate health and environmental risks from toxic metals (As, Cd, Cr, Hg, Ni and Pb) and airborne emissions of the following type of pollutants: carbon monoxide (CO), particulate matter (PM), nitrogen oxides (NO_x), sulfur dioxide (SO_2) and secondary species such as nitrate and sulfate aerosols (Spadaro, 2004). The impact pathway approach (IPA) is used to assess the impacts to human health, crops and materials (Spadaro, 2004). In the RiskPoll software the Simple and Robust versions of the Uniform World Models were implemented by Spadaro (1999), (Spadaro, 2004). Figure 14 shows the pathways considered for health impacts of air pollutants by the Uniform World Model.

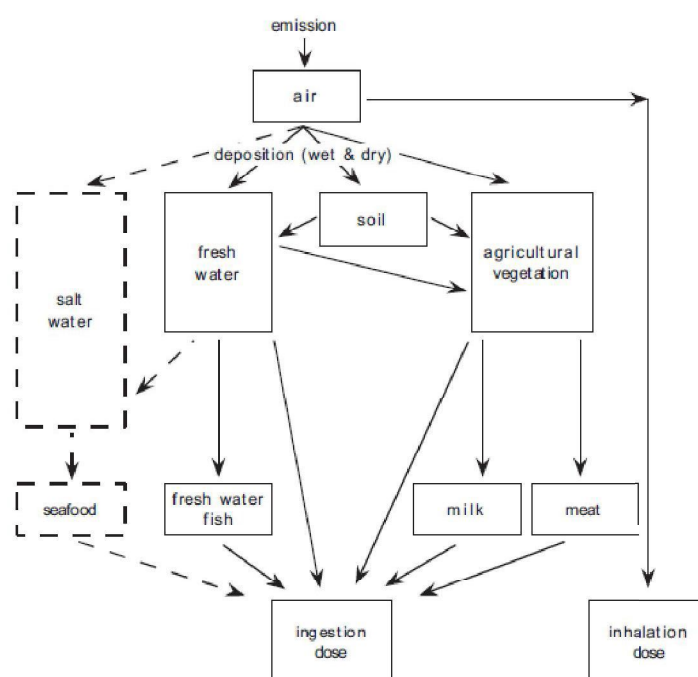


Figure 14: Different types of Exposure Response Functions (source: ExternE, 2005)

The Simple Uniform World Model (SUWM) assumes that the receptor distribution is constant, the ERF are linear and the calculation of damage costs is achieved through equilibrium models (steady state) even though the environment is never in equilibrium (ExternE, 2005; Spadaro, 2004). The disadvantage of SUWM is that estimates are not site specific meaning that local details are ignored in the analysis

which for primary pollutants may account for 75% or more of the total damage if the source happens to be located close to a large city (Spadaro, 1999; Spadaro, 2004). On the other hand, secondary pollutants are formed a long distance downwind of the emission source thus local conditions have little influence on the damage costs making SUWM more accurate (Spadaro, 2004). Either way SUWM can be a useful first estimate when there is limited input information (Friedrich & Bickel, 2001). Several corrections to the SUWM have been added to improve the local assessment for primary pollutants in the present version of RiskPoll (version 1.052) (Spadaro, 2004). The Robust Uniform World Model (RUWM), in contrast with SUWM, considers weather conditions, stack parameters and local receptor density near the source allowing site specific estimates (Spadaro, 2004). Both SUWM and RUWM offer greatly reduced input data, simplicity and transparency, the option to check the impact results from detailed assessments for consistency and the ease of doing sensitivity studies compared to detailed analyses (Spadaro, 2004). It is important to note that deviation between the SUWM and detailed models for secondary pollutants (e.g. sulfate and nitrate aerosols) are typically less than $\pm 35\%$, much smaller than primary pollutants (Spadaro, 2004). Figure 15 shows estimates of mortality impacts for different sites in Europe following the Impact Pathways approach (EcoSense model for Europe, ver. 2.0) and Simple Uniform World model (SUWM) (Spadaro, 2002). YOLL refers to Aggregate Years of Life Lost (loss in lifetime expectancy) across Europe.

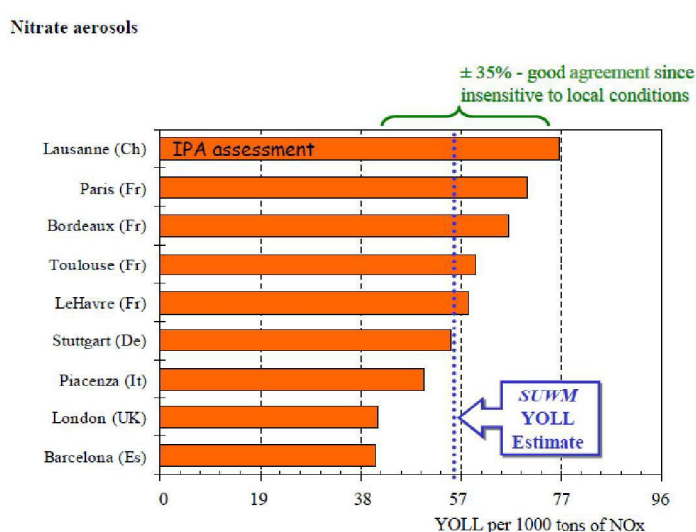


Figure 15: Estimates of mortality impacts for different sites in Europe following the Impact Pathways Approach (source: Spadaro, 2002)

Finally, for both individual and aggregate emissions of PM10 and SO2 via sulfates the SUWM is sufficiently adequate to predict the impacts and damage costs, with deviations less than $\pm 35\%$ for particulates and $\pm 20\%$ for sulfates. For nitrates, the SUWM predictions are very close with single-source EcoSense results (deviations less than 14%), but over-estimate the EcoSense multi-source estimates by a factor between 3 and 4 (Spadaro, 2002).

4.2 Available models

In RiskPoll four models are available, three of which estimate the human health impacts and monetary costs (QUERI, RUWM, URBAN) and one that estimates the impacts to crops and materials with the resulting economic costs (AGRIMAT). Each of them is using a different methodology and input dataset (based on “availability”) to estimate the physical impacts and damage costs. Table 3 shows the input requirements for each model. Common to all models are the assumptions of 1) single, elevated point source, 2) steady emission rate, 3) linear no threshold ERFs, 4) negligible local pollutant depletion and 5) flat terrain conditions.

4.2.1 QUERI (Basic, Intermediate and Best estimate)

Basic and Intermediate estimates are semi-empirical approaches in which the SUWM result is “adjusted” according to scaling factors that depend on stack parameters (height), ratio of local-to-regional population density and source location (Site ID). Best estimate uses a Gaussian dispersion model for the local analysis and SUWM for regional calculations. At the local scale, detailed population statistics (5 by 5 km resolution) and hourly meteorological data are used.

4.2.2 RUWM (Intermediate and Best estimate)

The RUWM differs from the QUERI model in the use of different simplifying assumptions to solve analytically the damage function equation. Also, it is assumed that there is a uniform distribution of local and regional population throughout the impact domain and average or typical conditions are used in the meteorological data for the local scale (with uniform windrose) (Spadaro, 2004).

4.2.3 URBAN (Best estimate)

In the URBAN model the human health impacts and monetary costs due to air emissions (from primary and secondary pollutants) from a source near a city are

estimated. Local population data can be used (5 by 5 km resolution) or a Gaussian-shaped function if there is a lack of data. Mean conditions are used in the weather data and a uniform windrose is assumed (Sparado, 2004).

4.2.4 AGRIMAT

With this model the impacts to crops and materials with the resulting economic costs from exposure to SO₂ are estimated (Sparado, 2004). AGRIMAT can approximate the damages to the following receptor types:

- Agricultural crops
- Barley, Oats, Potatoes, Rye, Sugar Beets and Wheat
- Building materials
- Galvanized steel, Limestone, Natural stone, Paint, Sandstone and Zinc.

Table 3: Input requirements for each model (source: Sparado, 2004)

INPUT DATA REQUIREMENTS FOR THE IMPACT ASSESSMENT MODELS IN RISKPOL							
Parameter	SUWM	QUERI			RUWM		URBAN
		Basic ^a	Intermediate	Best	Intermediate	Best	Best
<i>Local characteristics</i>							
o Urban or rural location		✓	✓	✓	✓	✓	Applies to urban sites only
o Receptor density		‡	✓		✓	✓	
o Receptor data (5 by 5 km ²)		‡	‡	✓	‡	‡	
<i>Regional characteristics</i>							
o Receptor density	✓	✓	✓	✓	✓	✓	✓
<i>Local weather data</i>							
o Mean wind speed						✓	✓
o Mean ambient temperature						✓	✓
o Pasquill class distribution						✓	✓
o Detailed hourly data				✓		§	§
<i>Stack data</i>							
o Height			✓	✓		✓	✓
o Exit diameter				✓		✓	✓
o Exhaust gas temperature		‡	‡	✓		✓	✓
o Exhaust gas velocity		‡	‡	✓		✓	✓
o Pollutant inventory	✓	✓	✓	✓	✓	✓	✓
o Pollutant depletion velocity	✓	✓	✓	✓	✓	✓	✓
<i>Other</i>							
o ER functions	✓	✓	✓	✓	✓	✓	✓

^a NB, Basic estimate input data for QUERI, RUWM and URBAN models are the same.

✓ mandatory input datum

‡ can be substituted for the local receptor density

§ can be substituted for mean weather statistics

‡ if known an improved impact estimate will be calculated

Input data for the AGRIMAT model include:

- o Background SO₂ concentration;
- o Background ambient temperature;
- o Background relative humidity;
- o Agricultural crop distribution;
- o Material distribution;
- o SO₂ emission rate and depletion velocity;
- o Monetary unit costs.

Input data can be specified for the entire impact domain (2000 x 2000 km area about the source) or for any portion(s) thereof.

4.3 RiskPoll models VS Detailed assessment (EcoSense model)

Figure 16 and 17 shows a comparison of mortality estimates between the RiskPoll models and the EcoSense model for Paris (France) and Stuttgart (Germany)

respectively. Comparison shows that the RiskPoll models are inside the $\pm 50\%$ deviation range. YOLL refers to Aggregate Years of Life Lost (loss in lifetime expectancy) across Europe.

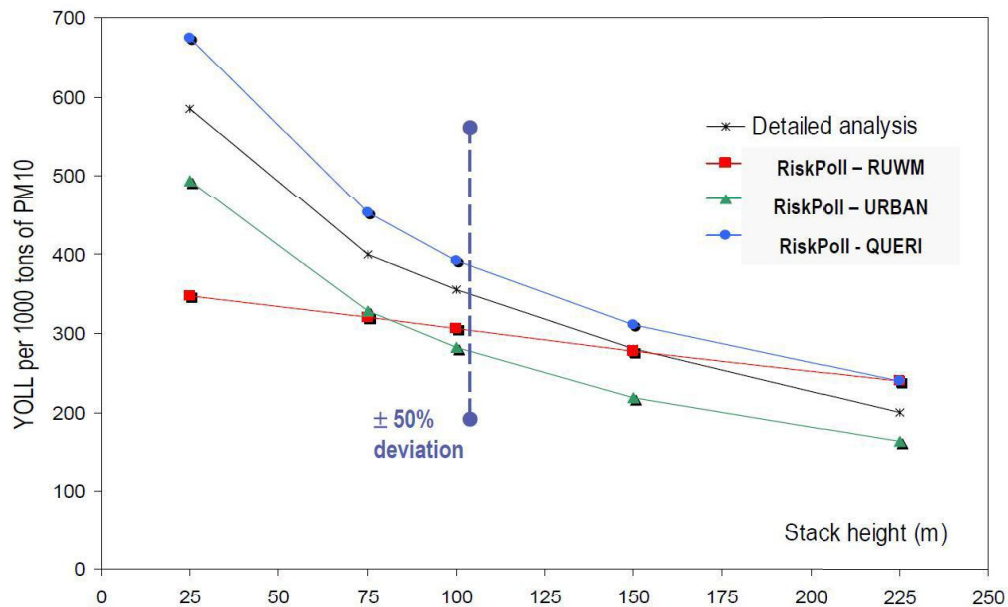


Figure 16: Comparison of mortality estimates between the RiskPoll models and the EcoSense model for Paris (France) (source: Spadaro, 2003)

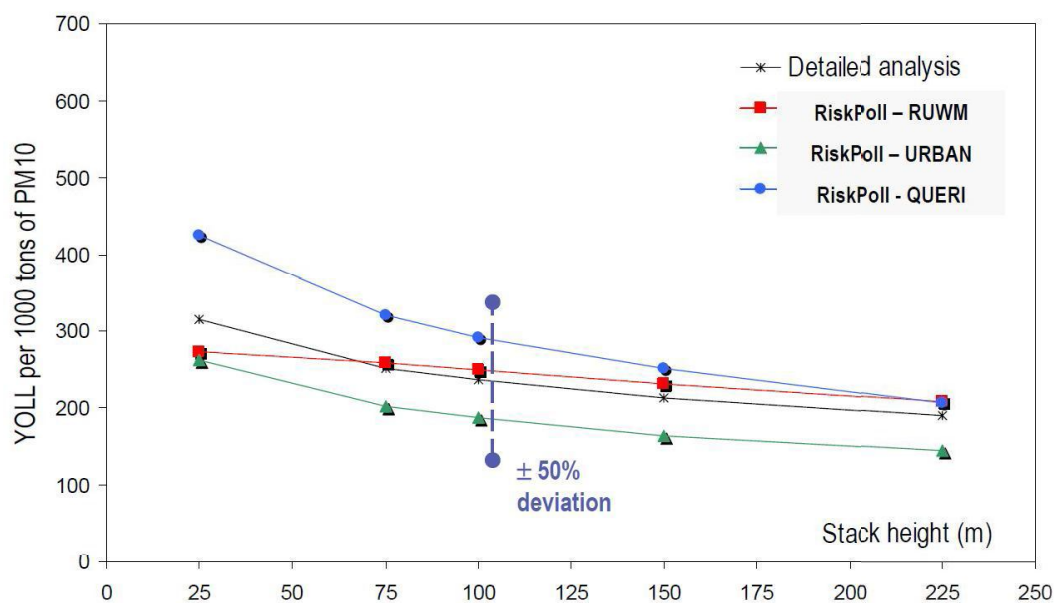


Figure 17: Comparison of mortality estimates between the RiskPoll models and the EcoSense model for Stuttgart (Germany) (source: Spadaro, 2003)

4.4 The QUERI model

4.4.1 Atmospheric dispersion

The main difference between the three models for human health impacts lies in the estimation of the local impacts as the regional impacts are calculated with the SUWM by all of them. In the Best estimate of RUWM model the detailed local Meteorological data (hourly values) are used to estimate average weather conditions (uniform wind rose) where the Best estimate of the URBAN model uses a “simplified” Gaussian model. In contrast, the QUERI Best algorithm uses a Gaussian plume for predicting local changes in air pollution (Industrial Source Complex (ISC)-Long-Term, Version 3.0) utilizing local meteorological data and space-dependent receptor data (Spadaro, 2002) making it the most sophisticated from the “simplified” calculations and it is the one that has been chosen for this study. Figure 18 shows a comparison between a detailed analysis (red line) and the Best estimate of QUERI.

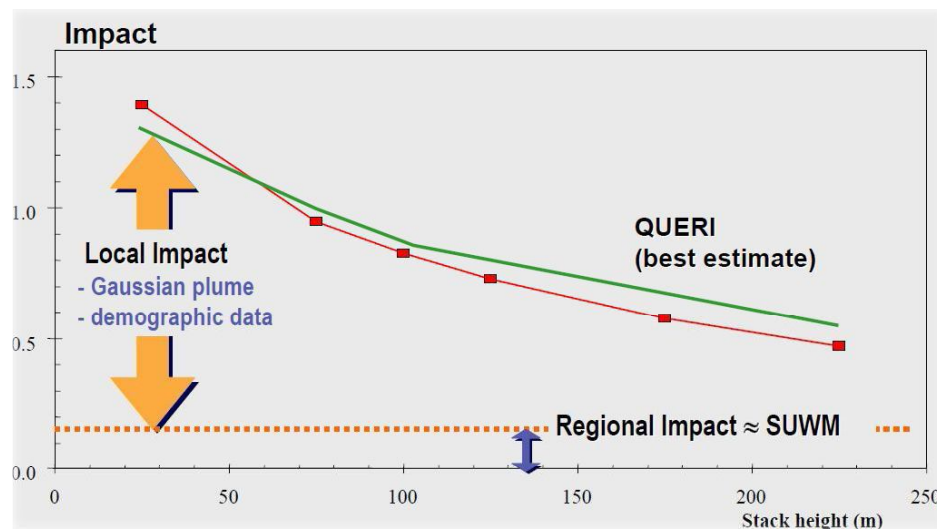


Figure 18: Comparison between a detailed analysis and the Best estimate of QUERI (source: Spadaro, 2002)

The Gaussian plume is a model which is detailed enough in the description of turbulent diffusion and vertical mixing but neglects chemical reactions and that's why it is the most economic way for predicting the concentration of the primary pollutants in the local scale (ExternE, 2005). In Figure 19 the model is visualized with the plume directed toward the positive axis x for simplicity.

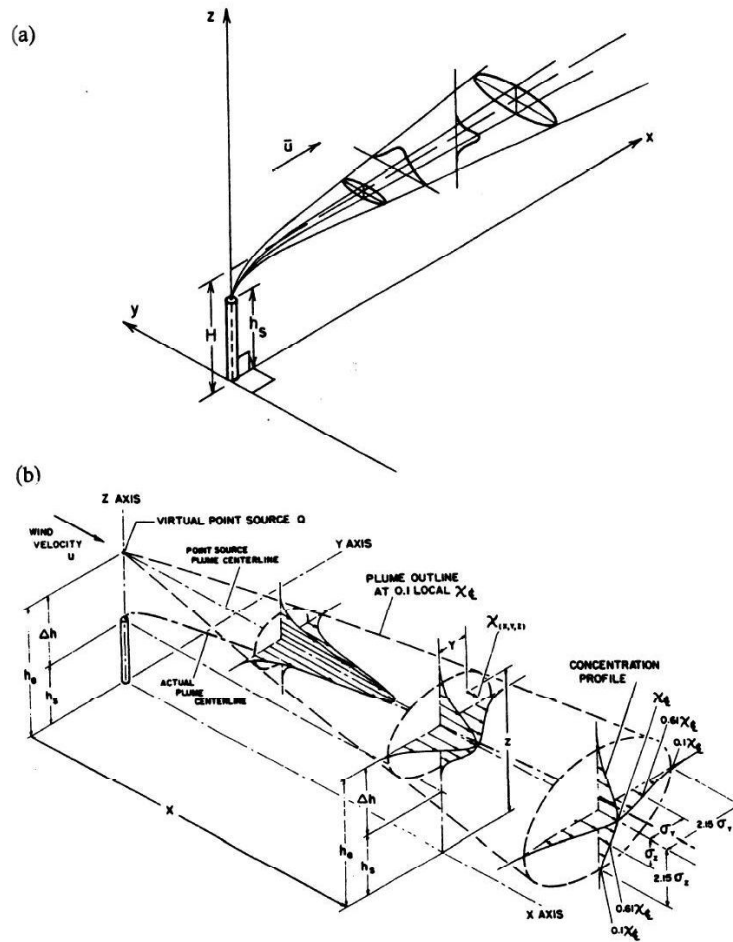


Figure 19: The Gaussian plume (source: Zannetti, 1990)

u : the average wind velocity vector (u_x, u_y, u_z) at the emission height

h_s : release height

h_e : effective stack height= $h_s + \Delta h$

Δh : plume rise (a function of emission parameters, meteorology and downwind distance)

σ_y : lateral standard diffusion parameter

σ_z : vertical standard diffusion parameter

It is assumed that the horizontal and vertical profiles can be modeled as two independent Normal shaped distributions, each one characterized by its own standard deviation or sigma parameter (σ_y and σ_z) (Spadaro, 2002). Figure 20 shows an overhead and a side view of a Gaussian plume where the x coordinate is aligned along the prevailing wind direction.

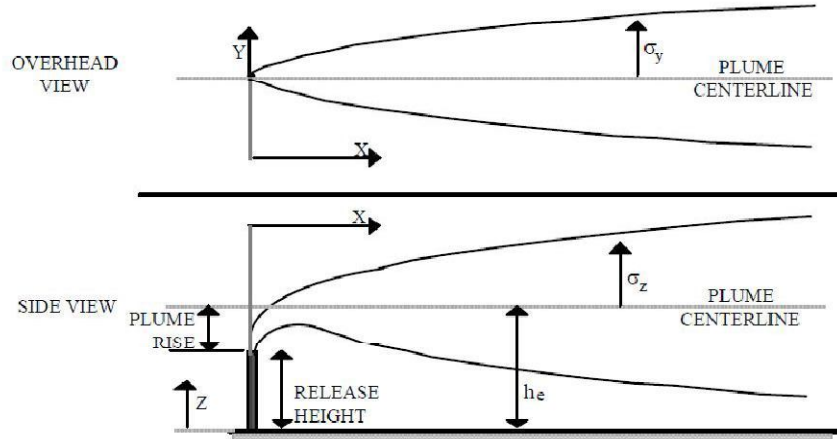


Figure 20: Overhead and side view of a Gaussian plume (source: Spadaro, 2002)

The three dimensional Gaussian concentration field $C(x, y, z)$ for steady state meteorological conditions and a constant emission source Q is:

$$C(x, y, z) = \frac{Q}{2\pi u \sigma_y \sigma_z} \exp\left(-\frac{y^2}{2\sigma_y^2}\right) \sum_{j=0, \pm 1, \dots} \left(\exp\left[\frac{(z + 2j h_{mix} - h_e)^2}{-2\sigma_z^2}\right] + \exp\left[\frac{(z + 2j h_{mix} + h_e)^2}{-2\sigma_z^2}\right] \right)$$

Where u is the mean wind speed at release height, z is the vertical distance from the ground, h_e the effective stack height, σ_y the lateral standard diffusion parameter, σ_z the vertical standard diffusion parameter and h_{mix} the mixing layer height (typical range is 200 to 2000 m) (Spadaro, 2002). **Annex 1** contains Table 12 to 17 which are used to find various parameters of the above equation. When the exhaust gas temperature exceeds the ambient temperature by at least 20 degrees the plume is buoyancy induced and the effective stack height h_e is estimated following the methodology in Table 12 (Spadaro, 2002). The functional expressions for σ_y and σ_z are summarized in Table 13.

The Pasquill classes can be found using the Pasquill method (Table 14) or from measurements of σ_θ (standard deviation of the horizontal wind direction fluctuations) or σ_w (standard deviation of vertical wind direction fluctuations) or the vertical temperature gradient $\Delta T / \Delta z$ as shown tables 15 and 16 (Zannetti, 1990). When the stability is found with the help of the standard deviation of the horizontal wind direction fluctuations, Table 17 must be used for corrections taking into account vertical diffusion at nighttime (Zannetti, 1990).

According to the User's Guide For The Industrial Source Complex (ISC3) Dispersion Models Volume II - Description Of Model Algorithms (EPA, 1995) ‘‘ In the long-term model, the area surrounding a continuous source of pollutants is divided into sectors of equal angular width corresponding to the sectors of the seasonal and annual frequency distributions of wind direction, wind speed, and stability. Seasonal or annual emissions from the source are partitioned among the sectors according to the frequencies of wind blowing toward the sectors. The concentration fields are translated to a common coordinate system and summed to obtain the total due to all sources’’. With the assumption that the meteorological data consist of N_i wind speed classes, N_j wind directions classes and N_k atmospheric stability categories the average concentration is given by (Friedrich & Bickel, 2001):

$$C = \frac{Q}{\sqrt{2\pi} R \Delta\theta} \sum_{i=1}^{N_i} \sum_{j=1}^{N_j} \sum_{k=1}^{N_k} \frac{f_{i,j,k} S_j V_{i,k}}{u_i \sigma_{z_k}}$$

Where:

C = long-term average concentration

Q = pollutant's emission rate

R = radial distance between the receptor and the emission source

$\Delta\theta$ = sector width in radians

$f_{i,j,k}$ = frequency of occurrence of the i th wind speed category, the j th wind direction category and the k th atmospheric stability category

u_i = mean wind speed of the i th wind speed category

σ_{z_k} = standard deviation of the vertical concentration distribution for the k th stability category

S_j = smoothing function

$V_{i,k}$ = vertical term for the i th wind speed category and the k th atmospheric stability category

4.4.2 Damage cost equation

The damage cost equation is then:

$$QUERI \text{ Damage cost (Best)} = \sum_j \Delta C_j \times \text{Receptor}_j \times ERF \times \text{Unit cost} + \text{Regional cost}$$

ΔC_j is the incremental concentration increase above the existing background at location j (Gaussian plume assessment) and Receptor_j is the number of people at

The diagram illustrates the chemical and physical processes in the atmosphere, showing the transition from a local domain to a regional domain.

Local domain: A smokestack emits pollutants (NO_x , SO_2 , PM_{10}) into the atmosphere. The height of the smokestack is h_s . The wind speed is U . The vertical distance from the smokestack to the regional domain is ΔH . A cross-sectional view of the concentration profile inside the plume is shown.

Regional domain: The pollutants are transported over a distance R_0 (Local domain) and R_{Impact} (Regional domain). The regional domain is characterized by a concentration profile O_3 .

Chemical pathways:

- Emission:** NO is emitted from a source (represented by a group of people).
- NO Cycle:** NO is oxidized to NO_2 by O_3 . NO_2 is photolyzed ($h\nu$) back to NO .
- NO₂ Pathways:** NO_2 reacts with OH to form HNO_3 . NO_2 also reacts with Aerosol and NH_3 to form Nitrate aerosol .
- Deposition:** HNO_3 and Nitrate aerosol undergo **Dry deposition** and **Wet deposition**.

R_o is taken 56 km from source and R_{impact} between 500 and 1000 km from source (500 km if source is near a large city -e.g., Paris- and 1000 km, otherwise). The SUWM cost estimate is calculated using the relationship:

Where,

Receptor is the mean receptor density over a radius of 500 to 1000 km from the source (p_{avg}).

Depletion velocity= characteristic velocity determining the rate at which a particular pollutant is removed from the atmosphere because of chemical transformation and deposition (dry and wet).

For primary pollutants, the SUWM local damage cost for a radius R_o is approximated by:

$$\frac{SUWM \text{ Local Damage cost}}{SUWM \text{ Damage cost}} = 1 - \exp\left(\frac{-t}{\tau}\right); \quad t = \frac{R_o}{U}$$

U is the wind speed (typical range: 2-4 m/s), t is the plume transit time and τ is the pollutant's time constant or atmospheric residence time (τ = mixing layer height / depletion velocity, with a typical range of 20 to 30 hours). Secondary pollutant local impacts are generally small (RiskPoll, 2004).

But,

$$SUWM \text{ Damage cost} - SUWM \text{ Local Damage cost} =$$

$$= SUWM \text{ Damage cost} - SUWM \text{ Damage cost} * \left[1 - \exp\left(\frac{-t}{\tau}\right)\right] =$$

$$= SUWM \text{ Damage cost} * (1 - 1 + \exp\left(\frac{-t}{\tau}\right)) = SUWM \text{ Damage cost} * \exp\left(\frac{-t}{\tau}\right)$$

So,

$$Regional \text{ cost} = SUWM \text{ Damage cost} \times \exp\left(\frac{-t}{\tau}\right)$$

4.4.3 Uncertainties of economic valuation

Finally, when the impacts are monetized, the lower and upper bounds of the damage cost range will also be indicated with 68% confidence interval assuming a lognormal probability density function (RiskPoll, 2004). In Rabl, A. & J.V. Spadaro (1999) data for uncertainty distributions for two particularly important parameters were examined: the value of life and the deposition velocity concluding that they are lognormal. The assumption of lognormality for the distribution of the damages appears to be well justified since the distributions with the largest spread do not seem to be different

from lognormal (Rabl, A. & J.V. Spadaro, 1999). Figure 22 shows an example of lognormal distribution for economic valuation: reference value for protection of human life, in £1990, as determined by 78 studies reviewed by Ives, Kemp and Thieme [1993]. Finally, the likelihood or probability that the value of a random event will lie within a well-defined interval about its median value is identified by a statistical concept: the confidence interval (CI). For most experiments, the 68% and 95% confidence limits are normally reported (Rabl, A. & J.V. Spadaro, 1999).

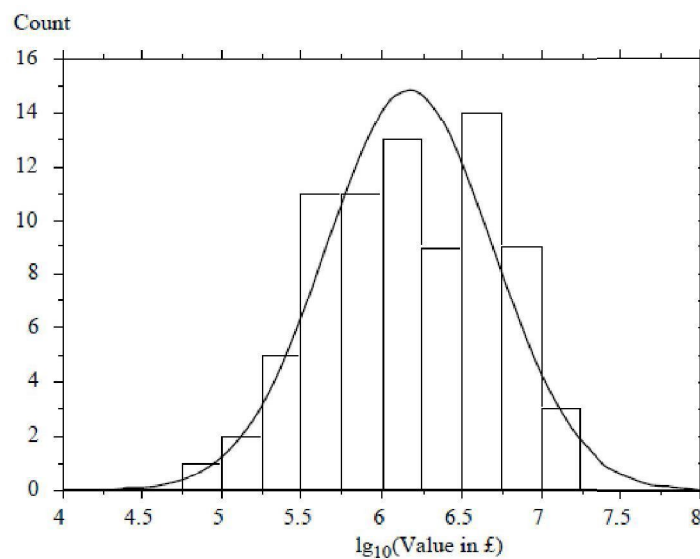


Figure 22: Example of lognormal distribution for economic valuation (source: Rabl, A. & J.V. Spadaro, 1999)

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Chapter 5: Case study

5.1 Description of case study

The purpose of this study is to estimate the external health costs of primary pollutants ($PM_{2.5}$, PM_{10} , SO_2 and NO_x) and secondary pollutants (nitrates and sulfates) that emitted from all coastal passenger ships and cruise ships that approach the port of Piraeus in Athens for one year. The methodology that has been used is the impact pathway approach-IPA (see Chapter3) with the help of the RiskPoll program and specifically the algorithm QUERI (see Chapter 4).

5.1.1 The port of Piraeus

The port of Piraeus is the most important port in Greece and holds the highest passenger traffic in Europe (third in the world), servicing about 20 million passengers annually (Tzannatos, 2010b). The passenger terminal is part of the city of Piraeus while the freight terminals of the port of Piraeus are not urbanized (Tzannatos, 2010b). According to the 2011 census, Piraeus is the fourth largest municipality in Greece, with a population of 163688 people. Figure 23 shows the main (passenger) port of Piraeus and Figure 24 shows the berth layout at the passenger port.



Figure 23: Photo of the main (passenger) port of Piraeus

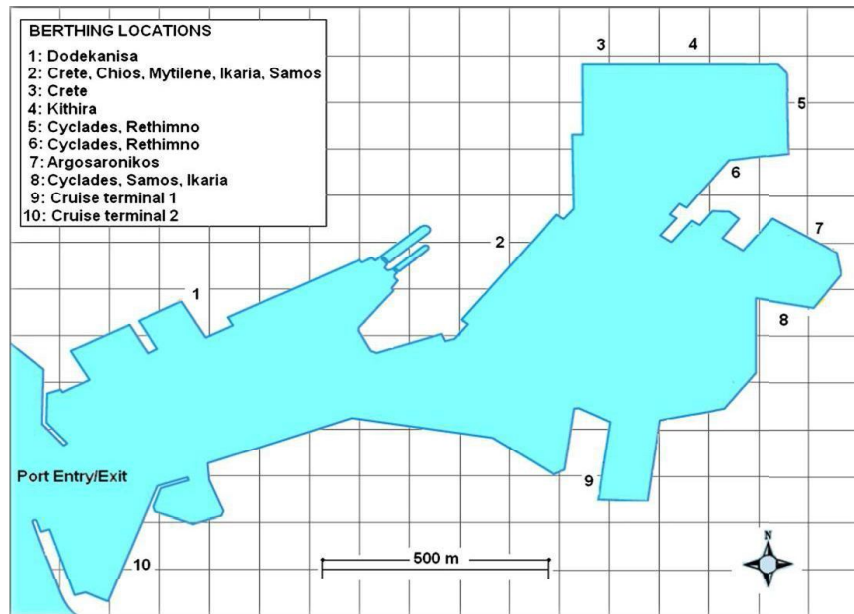


Figure 24: The berth layout at the passenger port of Piraeus (source: Tzannatos, 2010b)

Using an in-port ship activity-based methodology, Tzannatos (2010b) estimated the emissions of 124 cruise and 59 coastal passenger ships for the passenger port of Piraeus during a twelve-month period in 2008-2009. Table 4 shows the number of ships involved by type and their seasonal and overall number of calls (or departures) at the port of Piraeus. The methodology was applied for maneuvering and berthing of coastal passenger ships and cruise ships calling at the passenger port. As shown in Figure 25, NO_x emissions were found to be 1790 tons, whereas SO_2 and $PM_{2.5}$ emissions were estimated at 722 and 99 tons, respectively.

Table 4: The number of ships involved by type and their seasonal and overall number of calls (or departures) at the port of Piraeus (source: Tzannatos, 2010b)

Ship traffic statistics at the passenger port of Piraeus (1/6/08–31/5/09).

PERIOD ^a	Coastal passenger ships ^b		Cruise ships	
	Number of ships	Number of departures	Number of ships	Number of calls
Winter	59	1970	124	10
Spring		1918		206
Summer		3545		356
Autumn		2153		330
TOTAL	59	9586	124	902

^a Winter = December–January–February, Spring = March–April–May, Summer = June–July–August, Autumn = September–October–November.

^b Ro-Pax and all passenger vessels (hydrofoils, monohulls, catamaran).

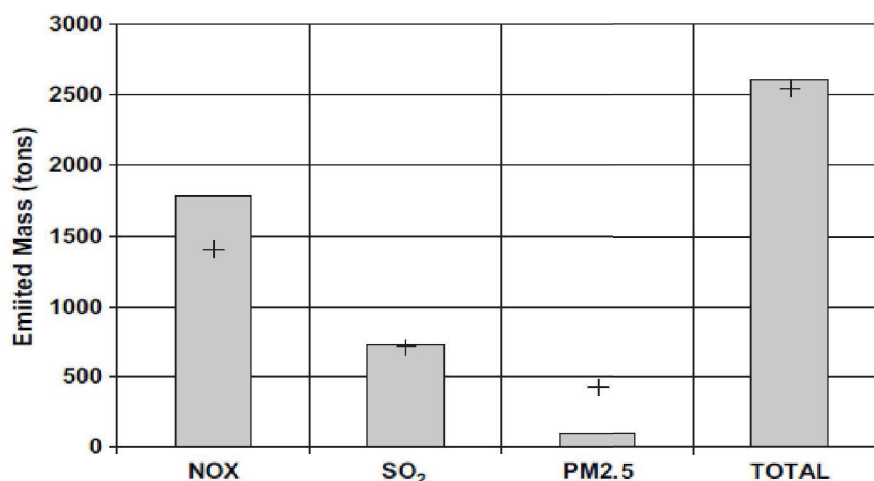


Figure 25: Emissions of 124 cruise and 59 coastal passenger ships for the passenger port of Piraeus during a twelve-month period in 2008-2009 (source: Tzannatos, 2010b)

5.2 Assumptions

The Gaussian model (see Chapter 4), used by the QUERI algorithm of RiskPoll, is referred to a stationary source with a constant emission through the year. It is assumed for our case that there is constant emission based on the fact that Piraeus has high ship traffic throughout the year (see Table 6). Also, as seen at Figure 24 berthing locations in Piraeus are spaced 500 m or less from each other inside a 2 by 2 km cell. It is assumed that the stationary source is in the middle of that cell. Furthermore, it is assumed that the emission of $PM_{2.5}$ is equal to $0.92 \cdot PM_{10}$ (EPA, 1999; EPA, 2009) and $PM_{2.5}$ ERF values are the PM_{10} values scaled by 1.67 (Spadaro, 2003; Rabl, 2001; Friedrich & Bickel, 2001; ExternE, 1998; Dockery & Pope, 1994). Finally, typical values of a passenger/cruise ship have been used as input at the optional data (see stack parameters in 5.3): stack height, stack diameter, flow velocity and gas temperature.

5.3 Input data

5.3.1 Meteo

Figure 26 shows the Meteo input data screen.

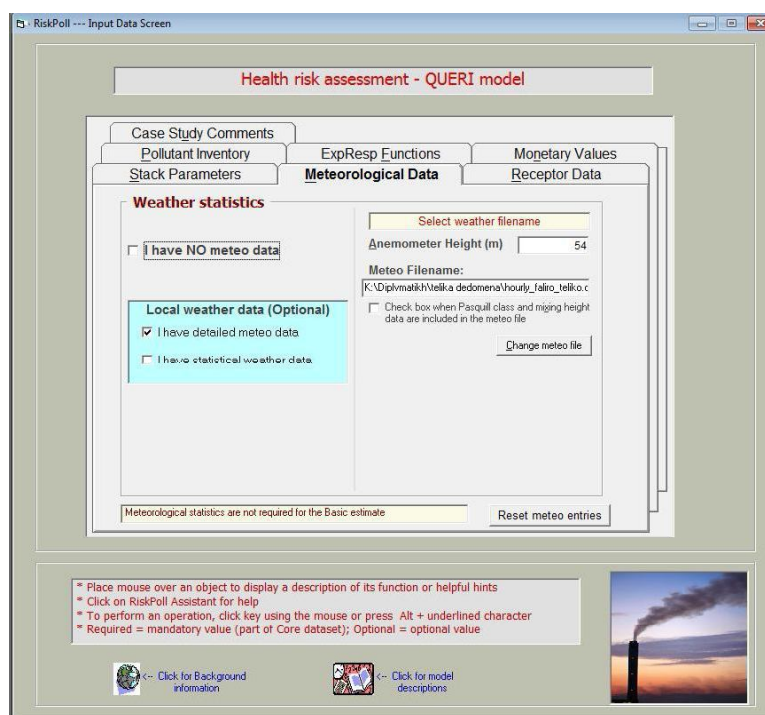


Figure 26: Meteo input data screen

Hourly values of wind speed, direction and ambient temperature for the period 4/6/2012-30/11/13 (19 months total) for Faliro (5 km from Piraeus) were obtained from the national observatory of Athens and imported from a file to the program like the one shown in Figure 27. A sample (the first week of 2013) of the meteo file that was used can be found at **Annex 2**. The anemometer height at which wind speed has been recorded is 54 m. The Pasquill class (show atmospheric stability) and mixing layer height (inversion layer) can be entered directly, however in this study (due to the lack of data) the QUERI computed these parameters by means of measured wind speed data and solar altitude (or insolation) angle (calculated on the basis of source coordinates) as discussed in Chapter 4.

Year of data

Month (1 - 12)

Day (1 - 31)

Hour (1 - 24)

89	1	1	1	0	2	279
89	1	1	2	0	2	279
89	1	1	3	0	2	279
89	1	1	4	20	1	278
89	1	1	5	20	1	278
89	1	1	6	20	1	278
89	1	1	7	20	2	278
89	1	1	8	20	2	278
89	1	1	9	20	2	278
89	1	1	10	80	3	277
89	1	1	11	80	3	277
89	1	1	12	80	3	277
89	1	1	13	60	3	278
89	1	1	14	60	3	278
89	1	1	15	60	3	278
89	1	1	16	40	3	279
.....						
89	12	31	9	140	2	272
89	12	31	10	140	2	272
89	12	31	11	140	2	272
89	12	31	12	140	2	272
89	12	31	13	170	1	272
89	12	31	14	170	1	272
89	12	31	15	170	1	272
89	12	31	16	130	2	273
89	12	31	17	130	2	273
89	12	31	18	130	2	273
89	12	31	19	120	2	272
89	12	31	20	120	2	272
89	12	31	21	120	2	272
89	12	31	22	130	1	272
89	12	31	23	130	1	272
89	12	31	24	130	1	272

Wind direction (deg from North)
 Wind speed (m/sec)
 Ambient temperature (K=°C+273)

Example of a meteorological datafile (Paris data)

Figure 27: Example of a meteo input file (source: Spadaro, 2003)

5.3.2 Pollutant

Figure 28 shows the Pollutant input data screen.

Health risk assessment - QUERI model

Stack Parameters
Meteorological Data
Receptor Data

Case Study Comments
ExpResp Functions
Monetary Values

Pollutant Inventory

Pollutant discharges and removal data

	SUWM calculation	Emission Rate tons/yr	Depletion Velocity cm/s
<input checked="" type="checkbox"/> Particles (PM10)	<input type="checkbox"/>	108	0.77
<input checked="" type="checkbox"/> Sulfur Dioxide (SO2)	<input type="checkbox"/>	722	0.81
<input checked="" type="checkbox"/> Sulfate aerosols			1.855
<input checked="" type="checkbox"/> Nitrogen Oxides (NOx)	<input type="checkbox"/>	1790	1.26
<input checked="" type="checkbox"/> Nitrate aerosols			1.025
<input type="checkbox"/> Carbon Monoxide (CO)			
<input checked="" type="checkbox"/> Other Pollutant	<input type="checkbox"/>	99	0.77

Other: Other [primary pollutant]
 PM10 = particles with aerodynamic diameter < 10 microns (0.001 mm)
 Check SUWM box to carry out a Simple Uniform World Model calculation.
 For a given pollutant, the annual emission rate (tons per year) and removal velocity (characterized by the depletion velocity, cm/s) must be specified. For secondary species (aerosols), the creation rate is related to the precursor emission rate, only the depletion velocity is required (SO2 for sulfates, NOx for nitrates).

Reset pollutant entries

* Place mouse over an object to display a description of its function or helpful hints
 * Click on RiskPoll Assistant for help
 * To perform an operation, click key using the mouse or press Alt + underlined character
 * Required = mandatory value (part of Core dataset); Optional = optional value

Click for Background information

Click for model descriptions

Figure 28: Pollutant input data screen

Emission rate (tons/yr) and deposition velocity (cm/s) are needed for the estimation of the impact. Emission rate was taken from Tzannatos 2010b (with $PM_{10} = PM_{2.5}/0.92$ as stated in 5.2) for one year (2008-2009) (see 5.1) and the deposition velocity (k) was taken as the mean of the values for Europe (k= 0.77 for PM_{10} and $PM_{2.5}$, k=0.81 for SO_2 , k=1.26 for NO_x , k=1.855 for Sulfate and k=1.025 for Nitrate) given by Spadaro (2003) in Table 5:

Table 5: Values of deposition velocity (k) for Europe (source: Spadaro, 2003)

The **depletion velocity** characterizes the atmospheric pollutant removal rate. Typical ranges for selected regions around the world are shown below. All values are in cm/sec.

	Europe	SE Asia	USA	S. America
PM_{10}	0.67-0.87	0.53-1.83	1.00	1.13-2.86
SO_2	0.73-0.89	0.49-1.16		0.84-2.08
NO_x	1.05-1.47	0.65-2.35		0.40-2.26
Sulfate	1.73-1.98	0.76-2.27		3.11-4.76
Nitrate	0.76-1.29	0.67-1.17		1.04-3.00

5.3.3 Stack parameters

Figure 29 shows the Stack Parameters input data screen

Health risk assessment - QUERI model

Case Study Comments | Pollutant Inventory | ExpResp Functions | Monetary Values | **Stack Parameters** | Meteorological Data | Receptor Data

Emission source characteristics

Longitude: 23.63706 Latitude: 37.94222

Source Location: 3

Stack Height (m): 25

Stack Diameter (m): 5

Flow Velocity (m/s): 10

Gas Temperature (K): 600

Optional data | Reset Optional values | Reset stack entries

Place mouse over an object to display a description of its function or helpful hints
 Click on RiskPoll Assistant for help
 To perform an operation, click key using the mouse or press: Alt + underlined character
 Required = mandatory value (part of Core dataset); Optional = optional value

Click for Background information | Click for model descriptions

File - New/Load/Save Case Study; Calculate - estimate Impacts/Costs; click on RiskPoll Assistant for Help ...

Figure 29: Stack Parameters input data screen

The program requires the source coordinates (longitude and latitude) and the source location. The site index is an integer from 0 to 6, as showing in Table 6:

Table 6: Explanation of site index integer (source: Spadaro, 2003)

Source Location	Comments
0	Source located in a rural area or country site (ratio of local to regional population density less than 2)
1	Source within a few km of a small-sized city, ex. Stuttgart in Germany (ratio of local to regional population density less than 6)
2	Source within a few km of a medium-sized city, ex. Milano in Italy (ratio of local to regional population density less than 10)
3	Source within a few km of a large city, ex. Paris in France (ratio of local to regional population density greater than 10)
4	Source lies between 15 and 25 km distant from a large city
5	Source lies between 25 and 40 km distant from a large city
6	Source located more than 40 km distant from a large city
0 or 1	Source located on a small island, ex. Crete in Greece, or near a large water body (ocean or lake), or close to a city surrounded mostly by unpopulated areas, ex. Finland in Europe

For Piraeus the source coordinates are: 23.63706 (longitude) and 37.94222 (latitude). The site index was taken 3. Therefore, the regional radius is 500 km (see 4.4.2).

Optional data:

1. Stack height
2. Stack diameter
3. Flow velocity
4. Gas temperature

For the case study the following typical values were chosen:

1. Stack height = 25 m, (General Arrangement of Blue Star Belos-see **Annex 3**)
2. Stack diameter = 5 m, (General Arrangement of Blue Star Belos-see **Annex 3**)
3. Flow velocity = 10 m/s, (EIA report, 2013)
4. Gas temperature = 600 K (Kyrtatos, 1993)

5.3.4 Receptor

Figure 30 shows the Receptor input data screen.

RiskPoll - Input Data Screen

Health risk assessment - QUERI model

Case Study Comments

Pollutant Inventory

Stack Parameters

ExpResp Functions

Meteorological Data

Monetary Values

Receptor Data

Receptor distribution

Regional Population (pers/km²)
regional size varies from 500 to 1000 km

Local Population (pers/km²)
typical local domain size (100 x 100 km)

Radius of Local Domain (km)
emission source located at the origin [0,0]
(10,000 km² = 56 km radius)

Local receptor data (Optional)

☐ I only have the local population density

☒ I have detailed local population statistics
(5x5 km resolution; area = 10,000 km²)

☐ I want to use a Gaussian function to model
population of an urban site (Site ID = 1,2,3)

Core data: Regional population density [persons per square km, pers/km²]

Select population datafile

Pop Filename:

* Place mouse over an object to display a description of its function or helpful hints

* Click on RiskPoll Assistant for help

* To perform an operation, click key using the mouse or press Alt + underlined character

* Required = mandatory value (part of Core dataset); Optional = optional value

Click for Background information

Click for model descriptions

Figure 30: Receptor input data screen

Local population data were entered in RiskPoll using a population file as the one shown in Figure 31. The numbers of persons living in each cell (400 in total) was found using Google Earth combined with the 2011 and 2001 population census released by ELSTAT (Hellenic Statistical Authority). The methodology was: finding the center and boundaries of each cell using the measure tool in Google Earth (measuring from the emission source in Piraeus) and referring to ELSTAT for the population living in that cell. **Annex 4** contains the population file that was created and used.

Example of a local population datafile (Paris population)

	-47.5	-42.5	-37.5	-32.5	-27.5	-22.5	-17.5	-12.5	-7.5	-2.5	2.5	7.5	12.5	17.5	22.5	27.5	32.5	37.5	42.5	47.5
47.5	2290	2290	10654	10654	5926	5926	11332	11332	8527	8527	9005	9005	3586	3586	3234	3234	3234	3234	3111	3111
42.5	2290	2290	10654	10654	5926	5926	11332	11332	8527	8527	9005	9005	3586	3586	3234	3234	3234	3234	3111	3111
37.5	5408	5408	20117	20117	20857	20857	20857	20857	20857	20857	20857	20857	14461	14461	14461	14461	14461	14461	14461	14461
32.5	6408	6408	20117	20117	20857	20857	20857	20857	20857	20857	20857	20857	14461	14461	14461	14461	14461	14461	14461	14461
27.5	14272	14272	16505	16505	18142	18142	18839	18839	20279	20279	20891	20891	20891	20891	16035	16035	16035	16035	16035	16035
22.5	14272	14272	16505	16505	18142	18142	18839	18839	20279	20279	20891	20891	20891	20891	16035	16035	16035	16035	16035	16035
17.5	13913	13913	14115	14115	14115	14115	14115	14115	21362	21362	95261	95261	91079	91079	64927	64927	64927	64927	4998	4998
12.5	13913	13913	14115	14115	14115	14115	14115	14115	21362	21362	95261	95261	91079	91079	64927	64927	64927	64927	4998	4998
7.5	8874	8874	14155	14155	14155	14155	14155	14155	15638	15638	39817	39817	184129	184129	39401	39401	39401	39401	5012	5012
2.5	8874	8874	14155	14155	14155	14155	14155	14155	15638	15638	39817	39817	184129	184129	39401	39401	39401	39401	5012	5012
-2.5	5792	5792	14179	14179	14179	14179	14179	14179	73713	73713	215026	215026	147021	147021	48806	48806	48806	48806	5020	5020
-7.5	5792	5792	14179	14179	14179	14179	14179	14179	73713	73713	215026	215026	147021	147021	48806	48806	48806	48806	5020	5020
-12.5	4929	4929	14184	14184	14184	14184	14184	14184	15638	15638	38007	38007	66520	66520	36635	36635	36635	36635	5022	5022
-17.5	4929	4929	14184	14184	14184	14184	14184	14184	15638	15638	38007	38007	66520	66520	36635	36635	36635	36635	5022	5022
-22.5	2475	2475	13448	13448	14224	14224	14920	14920	15814	15814	15814	15814	15567	15567	6385	6385	6385	6385	5036	5036
-27.5	2475	2475	13448	13448	14224	14224	14920	14920	15814	15814	15814	15814	15567	15567	6385	6385	6385	6385	5036	5036
-32.5	1721	1721	8643	8643	14247	14247	15366	15366	15840	15840	15840	15840	12185	12185	5045	5045	5045	5045	5045	5045
-37.5	1721	1721	8643	8643	14247	14247	15366	15366	15840	15840	15840	15840	12185	12185	5045	5045	5045	5045	5045	5045
-42.5	1722	1722	2848	2848	10623	10623	15615	15615	15847	15847	15847	15847	10044	10044	5047	5047	5047	5047	5047	5047
-47.5	1722	1722	2848	2848	10623	10623	15615	15615	15847	15847	15847	15847	10044	10044	5047	5047	5047	5047	5047	5047

Figure 31: Example of a population input file (source: Spadaro, 2003)

The local domain has an “effective” radius of 56 km equivalent to a square-shaped (cells) domain, with sides equal to 100 km (Spadaro, 2003). There are 400 cells in total, covering a surface area of 10000 km^2 . The emission source is at (0, 0) and the X, Y coordinates are referred to the distance of the center of every cell from the source. Each cell has a resolution of 5x5 km and the values in rows 2 through 20 and columns 2 through 20 represent the number of people living in each cell, with an area of 25 km^2 (Spadaro, 2003).

5.3.5 Exposure Response Functions (ERF) and Monetary Values

Figure 32 and Figure 33 shows the ERF and Monetary Values input data screen respectively. The ERF (values as of September 28th 2004) and unit damage costs (€₂₀₀₀) of the ExternE project of the European Commission were used for PM_{10} , SO_2 and NO_x . The $PM_{2.5}$ ERF values were taken as the PM_{10} values of ExternE project scaled by 1.67. **Annex 5** shows the ERF and monetary values that were used.

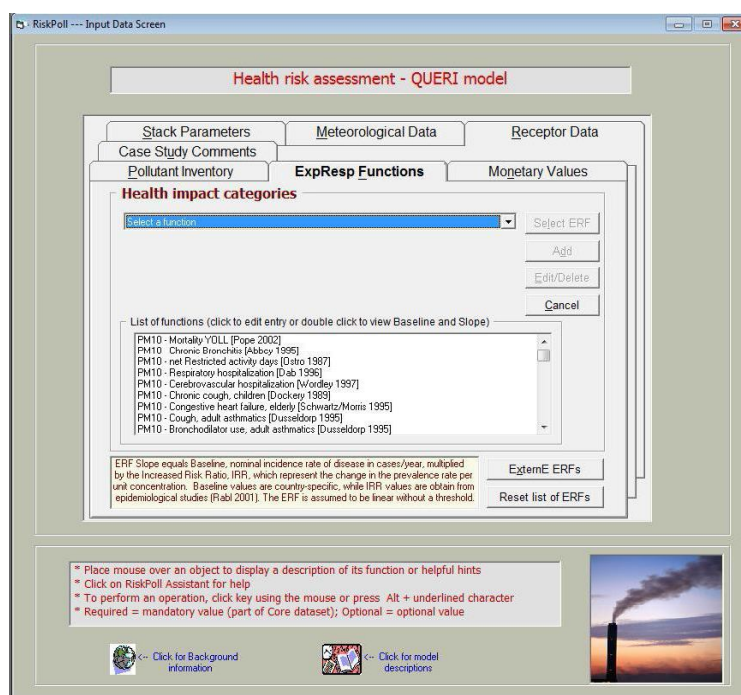


Figure 32: The ERF Values input data screen

RiskPoll --- Input Data Screen

Health risk assessment - QUERI model

Stack Parameters

Meteorological Data

Receptor Data

Case Study Comments

Pollutant Inventory

ExpResp Functions

Monetary Values

Unit cost data

Health Impact Category

US\$/case

PM10 - Mortality YOLL [Pope 2002]	50000
PM10 - Chronic Bronchitis [Abbey 1995]	169300
PM10 - net Restricted activity days [Ostro 1987]	110
PM10 - Respiratory hospitalization [Dab 1996]	4320
PM10 - Cerebrovascular hospitalization [Wordley 1997]	16730
PM10 - Chronic cough, children [Dockery 1989]	240
PM10 - Congestive heart failure, elderly [Schwartz/Morris 1995]	3260
PM10 - Cough, adult asthmatics [Dusseldorp 1995]	45
PM10 - Bronchodilator use, adult asthmatics [Dusseldorp 1995]	40
PM10 - Lower respiratory symptoms, adult asthmatics [Dusseldorp 1995]	8
PM10 - Cough, children asthmatics [Pope/Dockery 1992]	45
PM10 - Bronchodilator use, children asthmatics [Roemer 1993]	40

Unit costs are expressed in US dollars per impact case

Monetization is optional. To enter data into the table, double click on a line (or click once and press return) and then specify the unit cost (\$ per impact case). NB, a value of \$0 indicates that no damage cost for that health impact will be calculated, rather only the physical impact will be reported in the results.

Reset monetary entries

Place mouse over an object to display a description of its function or helpful hints

Click on RiskPoll Assistant for help

To perform an operation, click key using the mouse or press Alt + underlined character

Required = mandatory value (part of Core dataset); Optional = optional value

Click for Background information

Click for model descriptions

Figure 33: The Monetary Values input data screen

{ 80 }

References of Chapter 5

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Chapter 6: Results

6.1 Results presentation

The presentation of the results starts with Figure 35 which is the “View Results Screen” of the program.

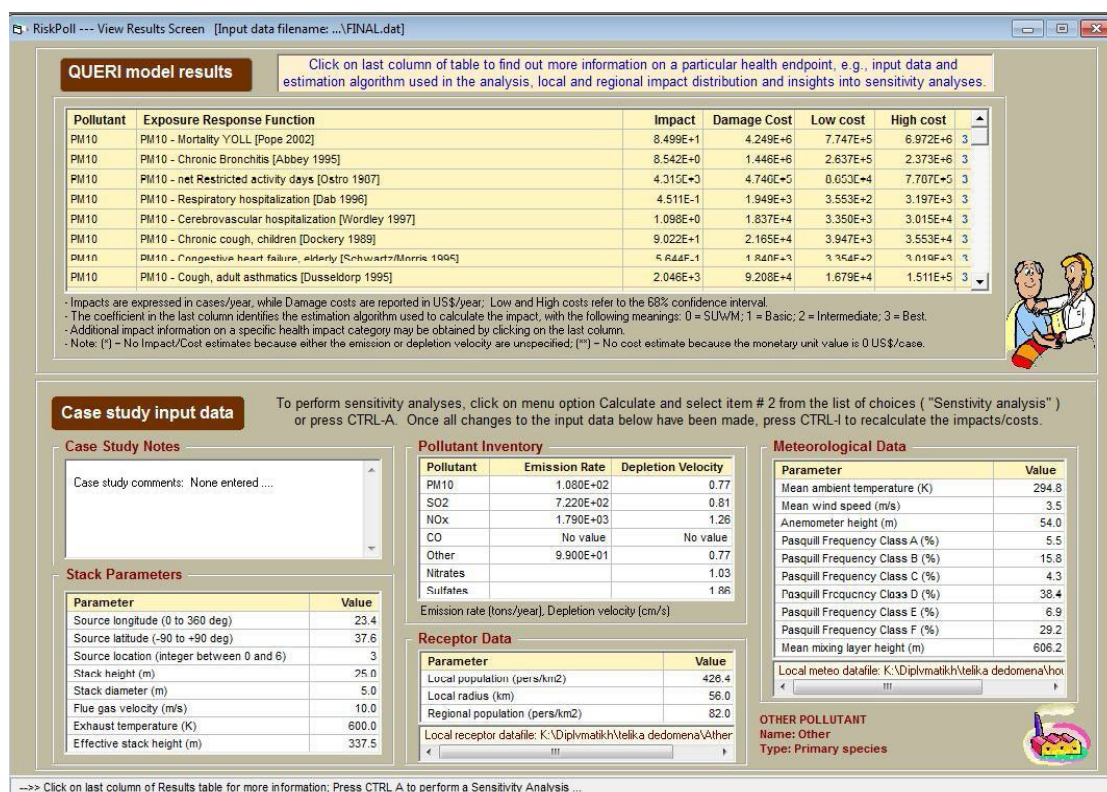


Figure 34: View results screen

More analytically, the case study results file included can be seen in **Annex 6**

6.1.1 QUERI Model Results

The results can be seen in Table 7. This table has 9 columns and 54 rows. More analytically:

Columns

- The first column contains the name of the pollutant under examination
- Second column gives information about the study from which the ERF (Exposure Response Functions) are taken (in the brackets) as well as the health impact that are referred to. It is reminded that the ERF are used for the quantification of impacts (for more information see 3.1) and in this study were used the ones of the ExternE project of the European Commission (values as

of September 28th 2004). The health impacts that these E-R functions implement are:

1. **Mortality**, expressed in YOLL per person per $\mu\text{g}/\text{m}^3$ of pollutant per yr (see 3.1 for more information about YOLL). As the ERF for long-term mortality are not available for SO₂, only the acute mortality contribution is calculated
2. **Chronic bronchitis**, expressed in cases chronic bronchitis per person per $\mu\text{g}/\text{m}^3$ of pollutant per yr.
3. **Net restricted activity days (net RADs)**, expressed in net RADs per person per $\mu\text{g}/\text{m}^3$ of pollutant per yr. Assume that all days in hospital for respiratory admissions (RHA), congestive heart failure (CHF) and cerebrovascular conditions (CVA) are also restricted activity days (RAD). Also assume that the average stay for each is 10, 7 and 45 days respectively. So, net RAD = RAD- (RHA *10) - (CHF*7) - (CVA *45) (Ostro, 1987).
4. **Respiratory hospital admissions (RHA)**, expressed in RHA per person per $\mu\text{g}/\text{m}^3$ of pollutant per yr.
5. **Cerebrovascular hospital admissions**, expressed in cerebrovascular hospital admissions per person per $\mu\text{g}/\text{m}^3$ of pollutant per yr.
6. **Chronic cough in children**, expressed in cases chronic cough in children per person per $\mu\text{g}/\text{m}^3$ of pollutant per yr.
7. **Congestive heart failure in elderly**, expressed in cases congestive heart failure in elderly per person per $\mu\text{g}/\text{m}^3$ of pollutant per yr.
8. **Cough in asthmatic adults**, expressed in cases cough in asthmatic adults in elderly per person per $\mu\text{g}/\text{m}^3$ of pollutant per yr.
9. **Bronchodilator use in asthmatic adults**, expressed in cases Bronchodilator use in asthmatic adults per person per $\mu\text{g}/\text{m}^3$ of pollutant per yr.
10. **Lower respiratory symptoms in asthmatic adults**, expressed in cases lower respiratory symptoms in asthmatic adults per person per $\mu\text{g}/\text{m}^3$ of pollutant per yr.
11. **Cough in asthmatic children**, expressed in cases cough in asthmatic children in elderly per person per $\mu\text{g}/\text{m}^3$ of pollutant per yr.
12. **Bronchodilator use in asthmatic children**, expressed in cases bronchodilator use in asthmatic children per person per $\mu\text{g}/\text{m}^3$ of pollutant per yr.

13. Bronchodilator use in asthmatic children, expressed in cases bronchodilator use in asthmatic children per person per $\mu\text{g}/\text{m}^3$ of pollutant per yr.

14. Lower respiratory symptoms in asthmatic children, expressed in cases lower respiratory symptoms in asthmatic children per person per $\mu\text{g}/\text{m}^3$ of pollutant per yr.

- The third column gives the impact of the corresponding health problem and is expressed in cases/year.

Impact = Regional Impact + Local Impact

Local Impact = $\sum_{\text{over all cells}} \text{local receptor distribution on (5 by 5 km)} \times \text{ERF} \times C_{\text{local}}$

Regional Impact = $\text{SUWM impacts} \times \exp\left(\frac{-t}{\tau}\right)$ (see 4.4.2)

Where, $\text{SUWM impacts} = \frac{\text{Emission} \times \text{Receptor} \times \text{ERF}}{\text{Depletion velocity}}$

- The fourth column gives the damage costs

$\text{QUERI Damage cost (Best)} = \sum_j \Delta C_j \times \text{Receptor}_j \times \text{ERF} \times \text{Unit cost} + \text{Regional cost}$ (see 4.4.2)

- Fifth and sixth column contain the lower cost and upper cost correspondingly. the lower and upper bounds of the damage cost range are indicated with 68% confidence interval assuming a lognormal probability density function (see 4.4)
- The coefficient in the eighth column identifies the estimation algorithm used to calculate the impact, with the following meanings:

Estimation code: 0

Impacts and damage costs were calculated using the Simple Uniform World Model (SUWM). Estimates depend on the following five parameters:

1. Pollutant emission rate
2. depletion velocity;
3. Exposure-Response Function (ERF) of health endpoint in question;
4. Regional receptor density and
5. Monetary unit cost

Estimation code: 3

Based on available input data, impacts and damages were calculated using the 'BEST Algorithm' of QUERI. From the following parameters have been used in the model: stack Height and Diameter; flue gas exhaust Temperature and Velocity; Site index; pollutant Emissions inventory and Depletion Velocity; Regional population density; detailed Local population statistics (5 by 5 km resolution); and detailed Meteorological parameters (hourly data).

- The ninth column gives the presentence of the local impact.

Table 7: QUERI model results

Pollutant	Exposure Response Function	Impact	Damage Cost	Lower Cost	Upper Cost	Estimation	Local impact (%)
PM10	Mortality YOLL [Pope 2002]	8.50E+01	4.25E+06	2.168E+6	1.0951E+7	3	84.8
PM10	Chronic Bronchitis [Abbey 1995]	8.54E+00	1.45E+06	4.820E+5	4.338E+6	3	84.8
PM10	net Restricted activity days [Ostro 1987]	4.32E+03	4.75E+05	1.582E+5	1.424E+6	3	84.8
PM10	Respiratory hospitalization [Dab 1996]	4.51E-01	1.95E+03	6.497E+2	5.847E+3	3	84.8
PM10	Cerebrovascular hospitalization [Wordley 1997]	1.10E+00	1.84E+04	6.127E+3	5.514E+4	3	84.9
PM10	Chronic cough, children [Dockery 1989]	9.02E+01	2.17E+04	7.217E+3	6.495E+4	3	84.8
PM10	Congestive heart failure, elderly [Schwartz/Morris 1995]	5.64E-01	1.84E+03	6.133E+2	5.520E+3	3	84.8
PM10	Cough, adult asthmatics [Dusseldorp 1995]	2.05E+03	9.21E+04	3.070E+4	2.763E+5	3	84.8
PM10	Bronchodilator use, adult asthmatics [Dusseldorp 1995]	9.94E+02	3.98E+04	1.325E+4	1.193E+5	3	84.8
PM10	Lower respiratory symptoms, adult asthmatics [Dusseldorp 1995]	3.71E+02	2.96E+03	9.880E+2	8.892E+3	3	84.8
PM10	Cough, children asthmatics [Pope/Dockery 1992]	4.08E+02	1.83E+04	6.113E+3	3.01E+04	3	84.8
PM10	Bronchodilator use, children asthmatics [Roemer 1993]	1.18E+02	4.73E+03	1.578E+3	1.420E+4	3	84.9
PM10	Lower respiratory symptoms, children asthmatics [Roemer 1993]	1.57E+02	1.26E+03	9.880E+2	3.765E+3	3	84.8
Sulfates	Mortality YOLL [Pope 2002]	3.95E+01	1.97E+06	6.577E+5	5.919E+6	0	(~ 0)
Sulfates	Chronic Bronchitis [Abbey 1995]	3.97E+00	6.72E+05	2.239E+5	2.015E+6	0	(~ 0)
Sulfates	net Restricted activity days [Ostro 1987]	2.00E+03	2.20E+05	7.347E+4	6.612E+5	0	(~ 0)
Sulfates	Respiratory hospitalization [Dab 1996]	2.10E-01	9.05E+02	3.017E+2	2.715E+3	0	(~ 0)
Sulfates	Cerebrovascular hospitalization [Wordley 1997]	5.10E-01	8.53E+03	2.844E+3	2.559E+4	0	(~ 0)

Sulfates	Chronic cough, children [Dockery 1989]	4.19E+01	1.01E+04	3.353E+3	3.018E+4	0	(~ 0)
Sulfates	Congestive heart failure, elderly [Schwartz/Morris 1995]	2.62E-01	8.55E+02	2.848E+2	2.564E+3	0	(~ 0)
Sulfates	Cough, adult asthmatics [Dusseldorp 1995]	9.50E+02	4.28E+04	1.425E+4	1.283E+5	0	(~ 0)
Sulfates	Bronchodilator use, adult asthmatics [Dusseldorp 1995]	4.62E+02	1.85E+04	6.153E+3	5.538E+4	0	(~ 0)
Sulfates	Lower respiratory symptoms, adult asthmatics [Dusseldorp 1995]	1.72E+02	1.38E+03	4.587E+2	4.128E+3	0	(~ 0)
Sulfates	Cough, children asthmatics [Pope/Dockery 1992]	1.89E+02	8.52E+03	2.839E+3	2.555E+4	0	(~ 0)
Sulfates	Bronchodilator use, children asthmatics [Roemer 1993]	5.50E+01	2.20E+03	7.327E+2	6.594E+3	0	(~ 0)
Sulfates	Lower respiratory symptoms, children asthmatics [Roemer 1993]	7.29E+01	5.83E+02	1.943E+2	1.749E+3	0	(~ 0)
Nitrates	Mortality YOLL [Pope 2002]	8.86E+01	4.43E+06	1.276E+6	1.328E+7	0	(~ 0)
Nitrates	Chronic Bronchitis [Abbey 1995]	8.90E+00	1.51E+06	5.023E+5	4.521E+6	0	(~ 0)
Nitrates	net Restricted activity days [Ostro 1987]	4.49E+03	4.94E+05	1.647E+5	1.482E+6	0	(~ 0)
Nitrates	Respiratory hospitalization [Dab 1996]	4.70E-01	2.03E+03	6.767E+2	6.090E+3	0	(~ 0)
Nitrates	Cerebrovascular hospitalization [Wordley 1997]	1.14E+00	1.91E+04	6.380E+3	5.742E+4	0	(~ 0)
Nitrates	Chronic cough, children [Dockery 1989]	9.40E+01	2.26E+04	7.520E+3	6.768E+4	0	(~ 0)
Nitrates	Congestive heart failure, elderly [Schwartz/Morris 1995]	5.90E-01	1.92E+03	6.413E+2	5.772E+3	0	(~ 0)

Nitrates	Cough, adult asthmatics [Dusseldorp 1995]	2.13E+03	9.58E+04	3.194E+4	2.875E+5	0	(~ 0)
Nitrates	Bronchodilator use, adult asthmatics [Dusseldorp 1995]	1.04E+03	4.14E+04	1.380E+4	1.242E+5	0	(~ 0)
Nitrates	Lower respiratory symptoms, adult asthmatics [Dusseldorp 1995]	3.85E+02	3.08E+03	1.027E+3	9.243E+3	0	(~ 0)
Nitrates	Cough, children asthmatics [Pope/Dockery 1992]	4.24E+02	1.91E+04	6.363E+3	5.727E+4	0	(~ 0)
Nitrates	Bronchodilator use, children asthmatics [Roemer 1993]	1.23E+02	4.92E+03	1.641E+3	1.477E+4	0	(~ 0)
Nitrates	Lower respiratory symptoms, children asthmatics [Roemer 1993]	1.64E+02	1.31E+03	4.360E+2	3.924E+3	0	(~ 0)
SO2	Mortality YOLL [Anderson/Toulomi 1996]	7.72E+00	5.79E+05	1.447E+5	2.315E+6	3	85.5
SO2	Respiratory hospitalization [Ponce de Leon 1996]	3.47E+00	1.50E+04	9.103E+3	4.494E+4	3	85.5
PM2.5	Mortality YOLL [Pope 2002]	1.30E+02	6.50E+06	2.168E+6	1.951E+7	3	84.8
PM2.5	Chronic Bronchitis [Abbey 1995]	1.31E+01	2.22E+06	7.383E+5	6.645E+6	3	84.8
PM2.5	net Restricted activity days [Ostro 1987]	6.61E+03	7.27E+05	2.425E+5	2.182E+6	3	84.8
PM2.5	Respiratory hospitalization [Dab 1996]	6.91E-01	2.99E+03	9.953E+2	8.958E+3	3	84.8
PM2.5	Cerebrovascular hospitalization [Wordley 1997]	1.28E+00	2.15E+04	7.153E+3	6.438E+4	3	84.8
PM2.5	Chronic cough, children [Dockery 1989]	1.38E+02	3.31E+04	1.104E+4	9.939E+4	3	84.9
PM2.5	Congestive heart failure, elderly [Schwartz/Morris 1995]	8.65E-01	2.82E+03	9.400E+2	8.460E+3	3	84.8
PM2.5	Cough, adult asthmatics [Dusseldorp 1995]	3.13E+03	1.41E+05	2.57E+04	2.31E+05	3	84.8
PM2.5	Bronchodilator use, adult asthmatics [Dusseldorp 1995]	1.52E+03	6.09E+04	2.030E+4	1.827E+5	3	84.8
PM2.5	Lower respiratory symptoms, adult asthmatics [Dusseldorp 1995]	5.67E+02	4.54E+03	1.513E+3	1.362E+4	3	84.8
PM2.5	Cough, children asthmatics [Pope/Dockery 1992]	6.23E+02	2.81E+04	9.350E+3	8.415E+4	3	84.8
PM2.5	Bronchodilator use, children asthmatics [Roemer 1993]	1.81E+02	7.25E+03	2.416E+3	2.174E+4	3	84.8
PM2.5	Lower respiratory symptoms, children asthmatics [Roemer 1993]	2.40E+02	1.92E+03	6.403E+2	5.763E+3	3	84.8

6.2 Sample of the results per pollutant (Mortality)

6.2.1 PM_{2.5} - Mortality YOLL [Pope 2002]

--- Health Impact ---

Pollutant: PM_{2.5}

Emission: 99 tons/yr

Depletion velocity: 0.77 cm/s

Endpoint: PM_{2.5} - Mortality YOLL [Pope 2002]

ERF slope: 6.5100E-04 cases/(yr.person.ug/m3)

Impact type: Long-term mortality

Unit cost: 50000 €/case

--- Results ---

Impact: 1.301E+2 cases per year, of which the Local and Regional contributions are, respectively: 1.103E+02 and 1.973E+01 cases per year. The local impact is 84.8% of the Total.

Damage cost: 6.503E+6 € per year

(68% confidence interval = 2.168E+6, 1.951E+7)

--- Estimation Code ---

Based on available input data, impacts and damages were calculated using the 'BEST Algorithm' in QUERI.

--- Data use ---

Of the available case study input data, these parameters were utilized: stack Height and Diameter; flue gas exhaust Temperature and Velocity; Site index; pollutant Emissions inventory and Depletion Velocities; Regional population density; detailed Local population statistics (5 by 5 km resolution); and detailed Meteorological parameters (hourly data).

--- Sensitivity analysis ---

Local concentrations were estimated using a Gaussian dispersion algorithm for urban conditions. Consequently, changing the Site index between 1 and 3 will not affect the results.

Whereas varying any of the other input parameters will have an influence on the impact/damage estimates.

6.2.2 PM₁₀ - Mortality YOLL [Pope 2002]

-- Health Impact --

Pollutant: PM₁₀

Emission: 108 tons/yr

Depletion velocity: 0.77 cm/s

Endpoint: PM₁₀ - Mortality YOLL [Pope 2002]

ERF slope: 3.9000E-04 cases/(yr.person.ug/m³)

Impact type: Long-term mortality

Unit cost: 50000 €/case

--- Results ---

Impact: 8.499E+1 cases per year, of which the Local and Regional contributions are, respectively: 7.210E+01 and 1.289E+01 cases per year. The local impact is 84.8% of the Total.

Damage cost: 4.250E+6 € per year

(68% confidence interval = 1.417E+6, 1.275E+7)

--- Estimation Code ---

Based on available input data, impacts and damages were calculated using the 'BEST Algorithm' in QUERI.

--- Data use ---

Of the available case study input data, these parameters were utilized: stack Height and Diameter; flue gas exhaust Temperature and Velocity; Site index; pollutant Emissions inventory and Depletion Velocities; Regional population density; detailed Local population statistics (5 by 5 km resolution); and detailed Meteorological parameters (hourly data).

--- Sensitivity analysis ---

Local concentrations were estimated using a Gaussian dispersion algorithm for urban conditions. Consequently, changing the Site index between 1 and 3 will not affect the results.

Whereas varying any of the other input parameters will have an influence on the impact/damage estimates.

6.2.3 Sulfates - Mortality YOLL [Pope 2002]

--- Health Impact ---

Pollutant: Sulfates

Emission of precursor pollutant (SO₂): 722 tons/yr

Depletion velocity: 1.86 cm/s

Endpoint: Sulfates - Mortality YOLL [Pope 2002]

ERF slope: 3.9000E-04 cases/(yr.person.ug/m³)

Impact type: Long-term mortality

Unit cost: 50000 €/case

--- Results ---

Impact: 3.947E+1 cases per year, of which the Local and Regional contributions are, respectively: ~ 0 and ~ 3.947E+01 cases per year.

Damage cost: 1.973E+6 € per year

(68% confidence interval = 6.577E+5, 5.919E+6)

Impacts and damage costs were calculated using the Simple Uniform World Model (SUWM). Estimates depend on the following five parameters: Pollutant emission rate and depletion velocity; Exposure-Response Function (ERF) of health endpoint in question; Regional receptor density and Monetary unit cost.

6.2.4 Nitrates - Mortality YOLL [Pope 2002]

--- Health Impact ---

Pollutant: Nitrates

Emission of precursor pollutant (NO_x): 1790 tons/yr

Depletion velocity: 1.03 cm/s

Endpoint: Nitrates - Mortality YOLL [Pope 2002]

ERF slope: 1.9500E-04 cases/(yr.person.ug/m³)

Impact type: Long-term mortality

Unit cost: 50000 €/case

--- Results ---

Impact: 8.855E+1 cases per year, of which the Local and Regional contributions are, respectively: ~ 0 and ~ 8.855E+01 cases per year.

Damage cost: 4.427E+6 € per year

(68% confidence interval = 1.276E+6, 1.328E+7)

Impacts and damage costs were calculated using the Simple Uniform World Model (SUWM). Estimates depend on the following five parameters: Pollutant emission rate and depletion velocity; Exposure-Response Function (ERF) of health endpoint in question; Regional receptor density and Monetary unit cost.

6.2.5 SO₂ - Mortality YOLL [Anderson/Toulomi 1996]

--- Health Impact ---

Pollutant: SO₂

Emission: 722 tons/yr

Depletion velocity: 0.81 cm/s

Endpoint: SO₂ - Mortality YOLL [Anderson/Toulomi 1996]

ERF slope: 5.3400E-06 cases/(yr.person.ug/m³)

Impact type: Short-term mortality

Unit cost: 75000 €/case

--- Results ---

Impact: 7.716E+0 cases per year, of which the Local and Regional contributions are, respectively: 6.600E+00 and 1.116E+00 cases per year. The local impact is 85.5% of the Total.

Damage cost: 5.787E+5 € per year

(68% confidence interval = 1.447E+5, 2.315E+6)

--- Estimation Code ---

Based on available input data, impacts and damages were calculated using the 'BEST Algorithm' in QUERI.

--- Data use ---

Of the available case study input data, these parameters were utilized: stack Height and Diameter; flue gas exhaust Temperature and Velocity; Site index; pollutant Emissions inventory and Depletion Velocities; Regional population density; detailed Local population statistics (5 by 5 km resolution); and detailed Meteorological parameters (hourly data).

--- Sensitivity analysis ---

Local concentrations were estimated using a Gaussian dispersion algorithm for urban conditions. Consequently, changing the Site index between 1 and 3 will not affect the results.

Whereas varying any of the other input parameters will have an influence on the impact/damage estimates.

For a more detailed review of impact assessment results the reader can see **Annex 7**.

6.3 Damage costs per pollutant and damage cost per kg of pollutant

Figure 35 and Figure 36 shows the damage costs per pollutant and the damage cost per kg of pollutant respectively. The Other Pollutant refers to $PM_{2.5}$ and Particles refer to PM_{10} .

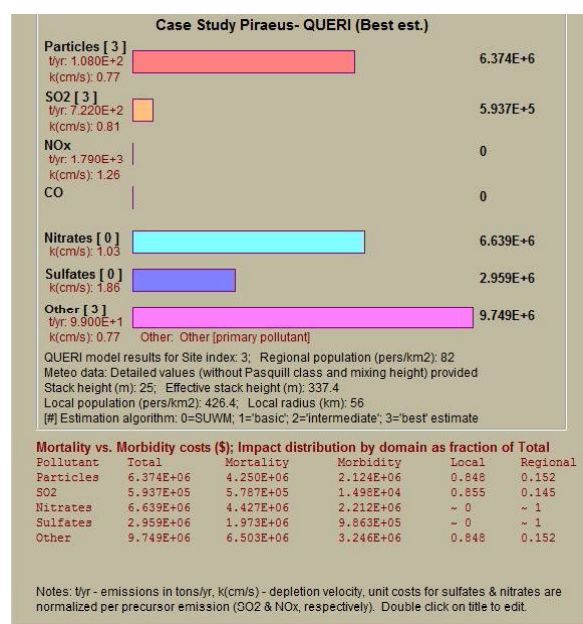


Figure 35: Damage costs per pollutant

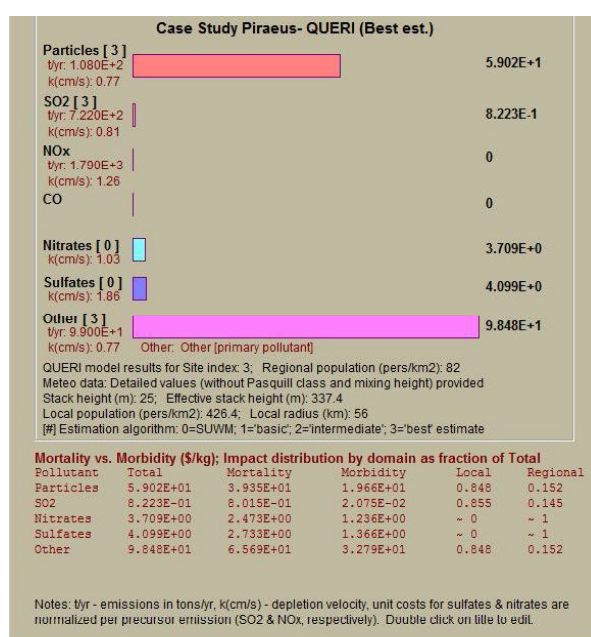


Figure 36: Damage cost per kg of pollutant

6.4 Local Concentration Profiles

The local concentration profiles in the 400 cells into which the local domain is subdivided are:

6.4.1 PM₁₀ Concentration Profile

Emission rate (tons/yr): 108

Peak concentration (µg/m³): 3.059E-01 at (X,Y) = (-2.5, 2.5)

Coordinates X and Y are measured in km along the horizontal and vertical directions, with source at (0,0); concentrations are expressed in µg/m³

	-47.5	-42.5	-37.5	-32.5	-27.5	-22.5	-17.5	-12.5	-7.5	-2.5	2.5	7.5	12.5	17.5	22.5	27.5	32.5	37.5	42.5	47.5
47.5	0.01253	0.01175	0.01062	0.00906	0.00697	0.00429	0.00266	0.00307	0.00348	0.00386	0.00422	0.00452	0.00474	0.00487	0.00474	0.00445	0.00414	0.00385	0.00356	0.0033
42.5	0.01216	0.01436	0.01334	0.0118	0.00961	0.00663	0.00286	0.00337	0.00389	0.00437	0.00483	0.00521	0.00547	0.0056	0.00525	0.00486	0.00448	0.00412	0.00378	0.00386
37.5	0.01152	0.01387	0.01674	0.01535	0.01316	0.00993	0.00545	0.00372	0.00439	0.00503	0.00563	0.00612	0.00642	0.00633	0.00584	0.00534	0.00485	0.00441	0.00452	0.00452
32.5	0.01057	0.013	0.01607	0.01995	0.01796	0.01464	0.00956	0.00411	0.00503	0.0059	0.00672	0.00736	0.0077	0.00721	0.00653	0.00587	0.00525	0.0054	0.00539	0.00528
27.5	0.00924	0.01166	0.01483	0.01899	0.02449	0.02143	0.01596	0.00725	0.00583	0.00709	0.00826	0.00912	0.00924	0.00829	0.00733	0.00645	0.00664	0.00659	0.00641	0.00615
22.5	0.00744	0.00973	0.01282	0.01708	0.02301	0.03131	0.02613	0.01598	0.00685	0.0088	0.0106	0.01179	0.01109	0.00962	0.00824	0.00852	0.00837	0.00802	0.00757	0.00711
17.5	0.00595	0.00715	0.00987	0.01387	0.01979	0.02875	0.0425	0.03225	0.00979	0.01141	0.01448	0.01598	0.01355	0.01118	0.0116	0.01119	0.01046	0.00966	0.00885	0.00759
12.5	0.00522	0.0063	0.00778	0.00987	0.01417	0.02261	0.03724	0.06356	0.03707	0.01573	0.02191	0.02149	0.01671	0.01734	0.01611	0.01447	0.01229	0.01008	0.00846	0.00723
7.5	0.00431	0.00518	0.00639	0.00812	0.01072	0.01404	0.02312	0.04904	0.1139	0.02325	0.03993	0.02968	0.03059	0.02699	0.01905	0.01444	0.01143	0.00935	0.00784	0.00671
2.5	0.00325	0.00384	0.00464	0.00578	0.00747	0.01017	0.01499	0.02511	0.05326	0.3059	0.07936	0.06882	0.03558	0.0229	0.01639	0.01252	0.01001	0.00827	0.007	0.00603
-2.5	0.00259	0.00298	0.00349	0.00418	0.00514	0.00652	0.00863	0.01207	0.01759	0.04452	0.1527	0.09301	0.0451	0.02753	0.01903	0.01421	0.01116	0.00909	0.00761	0.00651
-7.5	0.00236	0.00268	0.00309	0.00359	0.00422	0.00502	0.0061	0.00952	0.0165	0.1296	0.04273	0.05831	0.04809	0.03777	0.02623	0.01912	0.01468	0.01171	0.00962	0.00809
-12.5	0.00212	0.00237	0.00265	0.00296	0.00356	0.00469	0.00644	0.00921	0.03813	0.1018	0.07004	0.01532	0.03216	0.02855	0.02451	0.02096	0.01723	0.01374	0.01126	0.00942
-17.5	0.00188	0.00204	0.00244	0.00298	0.00371	0.00473	0.00616	0.01862	0.03843	0.07662	0.06097	0.00093	0.0147	0.02123	0.01952	0.01753	0.01564	0.01397	0.01247	0.01047
-22.5	0.00182	0.00213	0.00252	0.00303	0.00368	0.00454	0.01125	0.02112	0.03689	0.05963	0.05055	0.01214	0.00595	0.01217	0.01546	0.0145	0.01337	0.01225	0.01119	0.01024
-27.5	0.00188	0.00217	0.00253	0.00299	0.00355	0.00767	0.01338	0.02093	0.03348	0.04803	0.04219	0.01711	0.00145	0.00669	0.01004	0.01197	0.01137	0.01066	0.00994	0.00924
-32.5	0.00189	0.00217	0.0025	0.00289	0.00365	0.0093	0.014	0.02031	0.02986	0.0398	0.03576	0.01835	0.0027	0.00334	0.00638	0.00841	0.00966	0.00926	0.00879	0.00829
-37.5	0.00189	0.00213	0.00243	0.00439	0.0069	0.01005	0.01388	0.01956	0.02658	0.03373	0.03078	0.01812	0.00637	0.00126	0.00391	0.00584	0.00717	0.00804	0.00775	0.00742
-42.5	0.00186	0.00208	0.00354	0.00536	0.00759	0.01027	0.01343	0.01844	0.02377	0.0291	0.02687	0.01731	0.00825	0.00016	0.00222	0.00397	0.00528	0.00621	0.00684	0.00603
-47.5	0.00182	0.00294	0.00431	0.00596	0.00791	0.01019	0.01325	0.01723	0.02137	0.02548	0.02374	0.0163	0.00915	0.00261	0.00105	0.00261	0.00384	0.00477	0.00545	0.00593

Figure 37: PM₁₀ concentration profile

6.4.2 SO₂ Concentration Profile

Emission rate (tons/yr): 722

Peak concentration (µg/m³): 2.045E+00 at (X,Y) = (-2.5, 2.5)

Coordinates X and Y are measured in km along the horizontal and vertical directions, with source at (0,0); concentrations are expressed in µg/m³

	-47.5	-42.5	-37.5	-32.5	-27.5	-22.5	-17.5	-12.5	-7.5	-2.5	2.5	7.5	12.5	17.5	22.5	27.5	32.5	37.5	42.5	47.5
47.5	0.08379	0.07858	0.07102	0.06055	0.0466	0.02867	0.01781	0.02054	0.02325	0.02579	0.02819	0.03025	0.03171	0.03258	0.03171	0.02972	0.0277	0.02571	0.02382	0.02205
42.5	0.08126	0.096	0.08918	0.07889	0.06423	0.04432	0.01911	0.02254	0.02599	0.02924	0.03229	0.03486	0.03657	0.03744	0.03507	0.03251	0.02996	0.02753	0.02527	0.02583
37.5	0.07704	0.09271	0.1119	0.1026	0.08795	0.06637	0.03645	0.02486	0.02937	0.03364	0.03765	0.04093	0.04292	0.0423	0.03902	0.03567	0.03245	0.02946	0.03019	0.03023
32.5	0.07069	0.08693	0.1074	0.1334	0.1201	0.09785	0.06391	0.0275	0.03359	0.03945	0.04491	0.0492	0.05145	0.04819	0.04365	0.03922	0.03512	0.03607	0.03601	0.03531
27.5	0.06174	0.07794	0.09912	0.127	0.1637	0.1433	0.1067	0.04849	0.03895	0.04739	0.05523	0.06099	0.06177	0.05544	0.04903	0.0431	0.04441	0.04408	0.04282	0.04109
22.5	0.04974	0.06501	0.08571	0.1142	0.1538	0.2093	0.1747	0.1068	0.04577	0.05879	0.07087	0.0788	0.07415	0.0643	0.05509	0.05696	0.05596	0.05358	0.05064	0.04754
17.5	0.03975	0.04781	0.06601	0.09275	0.1323	0.1922	0.2841	0.2156	0.06545	0.07625	0.09683	0.1069	0.09061	0.07476	0.07753	0.07477	0.06993	0.06457	0.05913	0.05075
12.5	0.03488	0.04211	0.05199	0.06595	0.09473	0.1512	0.249	0.4249	0.2478	0.1051	0.1465	0.1437	0.1117	0.1159	0.1077	0.09671	0.08217	0.06741	0.05657	0.04836
7.5	0.0288	0.03465	0.04271	0.05426	0.0717	0.09087	0.1546	0.3278	0.7609	0.1564	0.267	0.1966	0.2045	0.1744	0.1274	0.09652	0.07611	0.0625	0.05241	0.04187
2.5	0.02171	0.02568	0.03105	0.03863	0.04991	0.06799	0.1002	0.1679	0.3561	2.045	0.5305	0.4467	0.2377	0.1531	0.1095	0.08373	0.06693	0.05527	0.04676	0.04033
-2.5	0.01723	0.0199	0.02335	0.02795	0.03433	0.04356	0.0577	0.0807	0.1176	0.2976	1.021	0.6218	0.3015	0.184	0.1273	0.09497	0.0746	0.06078	0.05088	0.04351
-7.5	0.01579	0.01795	0.02062	0.02399	0.02824	0.03354	0.04079	0.06363	0.1103	0.8665	0.2856	0.3898	0.3215	0.2525	0.1753	0.1278	0.09812	0.07828	0.06433	0.0541
-12.5	0.0142	0.01582	0.01769	0.0198	0.0238	0.03136	0.04304	0.06158	0.2549	0.6808	0.4683	0.1024	0.215	0.1908	0.1639	0.1402	0.1152	0.09187	0.07525	0.063
-17.5	0.01256	0.01366	0.01629	0.01989	0.02479	0.03161	0.04118	0.1245	0.2569	0.5122	0.4076	0.0662	0.08826	0.1419	0.1305	0.1172	0.1046	0.09337	0.08336	0.06967
-22.5	0.01218	0.01424	0.01685	0.02022	0.02461	0.03033	0.0752	0.1412	0.2466	0.3986	0.3379	0.08114	0.03975	0.08133	0.1033	0.09694	0.0894	0.08187	0.07484	0.06848
-27.5	0.01254	0.0145	0.01694	0.01996	0.02373	0.05128	0.08946	0.1399	0.2238	0.3211	0.282	0.1144	0.0097	0.0447	0.06709	0.07999	0.07601	0.07129	0.06643	0.06174
-32.5	0.01266	0.01449	0.01689	0.01933	0.03777	0.0622	0.09362	0.1358	0.1996	0.2661	0.239	0.1227	0.01808	0.02231	0.04266	0.05621	0.06458	0.06319	0.05873	0.0554
-37.5	0.01261	0.01427	0.01622	0.02933	0.04611	0.06716	0.0928	0.1308	0.1777	0.2255	0.2058	0.1211	0.04257	0.00841	0.02611	0.03902	0.04793	0.05374	0.05183	0.04959
-42.5	0.01242	0.01391	0.02366	0.03581	0.05071	0.06864	0.08981	0.1233	0.1589	0.1945	0.1797	0.1157	0.05514	0.00104	0.01481	0.02655	0.03529	0.04152	0.04575	0.04434
-47.5	0.01214	0.01965	0.02879	0.03981	0.0529	0.06813	0.0886	0.1152	0.1429	0.1704	0.1587	0.109	0.06118	0.01741	0.007	0.01747	0.02567	0.03189	0.03645	0.03966

Figure 38: SO₂ concentration profile

6.4.3 NO_x Concentration Profile

Emission rate (tons/yr): 1790

Peak concentration (µg/m³): 5.071E+00 at (X,Y) = (-2.5, 2.5)

Coordinates X and Y are measured in km along the horizontal and vertical directions, with source at (0,0); concentrations are expressed in $\mu\text{g}/\text{m}^3$

	-47.5	-42.5	-37.5	-32.5	-27.5	-22.5	-17.5	-12.5	-7.5	-2.5	2.5	7.5	12.5	17.5	22.5	27.5	32.5	37.5	42.5	47.5
47.5	0.2077	0.1948	0.1761	0.1501	0.1155	0.07108	0.04414	0.05091	0.05763	0.06394	0.06988	0.07499	0.07862	0.08076	0.07861	0.07369	0.06867	0.06375	0.05906	0.05467
42.5	0.2015	0.238	0.2211	0.1956	0.1592	0.1099	0.04739	0.05588	0.06443	0.07248	0.08005	0.08642	0.09067	0.09282	0.08694	0.08059	0.07429	0.06826	0.06265	0.05804
37.5	0.191	0.2298	0.2775	0.2544	0.218	0.1645	0.09036	0.06163	0.0728	0.0834	0.09333	0.1015	0.1064	0.1049	0.09673	0.08843	0.08045	0.07304	0.07484	0.07496
32.5	0.1753	0.2155	0.2664	0.3307	0.2977	0.2426	0.1585	0.06818	0.08328	0.09779	0.1113	0.122	0.1275	0.1195	0.1082	0.09723	0.08706	0.08944	0.08927	0.08755
27.5	0.1531	0.1932	0.2457	0.3148	0.4059	0.3553	0.2645	0.1202	0.09656	0.1175	0.1369	0.1512	0.1531	0.1374	0.1216	0.1069	0.1101	0.1093	0.1062	0.1019
22.5	0.1233	0.1612	0.2125	0.2831	0.3813	0.5189	0.4331	0.2648	0.1135	0.1458	0.1757	0.1954	0.1838	0.1594	0.1366	0.1412	0.1387	0.1328	0.1255	0.1179
17.5	0.09855	0.1185	0.1637	0.2299	0.328	0.4764	0.7044	0.5345	0.1623	0.189	0.2401	0.2649	0.2246	0.1854	0.1922	0.1854	0.1734	0.1601	0.1466	0.1258
12.5	0.08646	0.1044	0.1289	0.1635	0.2349	0.3748	0.6173	1.053	0.6144	0.2606	0.3631	0.3562	0.277	0.2873	0.267	0.2398	0.2037	0.1671	0.1403	0.1199
7.5	0.07141	0.05952	0.1059	0.1345	0.1770	0.2476	0.3832	0.6120	1.067	0.3653	0.6619	0.4940	0.507	0.4324	0.3157	0.2393	0.1694	0.155	0.13	0.1112
2.5	0.05382	0.06366	0.07698	0.09576	0.1237	0.1686	0.2485	0.4161	0.8827	5.071	1.315	1.107	0.5893	0.3795	0.2716	0.2076	0.1659	0.137	0.1159	0.09988
-2.5	0.04272	0.04933	0.05789	0.06931	0.0851	0.108	0.143	0.2001	0.2914	0.7379	2.531	1.542	0.7475	0.4563	0.3155	0.2355	0.185	0.1507	0.1262	0.1079
-7.5	0.03914	0.04449	0.05113	0.05947	0.07001	0.09315	0.1011	0.1578	0.2735	2.148	0.7081	0.9665	0.797	0.626	0.4347	0.3169	0.2433	0.1941	0.1595	0.1341
-12.5	0.0352	0.03921	0.04395	0.04908	0.059	0.07775	0.1067	0.1527	0.632	1.688	1.161	0.2539	0.533	0.4731	0.4063	0.3477	0.2866	0.2278	0.1866	0.1562
-17.5	0.03114	0.03387	0.04039	0.04931	0.06147	0.07838	0.1021	0.3086	0.637	1.27	1.011	0.01536	0.2436	0.3518	0.3235	0.2906	0.2593	0.2315	0.2067	0.1735
-22.5	0.0302	0.03529	0.04178	0.05014	0.06102	0.0752	0.1864	0.35	0.6114	0.9883	0.8378	0.2012	0.09654	0.2016	0.2562	0.2403	0.2217	0.203	0.1855	0.1698
-27.5	0.03109	0.03596	0.04199	0.04949	0.05882	0.1271	0.2218	0.3469	0.555	0.7961	0.6992	0.2836	0.02406	0.1108	0.1663	0.1983	0.1884	0.1767	0.1647	0.1531
-32.5	0.03139	0.03592	0.04137	0.04792	0.09365	0.1542	0.2321	0.3367	0.4949	0.6596	0.5926	0.3041	0.04482	0.05531	0.1058	0.1394	0.1601	0.1535	0.1456	0.1374
-37.5	0.03126	0.03537	0.0402	0.07272	0.1143	0.1665	0.2301	0.3242	0.4406	0.559	0.5102	0.3003	0.1055	0.02085	0.06474	0.09673	0.1188	0.1332	0.1285	0.1229
-42.5	0.03079	0.03448	0.05866	0.08877	0.1257	0.1702	0.2227	0.3056	0.3939	0.4823	0.4454	0.2869	0.1367	0.00259	0.03671	0.06583	0.08748	0.1029	0.1134	0.1099
-47.5	0.0301	0.04871	0.07138	0.0987	0.1311	0.1689	0.2197	0.2855	0.3542	0.4223	0.3935	0.2702	0.1517	0.04317	0.01734	0.0433	0.06364	0.07906	0.09036	0.09832

Figure 39: NO_x concentration profile

6.4.4 $\text{PM}_{2.5}$ Concentration Profile

Emission rate (tons/yr): 99

Peak concentration ($\mu\text{g}/\text{m}^3$): 2.804E-01 at (X,Y) = (-2.5, 2.5)

Coordinates X and Y are measured in km along the horizontal and vertical directions, with source at (0,0); concentrations are expressed in $\mu\text{g}/\text{m}^3$

	-47.5	-42.5	-37.5	-32.5	-27.5	-22.5	-17.5	-12.5	-7.5	-2.5	2.5	7.5	12.5	17.5	22.5	27.5	32.5	37.5	42.5	47.5
47.5	0.01149	0.01078	0.00974	0.0083	0.00639	0.00393	0.00244	0.00282	0.00319	0.00354	0.00387	0.00415	0.00435	0.00447	0.00435	0.00408	0.0038	0.00353	0.00327	0.00302
42.5	0.01114	0.01316	0.01223	0.01082	0.00881	0.00608	0.00262	0.00309	0.00356	0.00401	0.00443	0.00478	0.00502	0.00513	0.00481	0.00446	0.00411	0.00378	0.00347	0.00354
37.5	0.01056	0.01271	0.01535	0.01407	0.01206	0.0091	0.005	0.00341	0.00403	0.00461	0.00516	0.00561	0.00589	0.0058	0.00535	0.00489	0.00445	0.00404	0.00414	0.00415
32.5	0.00969	0.01192	0.01473	0.01829	0.01647	0.01342	0.00876	0.00377	0.00461	0.00541	0.00616	0.00675	0.00705	0.00661	0.00599	0.00538	0.00482	0.00495	0.00494	0.00484
27.5	0.00847	0.01069	0.01359	0.01741	0.02245	0.01965	0.01463	0.00665	0.00534	0.0065	0.00757	0.00836	0.00847	0.0076	0.00672	0.00591	0.00609	0.00604	0.00587	0.00564
22.5	0.00682	0.00891	0.01175	0.01586	0.02109	0.0287	0.02395	0.01465	0.00628	0.00806	0.00972	0.0108	0.01017	0.00882	0.00755	0.00781	0.00767	0.00735	0.00694	0.00652
17.5	0.00545	0.00658	0.00905	0.01272	0.01814	0.02635	0.03896	0.02956	0.00897	0.01045	0.01328	0.01465	0.01242	0.01025	0.01063	0.01025	0.00959	0.00885	0.00811	0.00896
12.5	0.00478	0.00577	0.00713	0.00904	0.01299	0.02073	0.03414	0.05826	0.03398	0.01442	0.02008	0.0197	0.01532	0.01589	0.01477	0.01326	0.01127	0.00924	0.00776	0.00663
7.5	0.00395	0.00475	0.00586	0.00744	0.00983	0.01369	0.02119	0.04495	0.1043	0.02131	0.03661	0.02737	0.02804	0.02382	0.01746	0.01323	0.01048	0.00857	0.00719	0.00615
2.5	0.00298	0.00352	0.00426	0.0053	0.00684	0.00932	0.01374	0.02302	0.04882	0.2804	0.07275	0.06125	0.03259	0.02099	0.01502	0.01148	0.00918	0.00758	0.00641	0.00553
-2.5	0.00236	0.00273	0.0032	0.00383	0.00471	0.00597	0.00791	0.01107	0.01612	0.04081	0.14	0.08526	0.04134	0.02524	0.01745	0.01302	0.01023	0.00833	0.00698	0.00597
-7.5	0.00217	0.00246	0.00283	0.00329	0.00387	0.0046	0.00559	0.00873	0.01513	0.1188	0.03917	0.05345	0.04408	0.03462	0.02404	0.01753	0.01345	0.01073	0.00882	0.00742
-12.5	0.00195	0.00217	0.00243	0.00272	0.00326	0.0043	0.0059	0.00844	0.03495	0.09335	0.06421	0.01404	0.02948	0.02617	0.02247	0.01923	0.0158	0.0126	0.01032	0.00864
-17.5	0.00172	0.00187	0.00223	0.00273	0.0034	0.00434	0.00565	0.01707	0.03523	0.07024	0.05589	0.00885	0.01347	0.01946	0.01789	0.01607	0.01434	0.0128	0.01143	0.00959
-22.5	0.00167	0.00195	0.00231	0.00277	0.00338	0.00416	0.01031	0.01936	0.03382	0.05466	0.04633	0.01113	0.00545	0.01115	0.01417	0.01329	0.01226	0.01123	0.01026	0.00939
-27.5	0.00172	0.00199	0.00232	0.00274	0.00325	0.00703	0.01227	0.01919	0.03069	0.04403	0.03867	0.01568	0.00133	0.00613	0.0082	0.01097	0.01042	0.00978	0.00911	0.00847
-32.5	0.00174	0.00199	0.00229	0.00265	0.00518	0.00853	0.01284	0.01862	0.02737	0.03648	0.03278	0.01682	0.00248	0.00306	0.00585	0.00771	0.00886	0.00849	0.00805	0.0076
-37.5	0.00173	0.00196	0.00222	0.00402	0.00632	0.00921	0.01272	0.01793	0.02437	0.03092	0.02822	0.01661	0.00584	0.00115	0.00358	0.00535	0.00657	0.00737	0.00711	0.0068
-42.5	0.0017	0.00191	0.00325	0.00491	0.00695	0.00941	0.01232	0.0189	0.02179	0.02668	0.02463	0.01587	0.00756	0.00014	0.00203	0.00364	0.00484	0.00569	0.00627	0.00608
-47.5	0.00166	0.00269	0.00395	0.00546	0.00725	0.00934	0.01215	0.01579	0.01959	0.02336	0.02177	0.01494	0.00839	0.000239	0.00096	0.0024	0.00352	0.00437	0.005	0.00544

Figure 40: $\text{PM}_{2.5}$ concentration profile

6.5 Concentration Contours

The concentration contours for each pollutant were made with the help of the concentration profiles. The contours help the reader to have a better understanding of how the pollutants are spread in the local domain. The red color indicates the area with the highest concentrations.

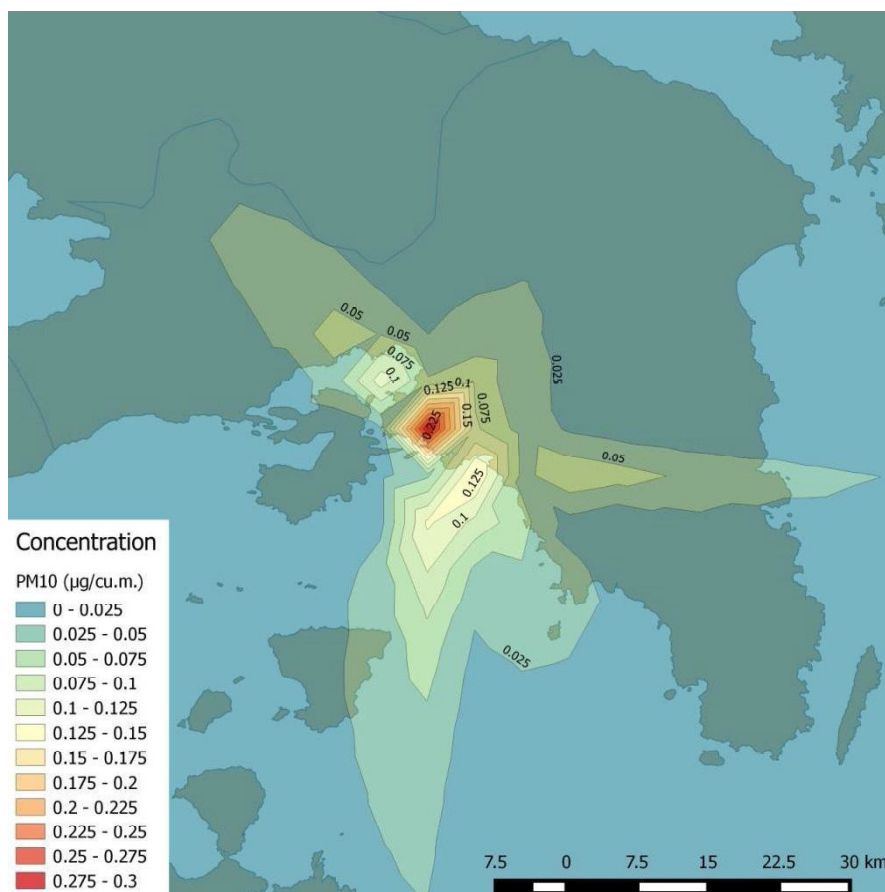


Figure 41: PM₁₀ concentration contour

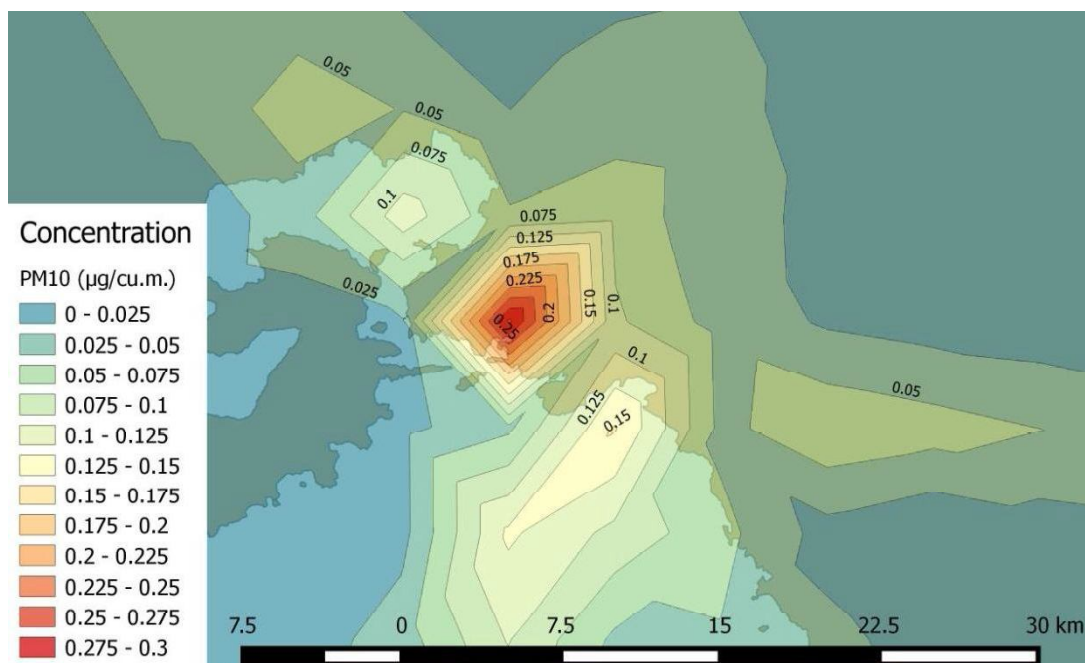


Figure 42: PM₁₀ concentration contour (with zoom)

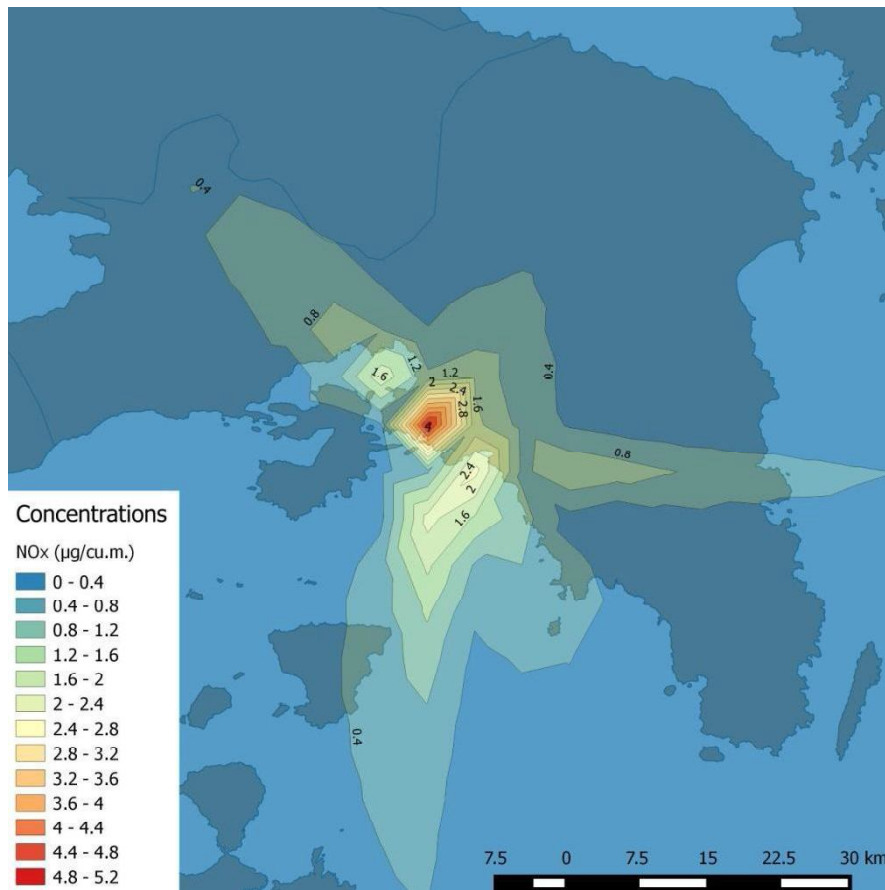


Figure 43: NO_x concentration contour

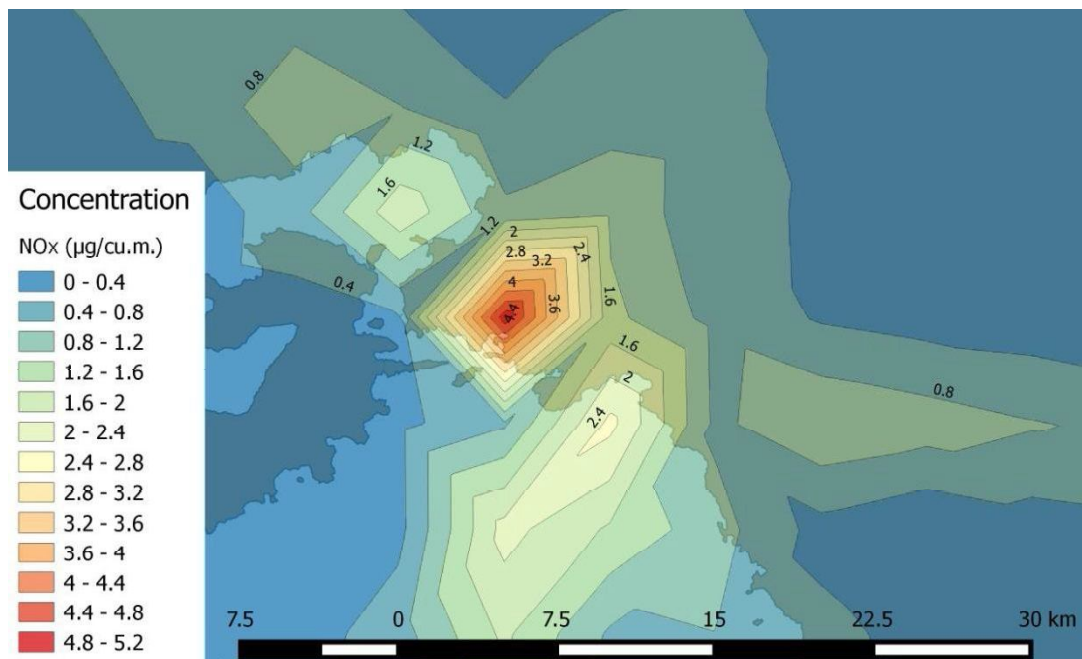


Figure 44: NO_x concentration contour (with zoom)

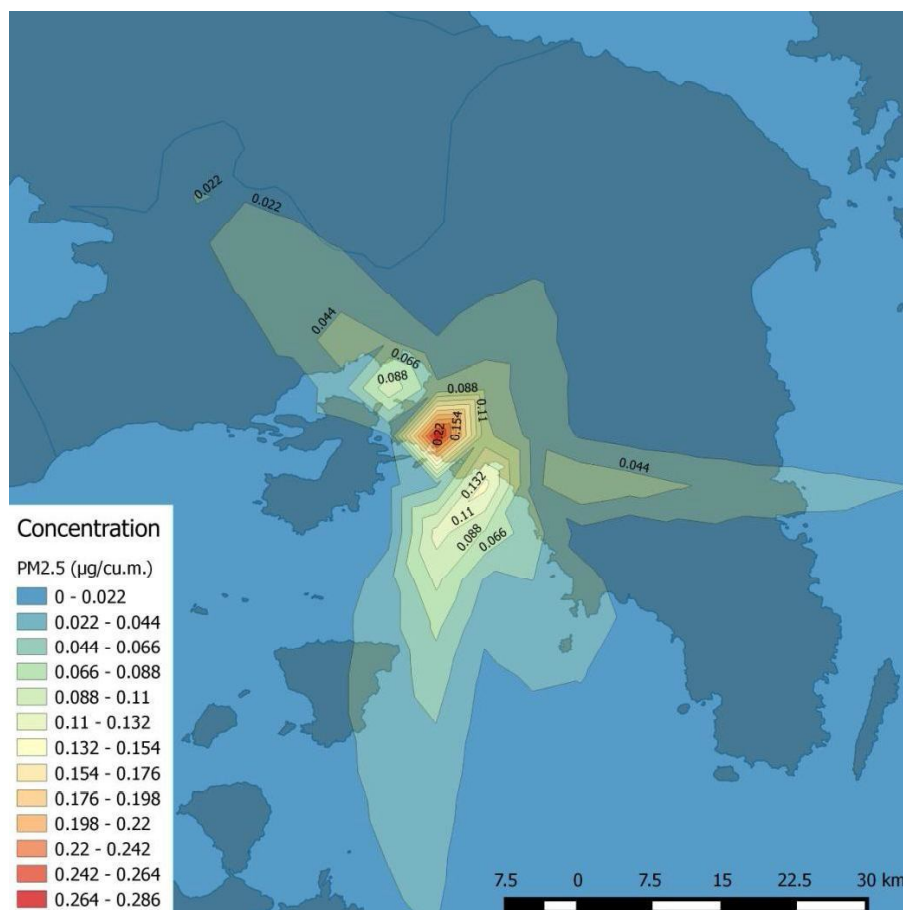


Figure 45: PM_{2.5} concentration contour

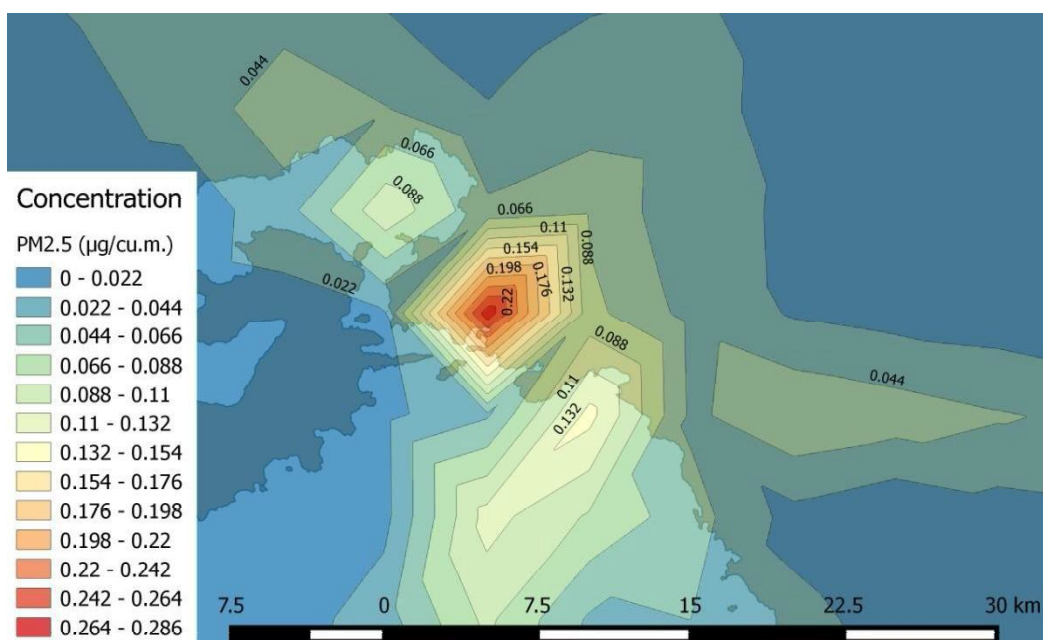


Figure 46: PM_{2.5} concentration contour (with zoom)

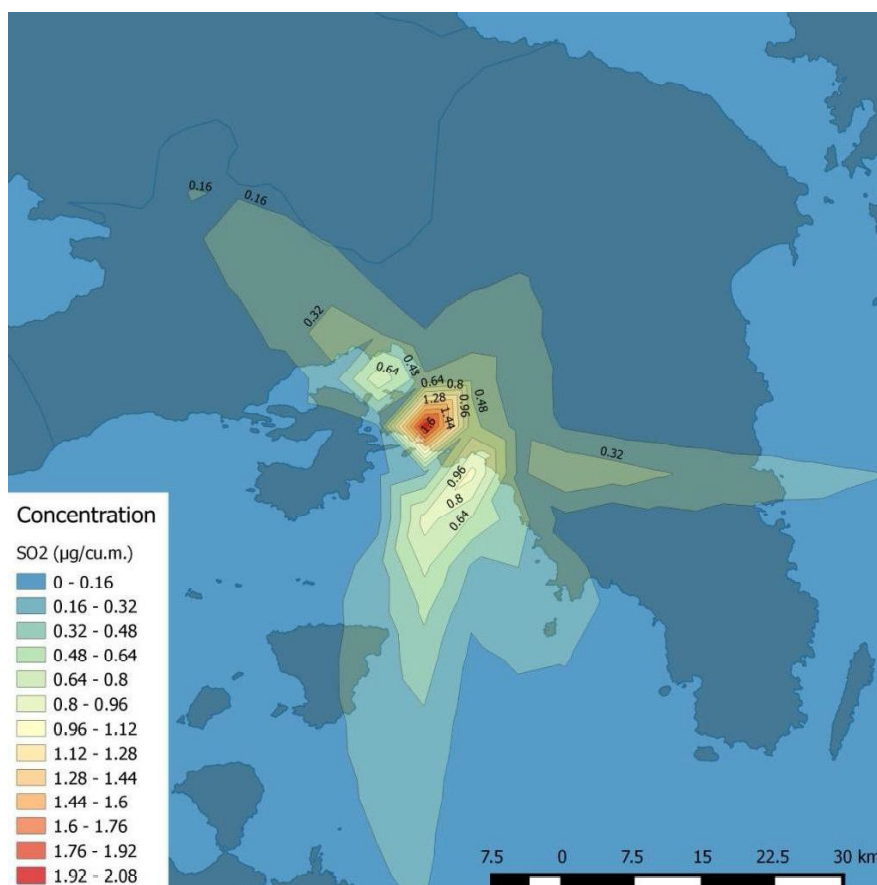


Figure 47: SO₂ concentration contour

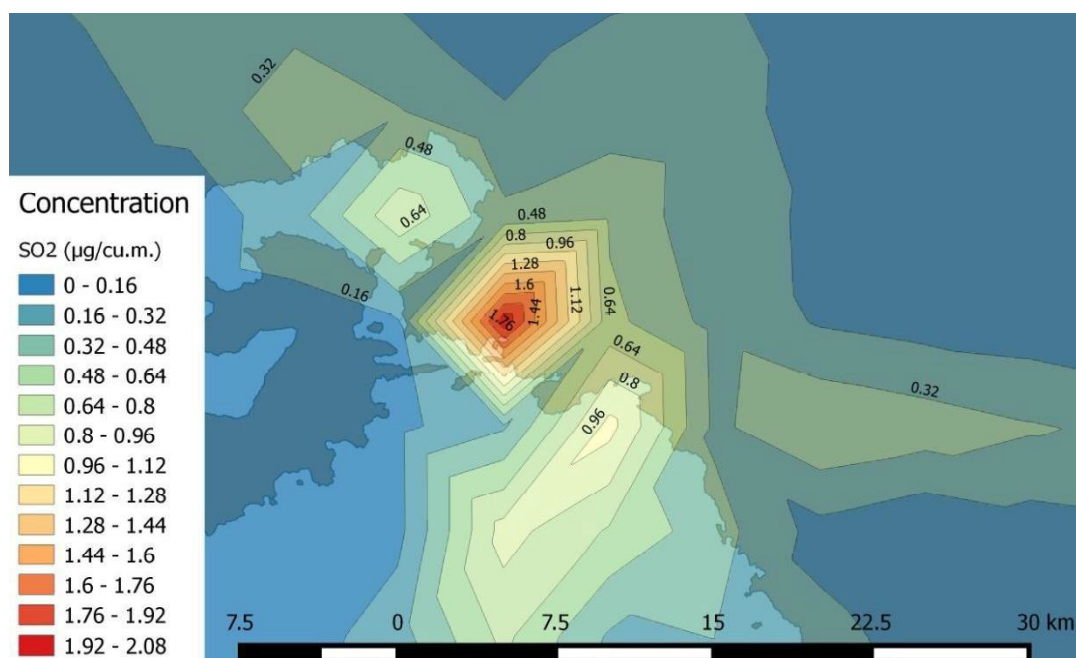


Figure 48: SO₂ concentration contour (with zoom)

6.5.1 Comparison with the air limit values (LV)

According to the annual report of air pollution (2013) the air limit values (LV) for the above pollutants are shown in Table 8:

Table 8: The air limit values (LV) for the pollutants under examination (source: Ministry Of Environment & Climate Change, 2013)

Pollutants	Yearly Limit Values (LV)
PM₁₀	40µg/m ³
PM_{2.5}	26µg/m ³
NO_x	40µg/m ³
SO₂	- (no yearly value)

It is obvious that the highest concentrations of the pollutants in the case study are well below the yearly limit values but that doesn't mean that they don't cause external costs in health.

References of Chapter 6

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Chapter 7: Analysis of case study results

7.1 Overall external cost

The purpose of the case study is the estimation of the external cost in health resulting from air pollutants emitted by coastal passenger ships and cruise ships approaching the port of Piraeus for the year 2008-2009. The estimation of RiskPoll's best algorithm QUERI of the above external cost is illustrated in Figure 49.

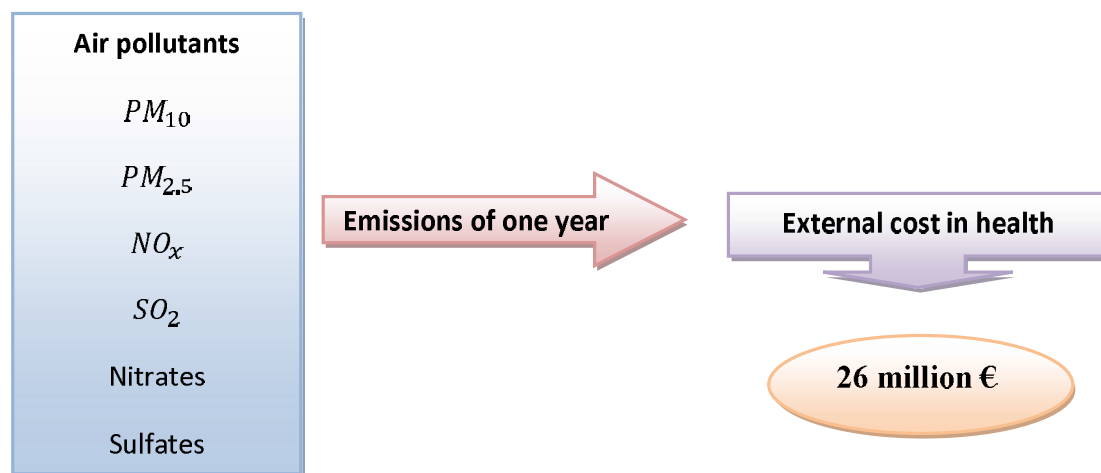


Figure 49: Estimation of RiskPoll's best algorithm QUERI

The exact amount of the external cost in health is 26.314.700 €₂₀₀₀ which derives as the sum of the external costs caused by the particular air pollutants under examination: PM_{10} , $PM_{2.5}$, NO_x , SO_2 , sulfates and nitrates.

7.2 External cost of primary and secondary pollutants

Primary pollutants are those emitted directly from ship's funnel whereas the secondary pollutants are formed later in approximately 56 km from the source when chemical reactions are taking place between primary air pollutants and the environment. The primary air pollutants in this study are: PM_{10} , $PM_{2.5}$, NO_x and SO_2 . The secondary pollutants are: sulfates and nitrates. The course of the formation of secondary pollutants is shown in Figure 50.

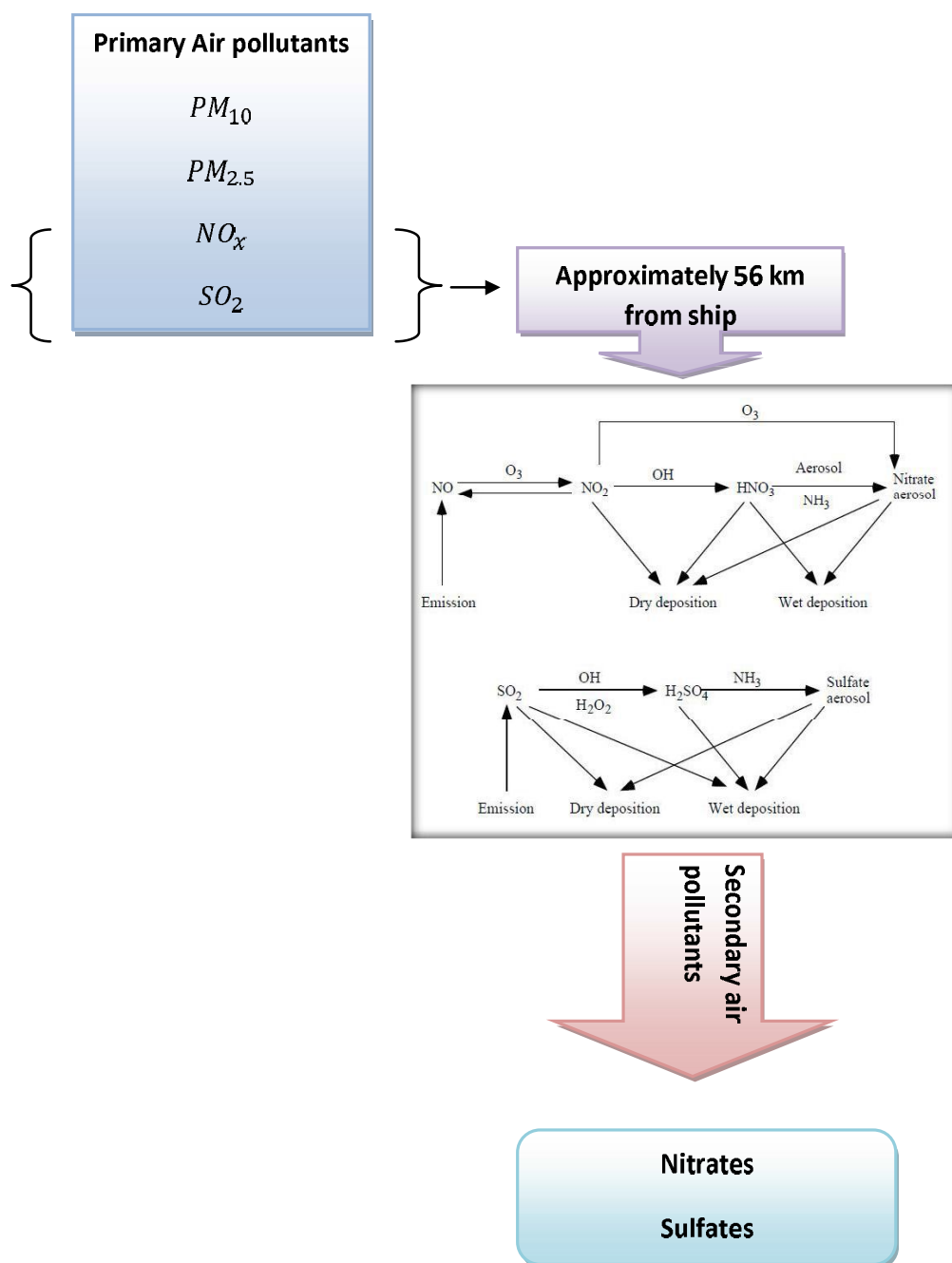


Figure 50: The course of formation of secondary pollutants

It is important to note that NO_x assumed to have zero external cost in health as a primary pollutant and all the external cost is caused by its secondary pollutant, the nitrates. This assumption has been used by the ExternE project of the European Commission and is based in several studies. Rabl (2001) stated “*The evidence for direct health impacts of NO_2 ; is mixed or weak, except possibly for morbidity of children for which according to Bascom et al [1996] “... meta-analysis indicates that a long term increase in exposure to NO_2 ; of 15 ppb is associated with an increase in*

illness odds of approximately 20% in children but not in adults.” The main damage attributable to NO_x seems to be the result of its secondary pollutants (O_3 and nitrates)”

Figure 51 shows the yearly external costs in health of each pollutant (primary and secondary).

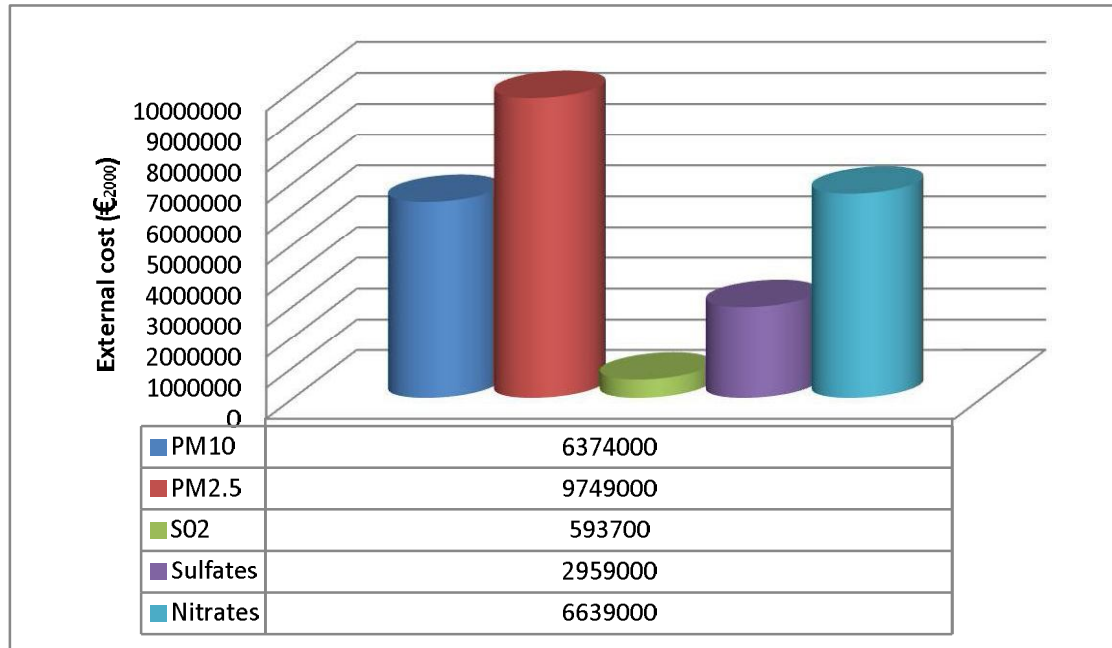


Figure 51: External cost in health of each pollutant for the year 2008-2009

Comments

According to the results, $PM_{2.5}$ causes the biggest external cost with nitrates coming second followed by PM_{10} , Sulfates, and SO_2 . It is interesting to notice that even though NO_x have zero external cost its secondary pollutant, the nitrates, have the second highest one. Furthermore, particles (PM_{10} and $PM_{2.5}$) are by far the main source of external costs reaching a total of 16 million $€_{2000}$ per year. Also, SO_2 as a primary pollutant has low external cost but as a secondary pollutant in the form of sulfates gives nearly 3 million $€_{2000}$ of external cost. Figure 52 gives a more clear view of the contribution of each pollutant in the overall external cost.

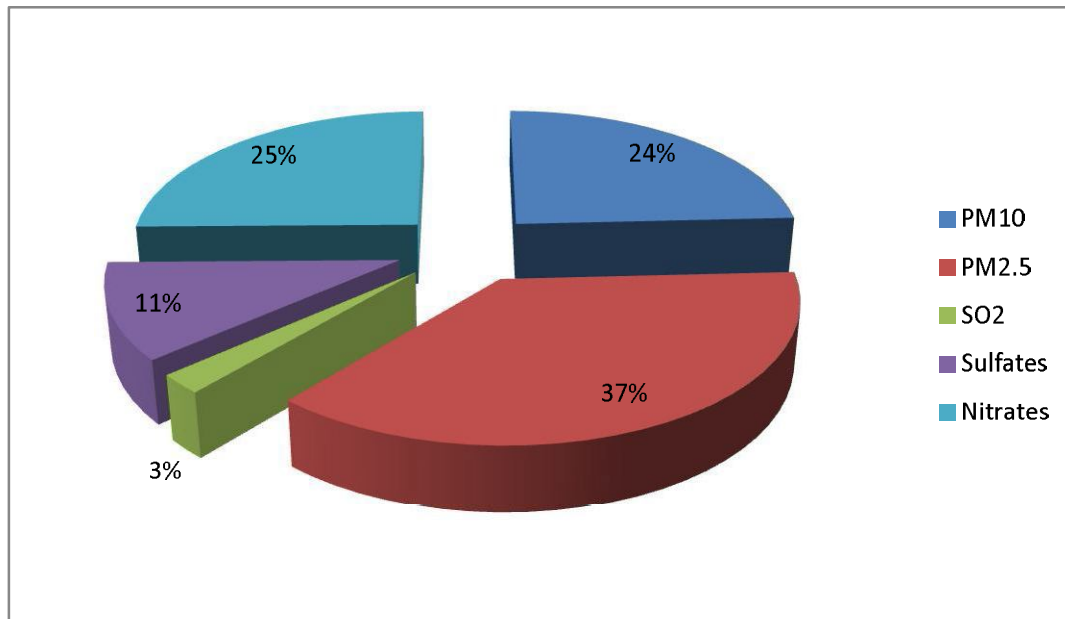


Figure 52: Presentence of each pollutant's contribution in the overall external cost

Comments

Taking into account all the pollutants (primary and secondary), particles contribute for more than 60% of the damage costs followed by the nitrates, sulfates and SO_2 . So, it is clear that as far as human health impacts regards, particles are the main source of the damage costs.

7.3 Mortality vs Morbidity

The impacts in human health from an air pollutant can be separated according to the mortality or morbidity that they cause. As it was said long-term mortality is measured in YOLL (Years Of Lost Life) the value of which is acquired by the willingness-to-pay (WTP) to avoid the risk of an anonymous premature death while morbidity is a sum of the cost of medical treatment for the illness, wage and productivity and one's willingness-to-pay (WTP) to avoid the risk of pain and suffering.

The external cost from mortality by all the pollutants is 17731700 €₂₀₀₀ while the external cost from morbidity is 8583000 €₂₀₀₀. Therefore, the presentence of mortality's and morbidity's costs in the overall external cost are 67% and 33% respectively.

The pollutant with the biggest mortality external cost as well as the biggest morbidity external cost is $PM_{2.5}$ (6503000 €₂₀₀₀ and 324000 €₂₀₀₀ respectively).

7.4 Local vs Regional impact

The local domain has an “effective” radius of 56 km while the regional domain has an “effective” radius between 500 and 1000 km from the source. Local impacts are determined using a 5 by 5 km gridded population distribution (entered by the user manually). The regional impact is based on the SUWM evaluation. Nitrates and sulfates have only regional impacts, while PM_{10} , $PM_{2.5}$ and SO_2 have each of them 85% local impacts and 15% regional impacts. Because particles are the main source of the overall external cost in health and 85% of their external cost is local it is therefore important to note that people living in Athens are mainly the ones at risk.

7.5 External cost per tonne of pollutant

The yearly external cost per tonne of pollutant is the best way to understand the damage of an air pollutant. Also, it is an important tool for future regulations because it shows which pollutant first should be subjected to emission control.

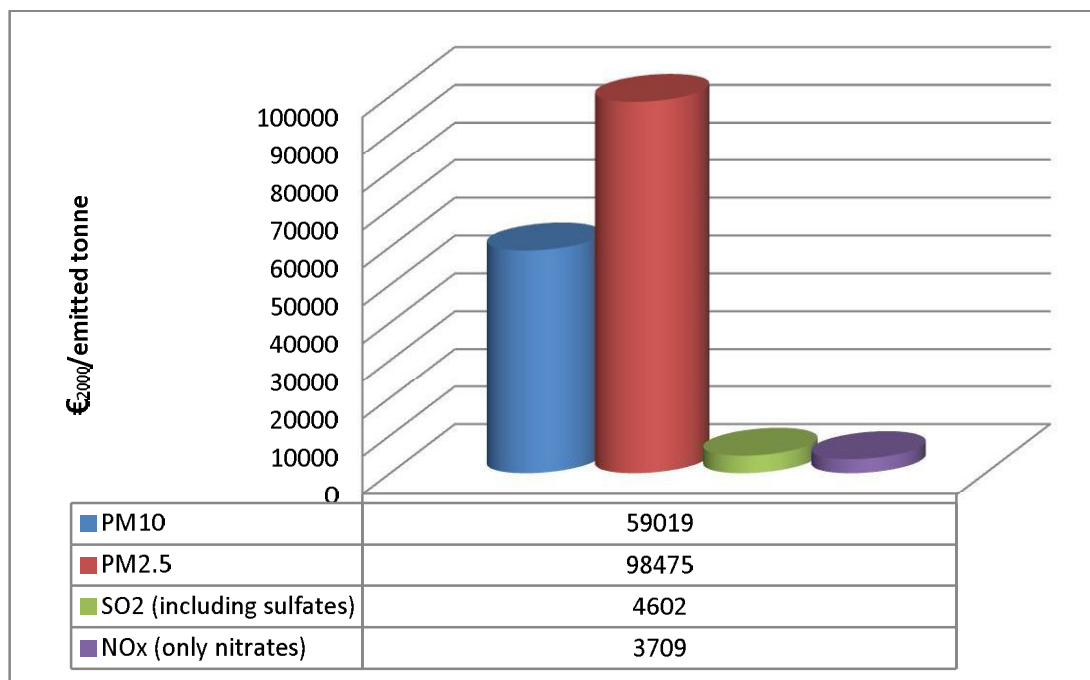


Figure 53: External cost per tonne of pollutant for the year 2008-2009

Comments

It is obvious that $PM_{2.5}$ have the biggest external cost per emitted tonne with 98475 $\text{€}_{2000}/\text{tonne}$. PM_{10} is following with 59019 $\text{€}_{2000}/\text{tonne}$, SO_2 with 4602 $\text{€}_{2000}/\text{tonne}$ (including the sulfates costs) and NO_x (only nitrates cost) with 3709 $\text{€}_{2000}/\text{tonne}$.

7.6 External cost per person

According to census 2011 the total resident population in Greece is 10815197 receptors and in Attica 3827624. Because the regional scale varies between 500 and 1000 km it is assumed that all Greece is affected by the pollutants. Also, it is assumed that the local population consists of the people living in Attica because the majority of the local population is concentrated there (see population file in **Annex 4**). Finally, the receptors in the regional scale are 6987573 (population in Greece minus the population in Athens). First Figure 54 shows the yearly external cost in health per receptor in total (local and regional), second Figure 55 shows the yearly external cost in health per receptor in the local scale and the third Figure 56 shows the yearly external cost in health per receptor in the regional scale.

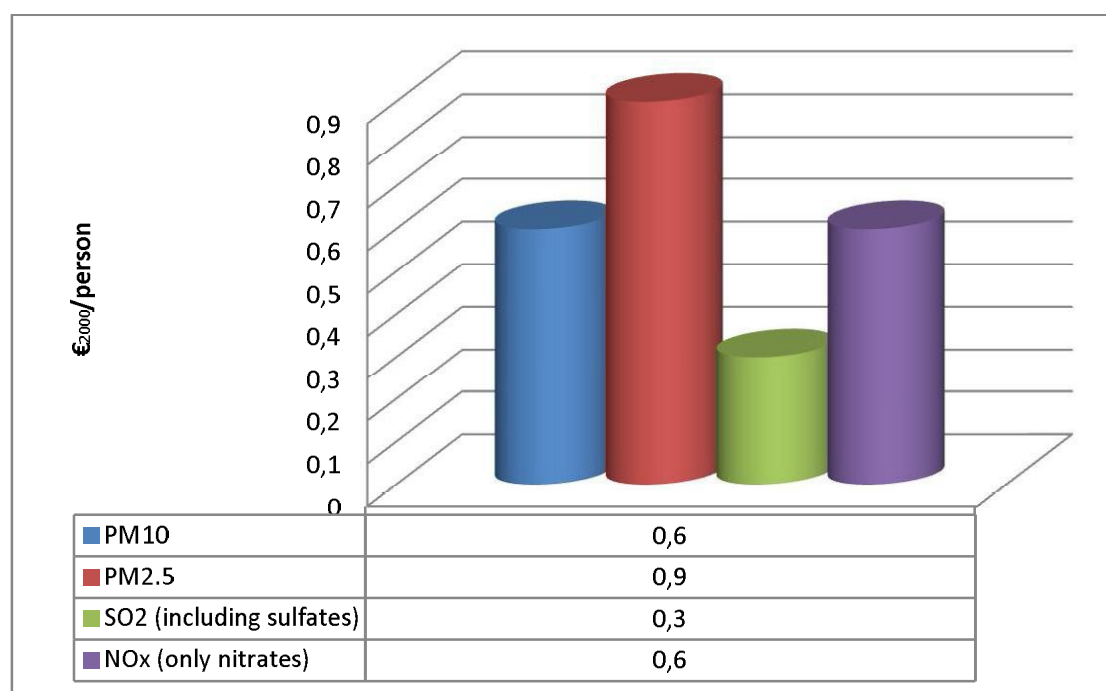


Figure 54: External cost per person (total-Greece) for the year 2008-2009

Comments

$PM_{2.5}$ cost every year nearly 1 €₂₀₀₀ per person (living in Greece), each of PM_{10} and NO_x (only the nitrates) cost 0.6 €₂₀₀₀ per person and SO_2 0.3 €₂₀₀₀ per person. That means a total of 2.5€₂₀₀₀ per person external cost every year and considering the size of the receptors (a whole country) this result is alarming.

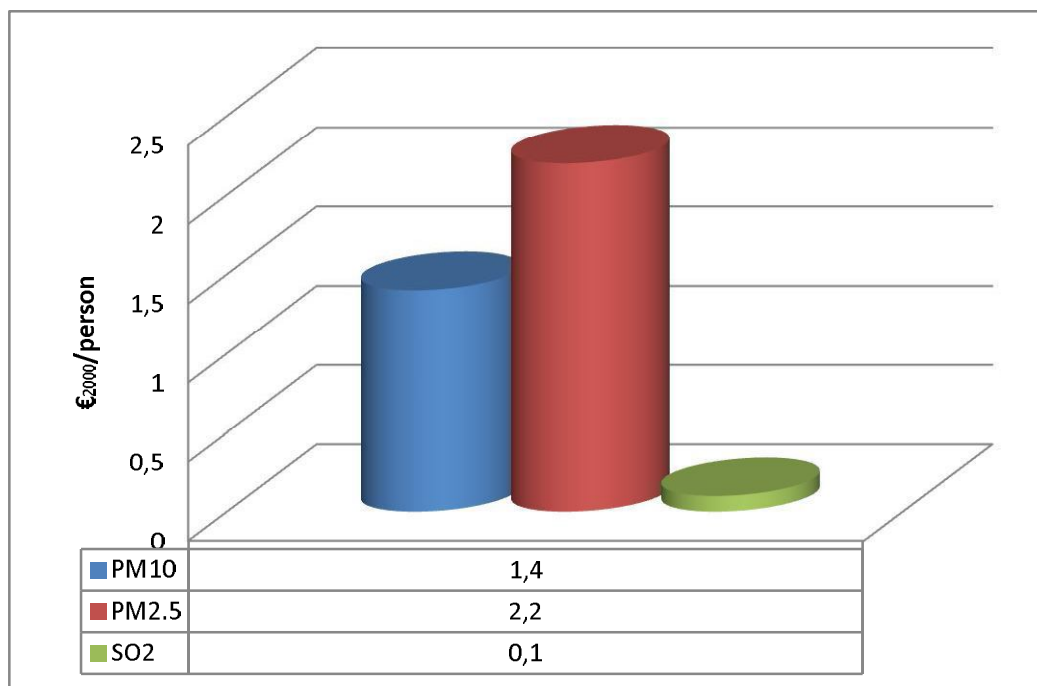


Figure 55: External cost per person (local-Athens) for the year 2008-2009

Comments

Here, $PM_{2.5}$ cost every year 2.2 €₂₀₀₀ per person (living in Athens), PM_{10} cost 1.4 €₂₀₀₀ per person and SO_2 0.1 €₂₀₀₀ per person. That means a total of nearly 4 €₂₀₀₀ per person external cost every year. It is reminded that the nitrates and the sulfates have only regional impacts.

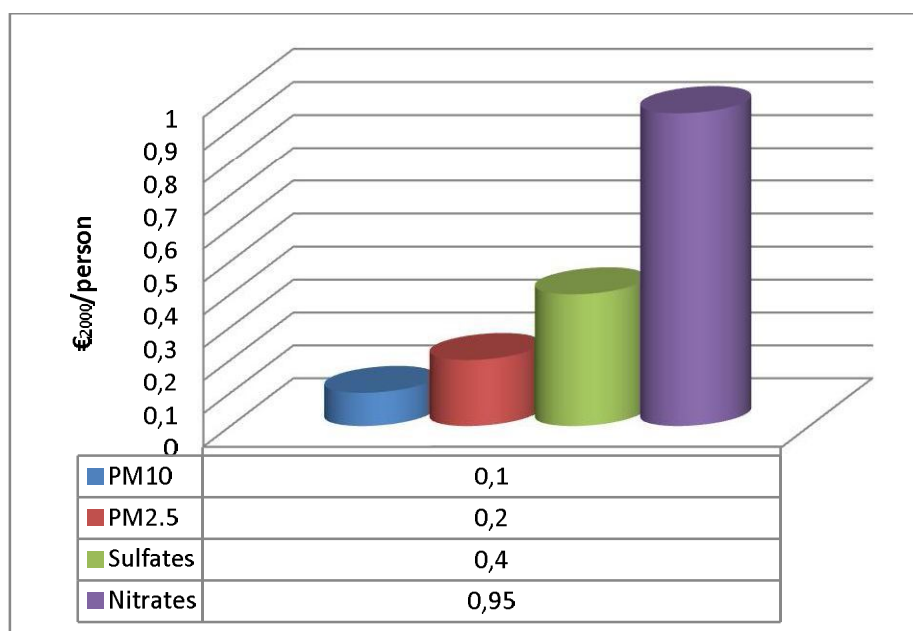


Figure 56: External cost per person (regional-Greece) for the year 2008-2009

Comments

In the regional scale, the nitrates give the biggest yearly external cost per person (1 €₂₀₀₀) followed by the sulfates (0.4 €₂₀₀₀), $PM_{2.5}$ (0.2 €₂₀₀₀) and PM_{10} (0.1 €₂₀₀₀). The total external cost per year in health is 1.7 €₂₀₀₀ per person for the people living outside Athens.

7.7 Point of maximum concentrations

Finally, the maximum concentration point of the Gaussian plume is at (X, Y) = (-2.5 km, 2.5 km) from the source and in that point all the pollutants reach their highest concentration. According to the concentration profiles and contours the point of maximum concentration is at Neo Ikonio in Perama.

7.8 Comparison with Tzannatos study

Tzannatos (2010b) also estimated the external costs of $PM_{2.5}$, NO_x , SO_2 for the same air emissions of coastal passenger ships and cruise ships approaching the port of Piraeus for the year 2008-2009 with the help of emission externality factors. According to his findings: *“the overall externalities were valued at almost 51 million euro, whereas the individual contribution of the pollutants was around 28, 14 and 9 million euro for the NO_x , SO_2 and $PM_{2.5}$ emissions, respectively”*. Because these values refer to year 2008 prices they must be brought to year 2000, in order to compare them with the results of this study with the help of CPI (Consumer Price Index). The Greek CPI in 2008 stood at 130.8 according to the OECD country statistical profiles (OECD, 2009) with base year 2000 (=100) (Tzannatos, 2010b). That means that the costs estimated by Tzannatos are 30.8% higher than those of the year 2000. So, the 2000 price values of Tzannatos estimations are: 35.3 M €₂₀₀₀, 19.4 M €₂₀₀₀, 9.7 M €₂₀₀₀, 6.2 M €₂₀₀₀ for the overall externalities of NO_x , SO_2 and $PM_{2.5}$ emissions, respectively. For $PM_{2.5}$ the results are very close to this study but for NO_x and SO_2 the deviations are big. These deviations are reasonable since Tzannatos estimated not only health costs but environmental costs as well, like the effects of SO_2 (acidity) on materials used in buildings and structures (excluding those of cultural value) and the effects of NO_x on arable crop yield. $PM_{2.5}$'s external costs are dominated completely by health costs and so the estimation of Tzannatos study is close to this study.

References of Chapter 7

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Chapter 8: Case study 2 (at ship level)

8.1 Description of the study

The purpose of this chapter is the estimation of the external cost in health caused by the air emissions of one coastal passenger ship for the year 2013-2014. This study focuses in the time frame between arriving and departing from the port of Piraeus. First, the travel log of the ship was acquired, containing data for the year 2013-2014. The time that the ship stayed in the port was found by subtracting the time of departure from the time of arrival. This process was repeated throughout the year acquiring by this way the hours of port time for the whole year. Finally, the average port time was found by dividing the sum of all the hours in port by the times that the ship approached Piraeus.

Average port time= 10 hours (125 approaches in total)

8.2 Assumptions and input data

It was assumed that the time for maneuvering in and out of the port is half an hour respectively. So, a total of 1 hour from the 10 hours in port is for maneuvering. According to the data collected, when the ship is at port only one auxiliary engine is working at 80% and when it is in maneuvering the main engine is working at 40% and one auxiliary engine at 40%. The auxiliary engine is a Daihatsu AL-28 model with 1800 HP and SFOC (Specific Fuel Oil Consumption) 175 gr/kwh while the main engine has 46200 HP and SFOC 135 gr/kwh. The emission factors for fuel consumption that were used are shown in Table 9.

Table 9: The emission factors for fuel consumption that were used

Emission Factors For Fuel Consumption			
	HFO (Heavy Fuel Oil)	MDO (Marine Diesel Oil)	
NO_x	15.88	12.11	gr/kwh
SO_2	9.29	6.9799	gr/kwh
PM	1.47	0.5551735	gr/kwh

By multiplying each emission factor with the hours in port and used engine power (for the main and auxiliary engine in port and in maneuvering) the emissions for every pollutant were found for one approach.

The final emissions for one year were estimated by multiplying the above emissions with the total approaches (125 in total) and found to be:

$$PM = 3.4 \text{ tn}$$

$$NO_x = 42.76 \text{ tn}$$

$$SO_2 = 26.99 \text{ tn}$$

According to ENTEC (2010), PM_{10} = 95% of total particulate matter and $PM_{2.5}$ = 90% of total particulate matter. So,

$$PM_{10} = 3.23 \text{ tn}$$

$$PM_{2.5} = 3.06 \text{ tn}$$

The input data in RiskPoll remain the same as the main case study with the exception of the pollutant inventory (the above values were used) and two stack parameters (stack height = 34 m and stack diameter = 1.6 m). Also, the assumptions for the stationary source and the $PM_{2.5}$ ERF values remain the same as the ones used in the main case study.

8.3 Results presentation

The presentation of the results starts with Figure which is the “View Results Screen” of the program.

QUERI model results

Click on last column of table to find out more information on a particular health endpoint, e.g., input data and estimation algorithm used in the analysis, local and regional impact distribution and insights into sensitivity analyses.

Pollutant	Exposure Response Function	Impact	Damage Cost	Low cost	High cost	
PM10	PM10 - Mortality YOLL [Pope 2002]	2.923E+0	1.462E+5	2.665E+4	2.398E+5	3
PM10	PM10 - Chronic Bronchitis [Abbey 1995]	2.938E-1	4.975E+4	9.069E+3	8.162E+4	3
PM10	PM10 - net Restricted activity days [Ostro 1987]	1.484E+2	1.633E+4	2.976E+3	2.679E+4	3
PM10	PM10 - Respiratory hospitalization [Dab 1996]	1.552E-2	6.703E+1	1.222E+1	1.100E+2	3
PM10	PM10 - Cerebrovascular hospitalization [Wordley 1997]	3.778E-2	6.321E+2	1.152E+2	1.037E+3	3
PM10	PM10 - Chronic cough, children [Dockery 1989]	3.103E+0	7.448E+2	1.358E+2	1.222E+3	3
PM10	PM10 - Congestive heart failure, elderly [Schwartz/Morris 1995]	1.941E-2	6.329E+1	1.154E+1	1.038E+2	3
PM10	PM10 - Cough, adult asthmatics [Dusseldorp 1995]	7.039E+1	3.167E+3	5.774E+2	5.197E+3	3

- Impacts are expressed in cases/year, while Damage costs are reported in US\$/year. Low and High costs refer to the 68% confidence interval.
 - The coefficient in the last column identifies the estimation algorithm used to calculate the impact, with the following meanings: 0 = SUWM, 1 = Basic, 2 = Intermediate, 3 = Best.
 - Additional impact information on a specific health impact category may be obtained by clicking on the last column.
 - Note: (*) = No Impact/Cost estimates because either the emission or depletion velocity are unspecified; (**) = No cost estimate because the monetary unit value is 0 US\$/case.

Case study input data

To perform sensitivity analyses, click on menu option Calculate and select item # 2 from the list of choices ("Sensitivity analysis") or press CTRL-A. Once all changes to the input data below have been made, press CTRL-I to recalculate the impacts/costs.

Case Study Notes

Case study comments: None entered

Stack Parameters

Parameter	Value
Source longitude (0 to 360 deg)	23.6
Source latitude (-90 to +90 deg)	37.9
Source location (integer between 0 and 6)	3
Stack height (m)	34.0
Stack diameter (m)	1.6
Flue gas velocity (m/s)	10.0
Exhaust temperature (K)	600.0
Effective stack height (m)	113.0

Pollutant Inventory

Pollutant	Emission Rate	Depletion Velocity
PM10	3.080E+00	0.77
SO2	2.488E+01	0.81
NOx	4.276E+01	1.26
CO	No value	No value
Other	2.910E+00	0.77
Nitrates		1.03
Sulfates		1.86

Emission rate (tons/year), Depletion velocity (cm/s)

Receptor Data

Parameter	Value
Local population (pers/km2)	426.4
Local radius (km)	56.0
Regional population (pers/km2)	82.0

Local receptor datafile: K:\Diplmatikh\velka dedomena\Ather

Meteorological Data

Parameter	Value
Mean ambient temperature (K)	294.8
Mean wind speed (m/s)	3.5
Anemometer height (m)	54.0
Pasquill Frequency Class A (%)	5.4
Pasquill Frequency Class B (%)	15.8
Pasquill Frequency Class C (%)	4.3
Pasquill Frequency Class D (%)	38.4
Pasquill Frequency Class E (%)	6.9
Pasquill Frequency Class F (%)	29.3
Mean mixing layer height (m)	605.5

Local meteo datafile: K:\Diplmatikh\velka dedomena\Ather

OTHER POLLUTANT
Name: Other
Type: Primary species

Figure 57: View Results Screen

QUERI Model Results

The results can be seen in Table 10.

Table 10: QUERI model results

Pollutant	Exposure Response Function	Impact	Damage Cost	Lower Cost	Upper Cost	Estimation	Local impact (%)
PM10	Mortality YOLL [Pope 2002]	2.923E+0	1.462E+5	4.873E+4	4.386E+5	3	87.4
PM10	Chronic Bronchitis [Abbey 1995]	2.938E-1	4.975E+4	1.658E+4	1.493E+5	3	87.4
PM10	net Restricted activity days [Ostro 1987]	1.484E+2	1.633E+4	5.443E+3	4.899E+4	3	87.4
PM10	Respiratory hospitalization [Dab 1996]	1.552E-2	6.703E+1	2.234E+1	2.011E+2	3	87.4
PM10	Cerebrovascular hospitalization [Wordley 1997]	3.778E-2	6.321E+2	2.107E+2	1.896E+3	3	87.4
PM10	Chronic cough, children [Dockery 1989]	3.103E+0	7.448E+2	2.483E+2	2.234E+3	3	87.4
PM10	Congestive heart failure, elderly [Schwartz/Morris 1995]	1.941E-2	6.329E+1	2.110E+1	1.899E+2	3	87.4
PM10	Cough, adult asthmatics [Dusseldorp 1995]	7.039E+1	3.167E+3	1.056E+3	9.501E+3	3	87.4
PM10	Bronchodilator use, adult asthmatics [Dusseldorp 1995]	3.418E+1	1.367E+3	4.557E+2	4.101E+3	3	87.4
PM10	Lower respiratory symptoms, adult asthmatics [Dusseldorp 1995]	1.274E+1	1.019E+2	3.397E+1	3.057E+2	3	87.4
PM10	Cough, children asthmatics [Pope/Dockery 1992]	1.402E+1	6.308E+2	2.103E+2	1.892E+3	3	87.4
PM10	Bronchodilator use, children asthmatics [Roemer 1993]	4.070E+0	1.628E+2	5.427E+1	4.884E+2	3	87.4
PM10	Lower respiratory symptoms, children asthmatics [Roemer 1993]	5.397E+0	4.318E+1	1.439E+1	1.295E+2	3	87.4
Sulfates	Mortality YOLL [Pope 2002]	1.360E+0	6.801E+4	2.267E+4	2.040E+5	0	(~ 0)
Sulfates	Chronic Bronchitis [Abbey 1995]	1.367E-1	2.314E+4	7.713E+3	6.942E+4	0	(~ 0)
Sulfates	net Restricted activity days [Ostro 1987]	6.905E+1	7.596E+3	2.532E+3	2.279E+4	0	(~ 0)
Sulfates	Respiratory hospitalization [Dab 1996]	7.219E-3	3.119E+1	1.040E+1	9.357E+1	0	(~ 0)
Sulfates	Cerebrovascular hospitalization [Wordley 1997]	1.758E-2	2.941E+2	9.803E+1	8.823E+2	0	(~ 0)

Sulfates	Chronic cough, children [Dockery 1989]	1.444E+0	3.465E+2	1.155E+2	1.040E+3	0	(~ 0)
Sulfates	Congestive heart failure, elderly [Schwartz/Morris 1995]	9.033E-3	2.945E+1	9.817E+0	8.835E+1	0	(~ 0)
Sulfates	Cough, adult asthmatics [Dusseldorp 1995]	3.275E+1	1.474E+3	4.913E+2	4.422E+3	0	(~ 0)
Sulfates	Bronchodilator use, adult asthmatics [Dusseldorp 1995]	1.590E+1	6.361E+2	2.120E+2	1.908E+3	0	(~ 0)
Sulfates	Lower respiratory symptoms, adult asthmatics [Dusseldorp 1995]	5.929E+0	4.743E+1	1.581E+1	1.423E+2	0	(~ 0)
Sulfates	Cough, children asthmatics [Pope/Dockery 1992]	6.522E+0	2.935E+2	9.783E+1	8.805E+2	0	(~ 0)
Sulfates	Bronchodilator use, children asthmatics [Roemer 1993]	1.894E+0	7.575E+1	2.525E+1	2.273E+2	0	(~ 0)
Sulfates	Lower respiratory symptoms, children asthmatics [Roemer 1993]	2.511E+0	2.009E+1	6.697E+0	6.027E+1	0	(~ 0)
Nitrates	Mortality YOLL [Pope 2002]	2.115E+0	1.058E+5	3.527E+4	3.174E+5	0	(~ 0)
Nitrates	Chronic Bronchitis [Abbey 1995]	2.126E-1	3.599E+4	1.200E+4	1.080E+5	0	(~ 0)
Nitrates	net Restricted activity days [Ostro 1987]	1.073E+2	1.180E+4	3.933E+3	3.540E+4	0	(~ 0)
Nitrates	Respiratory hospitalization [Dab 1996]	1.123E-2	4.850E+1	1.617E+1	1.455E+2	0	(~ 0)
Nitrates	Cerebrovascular hospitalization [Wordley 1997]	2.734E-2	4.573E+2	1.524E+2	1.372E+3	0	(~ 0)
Nitrates	Chronic cough, children [Dockery 1989]	2.245E+0	5.389E+2	1.800E+2	1.617E+3	0	(~ 0)
Nitrates	Congestive heart failure, elderly [Schwartz/Morris 1995]	1.410E-2	4.597E+1	1.532E+1	1.379E+2	0	(~ 0)

Nitrates	Cough, adult asthmatics [Dusseldorp 1995]	5.087E+1	2.289E+3	7.630E+2	6.867E+3	0	(~ 0)
Nitrates	Bronchodilator use, adult asthmatics [Dusseldorp 1995]	2.473E+1	9.893E+2	3.298E+2	2.968E+3	0	(~ 0)
Nitrates	Lower respiratory symptoms, adult asthmatics [Dusseldorp 1995]	9.198E+0	7.359E+1	2.453E+1	2.208E+2	0	(~ 0)
Nitrates	Cough, children asthmatics [Pope/Dockery 1992]	1.013E+1	4.559E+2	1.520E+2	1.380E+3	0	(~ 0)
Nitrates	Bronchodilator use, children asthmatics [Roemer 1993]	2.940E+0	1.176E+2	3.920E+1	3.528E+2	0	(~ 0)
Nitrates	Lower respiratory symptoms, children asthmatics [Roemer 1993]	3.905E+0	3.124E+1	1.041E+1	9.372E+1	0	(~ 0)
SO2	Mortality YOLL [Anderson/Toulomi 1996]	3.211E-1	2.409E+4	6.023E+3	9.636E+4	3	88.0
SO2	Respiratory hospitalization [Ponce de Leon 1996]	1.443E-1	6.235E+2	2.078E+2	1.871E+3	3	88.0
PM2.5	Mortality YOLL [Pope 2002]	4.611E+0	2.305E+5	7.683E+4	6.915E+5	3	87.4
PM2.5	Chronic Bronchitis [Abbey 1995]	4.639E-1	7.854E+4	2.618E+4	2.356E+5	3	87.4
PM2.5	net Restricted activity days [Ostro 1987]	2.344E+2	2.579E+4	8.597E+3	7.737E+4	3	87.4
PM2.5	Respiratory hospitalization [Dab 1996]	2.451E-2	1.059E+2	3.530E+1	3.177E+2	3	87.4
PM2.5	Cerebrovascular hospitalization [Wordley 1997]	4.547E-2	7.607E+2	2.536E+2	2.282E+3	3	87.4
PM2.5	Chronic cough, children [Dockery 1989]	4.894E+0	1.175E+3	3.917E+2	3.525E+3	3	87.4
PM2.5	Congestive heart failure, elderly [Schwartz/Morris 1995]	3.067E-2	9.997E+1	3.332E+1	2.999E+2	3	87.4
PM2.5	Cough, adult asthmatics [Dusseldorp 1995]	1.111E+2	4.997E+3	1.666E+3	1.499E+4	3	87.4
PM2.5	Bronchodilator use, adult asthmatics [Dusseldorp 1995]	5.397E+1	2.159E+3	7.197E+2	6.477E+3	3	87.4
PM2.5	Lower respiratory symptoms, adult asthmatics [Dusseldorp 1995]	2.011E+1	1.609E+2	5.363E+1	4.827E+2	3	87.4
PM2.5	Cough, children asthmatics [Pope/Dockery 1992]	2.210E+1	9.944E+2	3.315E+2	2.983E+3	3	87.4
PM2.5	Bronchodilator use, children asthmatics [Roemer 1993]	6.424E+0	2.569E+2	8.563E+1	7.707E+2	3	87.4
PM2.5	Lower respiratory symptoms, children asthmatics [Roemer 1993]	8.513E+0	6.810E+1	2.270E+1	2.043E+2	3	87.4

8.4 Sample of the results per pollutant (Mortality)

8.4.1 PM_{2.5} - Mortality YOLL [Pope 2002]

--- Health Impact ---

Pollutant: PM_{2.5}

Emission: 2.91 tons/yr

Depletion velocity: 0.77 cm/s

Endpoint: PM_{2.5} - Mortality YOLL [Pope 2002]

ERF slope: 6.5100E-04 cases/(yr.person.ug/m³)

Impact type: Long-term mortality

Unit cost: 50000 €/case

--- Results ---

Impact: 4.611E+0 cases per year, of which the Local and Regional contributions are, respectively: 4.031E+00 and 5.799E-01 cases per year. The local impact is 87.4% of the Total.

Damage cost: 2.305E+5 € per year

(68% confidence interval = 7.683E+4, 6.915E+5)

--- Estimation Code ---

Based on available input data, impacts and damages were calculated using the 'BEST Algorithm' in QUERI.

--- Data use ---

Of the available case study input data, these parameters were utilized: stack Height and Diameter; flue gas exhaust Temperature and Velocity; Site index; pollutant Emissions inventory and Depletion Velocities; Regional population density; detailed Local population statistics (5 by 5 km resolution); and detailed Meteorological parameters (hourly data).

--- Sensitivity analysis ---

Local concentrations were estimated using a Gaussian dispersion algorithm for urban conditions. Consequently, changing the Site index between 1 and 3 will not affect the results.

Whereas varying any of the other input parameters will have an influence on the impact/damage estimates.

8.4.2 PM₁₀ - Mortality YOLL [Pope 2002]]

--- Health Impact ---

Pollutant: PM10

Emission: 3.08 tons/yr

Depletion velocity: 0.77 cm/s

Endpoint: PM10 - Mortality YOLL [Pope 2002]

ERF slope: 3.9000E-04 cases/(yr.person.ug/m3)

Impact type: Long-term mortality

Unit cost: 50000 €/case

--- Results ---

Impact: 2.923E+0 cases per year, of which the Local and Regional contributions are, respectively: 2.556E+00 and 3.677E-01 cases per year. The local impact is 87.4% of the Total.

Damage cost: 1.462E+5 € per year

(68% confidence interval = 4.873E+4, 4.386E+5)

--- Estimation Code ---

Based on available input data, impacts and damages were calculated using the 'BEST Algorithm' in QUERI.

--- Data use ---

Of the available case study input data, these parameters were utilized: stack Height and Diameter; flue gas exhaust Temperature and Velocity; Site index; pollutant Emissions inventory and Depletion Velocities; Regional population density; detailed Local population statistics (5 by 5 km resolution); and detailed Meteorological parameters (hourly data).

--- Sensitivity analysis ---

Local concentrations were estimated using a Gaussian dispersion algorithm for urban conditions. Consequently, changing the Site index between 1 and 3 will not affect the results.

Whereas varying any of the other input parameters will have an influence on the impact/damage estimates.

8.4.3 Sulfates - Mortality YOLL [Pope 2002]

--- Health Impact ---

Pollutant: Sulfates

Emission of precursor pollutant (SO₂): 24.88 tons/yr

Depletion velocity: 1.86 cm/s

Endpoint: Sulfates - Mortality YOLL [Pope 2002]

ERF slope: 3.9000E-04 cases/(yr.person.ug/m³)

Impact type: Long-term mortality

Unit cost: 50000 €/case

--- Results ---

Impact: 1.360E+0 cases per year, of which the Local and Regional contributions are, respectively: ~ 0 and ~ 1.360E+00 cases per year.

Damage cost: 6.801E+4 € per year

(68% confidence interval = 2.267E+4, 2.040E+5)

Impacts and damage costs were calculated using the Simple Uniform World Model (SUWM). Estimates depend on the following five parameters: Pollutant emission rate and depletion velocity; Exposure-Response Function (ERF) of health endpoint in question; Regional receptor density and Monetary unit cost.

8.4.4 Nitrates - Mortality YOLL [Pope 2002]

--- Health Impact ---

Pollutant: Nitrates

Emission of precursor pollutant (NO_x): 42.76 tons/yr

Depletion velocity: 1.03 cm/s

Endpoint: Nitrates - Mortality YOLL [Pope 2002]

ERF slope: 1.9500E-04 cases/(yr.person.ug/m³)

Impact type: Long-term mortality

Unit cost: 50000 €/case

--- Results ---

Impact: 2.115E+0 cases per year, of which the Local and Regional contributions are, respectively: ~ 0 and ~ 2.115E+00 cases per year.

Damage cost: 1.058E+5 € per year

(68% confidence interval = 3.527E+4, 3.174E+5)

Impacts and damage costs were calculated using the Simple Uniform World Model (SUWM). Estimates depend on the following five parameters: Pollutant emission rate and depletion velocity; Exposure-Response Function (ERF) of health endpoint in question; Regional receptor density and Monetary unit cost.

8.4.5 SO₂ - Mortality YOLL [Anderson/Toulomi 1996]

--- Health Impact ---

Pollutant: SO₂

Emission: 24.88 tons/yr

Depletion velocity: 0.81 cm/s

Endpoint: SO₂ - Mortality YOLL [Anderson/Toulomi 1996]

ERF slope: 5.3400E-06 cases/(yr.person.ug/m³)

Impact type: Short-term mortality

Unit cost: 75000 €/case

--- Results ---

Impact: 3.211E-1 cases per year, of which the Local and Regional contributions are, respectively: 2.827E-01 and 3.846E-02 cases per year. The local impact is 88.0% of the Total.

Damage cost: 2.409E+4 € per year

(68% confidence interval = 6.023E+3, 9.636E+4)

--- Estimation Code ---

Based on available input data, impacts and damages were calculated using the 'BEST Algorithm' in QUERI.

--- Data use ---

Of the available case study input data, these parameters were utilized: stack Height and Diameter; flue gas exhaust Temperature and Velocity; Site index; pollutant Emissions inventory and Depletion Velocities; Regional population density; detailed Local population statistics (5 by 5 km resolution); and detailed Meteorological parameters (hourly data).

--- Sensitivity analysis ---

Local concentrations were estimated using a Gaussian dispersion algorithm for urban conditions. Consequently, changing the Site index between 1 and 3 will not affect the results.

Whereas varying any of the other input parameters will have an influence on the impact/damage estimates.

8.5 Damage costs per pollutant and damage costs per kg of pollutant

Figure 58 and Figure 59 show the graph of damage costs per pollutant and the graph of damage costs per kg of pollutant respectively. The Other Pollutant refers to $PM_{2.5}$ and Particles refer to PM_{10} .

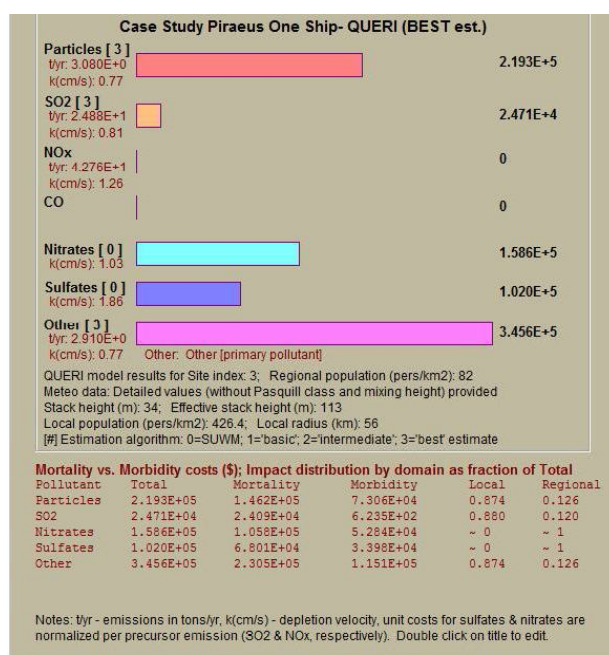


Figure 58: Graph of damage costs per pollutant

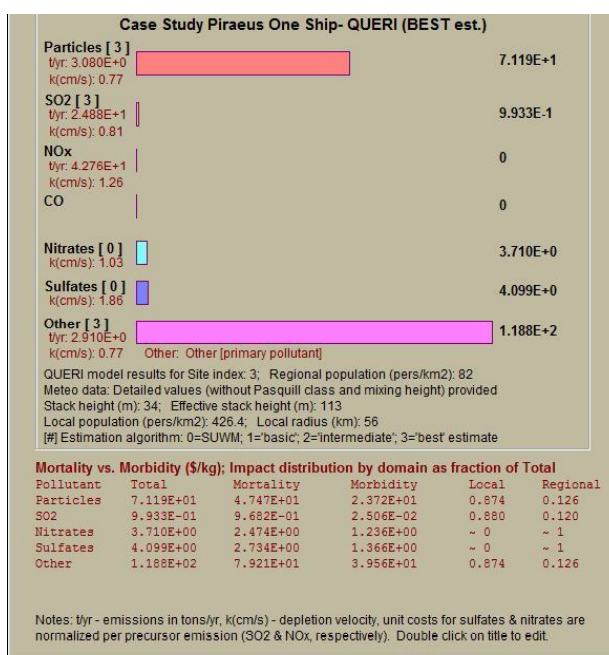


Figure 59: Graph of damage costs per kg of pollutant

8.6 Local Concentration Profiles

The local concentration profiles in the 400 cells into which the local domain is subdivided are shown in Figures 60-63:

8.6.1 PM₁₀ Concentration Profile

Emission rate (tons/yr): 3.08

Peak concentration (µg/m³): 1.380E-02 at (X,Y) = (-2.5, 2.5)

Coordinates X and Y are measured in km along the horizontal and vertical directions, with source at (0,0); concentrations are expressed in µg/m³

	-47.5	-42.5	-37.5	-32.5	-27.5	-22.5	-17.5	-12.5	-7.5	-2.5	2.5	7.5	12.5	17.5	22.5	27.5	32.5	37.5	42.5	47.5
47.5	0.00034	0.00032	0.00029	0.00025	0.00019	0.00012	7.2E-05	8.4E-05	9.5E-05	0.00011	0.00011	0.00012	0.00013	0.00013	0.00013	0.00012	0.00011	0.0001	9.7E-05	8.9E-05
42.5	0.00033	0.00039	0.00037	0.00032	0.00026	0.00018	7.8E-05	9.2E-05	0.00011	0.00012	0.00013	0.00014	0.00015	0.00015	0.00014	0.00013	0.00012	0.00011	0.0001	0.0001
37.5	0.00032	0.00038	0.00046	0.00042	0.00038	0.00027	0.00015	0.0001	0.00012	0.00014	0.00015	0.00017	0.00018	0.00017	0.00016	0.00015	0.00013	0.00012	0.00012	0.00012
32.5	0.00029	0.00036	0.00044	0.00055	0.0005	0.00041	0.00027	0.00011	0.00014	0.00016	0.00019	0.0002	0.00021	0.0002	0.00018	0.00016	0.00014	0.00015	0.00015	0.00014
27.5	0.00025	0.00032	0.00041	0.00052	0.00068	0.0006	0.00045	0.0002	0.00016	0.0002	0.00023	0.00025	0.00026	0.00023	0.0002	0.00018	0.00018	0.00018	0.00018	0.00017
22.5	0.0002	0.00027	0.00035	0.00047	0.00064	0.00088	0.00074	0.00045	0.00019	0.00025	0.0003	0.00033	0.00031	0.00027	0.00023	0.00024	0.00023	0.00022	0.00021	0.00019
17.5	0.00016	0.0002	0.00027	0.00039	0.00055	0.00081	0.00121	0.00093	0.00028	0.00033	0.00042	0.00046	0.00039	0.00032	0.00033	0.00031	0.00029	0.00027	0.00024	0.00021
12.5	0.00014	0.00017	0.00022	0.00027	0.0004	0.00064	0.00107	0.00186	0.0011	0.00047	0.00086	0.00064	0.00049	0.0005	0.00046	0.00041	0.00034	0.00028	0.00023	0.0002
7.5	0.00012	0.00014	0.00018	0.00023	0.0003	0.00043	0.00068	0.00148	0.00358	0.00077	0.00131	0.00064	0.00062	0.00076	0.00064	0.00041	0.00032	0.00026	0.00022	0.00018
2.5	8.9E-05	0.00011	0.00013	0.00016	0.00021	0.0003	0.00045	0.00079	0.00186	0.0138	0.00362	0.00228	0.0011	0.00068	0.00047	0.00036	0.00028	0.00023	0.00019	0.00017
-2.5	7.1E-05	8.2E-05	9.7E-05	0.00012	0.00015	0.00019	0.00026	0.00038	0.00061	0.00204	0.00736	0.00322	0.0014	0.00082	0.00055	0.0004	0.00031	0.00025	0.00021	0.00018
-7.5	6.5E-05	7.4E-05	8.5E-05	0.0001	0.00012	0.00014	0.00018	0.00029	0.00053	0.00444	0.00149	0.00187	0.00146	0.00111	0.00075	0.00054	0.00041	0.00033	0.00027	0.00022
-12.5	5.8E-05	6.5E-05	7.3E-05	8.2E-05	1E-04	0.00013	0.00019	0.00028	0.00116	0.00317	0.00218	0.00047	0.00095	0.00083	0.0007	0.00059	0.00048	0.00038	0.00031	0.00026
-17.5	5.1E-05	5.8E-05	6.7E-05	8.3E-05	0.0001	0.00014	0.00018	0.00055	0.00114	0.00228	0.00181	2.7E-05	0.00043	0.00061	0.00055	0.00049	0.00044	0.00039	0.00034	0.00029
-22.5	5E-05	5.9E-05	7E-05	8.5E-05	0.0001	0.00013	0.00032	0.00061	0.00107	0.00173	0.00146	0.00035	0.00017	0.00034	0.00043	0.0004	0.00037	0.00034	0.00031	0.00028
-27.5	5.2E-05	6E-05	7.1E-05	8.4E-05	0.0001	0.00022	0.00038	0.0006	0.00096	0.00137	0.0012	0.00049	4.1E-05	0.00019	0.00028	0.00033	0.00031	0.00029	0.00027	0.00025
-32.5	5.3E-05	6.1E-05	7E-05	8.2E-05	0.00016	0.00026	0.0004	0.00058	0.00084	0.00112	0.00101	0.00052	7.6E-05	9.3E-05	0.00018	0.00023	0.00027	0.00025	0.00024	0.00023
-37.5	5.3E-05	6E-05	6.9E-05	0.00012	0.00019	0.00028	0.00039	0.00055	0.00075	0.00094	0.00086	0.00051	0.00018	3.5E-05	0.00011	0.00016	0.0002	0.00022	0.00021	0.0002
-42.5	5.2E-05	5.9E-05	1E-04	0.00015	0.00021	0.00029	0.00038	0.00052	0.0006	0.00081	0.00075	0.00048	0.00023	4.3E-05	0.1E-05	0.00011	0.00014	0.00017	0.00019	0.00018
-47.5	5.1E-05	8.3E-05	0.00012	0.00017	0.00022	0.00029	0.00037	0.00048	0.00059	0.00071	0.00066	0.00045	0.00025	7.2E-05	2.9E-05	7.1E-05	0.0001	0.00013	0.00015	0.00016

Figure 60: PM₁₀ concentration profile

8.6.2 SO₂ Concentration Profile

Emission rate (tons/yr): 24.88

Peak concentration (µg/m³): 1.115E-01 at (X,Y) = (-2.5, 2.5)

Coordinates X and Y are measured in km along the horizontal and vertical directions, with source at (0,0); concentrations are expressed in µg/m³

	-47.5	-42.5	-37.5	-32.5	-27.5	-22.5	-17.5	-12.5	-7.5	-2.5	2.5	7.5	12.5	17.5	22.5	27.5	32.5	37.5	42.5	47.5
47.5	0.00276	0.00259	0.00235	0.002	0.00154	0.00095	0.00058	0.00067	0.00076	0.00085	0.00093	0.001	0.00104	0.00107	0.00104	0.00098	0.00091	0.00084	0.00078	0.00072
42.5	0.00268	0.00317	0.00295	0.00261	0.00213	0.00147	0.00063	0.00074	0.00086	0.00097	0.00107	0.00115	0.00121	0.00124	0.00116	0.00107	0.00099	0.00091	0.00083	0.00085
37.5	0.00254	0.00307	0.00371	0.00341	0.00292	0.00221	0.00121	0.00082	0.00097	0.00112	0.00125	0.00136	0.00142	0.0014	0.00129	0.00118	0.00107	0.00097	0.00099	0.00099
32.5	0.00234	0.00288	0.00357	0.00444	0.00401	0.00327	0.00214	0.00091	0.00112	0.00132	0.0015	0.00164	0.00172	0.00161	0.00145	0.0013	0.00116	0.00119	0.00119	0.00116
27.5	0.00204	0.00259	0.0033	0.00424	0.00548	0.00482	0.0036	0.00164	0.00131	0.00159	0.00186	0.00205	0.00208	0.00186	0.00164	0.00144	0.00148	0.00146	0.00142	0.00136
22.5	0.00164	0.00216	0.00286	0.00382	0.00517	0.00707	0.00594	0.00365	0.00156	0.002	0.00242	0.00269	0.00252	0.00218	0.00185	0.00191	0.00187	0.00178	0.00168	0.00157
17.5	0.00131	0.00159	0.00222	0.00312	0.00447	0.00654	0.00975	0.00748	0.00228	0.00266	0.00338	0.00371	0.00313	0.00256	0.00263	0.00252	0.00234	0.00215	0.00196	0.00168
12.5	0.00116	0.0014	0.00174	0.00222	0.00322	0.00519	0.00867	0.01501	0.00897	0.00381	0.00532	0.00517	0.00394	0.00403	0.00369	0.00328	0.00276	0.00225	0.00188	0.0016
7.5	0.00096	0.00116	0.00143	0.00184	0.00245	0.00347	0.00548	0.01196	0.02888	0.0062	0.0106	0.00758	0.00744	0.00614	0.0044	0.00329	0.00258	0.0021	0.00175	0.00149
2.5	0.00072	0.00086	0.00104	0.00131	0.00172	0.00238	0.00362	0.00637	0.01501	0.1115	0.0292	0.01843	0.00889	0.00547	0.00381	0.00287	0.00227	0.00186	0.00156	0.00134
-2.5	0.00057	0.00066	0.00078	0.00095	0.00118	0.00153	0.00208	0.00306	0.00489	0.01649	0.05947	0.026	0.01134	0.0066	0.00444	0.00326	0.00253	0.00205	0.0017	0.00145
-7.5	0.00052	0.0006	0.00069	0.00081	0.00096	0.00116	0.00143	0.00233	0.00427	0.03587	0.01207	0.01511	0.01183	0.00885	0.00608	0.00437	0.00332	0.00263	0.00215	0.0018
-12.5	0.00047	0.00052	0.00059	0.00068	0.0008	0.00108	0.00152	0.00223	0.00398	0.0256	0.01763	0.00377	0.00767	0.00688	0.00565	0.00477	0.00389	0.00308	0.00251	0.00209
-17.5	0.00041	0.00045	0.00054	0.00067	0.00085	0.0011	0.00145	0.00441	0.00917	0.01839	0.01462	0.00222	0.00343	0.00489	0.00446	0.00397	0.00352	0.00312	0.00277	0.00232
-22.5	0.0004	0.00047	0.00057	0.00069	0.00084	0.00105	0.00262	0.00493	0.00864	0.01395	0.01181	0.00284	0.00137	0.00277	0.00349	0.00326	0.00299	0.00273	0.00249	0.00227
-27.5	0.00042	0.00049	0.00057	0.00068	0.00082	0.00177	0.00309	0.00484	0.00773	0.01106	0.00969	0.00393	0.00033	0.00151	0.00225	0.00267	0.00253	0.00237	0.0022	0.00204
-32.5	0.00043	0.00049	0.00057	0.00066	0.00129	0.00213	0.00321	0.00466	0.00682	0.00906	0.00813	0.00417	0.00061	0.00075	0.00143	0.00187	0.00214	0.00205	0.00194	0.00183
-37.5	0.00043	0.00048	0.00055	0.001	0.00157	0.00229	0.00317	0.00445	0.00603	0.00762	0.00694	0.00409	0.00144	0.00028	0.00087	0.00129	0.00158	0.00177	0.00171	0.00163
-42.5	0.00042	0.00047	0.00081	0.00122	0.00172	0.00234	0.00306	0.00417	0.00535	0.00654	0.00603	0.00388	0.00185	3.5E-05	0.00049	0.00088	0.00116	0.00137	0.0015	0.00146
-47.5	0.00041	0.00067	0.00098	0.00135	0.0018	0.00231	0.003	0.00388	0.00479	0.0057	0.0053	0.00364	0.00204	0.00058	0.00023	0.00058	0.00084	0.00105	0.0012	0.0013

Figure 61: SO₂ concentration profile

8.6.3 NO_x Concentration Profile

Emission rate (tons/yr): 42.76

Peak concentration ($\mu\text{g}/\text{m}^3$): 1.916E-01 at (X,Y) = (-2.5, 2.5)

Coordinates X and Y are measured in km along the horizontal and vertical directions, with source at (0,0); concentrations are expressed in $\mu\text{g}/\text{m}^3$

	-47.5	-42.5	-37.5	-32.5	-27.5	-22.5	-17.5	-12.5	-7.5	-2.5	2.5	7.5	12.5	17.5	22.5	27.5	32.5	37.5	42.5	47.5
47.5	0.00475	0.00446	0.00403	0.00344	0.00265	0.00163	0.001	0.00116	0.00131	0.00146	0.0016	0.00171	0.00179	0.00184	0.00179	0.00168	0.00156	0.00145	0.00134	0.00124
42.5	0.00461	0.00545	0.00507	0.00449	0.00366	0.00252	0.00108	0.00128	0.00147	0.00166	0.00183	0.00198	0.00208	0.00212	0.00199	0.00184	0.0017	0.00156	0.00143	0.00146
37.5	0.00437	0.00527	0.00638	0.00586	0.00503	0.0038	0.00208	0.00141	0.00167	0.00192	0.00215	0.00234	0.00245	0.00241	0.00222	0.00203	0.00184	0.00167	0.00171	0.00171
32.5	0.00402	0.00495	0.00613	0.00763	0.00689	0.00562	0.00368	0.00157	0.00193	0.00226	0.00258	0.00282	0.00295	0.00276	0.00249	0.00224	0.002	0.00205	0.00204	0.002
27.5	0.00351	0.00444	0.00567	0.00728	0.00942	0.00828	0.00619	0.00281	0.00225	0.00274	0.0032	0.00353	0.00357	0.0032	0.00282	0.00247	0.00254	0.00251	0.00243	0.00233
22.5	0.00283	0.00371	0.00491	0.00657	0.00889	0.01216	0.01021	0.00528	0.00268	0.00344	0.00416	0.00462	0.00433	0.00374	0.00319	0.00328	0.00321	0.00306	0.00288	0.0027
17.5	0.00226	0.00273	0.00379	0.00535	0.00769	0.01124	0.01676	0.01286	0.00392	0.00456	0.0058	0.00638	0.00538	0.00439	0.00453	0.00433	0.00403	0.0037	0.00337	0.00289
12.5	0.00198	0.00241	0.00299	0.00382	0.00553	0.00893	0.01489	0.0258	0.01542	0.00655	0.00913	0.00888	0.00677	0.00692	0.00634	0.00563	0.00475	0.00387	0.00324	0.00276
7.5	0.00164	0.00199	0.00246	0.00315	0.00421	0.00596	0.00942	0.02056	0.04964	0.01065	0.01822	0.01303	0.01279	0.01056	0.00756	0.00566	0.00444	0.0036	0.00301	0.00256
2.5	0.00124	0.00147	0.00179	0.00225	0.00295	0.0041	0.00622	0.01095	0.02579	0.1916	0.05018	0.03167	0.01527	0.00939	0.00655	0.00493	0.0039	0.0032	0.00269	0.00231
-2.5	0.00098	0.00114	0.00135	0.00163	0.00203	0.00262	0.00358	0.00526	0.00841	0.02833	0.1022	0.04468	0.01949	0.01134	0.00763	0.0056	0.00435	0.00352	0.00293	0.00249
-7.5	0.0009	0.00103	0.00119	0.00139	0.00165	0.00199	0.00246	0.004	0.00734	0.06166	0.02074	0.02597	0.02033	0.01539	0.01046	0.00751	0.00571	0.00452	0.0037	0.0031
-12.5	0.00081	0.0009	0.00101	0.00114	0.00138	0.00186	0.00261	0.00382	0.01613	0.04401	0.0303	0.00648	0.01318	0.01148	0.0097	0.0082	0.00668	0.00529	0.00431	0.0036
-17.5	0.00071	0.00077	0.00093	0.00115	0.00146	0.00188	0.00249	0.00758	0.01576	0.03161	0.02513	0.00038	0.0059	0.0084	0.00766	0.00682	0.00604	0.00536	0.00477	0.00399
-22.5	0.00069	0.00082	0.00097	0.00118	0.00145	0.00181	0.0045	0.00847	0.01485	0.02397	0.02029	0.00487	0.00235	0.00476	0.006	0.00561	0.00514	0.00469	0.00427	0.0039
-27.5	0.00072	0.00084	0.00099	0.00117	0.0014	0.00304	0.0053	0.00832	0.01328	0.019	0.01666	0.00676	0.00057	0.0026	0.00387	0.00459	0.00435	0.00407	0.00378	0.00351
-32.5	0.00073	0.00084	0.00098	0.00114	0.00222	0.00366	0.00552	0.00801	0.01172	0.01557	0.01397	0.00717	0.00106	0.00129	0.00245	0.00321	0.00368	0.00352	0.00333	0.00314
-37.5	0.00073	0.00083	0.00095	0.00172	0.0027	0.00394	0.00545	0.00765	0.01035	0.01309	0.01193	0.00702	0.00247	0.00048	0.00149	0.00222	0.00272	0.00305	0.00293	0.0028
-42.5	0.00072	0.00081	0.00138	0.00209	0.00296	0.00401	0.00525	0.00717	0.0092	0.01123	0.01036	0.00667	0.00318	6E-05	0.00084	0.00151	0.002	0.00235	0.00258	0.0025
-47.5	0.00071	0.00115	0.00168	0.00232	0.00308	0.00397	0.00515	0.00687	0.00824	0.00979	0.00911	0.00626	0.00351	0.001	0.0004	0.00099	0.00145	0.0018	0.00205	0.00223

Figure 62: NO_x concentration profile

8.6.4 PM_{2.5} Concentration Profile

Emission rate (tons/yr): 2.91

Peak concentration ($\mu\text{g}/\text{m}^3$): 1.304E-02 at (X,Y) = (-2.5, 2.5)

Coordinates X and Y are measured in km along the horizontal and vertical directions, with source at (0,0); concentrations are expressed in $\mu\text{g}/\text{m}^3$

	-47.5	-42.5	-37.5	-32.5	-27.5	-22.5	-17.5	-12.5	-7.5	-2.5	2.5	7.5	12.5	17.5	22.5	27.5	32.5	37.5	42.5	47.5
47.5	0.00032	0.0003	0.00027	0.00023	0.00018	0.00011	6.8E-05	7.9E-05	8.9E-05	9.9E-05	0.00011	0.00012	0.00012	0.00013	0.00012	0.00011	0.00011	9.9E-05	9.1E-05	8.4E-05
42.5	0.00031	0.00037	0.00035	0.00031	0.00025	0.00017	7.4E-05	8.7E-05	0.0001	0.00011	0.00012	0.00013	0.00014	0.00014	0.00014	0.00013	0.00012	0.00011	9.7E-05	9.9E-05
37.5	0.0003	0.00038	0.00043	0.0004	0.00034	0.00026	0.00014	9.6E-05	0.00011	0.00013	0.00015	0.00016	0.00017	0.00016	0.00015	0.00014	0.00013	0.00011	0.00012	0.00012
32.5	0.00027	0.00034	0.00042	0.00052	0.00047	0.00038	0.00025	0.00011	0.00013	0.00015	0.00018	0.00019	0.0002	0.00019	0.00017	0.00015	0.00014	0.00014	0.00014	0.00014
27.5	0.00024	0.0003	0.00039	0.0005	0.00064	0.00056	0.00042	0.00019	0.00015	0.00019	0.00022	0.00024	0.00024	0.00022	0.00019	0.00017	0.00017	0.00017	0.00017	0.00016
22.5	0.00019	0.00025	0.00033	0.00045	0.00061	0.00083	0.00069	0.00043	0.00018	0.00023	0.00028	0.00031	0.00029	0.00025	0.00022	0.00022	0.00022	0.00021	0.0002	0.00018
17.5	0.00015	0.00019	0.00026	0.00036	0.00052	0.00077	0.00114	0.00088	0.00027	0.00031	0.00039	0.00043	0.00037	0.0003	0.00031	0.00029	0.00027	0.00025	0.00023	0.0002
12.5	0.00014	0.00016	0.0002	0.00026	0.00038	0.00061	0.00101	0.00176	0.00105	0.00045	0.00062	0.0006	0.00046	0.00047	0.00043	0.00038	0.00032	0.00026	0.00022	0.00019
7.5	0.00011	0.00014	0.00017	0.00021	0.00029	0.00041	0.00064	0.0014	0.00038	0.00077	0.00124	0.00069	0.00087	0.00072	0.00061	0.00048	0.0003	0.00026	0.0002	0.00017
2.5	8.4E-05	0.0001	0.00012	0.00015	0.0002	0.00028	0.00042	0.00075	0.00176	0.01304	0.00342	0.00216	0.00104	0.00064	0.00045	0.00034	0.00027	0.00022	0.00018	0.00016
-2.5	6.7E-05	7.8E-05	9.2E-05	0.00011	0.00014	0.00018	0.00024	0.00036	0.00057	0.00193	0.00696	0.00304	0.00133	0.00077	0.00052	0.00038	0.0003	0.00024	0.0002	0.00017
-7.5	6.1E-05	7E-05	8.1E-05	9.5E-05	0.00011	0.00014	0.00017	0.00027	0.0005	0.0042	0.00141	0.00177	0.00138	0.00105	0.00071	0.00051	0.00039	0.00031	0.00025	0.00021
-12.5	5.5E-05	6.1E-05	6.9E-05	7.7E-05	9.4E-05	0.00013	0.00018	0.00026	0.0011	0.003	0.00206	0.00044	0.0009	0.00078	0.00066	0.00056	0.00045	0.00036	0.00029	0.00024
-17.5	4.8E-05	5.3E-05	6.3E-05	7.8E-05	9.9E-05	0.00013	0.00017	0.00052	0.00107	0.00215	0.00171	2.6E-05	0.0004	0.00057	0.00052	0.00046	0.00041	0.00037	0.00032	0.00027
-22.5	4.7E-05	5.6E-05	6.6E-05	8E-05	9.9E-05	0.00012	0.00031	0.00058	0.00101	0.00163	0.00138	0.00033	0.00016	0.00032	0.00041	0.00038	0.00035	0.00032	0.00029	0.00027
-27.5	4.9E-05	5.7E-05	6.7E-05	8E-05	9.6E-05	0.00021	0.00036	0.00057	0.0009	0.00129	0.00113	0.00046	3.9E-05	0.00018	0.00026	0.00031	0.0003	0.00028	0.00026	0.00024
-32.5	5E-05	5.7E-05	6.6E-05	7.7E-05	0.00015	0.00025	0.00038	0.00054	0.0008	0.00106	0.00095	0.00049	7.2E-05	8.8E-05	0.00017	0.00022	0.00025	0.00024	0.00023	0.00021
-37.5	5E-05	5.7E-05	6.5E-05	0.00012	0.00018	0.00027	0.00037	0.00052	0.0007	0.00089	0.00081	0.00048	0.00017	3.3E-05	0.0001	0.00015	0.00019	0.00021	0.0002	0.00019
-42.5	4.9E-05	5.5E-05	6.4E-05	0.00014	0.0002	0.00027	0.00036	0.00049	0.00063	0.00076	0.0007	0.00045	0.00022	4.1E-05	5.7E-05	0.0001	0.00014	0.00016	0.00018	0.00017
-47.5	4.8E-05	7.8E-05	0.00011	0.00016	0.00021	0.00027	0.00035	0.00045	0.00056	0.00067	0.00062	0.00043	0.00024	6.8E-05	2.7E-05	6.7E-05	9.9E-05	0.00012	0.00014	0.00015

Figure 63: PM_{2.5} concentration profile

Chapter 9: Analysis of case study 2 results

9.1 Overall external cost

The external cost in health caused by all the pollutants under examination was estimated by RiskPoll to be 849670 €₂₀₀₀ for the year 2013-2014. The main case study gave us 26 million €₂₀₀₀ of external cost in health for 183 ships (124 cruise ships and 54 coastal passenger ships) but that doesn't mean that one ship's external cost will be 183/26 because every ship has different port times (especially cruise ships), different emissions as well as different features (stack height, diameter, etc).

9.2 External cost of primary and secondary pollutants

Figure 64 shows the yearly external costs of each pollutant (primary and secondary).

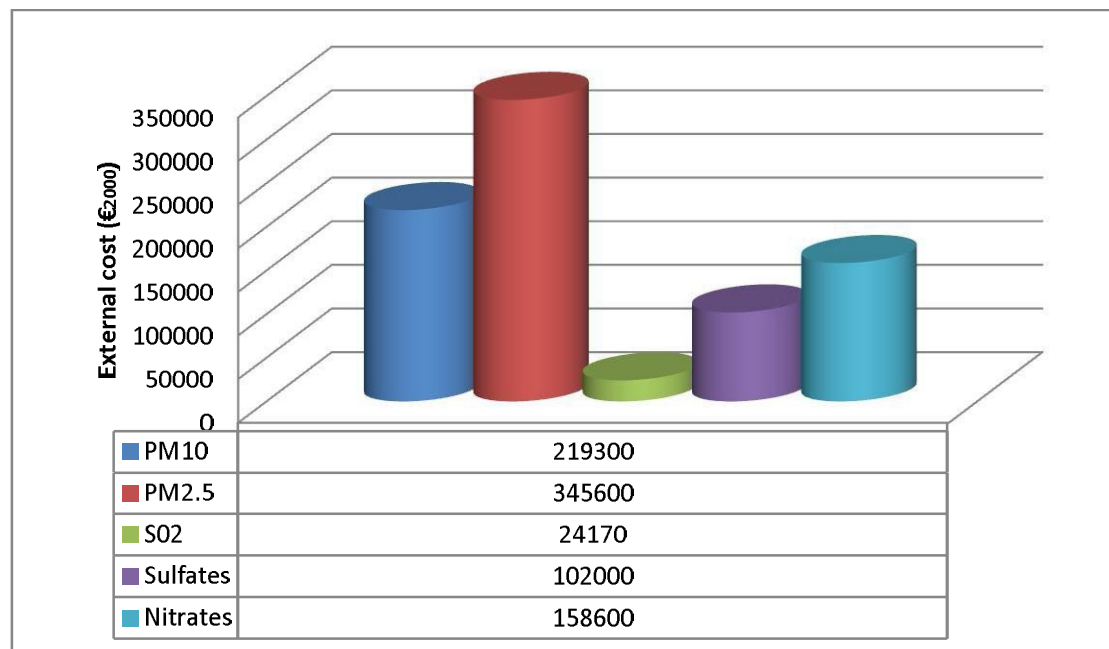


Figure 64: External cost in health of each pollutant for the year 2013-2014

Comments

According to the results, $PM_{2.5}$ causes the biggest external cost with PM_{10} coming second followed by the nitrates, the sulfates and SO_2 . It is interesting to notice that even though NO_x have zero external cost its secondary pollutant, the nitrates, have the third highest one. Furthermore, particles (PM_{10} and $PM_{2.5}$) are by far the main source of external costs reaching a total of 570 thousand €₂₀₀₀ per year. Also, SO_2 as a primary pollutant has low external cost (24 thousand €₂₀₀₀ per year) but as a secondary pollutant in the form of sulfates gives 102 thousand €₂₀₀₀ of external cost.

Figure 65 gives a more clear view of the contribution of each pollutant in the overall external cost.

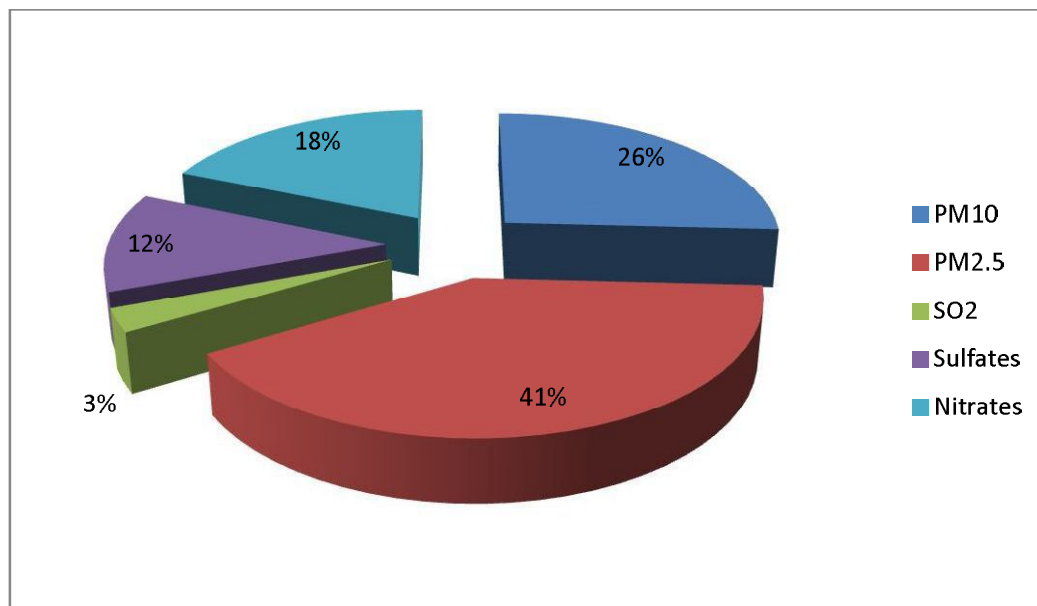


Figure 65: Presence of each pollutant's contribution in the overall external cost

Comments

Taking into account all the pollutants (primary and secondary), particles contribute for more than 70% of the damage costs followed by the nitrates, sulfates and SO_2 . So, it is clear that as far as human health impacts regards, particles are the main source of the damage costs.

9.3 Mortality vs Morbidity

The external cost from mortality by all the pollutants is 574600 €₂₀₀₀ while the external cost from morbidity is 275564 €₂₀₀₀. Therefore, the presence of mortality's and morbidity's costs in the overall external cost are 68% and 32% respectively.

The pollutant with the biggest mortality external cost as well as the biggest morbidity external cost is $PM_{2.5}$ (230500 €₂₀₀₀ and 115100 €₂₀₀₀ respectively).

9.4 Local vs Regional impact

Nitrates and sulfates have only regional impacts while PM_{10} and $PM_{2.5}$ have each of them 87% local impacts and 13% regional impacts and SO_2 has 88% local impacts and 12% regional impacts. Because particles are the main source of the overall external

cost in health and 87% of their external cost is local it is therefore important to note that people living in Athens are mainly the ones at risk.

9.5 External cost per tonne of pollutant

As it was said the yearly external cost per tonne of pollutant is the best way to understand the damage of an air pollutant

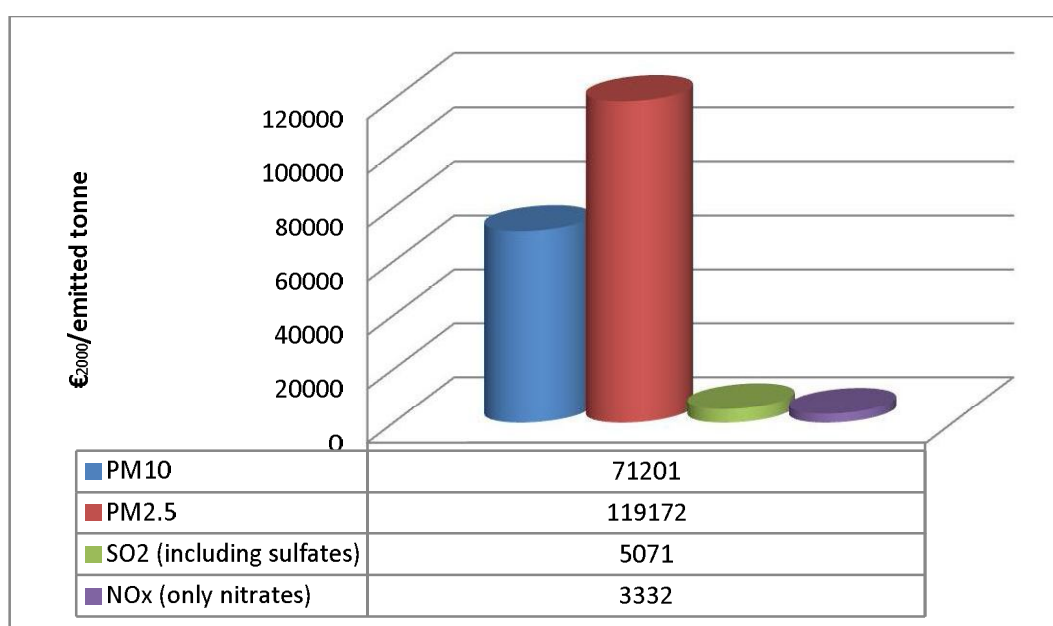


Figure 66: External cost per tonne of pollutant for the year 2013-2014

Comments

It is obvious that $PM_{2.5}$ have the biggest external cost per emitted tonne with 119172 €₂₀₀₀/tonne. PM_{10} is following with 71201 €₂₀₀₀/tonne, SO_2 with 5071 €₂₀₀₀/tonne (including the sulfates costs) and NO_x (only nitrates cost) with 3332 €₂₀₀₀/tonne.

Chapter 10: Comparison with other sectors

10.1 Comparison with the industrial sector

As it was shown in paragraph 7.6 the cost per receptor is higher in the local domain which is mainly consisting by the people living in Athens. Furthermore, in Figure 55 it is clear that particles are the main contributor in the external cost per person in Athens. It was therefore essential to give a first estimate of the magnitude of this cost compared to the external cost of particles in Athens from other sources. According to Institute for Environmental Research and Sustainable Development (IERSD) (2007) *“As for air pollutants the major contribution to the total external cost due to air pollutants comes from PM_{10} , which are responsible for half of externalities associated with industrial activity in Athens reaching 94.3 M€₂₀₀₀per year”*. Because IERSD (2007) refers only to PM_{10} , the comparison will not include $PM_{2.5}$. IERSD (2007) examines 9200 industrial units and Table 11 shows the industrial activities that were taken into account.

Table 11: The industrial activities that were taken into account (source: IERSD, 2007)

Industrial sector
Food and drinks
Textiles
Leather tanning
Wood processing
Paper and pulp
Printing
Petroleum industry
Chemical industry
Plastic products
Non-metallic minerals
Metal processing
Electroplating
Batteries
Furniture

The external cost (dominated completely by the health costs) per person living in Athens for one year caused by the industrial sector is: $94300000/3827624=24.6\text{€}_{2000}$. According to the results of Figure 55 in paragraph 7.6 the health cost per person living in Athens for one year caused by PM_{10} emitted from coastal passenger ships and cruise ships in Piraeus is 1.4€_{2000} .

So, PM_{10} 's yearly external cost in health per person living in Athens from coastal passenger ships and cruise ships is 5.7% of the ones from the industrial sector. It is a big presentence taking into account that the number of industrial units is 50 times the number of ships (9200 industrial units and only 183 ships).

10.2 Comparison with the road transport sector

Friedrich & Bickel (2001) estimated for Athens that the external cost (dominated completely by the health costs) of $PM_{2.5}$ for a petrol car EURO II is 1.32€_{2000} per 100 vkm (vehicle kilometers). The number of cars in Athens is about 1500000 (nearly all of them are petrol cars because of the ban of the diesel cars that was in force until 2011 for Athens) and it is assumed that they travel approximately 5000 vkm/year. So, $1.32*1500000*5000/100=99000000\text{€}_{2000}$. The above result is in line with the OECD (2014) which stated that "*The available literature, read with care, suggests that, in the EU24, road transport's share of the economic cost, properly calculated, is likely to be $\approx 50\%$* ". So, if the external cost from particles is mainly derived from the road transport sector and the industrial sector (which is logical because these are the two larger sectors) then each of them should have 50% share in the external cost. In this case the transport sector gives 99000000€_{2000} and from the previous paragraph the industrial sector gives 94300000€_{2000} (a 50%-50% contribution). The higher external cost of the transport sector is justified from the fact that the pollutant into consideration is $PM_{2.5}$ and not PM_{10} (as in the industrial sector). The health cost per person living in Athens for the road transport sector is $99000000/3827624=25.9\text{€}_{2000}$. According to the results of Figure 55 in paragraph 7.6 the health cost per person living in Athens for one year caused by $PM_{2.5}$ emitted from coastal passenger ships and cruise ships in Piraeus is 2.2€_{2000} . Therefore, $PM_{2.5}$'s yearly external cost in health per person living in Athens from coastal passenger ships and cruise ships is 8.5% of the ones from the road transport sector.

10.3 Comments

The yearly external cost (from health impacts) due to coastal passenger ships and cruise ships was compared to external costs of road transport and industry in the metropolitan area of Athens. The shipping sector's cost is 8.5% compared to the cost from the transport sector and 5.7% compared to the cost from the industrial sector as it is shown in Figures 67 and 68. The slight difference is attributed to the fact that in the case of the transport sector the pollutant into consideration is $PM_{2.5}$. This indicates again that the major contributors in the yearly external cost in health per people living in Athens from particles are the industrial and transport sectors with coastal passenger and cruise ships contributing only a small portion in this cost.

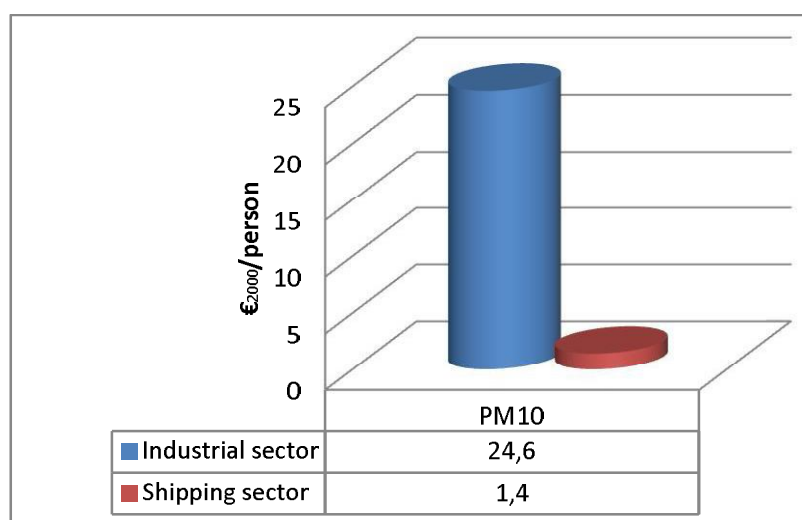


Figure 67: Comparison between the industrial and the shipping sectors costs per person in Athens

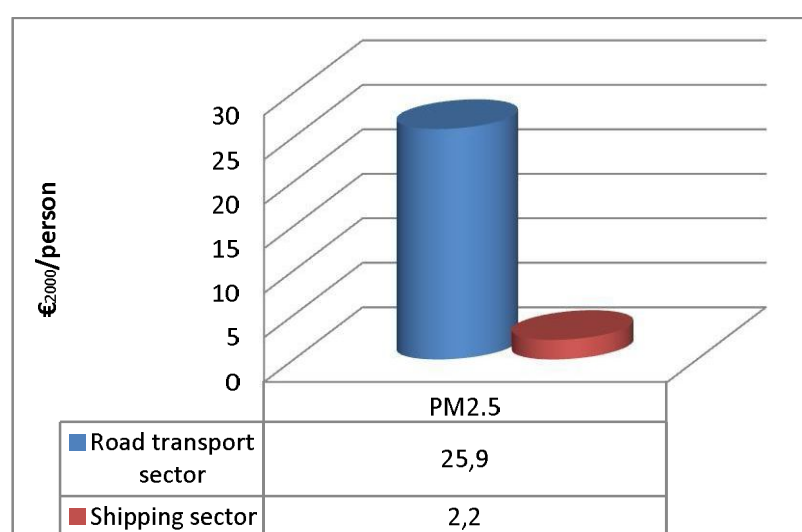


Figure 68: Comparison between the road and the shipping sectors costs per person in Athens

References of Chapter 10

Friedrich R, Bickel P (eds.) (2001) Environmental External Costs of Transport. Springer-Verlag, Berlin Heidelberg New York

Institute for Environmental Research and Sustainable Development (IERSD) (2007). “Environmental Damage Costs from Airborne Pollution of Industrial Activities in the Greater Athens, Greece, Area and the Resulting Benefit from the Introduction of BAT”. Environmental Impact Assessment Review. National Observatory of Athens, Athens, Greece.

OECD (2014), *The Cost of Air Pollution: Health Impacts of Road Transport*, OECD Publishing. <http://dx.doi.org/10.1787/9789264210448-en>

Chapter 11: Conclusion-Discussion

11.1 Conclusion

This study focused in the estimation of the yearly external health costs from air pollutants emitted by coastal passenger ships and cruise ships approaching the port of Piraeus for the year 2008-2009. The preferred method was the Impact Pathway Assessment (IPA) which has been used by the ExternE, a number of research projects funded by the European Commission, Directorate-General (DG) Research for the assessment of external costs derived and correlated with the energy. The IPA (Impact Pathway Approach) is considered the best for calculating this kind of costs. Also, the presentation and analysis of the results tried to be as detailed as possible with a large number of figures, tables and comments. The second part of this study made an extra estimation of the yearly external health costs from air emissions of one passenger ship approaching the port of Piraeus for the year 2013-2014 with the same methodology. In the end and because Athens is the city which is affected the most, it was important to give a comparison between the yearly external health costs per person living in Athens caused by particles (PM_{10} or $PM_{2.5}$ according with which sector the comparison was made) emitted from coastal passenger ships and cruise ships and the two major contributors in the health external costs: the industrial sector (PM_{10}) and the transport sector ($PM_{2.5}$).

11.2 Discussion

In this paragraph, suggestions for improvement and further study in estimating the external health costs from shipping's air pollutants are given. The most obvious improvement would be the use of a program designed specifically for this task. This includes a new dispersion model for air pollutants emitted by ship's funnel taking into account analytical meteorological data and most importantly the ship movements (maneuvering in port or travelling in open sea). This way the overall external costs will be acquired and not only the ones when the ship is at the port. Also, another improvement would be a detailed inventory of air emissions of coastal passenger ships and cruise ships in Piraeus with a 24 hour monitoring of shipping traffic, possibly by using AIS (Automatic Identification System). Furthermore, the estimation of the external costs could include commercial ships as well as other types of ships.

Finally, it would be interesting to examine the changes in the external health costs from applications of different technologies (like cold ironing) in shipping so comparative and viability analysis could be made.

Annex 1: Tables which are used to find various parameters of the three dimensional Gaussian concentration field C(x, y, z)

Table 12: Formulae for predicting plume rise under buoyancy driven conditions (source: Spadaro, 2002; Brode and Wang, 1992)

Parameter	Formula	Value [‡]
Briggs Buoyancy Flux	$F_B = g V_E D_E^2 \left(\frac{\Delta T}{4 T_E} \right)$	$F_B = 91 \text{ m}^4/\text{s}^3$
<i>if $F_B < 55$</i>		
Plume rise for unstable (Pasquill classes A, B and C) or neutral (Pasquill class D) atmospheric conditions	$\Delta H = 21.425 \frac{F_B^{0.75}}{U}$	$\Delta H = 166 \text{ m}$
<i>if $F_B \geq 55$</i>		
	$\Delta H = 38.71 \frac{F_B^{0.60}}{U}$	
<i>Plume rise for stable dispersion (Pasquill classes E and F)</i>		
	$\Delta H = 2.6 \left(\frac{F_B T_A}{U g \partial \theta / \partial z} \right)^{0.33}$	$\Delta H = 87 \text{ m (class E)}$ $\Delta H = 72 \text{ m (class F)}$
	$\partial \theta / \partial z = 0.020 \text{ K/m for Class E}$ $\partial \theta / \partial z = 0.035 \text{ K/m for Class F}$	

[‡] Estimate based on input data: $V_E = 14 \text{ m/s}$, $D_E = 2.9 \text{ m}$, $T_E = 413 \text{ K}$, $T_A = 283 \text{ K}$, $U = 3.5 \text{ m/s}$

- (1) Wind speed at release height h_S is calculated by the formula: $U = U_{REF} \times (h_S / H_{REF})^P$, where P is the wind profile exponent given below and H_{REF} is the anemometer height.

Local conditions	Stability category					
	A	B	C	D	E	F
Rural exponent	0.07	0.07	0.10	0.15	0.35	0.35
Urban exponent	0.15	0.15	0.20	0.25	0.30	0.30

- (2) Plume rise is buoyancy driven if the following criteria are satisfied (typically, $\Delta T \geq 20 \text{ K}$):

Unstable or neutral atmosphere

$$F_B < 55, \quad \Delta T \geq 0.0297 T_E V_E^{0.33} / D_E^{0.67} \quad F_B \geq 55, \quad \Delta T \geq 0.00575 T_E V_E^{0.67} / D_E^{0.33}$$

Stable atmosphere

$$\Delta T \geq 0.19582 T_E V_E \sqrt{\frac{g \partial \theta / \partial z}{T_A}} \text{ for all } F_B \text{ values.}$$

List of symbols

D_E Stack inner diameter (m)
 g Acceleration due to gravity (9.81 m/s^2)
 h_E $h_S + \Delta H$ (Effective stack height in m)
 P Wind profile exponent
 U Wind speed at stack height h_S (m/s)
 z Vertical distance (m)
 ΔT $T_E - T_A$ (T_A is the air temperature in K)

F_B Briggs buoyancy flux (m^4/s^3)
 h_S Stack height (m)
 H_{REF} Anemometer height (m)
 T_E Exhaust gas exit temperature (K)
 V_E Exhaust gas exit speed (m/s)
 ΔH Plume rise (m)
 $\partial \theta / \partial z$ Potential temperature gradient (K/m)

Table 13: Lateral σ_y and vertical σ_z diffusion coefficients for Gaussian plume model (source: Spadaro, 2002; Zannetti, 1990)

$$\sigma = ar(1 + br)^c; \quad r = \text{downwind distance in meters}$$

Lateral dispersion coefficient, σ_y (m)

RURAL conditions

Pasquill class A	Pasquill class B	Pasquill class C	Pasquill class D	Pasquill class E	Pasquill class F
a = 0.22	a = 0.16	a = 0.11	a = 0.08	a = 0.06	a = 0.04
b = 0.0001	b = 0.0001	b = 0.0001	b = 0.0001	b = 0.0001	b = 0.0001
c = -0.5	c = -0.5	c = -0.5	c = -0.5	c = -0.5	c = -0.5

URBAN conditions

Pasquill class A	Pasquill class B	Pasquill class C	Pasquill class D	Pasquill class E	Pasquill class F
a = 0.32	a = 0.32	a = 0.22	a = 0.16	a = 0.11	a = 0.11
b = 0.0004	b = 0.0004	b = 0.0004	b = 0.0004	b = 0.0004	b = 0.0004
c = -0.5	c = -0.5	c = -0.5	c = -0.5	c = -0.5	c = -0.5

Vertical dispersion coefficient, σ_z (m)

RURAL conditions

Pasquill class A	Pasquill class B	Pasquill class C	Pasquill class D	Pasquill class E	Pasquill class F
a = 0.20	a = 0.12	a = 0.08	a = 0.06	a = 0.03	a = 0.016
b = 0	b = 0	b = 0.0002	b = 0.0015	b = 0.0003	b = 0.0003
c = 0	c = 0	c = -0.5	c = -0.5	c = -1	c = -1

URBAN conditions

Pasquill class A	Pasquill class B	Pasquill class C	Pasquill class D	Pasquill class E	Pasquill class F
a = 0.24	a = 0.24	a = 0.20	a = 0.14	a = 0.08	a = 0.08
b = 0.001	b = 0.001	b = 0	b = 0.0003	b = 0.0015	b = 0.0015
c = 0.5	c = 0.5	c = 0	c = -0.5	c = -0.5	c = -0.5

Table 14: Pasquill dispersion classes (source: Zannetti, 1990; Dobbins, 1979; Pasquill, 1974)

		Surface Wind Speed (m/s)				
		<2.0	2 to <3	3 to <5	5 to <6	≥6
Day	Strong Insolation	A	A-B	B	C	C
	Moderate Insolation	A-B	B	B-C	C-D	D
	Slight Insolation	B	C	C	D	D
Day or Night	Overcast	D	D	D	D	D
Night	Thin overcast or					
	≥0.5 cloud cover	—	E	D	D	D
	≤0.4 cloud cover	—	F	E	D	D

Notes: 1. Strong insolation corresponds to a solar elevation angle of 60° or more above the horizon. Slight insolation corresponds to a solar elevation angle of 15° to 35°.

2. Pollutants emitted under clear nighttime skies with winds less than 2.0 m/s, more recently defined to be class G, may be subject to unsteady meandering which renders the prediction of concentrations at downwind locations unreliable.

Where: A, very unstable; B, unstable; C, slightly unstable; D, neutral; E, slightly unstable; F, stable; G, very stable

Table 15: Classification of atmospheric stability (source: Zannetti, 1990; DeMarrais, 1978; Best et al., 1986; Hanna, 1989)

Stability classification	Pasquill categories	σ_θ (*) (degrees)	ΔT temperature change with height (°C 10^{-2} m $^{-1}$)	R_i gradient Richardson number at 2 m	σ_w/\bar{u}
Extremely unstable	A	25.0	< -1.9	-0.9	> 0.15
Moderately unstable	B	20.0	-1.9 to -1.7	-0.5	[0.1 - 0.15]
Slightly unstable	C	15.0	-1.7 to -1.5	-0.15	
Neutral	D	10.0	-1.5 to -0.5	0	0.05 - 0.1
Slightly stable	E	5.0	-0.5 to 1.5	0.4	[0.0 - 0.05]
Moderately stable	F	2.5	1.5 to 4.0	[0.8]	
Extremely stable	G	1.7	> 4.0		

(*) Standard deviation of horizontal wind direction fluctuation over a period of 15 minutes to 1 hour. The values shown are averages for each stability classification.

Table 16: Classification of atmospheric stability (source: Zannetti, 1990; U.S. EPA, 1986; Irwin, 1980)

Pasquill stability categories	Standard deviation of the horizontal wind direction fluctuations ² (degrees)	Standard Deviation of the vertical wind direction fluctuations ² (degrees)
A	Greater than 22.5°	Greater than 11.5°
B	17.5 to 22.5°	10.0° to 11.5°
C	12.5° to 17.5°	7.8° to 10.0°
D	7.5° to 12.5°	5.0° to 7.8°
E	3.8° to 7.5°	2.4° to 5.0°
F	Less than 3.8°	Less than 2.4°

¹ These criteria are appropriate for steady-state conditions, a measurement height of 10 m, for level terrain, and an aerodynamic surface roughness length of 15 cm. Care should be taken that the wind sensor is responsive enough for use in measuring wind direction fluctuation.

² A surface roughness factor of $(z_o/15 \text{ cm})^{0.2}$, where z_o is the average surface roughness in centimeters within a radius of 1-3 km of the source, may be applied to the table values. This factor, while theoretically sound, has not been subjected to rigorous testing and may not improve the estimates in all circumstances.

Table 17: Classification of atmospheric stability (source: Zannetti, 1990; U.S. EPA, 1986; Irwin, 1980)

If the σ_θ stability category is	And the wind speed at 10 m is (m s ⁻¹)	Then the Pasquill stability category is
A	< 2.9	F
	2.9 to 3.6	E
	≥ 3.6	D
B	< 2.4	F
	2.4 to 3.0	E
	≥ 3.0	D
C	< 2.4	E
	≥ 2.4	D
D	wind speed not considered	D
E	wind speed not considered	E
F	wind speed not considered	F

(*) Nighttime is considered to be from one hour before sunset to one hour after sunrise.

Annex 2: Sample of meteo input data (Faliro meteo station)

2013	1	1	1	337.5	0.89	284.3
2013	1	1	2	292.5	0.00	284.2
2013	1	1	3	0	0.44	284.3
2013	1	1	4	337.5	0.44	283.9
2013	1	1	5	22.5	0.44	283.6
2013	1	1	6	22.5	0.44	283.5
2013	1	1	7	22.5	0.44	283.8
2013	1	1	8	22.5	0.00	283.4
2013	1	1	9	22.5	0.00	284.1
2013	1	1	10	337.5	0.44	285.6
2013	1	1	11	270	0.00	286.5
2013	1	1	12	45	0.89	286.5
2013	1	1	13	337.5	0.44	287.4
2013	1	1	14	315	0.89	287.7
2013	1	1	15	270	0.89	287.3
2013	1	1	16	22.5	0.44	286.9
2013	1	1	17	45	0.00	286.3
2013	1	1	18	45	1.33	285.9
2013	1	1	19	22.5	0.00	285.4
2013	1	1	20	292.5	0.00	284.9
2013	1	1	21	45	0.00	284.4

2013	1	1	22	0	0.44	284.2
2013	1	1	23	45	0.00	284.2
2013	1	1	24	337.5	0.44	283.4
2013	1	2	1	22.5	0.00	283.2
2013	1	2	2	337.5	0.44	282.5
2013	1	2	3	22.5	0.44	282.2
2013	1	2	4	22.5	0.44	281.7
2013	1	2	5	22.5	0.44	281.6
2013	1	2	6	337.5	0.44	281.3
2013	1	2	7	0	0.00	281.5
2013	1	2	8	337.5	0.00	282.3
2013	1	2	9	337.5	0.00	282.3
2013	1	2	10	337.5	0.00	284.3
2013	1	2	11	337.5	0.00	286.6
2013	1	2	12	247.5	0.89	286.9
2013	1	2	13	225	0.44	287.2
2013	1	2	14	225	0.44	287.8
2013	1	2	15	157.5	0.44	287.8
2013	1	2	16	157.5	0.44	287.3
2013	1	2	17	157.5	0.44	287
2013	1	2	18	135	0.00	286.7
2013	1	2	19	135	0.00	286.3
2013	1	2	20	135	0.00	286

2013	1	2	21	135	0.00	285.5
2013	1	2	22	337.5	0.00	284.7
2013	1	2	23	337.5	0.00	284.7
2013	1	2	24	337.5	0.00	284.3
2013	1	3	1	337.5	0.44	283.6
2013	1	3	2	337.5	0.44	283.8
2013	1	3	3	337.5	0.44	282.9
2013	1	3	4	337.5	0.44	283.1
2013	1	3	5	337.5	0.44	282.8
2013	1	3	6	337.5	0.44	282.7
2013	1	3	7	337.5	0.00	282.5
2013	1	3	8	337.5	0.44	282.4
2013	1	3	9	337.5	0.00	283.5
2013	1	3	10	337.5	0.00	284.6
2013	1	3	11	0	0.89	286.7
2013	1	3	12	315	0.44	287.9
2013	1	3	13	202.5	0.44	288.4
2013	1	3	14	247.5	1.33	288.1
2013	1	3	15	202.5	0.89	288.3
2013	1	3	16	225	0.00	287.9
2013	1	3	17	225	0.00	287.7
2013	1	3	18	337.5	0.44	287.2
2013	1	3	19	22.5	0.44	286.6

2013	1	3	20	22.5	0.89	286.2
2013	1	3	21	0	0.00	285.7
2013	1	3	22	45	0.44	285.2
2013	1	3	23	315	0.00	284.8
2013	1	3	24	315	0.00	285.3
2013	1	4	1	315	0.00	285.1
2013	1	4	2	315	0.00	284.8
2013	1	4	3	315	0.00	284.3
2013	1	4	4	337.5	0.00	284.4
2013	1	4	5	22.5	0.00	284.2
2013	1	4	6	22.5	0.00	283.6
2013	1	4	7	22.5	0.00	283
2013	1	4	8	247.5	0.00	283
2013	1	4	9	90	0.00	284.1
2013	1	4	10	45	0.00	285.1
2013	1	4	11	0	0.44	286.7
2013	1	4	12	225	0.44	287.3
2013	1	4	13	0	0.00	288.2
2013	1	4	14	225	1.33	288.8
2013	1	4	15	270	0.89	288.8
2013	1	4	16	292.5	0.89	288.5
2013	1	4	17	270	0.44	287.6
2013	1	4	18	225	0.00	287.2

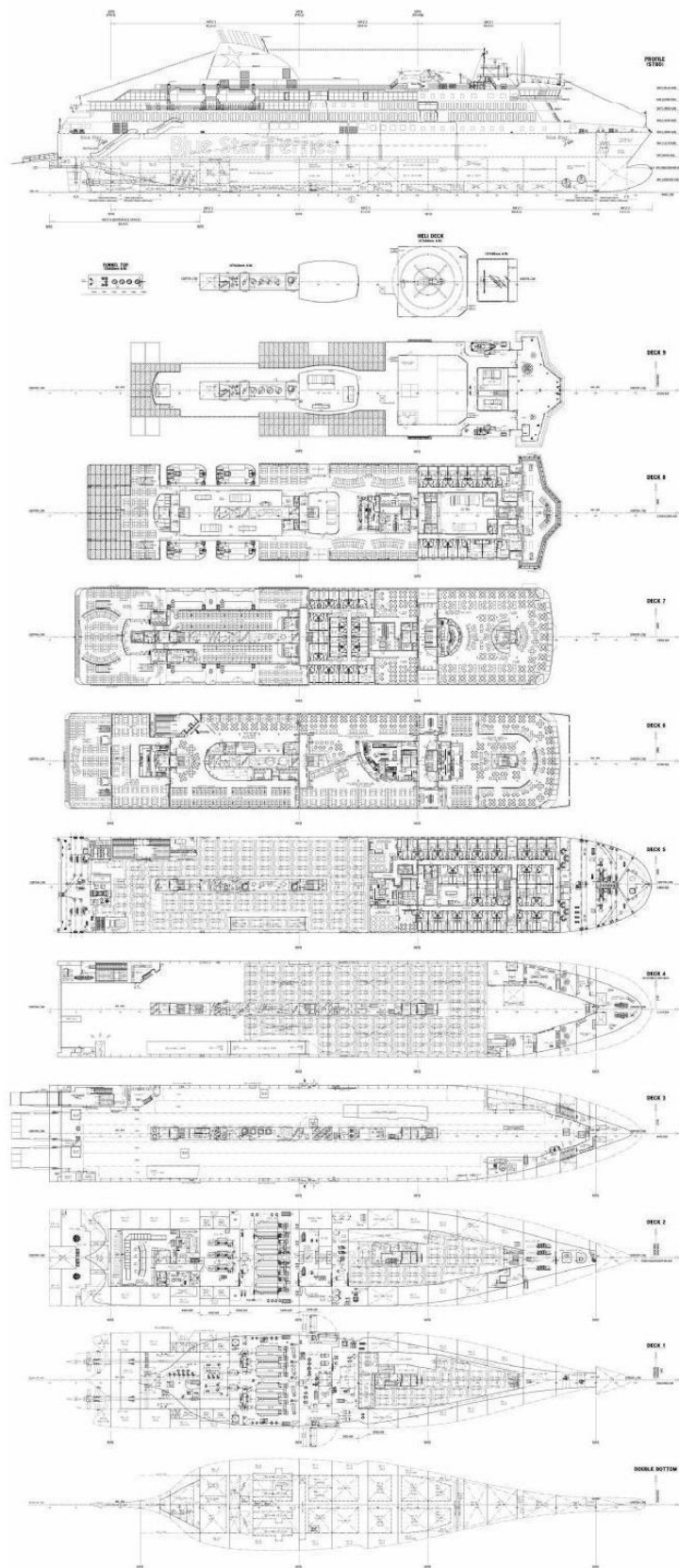
2013	1	4	19	270	0.00	286.4
2013	1	4	20	22.5	0.00	285.8
2013	1	4	21	22.5	0.00	285.6
2013	1	4	22	22.5	0.00	284.9
2013	1	4	23	22.5	0.44	284.2
2013	1	4	24	22.5	0.00	284.1
2013	1	5	1	247.5	0.44	284
2013	1	5	2	315	0.00	284.1
2013	1	5	3	247.5	0.00	283.9
2013	1	5	4	270	0.89	284.4
2013	1	5	5	270	0.89	284.6
2013	1	5	6	270	0.44	284.3
2013	1	5	7	270	0.44	283.8
2013	1	5	8	270	0.00	283.7
2013	1	5	9	292.5	0.00	283.7
2013	1	5	10	315	0.89	285.7
2013	1	5	11	315	0.89	286.6
2013	1	5	12	337.5	0.89	287.6
2013	1	5	13	337.5	1.78	288.1
2013	1	5	14	337.5	0.44	287.4
2013	1	5	15	292.5	0.44	287
2013	1	5	16	292.5	0.00	286.7
2013	1	5	17	292.5	0.00	286.5

2013	1	5	18	292.5	0.00	286.3
2013	1	5	19	292.5	0.00	286.3
2013	1	5	20	292.5	0.00	286.1
2013	1	5	21	292.5	0.00	285.8
2013	1	5	22	292.5	0.00	285.2
2013	1	5	23	292.5	0.00	284.8
2013	1	5	24	112.5	0.00	284.5
2013	1	6	1	112.5	0.00	283.8
2013	1	6	2	337.5	0.00	284.2
2013	1	6	3	22.5	0.00	284.2
2013	1	6	4	0	0.00	284.1
2013	1	6	5	315	0.44	284
2013	1	6	6	315	1.33	284.6
2013	1	6	7	315	2.69	282.9
2013	1	6	8	315	3.14	282.6
2013	1	6	9	0	2.22	282.9
2013	1	6	10	315	2.22	282.7
2013	1	6	11	22.5	2.69	281.2
2013	1	6	12	0	2.22	281.6
2013	1	6	13	0	2.22	282.6
2013	1	6	14	337.5	2.69	282.8
2013	1	6	15	337.5	2.69	282.6
2013	1	6	16	0	2.69	281.8

2013	1	6	17	22.5	2.69	281.6
2013	1	6	18	22.5	1.78	281.7
2013	1	6	19	22.5	2.69	280.6
2013	1	6	20	22.5	1.78	280.3
2013	1	6	21	22.5	1.33	280.3
2013	1	6	22	270	0.44	280.6
2013	1	6	23	45	0.89	280.8
2013	1	6	24	0	0.44	280.7
2013	1	7	1	315	1.78	280.4
2013	1	7	2	315	1.33	280.2
2013	1	7	3	315	1.78	280
2013	1	7	4	22.5	0.44	279.4
2013	1	7	5	247.5	0.89	279.1
2013	1	7	6	315	0.44	279.3
2013	1	7	7	315	0.00	278.9
2013	1	7	8	292.5	0.89	279.3
2013	1	7	9	292.5	0.44	280.2
2013	1	7	10	67.5	0.44	280.2
2013	1	7	11	45	0.44	282.3
2013	1	7	12	202.5	0.44	283.8
2013	1	7	13	225	0.89	284.3
2013	1	7	14	315	0.44	285.7
2013	1	7	15	270	0.44	285.9

2013	1	7	16	45	2.22	285.2
2013	1	7	17	0	2.22	283.7
2013	1	7	18	45	3.14	283
2013	1	7	19	315	1.33	282.1
2013	1	7	20	0	2.22	282.4
2013	1	7	21	0	2.69	281.4
2013	1	7	22	0	2.69	281.5
2013	1	7	23	22.5	4.03	281.4
2013	1	7	24	22.5	4.03	280.9

Annex 3: General Arrangement of Blue Star Belos



BLUE STAR DELOS • Scale 1:750

Annex 4: Population distribution (local scale)

	-47.5	-42.5	-37.5	-32.5	-27.5	-22.5	-17.5	-12.5	-7.5	-2.5	2.5	7.5	12.5	17.5	22.5	27.5	32.5	37.5	42.5	47.5
47.5	4743	0	0	0	0	1071	1070	4726	8177	991	0	3156	0	0	4141	54	0	590	474	
42.5	2954	6469	0	129	36477	0	752	1267	871	5122	9286	795	3410	2723	0	0	0	0	0	968
37.5	0	6038	642	1155	86	557	0	1267	406	1292	110	910	603	4373	3728	1904	0	0	0	1182
32.5	608	1020	2569	1549	1109	0	156	905	929	0	0	5184	514	3359	307	174	0	0	0	0
27.5	0	0	7	984	0	60	26	249	1215	0	0	0	959	3642	264	1674	864	0	0	
22.5	0	0	80	130	1269	616	0	0	0	0	6200	7911	40193	104	15554	0	0	0	0	
17.5	0	0	172	0	0	143	496	0	150	296	33565	106943	101602	2979	0	823	0	0	0	0
12.5	0	412	412	0	0	0	0	17885	29902	30251	58979	62529	177669	65675	34934	0	998	0	0	0
7.5	0	10203	0	72	27672	587	8480	194	0	2606	245857	785920	160505	158633	54415	2009	13091	0	0	0
2.5	0	1972	1972	24	331	331	816	25730	25389	91045	209288	911804	158792	26668	10203	10000	33821	23618	0	0
-2.5	5960	5960	0	0	0	0	3652	408	1956	0	0	64021	6688	891	30307	10000	39	0	0	0
-7.5	0	0	0	0	6	0	192	108	0	0	3344	3344	0	297	2040	7131	0	0	0	
-12.5	0	0	0	0	0	0	0	0	0	0	250	32500	3204	14424	14424	6458	203	0	0	
-17.5	0	0	0	0	0	0	7783	1495	291	0	0	0	0	1000	0	126	479	0	0	
-22.5	30	0	0	0	0	0	7783	157	157	0	0	0	0	2102	7189	687	265	0	0	
-27.5	0	0	0	0	920	920	823	823	104	0	0	0	0	6	2051	687	8558	8558	0	0
-32.5	1733	1733	0	0	16	136	136	823	0	0	0	0	0	0	0	453	453	453	0	
-37.5	1733	1733	318	35	1212	1212	0	0	0	0	0	0	0	0	0	0	0	0	0	
-42.5	805	805	805	805	0	1150	4348	4348	0	0	0	0	0	0	0	0	0	0	0	
-47.5	805	805	805	805	1150	1150	4348	4348	0	0	0	0	0	0	0	0	0	0	0	

Annex 5: ERF and monetary values

Data per line: Pollutant, ERF name, Endpoint type, ERF slope in cases/(yr.pers.ug/m³) and unit cost in €₂₀₀₀

"PM10", "PM10 - Mortality YOLL [Pope 2002]", "Long-term mortality", 3.90E-04, 50000
"PM10", "PM10 - Chronic Bronchitis [Abbey 1995]", "Morbidity", 3.92E-05, 169300
"PM10", "PM10 - net Restricted activity days [Ostro 1987]", "Morbidity", 1.98E-02, 110
"PM10", "PM10 - Respiratory hospitalization [Dab 1996]", "Morbidity", 2.07E-06, 4320
"PM10", "PM10 - Cerebrovascular hospitalization [Wordley 1997]", "Morbidity", 5.04E-06, 16730
"PM10", "PM10 - Chronic cough, children [Dockery 1989]", "Morbidity", 4.14E-04, 240
"PM10", "PM10 - Congestive heart failure, elderly [Schwartz/Morris 1995]", "Morbidity", 2.59E-06, 3260
"PM10", "PM10 - Cough, adult asthmatics [Dusseldorp 1995]", "Morbidity", 9.39E-03, 45
"PM10", "PM10 - Bronchodilator use, adult asthmatics [Dusseldorp 1995]", "Morbidity", 4.56E-03, 40
"PM10", "PM10 - Lower respiratory symptoms, adult asthmatics [Dusseldorp 1995]", "Morbidity", 1.70E-03, 8
"PM10", "PM10 - Cough, children asthmatics [Pope/Dockery 1992]", "Morbidity", 1.87E-03, 45
"PM10", "PM10 - Bronchodilator use, children asthmatics [Roemer 1993]", "Morbidity", 5.43E-04, 40
"PM10", "PM10 - Lower respiratory symptoms, children asthmatics [Roemer 1993]", "Morbidity", 7.20E-04, 8
"Sulfates", "Sulfates - Mortality YOLL [Pope 2002]", "Long-term mortality", 3.90E-04, 50000
"Sulfates", "Sulfates - Chronic Bronchitis [Abbey 1995]", "Morbidity", 3.92E-05, 169300
"Sulfates", "Sulfates - net Restricted activity days [Ostro 1987]", "Morbidity", 1.98E-02, 110
"Sulfates", "Sulfates - Respiratory hospitalization [Dab 1996]", "Morbidity", 2.07E-06, 4320
"Sulfates", "Sulfates - Cerebrovascular hospitalization [Wordley 1997]", "Morbidity", 5.04E-06, 16730
"Sulfates", "Sulfates - Chronic cough, children [Dockery 1989]", "Morbidity", 4.14E-04, 240
"Sulfates", "Sulfates - Congestive heart failure, elderly [Schwartz/Morris 1995]", "Morbidity", 2.59E-06, 3260
"Sulfates", "Sulfates - Cough, adult asthmatics [Dusseldorp 1995]", "Morbidity", 9.39E-03, 45
"Sulfates", "Sulfates - Bronchodilator use, adult asthmatics [Dusseldorp 1995]", "Morbidity", 4.56E-03, 40
"Sulfates", "Sulfates - Lower respiratory symptoms, adult asthmatics [Dusseldorp 1995]", "Morbidity", 1.70E-03, 8

"Sulfates", "Sulfates - Cough, children asthmatics [Pope/Dockery 1992]", "Morbidity", 1.87E-03, 45

"Sulfates", "Sulfates - Bronchodilator use, children asthmatics [Roemer 1993]", "Morbidity", 5.43E-04, 40

"Sulfates", "Sulfates - Lower respiratory symptoms, children asthmatics [Roemer 1993]", "Morbidity", 7.20E-04, 8

"Nitrates", "Nitrates - Mortality YOLL [Pope 2002]", "Long-term mortality", 1.95E-04, 50000

"Nitrates", "Nitrates - Chronic Bronchitis [Abbey 1995]", "Morbidity", 1.96E-05, 169300

"Nitrates", "Nitrates - net Restricted activity days [Ostro 1987]", "Morbidity", 9.89E-03, 110

"Nitrates", "Nitrates - Respiratory hospitalization [Dab 1996]", "Morbidity", 1.035E-06, 4320

"Nitrates", "Nitrates - Cerebrovascular hospitalization [Wordley 1997]", "Morbidity", 2.52E-06, 16730

"Nitrates", "Nitrates - Chronic cough, children [Dockery 1989]", "Morbidity", 2.07E-04, 240

"Nitrates", "Nitrates - Congestive heart failure, elderly [Schwartz/Morris 1995]", "Morbidity", 1.30E-06, 3260

"Nitrates", "Nitrates - Cough, adult asthmatics [Dusseldorp 1995]", "Morbidity", 4.69E-03, 45

"Nitrates", "Nitrates - Bronchodilator use, adult asthmatics [Dusseldorp 1995]", "Morbidity", 2.28E-03, 40

"Nitrates", "Nitrates - Lower respiratory symptoms, adult asthmatics [Dusseldorp 1995]", "Morbidity", 8.48E-04, 8

"Nitrates", "Nitrates - Cough, children asthmatics [Pope/Dockery 1992]", "Morbidity", 9.34E-04, 45

"Nitrates", "Nitrates - Bronchodilator use, children asthmatics [Roemer 1993]", "Morbidity", 2.71E-04, 40

"Nitrates", "Nitrates - Lower respiratory symptoms, children asthmatics [Roemer 1993]", "Morbidity", 3.60E-04, 8

"SO2", "SO2 - Mortality YOLL [Anderson/Toulomi 1996]", "Short-term mortality", 5.34E-06, 75000

"SO2", "SO2 - Respiratory hospitalization [Ponce de Leon 1996]", "Morbidity", 2.40E-06, 4320

"PM2.5", "PM2.5 - Mortality YOLL [Pope 2002]", "Long-term mortality", 6.51E-04, 50000

"PM2.5", "PM2.5 - Chronic Bronchitis [Abbey 1995]", "Morbidity", 6.55E-05, 169300

"PM2.5", "PM2.5 - net Restricted activity days [Ostro 1987]", "Morbidity", 3.31E-02, 110

"PM2.5", "PM2.5 - Respiratory hospitalization [Dab 1996]", "Morbidity", 3.46E-06, 4320

"PM2.5", "PM2.5 - Cerebrovascular hospitalization [Wordley 1997]", "Morbidity", 6.42E-06, 16730

"PM2.5", "PM2.5 - Chronic cough, children [Dockery 1989]", "Morbidity", 6.91E-04, 240

"PM2.5", "PM2.5 - Congestive heart failure, elderly [Schwartz/Morris 1995]", "Morbidity", 4.33E-06, 3260

"PM2.5", "PM2.5 - Cough, adult asthmatics [Dusseldorp 1995]", "Morbidity", 15.68E-03, 45

"PM2.5", "PM2.5 - Bronchodilator use, adult asthmatics [Dusseldorp 1995]", "Morbidity", 7.62E-03, 40

"PM2.5", "PM2.5 - Lower respiratory symptoms, adult asthmatics [Dusseldorp 1995]", "Morbidity", 2.84E-03, 8

"PM2.5", "PM2.5 - Cough, children asthmatics [Pope/Dockery 1992]", "Morbidity", 3.12E-03, 45

"PM2.5", "PM2.5 - Bronchodilator use, children asthmatics [Roemer 1993]", "Morbidity", 9.07E-04, 40

"PM2.5", "PM2.5 - Lower respiratory symptoms, children asthmatics [Roemer 1993]", "Morbidity", 12.02E-04, 8

Annex 6: Case study results file

Stack Parameters

Source Longitude (deg):	23.63706
Source Latitude (deg):	37.94222
Source Location:	3
Stack Height (m):	25.0
Stack Diameter (m):	5.0
Exhaust Gas Velocity (m/s):	10.0
Exhaust Gas Temperature (K):	600.0
Effective Stack Height (m):	337.4

- (1) Longitude: 0 to 360 deg; positive direction is West of Greenwich Meridian.
- (2) Latitude: -90 to +90 deg about the Equator.
- (3) Location: 0 = rural site
1, 2, 3 = near small, medium or large city
4 = 25 km or less from a large urban center
5 = 40 km or less from a large city, and
6 = more than 40 km from a large city.
- (4) Effective height is the sum of actual stack height and plume rise.

Pollutant Inventory

Name	Emission Rate (tons/year)	Depletion Velocity (cm/s)
PM10	1.080E+02	0.77
SO2	7.220E+02	0.81
NOx	1.790E+03	1.26
PM2.5	9.900E+01	0.77
Nitrates		1.03
Sulfates		1.86

- (5) Precursor pollutant for Nitrates is NO2.
- (6) Precursor pollutant for Sulfates is SO2.
- (7) The pollutant removal rate is characterized by the Depletion velocity, which accounts for 'dry' & 'wet' deposition and atmospheric chemical transformation.

Receptor Data

Regional Receptor Density (pers/km): 82

Local Receptor Density (pers/km²): 426.4

Radius of Local Domain (km): 56.0

(8) Regional density is estimated using a radius of 500-1000 km about the source. This surface area covers both land and water.

(9) Local receptors are the number of persons living within the local domain (100 by 100 km²), with the source located at the coordinate origin. The local population resolution scale is 5 by 5 km².

Meteorological Data

Mean Air Temperature (K): 294.8

Mean Local Wind Speed (m/s): 3.5

Anemometer Height (m): 54

Pasquill Distribution Class A (%): 5.4

Pasquill Distribution Class B (%): 15.8

Pasquill Distribution Class C (%): 4.3

Pasquill Distribution Class D (%): 38.4

Pasquill Distribution Class E (%): 6.9

Pasquill Distribution Class F (%): 29.3

Mean mixing layer height (m): 605.5

(10) Air and wind data are mean values during the impact assessment period.

(11) Anemometer height is the height at which the wind speed is measured.

(12) Pasquill classes are a measure of atmospheric turbulence level during pollutant transport. Class types include:

A, B, C = Very to Slightly Unstable;

D = Neutral, and

E, F = Slightly to Stable atmospheric conditions.

(13) Mixing height is the layer of air above the ground (troposphere) where mass and energy transport is significant.

Human Health Categories of Impact

See Annex 5.

Annex 7: Case study detailed review of impact assessment results

Impacts and damage costs were calculated using the Simple Uniform World Model (SUWM). Estimates depend on the following five parameters:

1. Pollutant emission rate
2. depletion velocity;
3. Exposure-Response Function (ERF) of health endpoint in question;
4. Regional receptor density and
5. Monetary unit cost

Estimation code 3

Based on available input data, impacts and damages were calculated using the 'BEST Algorithm' in QUERI. Of the available case study input data, The following parameters were utilized: stack Height and Diameter; flue gas exhaust Temperature and Velocity; Site index; pollutant Emissions inventory and Depletion Velocities; Regional population density; detailed Local population statistics (5 by 5 km resolution); and detailed Meteorological parameters (hourly data).

A review of impact assessment results is provided below:

PM10 - Mortality YOLL [Pope 2002]

-- Health Impact ---

Pollutant: PM10

Emission: 108 tons/yr

Depletion velocity: 0.77 cm/s

Endpoint: PM10 - Mortality YOLL [Pope 2002]

ERF slope: 3.9000E-04 cases/(yr.person.ug/m3)

Impact type: Long-term mortality

Unit cost: 50000 €/case

--- Results ---

Impact: 8.499E+1 cases per year, of which the Local and Regional contributions are, respectively: 7.210E+01 and 1.289E+01 cases per year. The local impact is 84.8% of the Total.

Damage cost: 4.250E+6 € per year

(68% confidence interval = 1.417E+6, 1.275E+7)

--- Estimation Code ---

Based on available input data, impacts and damages were calculated using the 'BEST Algorithm' in QUERI.

--- Data use ---

Of the available case study input data, these parameters were utilized: stack Height and Diameter; flue gas exhaust Temperature and Velocity; Site index; pollutant Emissions inventory and Depletion Velocities; Regional population density; detailed Local population statistics (5 by 5 km resolution); and detailed Meteorological parameters (hourly data).

--- Sensitivity analysis ---

Local concentrations were estimated using a Gaussian dispersion algorithm for urban conditions. Consequently, changing the Site index between 1 and 3 will not affect the results.

Whereas varying any of the other input parameters will have an influence on the impact/damage estimates.

PM10 - Chronic Bronchitis [Abbey 1995]

--- Health Impact ---

Pollutant: PM10

Emission: 108 tons/yr

Depletion velocity: 0.77 cm/s

Endpoint: PM10 - Chronic Bronchitis [Abbey 1995]

ERF slope: 3.9200E-05 cases/(yr.person.ug/m3)

Impact type: Morbidity

Unit cost: 169300 €/case

--- Results ---

Impact: 8.543E+0 cases per year, of which the Local and Regional contributions are, respectively: 7.247E+00 and 1.296E+00 cases per year. The local impact is 84.8% of the Total.

Damage cost: 1.446E+6 € per year

(68% confidence interval = 4.820E+5, 4.338E+6)

--- Estimation Code ---

Based on available input data, impacts and damages were calculated using the 'BEST Algorithm' in QUERI.--- Data use ---

Of the available case study input data, these parameters were utilized: stack Height and Diameter; flue gas exhaust Temperature and Velocity; Site index; pollutant Emissions inventory and Depletion Velocities; Regional population density; detailed Local population statistics (5 by 5 km resolution); and detailed Meteorological parameters (hourly data).

--- Sensitivity analysis ---

Local concentrations were estimated using a Gaussian dispersion algorithm for urban conditions. Consequently, changing the Site index between 1 and 3 will not affect the results.

Whereas varying any of the other input parameters will have an influence on the impact/damage estimates.

PM10 - net Restricted activity days [Ostro 1987]

--- Health Impact ---

Pollutant: PM10

Emission: 108 tons/yr

Depletion velocity: 0.77 cm/s

Endpoint: PM10 - net Restricted activity days [Ostro 1987]

ERF slope: 1.9800E-02 cases/(yr.person.ug/m3)

Impact type: Morbidity

Unit cost: 110 €/case

--- Results ---

Impact: 4.315E+3 cases per year, of which the Local and Regional contributions are, respectively: 3.661E+03 and 6.546E+02 cases per year. The local impact is 84.8% of the Total.

Damage cost: 4.747E+5 € per year

(68% confidence interval = 1.582E+5, 1.424E+6)

--- Estimation Code ---

Based on available input data, impacts and damages were calculated using the 'BEST Algorithm' in QUERI.

--- Data use ---

Of the available case study input data, these parameters were utilized: stack Height and Diameter; flue gas exhaust Temperature and Velocity; Site index; pollutant Emissions inventory and Depletion Velocities; Regional population density; detailed

Local population statistics (5 by 5 km resolution); and detailed Meteorological parameters (hourly data).

--- Sensitivity analysis ---

Local concentrations were estimated using a Gaussian dispersion algorithm for urban conditions. Consequently, changing the Site index between 1 and 3 will not affect the results.

Whereas varying any of the other input parameters will have an influence on the impact/damage estimates.

PM10 - Respiratory hospitalization [Dab 1996]

--- Health Impact ---

Pollutant: PM10

Emission: 108 tons/yr

Depletion velocity: 0.77 cm/s

Endpoint: PM10 - Respiratory hospitalization [Dab 1996]

ERF slope: 2.0700E-06 cases/(yr.person.ug/m3)

Impact type: Morbidity

Unit cost: 4320 €/case

--- Results ---

Impact: 4.511E-1 cases per year, of which the Local and Regional contributions are, respectively: 3.827E-01 and 6.843E-02 cases per year. The local impact is 84.8% of the Total.

Damage cost: 1.949E+3 € per year

(68% confidence interval = 6.497E+2, 5.847E+3)

--- Estimation Code ---

Based on available input data, impacts and damages were calculated using the 'BEST Algorithm' in QUERI.

--- Data use ---

Of the available case study input data, these parameters were utilized: stack Height and Diameter; flue gas exhaust Temperature and Velocity; Site index; pollutant Emissions inventory and Depletion Velocities; Regional population density; detailed Local population statistics (5 by 5 km resolution); and detailed Meteorological parameters (hourly data).

--- Sensitivity analysis ---

Local concentrations were estimated using a Gaussian dispersion algorithm for urban conditions. Consequently, changing the Site index between 1 and 3 will not affect the results.

Whereas varying any of the other input parameters will have an influence on the impact/damage estimates.

PM10 - Cerebrovascular hospitalization [Wordley 1997]

--- Health Impact ---

Pollutant: PM10

Emission: 108 tons/yr

Depletion velocity: 0.77 cm/s

Endpoint: PM10 - Cerebrovascular hospitalization [Wordley 1997]

ERF slope: 5.0400E-06 cases/(yr.person.ug/m3)

Impact type: Morbidity

Unit cost: 16730 €/case

--- Results ---

Impact: 1.098E+0 cases per year, of which the Local and Regional contributions are, respectively: 9.318E-01 and 1.666E-01 cases per year. The local impact is 84.9% of the Total.

Damage cost: 1.838E+4 € per year

(68% confidence interval = 6.127E+3, 5.514E+4)

--- Estimation Code ---

Based on available input data, impacts and damages were calculated using the 'BEST Algorithm' in QUERI.

-- Data use ---

Of the available case study input data, these parameters were utilized: stack Height and Diameter; flue gas exhaust Temperature and Velocity; Site index; pollutant Emissions inventory and Depletion Velocities; Regional population density; detailed Local population statistics (5 by 5 km resolution); and detailed Meteorological parameters (hourly data).

--- Sensitivity analysis ---

Local concentrations were estimated using a Gaussian dispersion algorithm for urban conditions. Consequently, changing the Site index between 1 and 3 will not affect the results.

Whereas varying any of the other input parameters will have an influence on the impact/damage estimates.

Chronic cough, children [Dockery 1989]

--- Health Impact ---

Pollutant: PM10

Emission: 108 tons/yr

Depletion velocity: 0.77 cm/s

Endpoint: PM10 - Chronic cough, children [Dockery 1989]

ERF slope: 4.1400E-04 cases/(yr.person.ug/m3)

Impact type: Morbidity

Unit cost: 240 €/case

--- Results ---

Impact: 9.022E+1 cases per year, of which the Local and Regional contributions are, respectively: 7.654E+01 and 1.369E+01 cases per year. The local impact is 84.8% of the Total.

Damage cost: 2.165E+4 € per year

(68% confidence interval = 7.217E+3, 6.495E+4)

--- Estimation Code ---

Based on available input data, impacts and damages were calculated using the 'BEST Algorithm' in QUERI.

--- Data use ---

Of the available case study input data, these parameters were utilized: stack Height and Diameter; flue gas exhaust Temperature and Velocity; Site index; pollutant Emissions inventory and Depletion Velocities; Regional population density; detailed Local population statistics (5 by 5 km resolution); and detailed Meteorological parameters (hourly data).

--- Sensitivity analysis ---

Local concentrations were estimated using a Gaussian dispersion algorithm for urban conditions. Consequently, changing the Site index between 1 and 3 will not affect the results.

Whereas varying any of the other input parameters will have an influence on the impact/damage estimates.

PM10 - Congestive heart failure, elderly [Schwartz/Morris 1995]

--- Health Impact ---

Pollutant: PM10

Emission: 108 tons/yr

Depletion velocity: 0.77 cm/s

Endpoint: PM10 - Congestive heart failure, elderly [Schwartz/Morris 1995]

ERF slope: 2.5900E-06 cases/(yr.person.ug/m3)

Impact type: Morbidity

Unit cost: 3260 €/case

--- Results ---

Impact: 5.644E-1 cases per year, of which the Local and Regional contributions are, respectively: 4.788E-01 and 8.562E-02 cases per year. The local impact is 84.8% of the Total.

Damage cost: 1.840E+3 € per year

(68% confidence interval = 6.133E+2, 5.520E+3)

--- Estimation Code ---

Based on available input data, impacts and damages were calculated using the 'BEST Algorithm' in QUERI.

--- Data use ---

Of the available case study input data, these parameters were utilized: stack Height and Diameter; flue gas exhaust Temperature and Velocity; Site index; pollutant Emissions inventory and Depletion Velocities; Regional population density; detailed Local population statistics (5 by 5 km resolution); and detailed Meteorological parameters (hourly data).

--- Sensitivity analysis ---

Local concentrations were estimated using a Gaussian dispersion algorithm for urban conditions. Consequently, changing the Site index between 1 and 3 will not affect the results.

Whereas varying any of the other input parameters will have an influence on the impact/damage estimates.

PM10 - Cough, adult asthmatics [Dusseldorp 1995]

--- Health Impact ---

Pollutant: PM10

Emission: 108 tons/yr

Depletion velocity: 0.77 cm/s

Endpoint: PM10 - Cough, adult asthmatics [Dusseldorp 1995]

ERF slope: 9.3900E-03 cases/(yr.person.ug/m3)

Impact type: Morbidity

Unit cost: 45 €/case

--- Results ---

Impact: 2.046E+3 cases per year, of which the Local and Regional contributions are, respectively: 1.736E+03 and 3.104E+02 cases per year. The local impact is 84.8% of the Total.

Damage cost: 9.209E+4 € per year

(68% confidence interval = 3.070E+4, 2.763E+5)

--- Estimation Code ---

Based on available input data, impacts and damages were calculated using the 'BEST Algorithm' in QUERI.

--- Data use ---

Of the available case study input data, these parameters were utilized: stack Height and Diameter; flue gas exhaust Temperature and Velocity; Site index; pollutant Emissions inventory and Depletion Velocities; Regional population density; detailed Local population statistics (5 by 5 km resolution); and detailed Meteorological parameters (hourly data).

--- Sensitivity analysis ---

Local concentrations were estimated using a Gaussian dispersion algorithm for urban conditions. Consequently, changing the Site index between 1 and 3 will not affect the results.

Whereas varying any of the other input parameters will have an influence on the impact/damage estimates.

PM10 - Bronchodilator use, adult asthmatics [Dusseldorp 1995]

--- Health Impact ---

Pollutant: PM10

Emission: 108 tons/yr

Depletion velocity: 0.77 cm/s

Endpoint: PM10 - Bronchodilator use, adult asthmatics [Dusseldorp 1995]

ERF slope: 4.5600E-03 cases/(yr.person.ug/m3)

Impact type: Morbidity

Unit cost: 40 €/case

--- Results ---

Impact: 9.938E+2 cases per year, of which the Local and Regional contributions are, respectively: 8.430E+02 and 1.507E+02 cases per year. The local impact is 84.8% of the Total.

Damage cost: 3.975E+4 € per year

(68% confidence interval = 1.325E+4, 1.193E+5)

--- Estimation Code ---

Based on available input data, impacts and damages were calculated using the 'BEST Algorithm' in QUERI.

--- Data use ---

Of the available case study input data, these parameters were utilized: stack Height and Diameter; flue gas exhaust Temperature and Velocity; Site index; pollutant Emissions inventory and Depletion Velocities; Regional population density; detailed Local population statistics (5 by 5 km resolution); and detailed Meteorological parameters (hourly data).

--- Sensitivity analysis ---

Local concentrations were estimated using a Gaussian dispersion algorithm for urban conditions. Consequently, changing the Site index between 1 and 3 will not affect the results.

Whereas varying any of the other input parameters will have an influence on the impact/damage estimates.

PM10 - Lower respiratory symptoms, adult asthmatics [Dusseldorp 1995]

--- Health Impact ---

Pollutant: PM10

Emission: 108 tons/yr

Depletion velocity: 0.77 cm/s

Endpoint: PM10 - Lower respiratory symptoms, adult asthmatics [Dusseldorp 1995]

ERF slope: 1.7000E-03 cases/(yr.person.ug/m3)

Impact type: Morbidity

Unit cost: 8 €/case

--- Results ---

Impact: 3.705E+2 cases per year, of which the Local and Regional contributions are, respectively: 3.143E+02 and 5.620E+01 cases per year. The local impact is 84.8% of the Total.

Damage cost: 2.964E+3 € per year

(68% confidence interval = 9.880E+2, 8.892E+3)

--- Estimation Code ---

Based on available input data, impacts and damages were calculated using the 'BEST Algorithm' in QUERI.

--- Data use ---

Of the available case study input data, these parameters were utilized: stack Height and Diameter; flue gas exhaust Temperature and Velocity; Site index; pollutant Emissions inventory and Depletion Velocities; Regional population density; detailed Local population statistics (5 by 5 km resolution); and detailed Meteorological parameters (hourly data).

--- Sensitivity analysis ---

Local concentrations were estimated using a Gaussian dispersion algorithm for urban conditions. Consequently, changing the Site index between 1 and 3 will not affect the results.

Whereas varying any of the other input parameters will have an influence on the impact/damage estimates.

PM10 - Cough, children asthmatics [Pope/Dockery 1992]

--- Health Impact ---

Pollutant: PM10

Emission: 108 tons/yr

Depletion velocity: 0.77 cm/s

Endpoint: PM10 - Cough, children asthmatics [Pope/Dockery 1992]

ERF slope: 1.8700E-03 cases/(yr.person.ug/m3)

Impact type: Morbidity

Unit cost: 45 €/case

--- Results ---

Impact: 4.075E+2 cases per year, of which the Local and Regional contributions are, respectively: 3.457E+02 and 6.182E+01 cases per year. The local impact is 84.8% of the Total.

Damage cost: 1.834E+4 € per year

(68% confidence interval = 6.113E+3, 5.502E+4)

--- Estimation Code ---

Based on available input data, impacts and damages were calculated using the 'BEST Algorithm' in QUERI.

--- Data use ---

Of the available case study input data, these parameters were utilized: stack Height and Diameter; flue gas exhaust Temperature and Velocity; Site index; pollutant Emissions inventory and Depletion Velocities; Regional population density; detailed Local population statistics (5 by 5 km resolution); and detailed Meteorological parameters (hourly data).

--- Sensitivity analysis ---

Local concentrations were estimated using a Gaussian dispersion algorithm for urban conditions. Consequently, changing the Site index between 1 and 3 will not affect the results.

Whereas varying any of the other input parameters will have an influence on the impact/damage estimates.

PM10 - Bronchodilator use, children asthmatics [Roemer 1993]

--- Health Impact ---

Pollutant: PM10

Emission: 108 tons/yr

Depletion velocity: 0.77 cm/s

Endpoint: PM10 - Bronchodilator use, children asthmatics [Roemer 1993]

ERF slope: 5.4300E-04 cases/(yr.person.ug/m3)

Impact type: Morbidity

Unit cost: 40 €/case

--- Results ---

Impact: 1.183E+2 cases per year, of which the Local and Regional contributions are, respectively: 1.004E+02 and 1.795E+01 cases per year. The local impact is 84.9% of the Total.

Damage cost: 4.734E+3 € per year

(68% confidence interval = 1.578E+3, 1.420E+4)

--- Estimation Code ---

Based on available input data, impacts and damages were calculated using the 'BEST Algorithm' in QUERI.

--- Data use ---

Of the available case study input data, these parameters were utilized: stack Height and Diameter; flue gas exhaust Temperature and Velocity; Site index; pollutant Emissions inventory and Depletion Velocities; Regional population density; detailed Local population statistics (5 by 5 km resolution); and detailed Meteorological parameters (hourly data).

--- Sensitivity analysis ---

Local concentrations were estimated using a Gaussian dispersion algorithm for urban conditions. Consequently, changing the Site index between 1 and 3 will not affect the results.

Whereas varying any of the other input parameters will have an influence on the impact/damage estimates.

PM10 - Lower respiratory symptoms, children asthmatics [Roemer 1993]

--- Health Impact ---

Pollutant: PM10

Emission: 108 tons/yr

Depletion velocity: 0.77 cm/s

Endpoint: PM10 - Lower respiratory symptoms, children asthmatics [Roemer 1993]

ERF slope: 7.2000E-04 cases/(yr.person.ug/m3)

Impact type: Morbidity

Unit cost: 8 €/case

--- Results ---

Impact: 1.569E+2 cases per year, of which the Local and Regional contributions are, respectively: 1.331E+02 and 2.380E+01 cases per year. The local impact is 84.8% of the Total.

Damage cost: 1.255E+3 € per year

(68% confidence interval = 4.183E+2, 3.765E+3)

--- Estimation Code ---

Based on available input data, impacts and damages were calculated using the 'BEST Algorithm' in QUERI.

--- Data use ---

Of the available case study input data, these parameters were utilized: stack Height and Diameter; flue gas exhaust Temperature and Velocity; Site index; pollutant Emissions inventory and Depletion Velocities; Regional population density; detailed

Local population statistics (5 by 5 km resolution); and detailed Meteorological parameters (hourly data).

--- Sensitivity analysis ---

Local concentrations were estimated using a Gaussian dispersion algorithm for urban conditions. Consequently, changing the Site index between 1 and 3 will not affect the results.

Whereas varying any of the other input parameters will have an influence on the impact/damage estimates.

Sulfates - Mortality YOLL [Pope 2002]

--- Health Impact ---

Pollutant: Sulfates

Emission of precursor pollutant (SO₂): 722 tons/yr

Depletion velocity: 1.86 cm/s

Endpoint: Sulfates - Mortality YOLL [Pope 2002]

ERF slope: 3.9000E-04 cases/(yr.person.ug/m³)

Impact type: Long-term mortality

Unit cost: 50000 €/case

--- Results ---

Impact: 3.947E+1 cases per year, of which the Local and Regional contributions are, respectively: ~ 0 and ~ 3.947E+01 cases per year.

Damage cost: 1.973E+6 € per year

(68% confidence interval = 6.577E+5, 5.919E+6)

Impacts and damage costs were calculated using the Simple Uniform World Model (SUWM). Estimates depend on the following five parameters: Pollutant emission rate and depletion velocity; Exposure-Response Function (ERF) of health endpoint in question; Regional receptor density and Monetary unit cost.

Sulfates - Chronic Bronchitis [Abbey 1995]

--- Health Impact ---

Pollutant: Sulfates

Emission of precursor pollutant (SO₂): 722 tons/yr

Depletion velocity: 1.86 cm/s

Endpoint: Sulfates - Chronic Bronchitis [Abbey 1995]

ERF slope: 3.9200E-05 cases/(yr.person.ug/m³)

Impact type: Morbidity

Unit cost: 169300 €/case

--- Results ---

Impact: 3.967E+0 cases per year, of which the Local and Regional contributions are, respectively: ~ 0 and $\sim 3.967E+00$ cases per year.

Damage cost: 6.717E+5 € per year

(68% confidence interval = 2.239E+5, 2.015E+6)

Impacts and damage costs were calculated using the Simple Uniform World Model (SUWM). Estimates depend on the following five parameters: Pollutant emission rate and depletion velocity; Exposure-Response Function (ERF) of health endpoint in question; Regional receptor density and Monetary unit cost.

Sulfates - net Restricted activity days [Ostro 1987]

--- Health Impact ---

Pollutant: Sulfates

Emission of precursor pollutant (SO₂): 722 tons/yr

Depletion velocity: 1.86 cm/s

Endpoint: Sulfates - net Restricted activity days [Ostro 1987]

ERF slope: 1.9800E-02 cases/(yr.person.ug/m³)

Impact type: Morbidity

Unit cost: 110 €/case

--- Results ---

Impact: 2.004E+3 cases per year, of which the Local and Regional contributions are, respectively: ~ 0 and $\sim 2.004E+03$ cases per year.

Damage cost: 2.204E+5 € per year

(68% confidence interval = 7.347E+4, 6.612E+5)

Impacts and damage costs were calculated using the Simple Uniform World Model (SUWM). Estimates depend on the following five parameters: Pollutant emission rate and depletion velocity; Exposure-Response Function (ERF) of health endpoint in question; Regional receptor density and Monetary unit cost.

Sulfates - Respiratory hospitalization [Dab 1996]

--- Health Impact ---

Pollutant: Sulfates

Emission of precursor pollutant (SO₂): 722 tons/yr

Depletion velocity: 1.86 cm/s

Endpoint: Sulfates - Respiratory hospitalization [Dab 1996]

ERF slope: 2.0700E-06 cases/(yr.person.ug/m3)

Impact type: Morbidity

Unit cost: 4320 €/case

--- Results ---

Impact: 2.095E-1 cases per year, of which the Local and Regional contributions are, respectively: ~ 0 and ~ 2.095E-01 cases per year.

Damage cost: 9.050E+2 € per year

(68% confidence interval = 3.017E+2, 2.715E+3)

Impacts and damage costs were calculated using the Simple Uniform World Model (SUWM). Estimates depend on the following five parameters: Pollutant emission rate and depletion velocity; Exposure-Response Function (ERF) of health endpoint in question; Regional receptor density and Monetary unit cost.

Sulfates - Cerebrovascular hospitalization [Wordley 1997]

--- Health Impact ---

Pollutant: Sulfates

Emission of precursor pollutant (SO2): 722 tons/yr

Depletion velocity: 1.86 cm/s

Endpoint: Sulfates - Cerebrovascular hospitalization [Wordley 1997]

ERF slope: 5.0400E-06 cases/(yr.person.ug/m3)

Impact type: Morbidity

Unit cost: 16730 €/case

--- Results ---

Impact: 5.101E-1 cases per year, of which the Local and Regional contributions are, respectively: ~ 0 and ~ 5.101E-01 cases per year.

Damage cost: 8.533E+3 € per year

(68% confidence interval = 2.844E+3, 2.559E+4)

Impacts and damage costs were calculated using the Simple Uniform World Model (SUWM). Estimates depend on the following five parameters: Pollutant emission rate and depletion velocity; Exposure-Response Function (ERF) of health endpoint in question; Regional receptor density and Monetary unit cost.

Sulfates - Chronic cough, children [Dockery 1989]

--- Health Impact ---

Pollutant: Sulfates

Emission of precursor pollutant (SO2): 722 tons/yr

Depletion velocity: 1.86 cm/s

Endpoint: Sulfates - Chronic cough, children [Dockery 1989]

ERF slope: 4.1400E-04 cases/(yr.person.ug/m³)

Impact type: Morbidity

Unit cost: 240 €/case

--- Results ---

Impact: 4.190E+1 cases per year, of which the Local and Regional contributions are, respectively: ~ 0 and ~ 4.190E+01 cases per year.

Damage cost: 1.006E+4 € per year

(68% confidence interval = 3.353E+3, 3.018E+4)

Impacts and damage costs were calculated using the Simple Uniform World Model (SUWM). Estimates depend on the following five parameters: Pollutant emission rate and depletion velocity; Exposure-Response Function (ERF) of health endpoint in question; Regional receptor density and Monetary unit cost.

Sulfates - Congestive heart failure, elderly [Schwartz/Morris 1995]

--- Health Impact ---

Pollutant: Sulfates

Emission of precursor pollutant (SO₂): 722 tons/yr

Depletion velocity: 1.86 cm/s

Endpoint: Sulfates - Congestive heart failure, elderly [Schwartz/Morris 1995]

ERF slope: 2.5900E-06 cases/(yr.person.ug/m³)

Impact type: Morbidity

Unit cost: 3260 €/case

--- Results ---

Impact: 2.621E-1 cases per year, of which the Local and Regional contributions are, respectively: ~ 0 and ~ 2.621E-01 cases per year.

Damage cost: 8.545E+2 € per year

(68% confidence interval = 2.848E+2, 2.564E+3)

Impacts and damage costs were calculated using the Simple Uniform World Model (SUWM). Estimates depend on the following five parameters: Pollutant emission rate and depletion velocity; Exposure-Response Function (ERF) of health endpoint in question; Regional receptor density and Monetary unit cost.

Sulfates - Cough, adult asthmatics [Dusseldorp 1995]

--- Health Impact ---

Pollutant: Sulfates

Emission of precursor pollutant (SO₂): 722 tons/yr

Depletion velocity: 1.86 cm/s

Endpoint: Sulfates - Cough, adult asthmatics [Dusseldorp 1995]

ERF slope: 9.3900E-03 cases/(yr.person.ug/m³)

Impact type: Morbidity

Unit cost: 45 €/case

--- Results ---

Impact: 9.503E+2 cases per year, of which the Local and Regional contributions are, respectively: ~ 0 and ~ 9.503E+02 cases per year.

Damage cost: 4.276E+4 € per year

(68% confidence interval = 1.425E+4, 1.283E+5)

Impacts and damage costs were calculated using the Simple Uniform World Model (SUWM). Estimates depend on the following five parameters: Pollutant emission rate and depletion velocity; Exposure-Response Function (ERF) of health endpoint in question; Regional receptor density and Monetary unit cost.

Sulfates - Bronchodilator use, adult asthmatics [Dusseldorp 1995]

--- Health Impact ---

Pollutant: Sulfates

Emission of precursor pollutant (SO₂): 722 tons/yr

Depletion velocity: 1.86 cm/s

Endpoint: Sulfates - Bronchodilator use, adult asthmatics [Dusseldorp 1995]

ERF slope: 4.5600E-03 cases/(yr.person.ug/m³)

Impact type: Morbidity

Unit cost: 40 €/case

--- Results ---

Impact: 4.615E+2 cases per year, of which the Local and Regional contributions are, respectively: ~ 0 and ~ 4.615E+02 cases per year.

Damage cost: 1.846E+4 € per year

(68% confidence interval = 6.153E+3, 5.538E+4)

Impacts and damage costs were calculated using the Simple Uniform World Model (SUWM). Estimates depend on the following five parameters: Pollutant emission rate and depletion velocity; Exposure-Response Function (ERF) of health endpoint in question; Regional receptor density and Monetary unit cost.

Sulfates - Lower respiratory symptoms, adult asthmatics [Dusseldorp 1995]

--- Health Impact ---

Pollutant: Sulfates

Emission of precursor pollutant (SO₂): 722 tons/yr

Depletion velocity: 1.86 cm/s

Endpoint: Sulfates - Lower respiratory symptoms, adult asthmatics [Dusseldorp 1995]

ERF slope: 1.7000E-03 cases/(yr.person.ug/m³)

Impact type: Morbidity

Unit cost: 8 €/case

--- Results ---

Impact: 1.720E+2 cases per year, of which the Local and Regional contributions are, respectively: ~ 0 and ~ 1.720E+02 cases per year.

Damage cost: 1.376E+3 € per year

(68% confidence interval = 4.587E+2, 4.128E+3)

Impacts and damage costs were calculated using the Simple Uniform World Model (SUWM). Estimates depend on the following five parameters: Pollutant emission rate and depletion velocity; Exposure-Response Function (ERF) of health endpoint in question; Regional receptor density and Monetary unit cost.

Sulfates - Cough, children asthmatics [Pope/Dockery 1992]

--- Health Impact ---

Pollutant: Sulfates

Emission of precursor pollutant (SO₂): 722 tons/yr

Depletion velocity: 1.86 cm/s

Endpoint: Sulfates - Cough, children asthmatics [Pope/Dockery 1992]

ERF slope: 1.8700E-03 cases/(yr.person.ug/m³)

Impact type: Morbidity

Unit cost: 45 €/case

--- Results ---

Impact: 1.893E+2 cases per year, of which the Local and Regional contributions are, respectively: ~ 0 and ~ 1.893E+02 cases per year.

Damage cost: 8.516E+3 € per year

(68% confidence interval = 2.839E+3, 2.555E+4)

Impacts and damage costs were calculated using the Simple Uniform World Model (SUWM). Estimates depend on the following five parameters: Pollutant emission rate and depletion velocity; Exposure-Response Function (ERF) of health endpoint in question; Regional receptor density and Monetary unit cost.

Sulfates - Bronchodilator use, children asthmatics [Roemer 1993]

--- Health Impact ---

Pollutant: Sulfates

Emission of precursor pollutant (SO₂): 722 tons/yr

Depletion velocity: 1.86 cm/s

Endpoint: Sulfates - Bronchodilator use, children asthmatics [Roemer 1993]

ERF slope: 5.4300E-04 cases/(yr.person.ug/m³)

Impact type: Morbidity

Unit cost: 40 €/case

--- Results ---

Impact: 5.495E+1 cases per year, of which the Local and Regional contributions are, respectively: ~ 0 and ~ 5.495E+01 cases per year.

Damage cost: 2.198E+3 € per year

(68% confidence interval = 7.327E+2, 6.594E+3)

Impacts and damage costs were calculated using the Simple Uniform World Model (SUWM). Estimates depend on the following five parameters: Pollutant emission rate and depletion velocity; Exposure-Response Function (ERF) of health endpoint in question; Regional receptor density and Monetary unit cost.

Sulfates - Lower respiratory symptoms, children asthmatics [Roemer 1993]

--- Health Impact ---

Pollutant: Sulfates

Emission of precursor pollutant (SO₂): 722 tons/yr

Depletion velocity: 1.86 cm/s

Endpoint: Sulfates - Lower respiratory symptoms, children asthmatics [Roemer 1993]

ERF slope: 7.2000E-04 cases/(yr.person.ug/m³)

Impact type: Morbidity

Unit cost: 8 €/case

--- Results ---

Impact: $7.287\text{E}+1$ cases per year, of which the Local and Regional contributions are, respectively: ~ 0 and $\sim 7.287\text{E}+01$ cases per year.

Damage cost: $5.829\text{E}+2$ € per year

(68% confidence interval = $1.943\text{E}+2$, $1.749\text{E}+3$)

Impacts and damage costs were calculated using the Simple Uniform World Model (SUWM). Estimates depend on the following five parameters: Pollutant emission rate and depletion velocity; Exposure-Response Function (ERF) of health endpoint in question; Regional receptor density and Monetary unit cost.

Nitrates - Mortality YOLL [Pope 2002]

--- Health Impact ---

Pollutant: Nitrates

Emission of precursor pollutant (NO_x): 1790 tons/yr

Depletion velocity: 1.03 cm/s

Endpoint: Nitrates - Mortality YOLL [Pope 2002]

ERF slope: $1.9500\text{E}-04$ cases/(yr.person.ug/m³)

Impact type: Long-term mortality

Unit cost: 50000 €/case

--- Results ---

Impact: $8.855\text{E}+1$ cases per year, of which the Local and Regional contributions are, respectively: ~ 0 and $\sim 8.855\text{E}+01$ cases per year.

Damage cost: $4.427\text{E}+6$ € per year

(68% confidence interval = $1.276\text{E}+6$, $1.328\text{E}+7$)

Impacts and damage costs were calculated using the Simple Uniform World Model (SUWM). Estimates depend on the following five parameters: Pollutant emission rate and depletion velocity; Exposure-Response Function (ERF) of health endpoint in question; Regional receptor density and Monetary unit cost.

Nitrates - Chronic Bronchitis [Abbey 1995]

--- Health Impact ---

Pollutant: Nitrates

Emission of precursor pollutant (NO_x): 1790 tons/yr

Depletion velocity: 1.03 cm/s

Endpoint: Nitrates - Chronic Bronchitis [Abbey 1995]

ERF slope: $1.9600\text{E}-05$ cases/(yr.person.ug/m³)

Impact type: Morbidity

Unit cost: 169300 €/case

--- Results ---

Impact: 8.900E+0 cases per year, of which the Local and Regional contributions are, respectively: ~ 0 and $\sim 8.900\text{E}+00$ cases per year.

Damage cost: 1.507E+6 € per year

(68% confidence interval = 5.023E+5, 4.521E+6)

Impacts and damage costs were calculated using the Simple Uniform World Model (SUWM). Estimates depend on the following five parameters: Pollutant emission rate and depletion velocity; Exposure-Response Function (ERF) of health endpoint in question; Regional receptor density and Monetary unit cost.

Nitrates - net Restricted activity days [Ostro 1987]

--- Health Impact ---

Pollutant: Nitrates

Emission of precursor pollutant (NO_x): 1790 tons/yr

Depletion velocity: 1.03 cm/s

Endpoint: Nitrates - net Restricted activity days [Ostro 1987]

ERF slope: 9.8900E-03 cases/(yr.person.ug/m³)

Impact type: Morbidity

Unit cost: 110 €/case

--- Results ---

Impact: 4.491E+3 cases per year, of which the Local and Regional contributions are, respectively: ~ 0 and $\sim 4.491\text{E}+03$ cases per year.

Damage cost: 4.940E+5 € per year

(68% confidence interval = 1.647E+5, 1.482E+6)

Impacts and damage costs were calculated using the Simple Uniform World Model (SUWM). Estimates depend on the following five parameters: Pollutant emission rate and depletion velocity; Exposure-Response Function (ERF) of health endpoint in question; Regional receptor density and Monetary unit cost.

Nitrates - Respiratory hospitalization [Dab 1996]

--- Health Impact ---

Pollutant: Nitrates

Emission of precursor pollutant (NO_x): 1790 tons/yr

Depletion velocity: 1.03 cm/s

Endpoint: Nitrates - Respiratory hospitalization [Dab 1996]

ERF slope: 1.0350E-06 cases/(yr.person.ug/m3)

Impact type: Morbidity

Unit cost: 4320 €/case

--- Results ---

Impact: 4.700E-1 cases per year, of which the Local and Regional contributions are, respectively: ~ 0 and ~ 4.700E-01 cases per year.

Damage cost: 2.030E+3 € per year

(68% confidence interval = 6.767E+2, 6.090E+3)

Impacts and damage costs were calculated using the Simple Uniform World Model (SUWM). Estimates depend on the following five parameters: Pollutant emission rate and depletion velocity; Exposure-Response Function (ERF) of health endpoint in question; Regional receptor density and Monetary unit cost.

Nitrates - Cerebrovascular hospitalization [Wordley 1997]

--- Health Impact ---

Pollutant: Nitrates

Emission of precursor pollutant (NOx): 1790 tons/yr

Depletion velocity: 1.03 cm/s

Endpoint: Nitrates - Cerebrovascular hospitalization [Wordley 1997]

ERF slope: 2.5200E-06 cases/(yr.person.ug/m3)

Impact type: Morbidity

Unit cost: 16730 €/case

--- Results ---

Impact: 1.144E+0 cases per year, of which the Local and Regional contributions are, respectively: ~ 0 and ~ 1.144E+00 cases per year.

Damage cost: 1.914E+4 € per year

(68% confidence interval = 6.380E+3, 5.742E+4)

Impacts and damage costs were calculated using the Simple Uniform World Model (SUWM). Estimates depend on the following five parameters: Pollutant emission rate and depletion velocity; Exposure-Response Function (ERF) of health endpoint in question; Regional receptor density and Monetary unit cost.

Nitrates - Chronic cough, children [Dockery 1989]

--- Health Impact ---

Pollutant: Nitrates

Emission of precursor pollutant (NOx): 1790 tons/yr

Depletion velocity: 1.03 cm/s

Endpoint: Nitrates - Chronic cough, children [Dockery 1989]

ERF slope: 2.0700E-04 cases/(yr.person.ug/m³)

Impact type: Morbidity

Unit cost: 240 €/case

--- Results ---

Impact: 9.400E+1 cases per year, of which the Local and Regional contributions are, respectively: ~ 0 and ~ 9.400E+01 cases per year.

Damage cost: 2.256E+4 € per year

(68% confidence interval = 7.520E+3, 6.768E+4)

Impacts and damage costs were calculated using the Simple Uniform World Model (SUWM). Estimates depend on the following five parameters: Pollutant emission rate and depletion velocity; Exposure-Response Function (ERF) of health endpoint in question; Regional receptor density and Monetary unit cost.

Nitrates - Congestive heart failure, elderly [Schwartz/Morris 1995]

--- Health Impact ---

Pollutant: Nitrates

Emission of precursor pollutant (NO_x): 1790 tons/yr

Depletion velocity: 1.03 cm/s

Endpoint: Nitrates - Congestive heart failure, elderly [Schwartz/Morris 1995]

ERF slope: 1.3000E-06 cases/(yr.person.ug/m³)

Impact type: Morbidity

Unit cost: 3260 €/case

--- Results ---

Impact: 5.903E-1 cases per year, of which the Local and Regional contributions are, respectively: ~ 0 and ~ 5.903E-01 cases per year.

Damage cost: 1.924E+3 € per year

(68% confidence interval = 6.413E+2, 5.772E+3)

Impacts and damage costs were calculated using the Simple Uniform World Model (SUWM). Estimates depend on the following five parameters: Pollutant emission rate and depletion velocity; Exposure-Response Function (ERF) of health endpoint in question; Regional receptor density and Monetary unit cost.

Nitrates - Cough, adult asthmatics [Dusseldorp 1995]

--- Health Impact ---

Pollutant: Nitrates

Emission of precursor pollutant (NO_x): 1790 tons/yr

Depletion velocity: 1.03 cm/s

Endpoint: Nitrates - Cough, adult asthmatics [Dusseldorp 1995]

ERF slope: 4.6900E-03 cases/(yr.person.ug/m³)

Impact type: Morbidity

Unit cost: 45 €/case

--- Results ---

Impact: 2.130E+3 cases per year, of which the Local and Regional contributions are, respectively: ~ 0 and ~ 2.130E+03 cases per year.

Damage cost: 9.583E+4 € per year

(68% confidence interval = 3.194E+4, 2.875E+5)

Impacts and damage costs were calculated using the Simple Uniform World Model (SUWM). Estimates depend on the following five parameters: Pollutant emission rate and depletion velocity; Exposure-Response Function (ERF) of health endpoint in question; Regional receptor density and Monetary unit cost.

Nitrates - Bronchodilator use, adult asthmatics [Dusseldorp 1995]

--- Health Impact ---

Pollutant: Nitrates

Emission of precursor pollutant (NO_x): 1790 tons/yr

Depletion velocity: 1.03 cm/s

Endpoint: Nitrates - Bronchodilator use, adult asthmatics [Dusseldorp 1995]

ERF slope: 2.2800E-03 cases/(yr.person.ug/m³)

Impact type: Morbidity

Unit cost: 40 €/case

--- Results ---

Impact: 1.035E+3 cases per year, of which the Local and Regional contributions are, respectively: ~ 0 and ~ 1.035E+03 cases per year.

Damage cost: 4.141E+4 € per year

(68% confidence interval = 1.380E+4, 1.242E+5)

Impacts and damage costs were calculated using the Simple Uniform World Model (SUWM). Estimates depend on the following five parameters: Pollutant emission rate and depletion velocity; Exposure-Response Function (ERF) of health endpoint in question; Regional receptor density and Monetary unit cost.

Nitrates - Lower respiratory symptoms, adult asthmatics [Dusseldorp 1995]

--- Health Impact ---

Pollutant: Nitrates

Emission of precursor pollutant (NO_x): 1790 tons/yr

Depletion velocity: 1.03 cm/s

Endpoint: Nitrates - Lower respiratory symptoms, adult asthmatics [Dusseldorp 1995]

ERF slope: 8.4800E-04 cases/(yr.person.ug/m³)

Impact type: Morbidity

Unit cost: 8 €/case

--- Results ---

Impact: 3.851E+2 cases per year, of which the Local and Regional contributions are, respectively: ~ 0 and ~ 3.851E+02 cases per year.

Damage cost: 3.081E+3 € per year

(68% confidence interval = 1.027E+3, 9.243E+3)

Impacts and damage costs were calculated using the Simple Uniform World Model (SUWM). Estimates depend on the following five parameters: Pollutant emission rate and depletion velocity; Exposure-Response Function (ERF) of health endpoint in question; Regional receptor density and Monetary unit cost.

Nitrates - Cough, children asthmatics [Pope/Dockery 1992]

--- Health Impact ---

Pollutant: Nitrates

Emission of precursor pollutant (NO_x): 1790 tons/yr

Depletion velocity: 1.03 cm/s

Endpoint: Nitrates - Cough, children asthmatics [Pope/Dockery 1992]

ERF slope: 9.3400E-04 cases/(yr.person.ug/m³)

Impact type: Morbidity

Unit cost: 45 €/case

--- Results ---

Impact: 4.241E+2 cases per year, of which the Local and Regional contributions are, respectively: ~ 0 and ~ 4.241E+02 cases per year.

Damage cost: 1.909E+4 € per year

(68% confidence interval = 6.363E+3, 5.727E+4)

Impacts and damage costs were calculated using the Simple Uniform World Model (SUWM). Estimates depend on the following five parameters: Pollutant emission rate and depletion velocity; Exposure-Response Function (ERF) of health endpoint in question; Regional receptor density and Monetary unit cost.

Nitrates - Bronchodilator use, children asthmatics [Roemer 1993]

--- Health Impact ---

Pollutant: Nitrates

Emission of precursor pollutant (NO_x): 1790 tons/yr

Depletion velocity: 1.03 cm/s

Endpoint: Nitrates - Bronchodilator use, children asthmatics [Roemer 1993]

ERF slope: 2.7100E-04 cases/(yr.person.ug/m³)

Impact type: Morbidity

Unit cost: 40 €/case

--- Results ---

Impact: 1.231E+2 cases per year, of which the Local and Regional contributions are, respectively: ~ 0 and ~ 1.231E+02 cases per year.

Damage cost: 4.922E+3 € per year

(68% confidence interval = 1.641E+3, 1.477E+4)

Impacts and damage costs were calculated using the Simple Uniform World Model (SUWM). Estimates depend on the following five parameters: Pollutant emission rate and depletion velocity; Exposure-Response Function (ERF) of health endpoint in question; Regional receptor density and Monetary unit cost.

Nitrates - Lower respiratory symptoms, children asthmatics [Roemer 1993]

--- Health Impact ---

Pollutant: Nitrates

Emission of precursor pollutant (NO_x): 1790 tons/yr

Depletion velocity: 1.03 cm/s

Endpoint: Nitrates - Lower respiratory symptoms, children asthmatics [Roemer 1993]

ERF slope: 3.6000E-04 cases/(yr.person.ug/m³)

Impact type: Morbidity

Unit cost: 8 €/case

--- Results ---

Impact: 1.635E+2 cases per year, of which the Local and Regional contributions are, respectively: ~ 0 and ~ 1.635E+02 cases per year.

Damage cost: 1.308E+3 € per year

(68% confidence interval = 4.360E+2, 3.924E+3)

Impacts and damage costs were calculated using the Simple Uniform World Model (SUWM). Estimates depend on the following five parameters: Pollutant emission rate and depletion velocity; Exposure-Response Function (ERF) of health endpoint in question; Regional receptor density and Monetary unit cost.

SO₂ - Mortality YOLL [Anderson/Toulomi 1996]

--- Health Impact ---

Pollutant: SO₂

Emission: 722 tons/yr

Depletion velocity: 0.81 cm/s

Endpoint: SO₂ - Mortality YOLL [Anderson/Toulomi 1996]

ERF slope: 5.3400E-06 cases/(yr.person.ug/m³)

Impact type: Short-term mortality

Unit cost: 75000 €/case

--- Results ---

Impact: 7.716E+0 cases per year, of which the Local and Regional contributions are, respectively: 6.600E+00 and 1.116E+00 cases per year. The local impact is 85.5% of the Total.

Damage cost: 5.787E+5 € per year

(68% confidence interval = 1.447E+5, 2.315E+6)

--- Estimation Code ---

Based on available input data, impacts and damages were calculated using the 'BEST Algorithm' in QUERI.

--- Data use ---

Of the available case study input data, these parameters were utilized: stack Height and Diameter; flue gas exhaust Temperature and Velocity; Site index; pollutant Emissions inventory and Depletion Velocities; Regional population density; detailed Local population statistics (5 by 5 km resolution); and detailed Meteorological parameters (hourly data).

--- Sensitivity analysis ---

Local concentrations were estimated using a Gaussian dispersion algorithm for urban conditions. Consequently, changing the Site index between 1 and 3 will not affect the results.

Whereas varying any of the other input parameters will have an influence on the impact/damage estimates.

SO₂ - Respiratory hospitalization [Ponce de Leon 1996]

--- Health Impact ---

Pollutant: SO₂

Emission: 722 tons/yr

Depletion velocity: 0.81 cm/s

Endpoint: SO₂ - Respiratory hospitalization [Ponce de Leon 1996]

ERF slope: 2.4000E-06 cases/(yr.person.ug/m³)

Impact type: Morbidity

Unit cost: 4320 €/case

--- Results ---

Impact: 3.468E+0 cases per year, of which the Local and Regional contributions are, respectively: 2.966E+00 and 5.016E-01 cases per year. The local impact is 85.5% of the Total.

Damage cost: 1.498E+4 € per year

(68% confidence interval = 9.103E+3, 4.494E+4)

--- Estimation Code ---

Based on available input data, impacts and damages were calculated using the 'BEST Algorithm' in QUERI.

--- Data use ---

Of the available case study input data, these parameters were utilized: stack Height and Diameter; flue gas exhaust Temperature and Velocity; Site index; pollutant Emissions inventory and Depletion Velocities; Regional population density; detailed Local population statistics (5 by 5 km resolution); and detailed Meteorological parameters (hourly data).

--- Sensitivity analysis ---

Local concentrations were estimated using a Gaussian dispersion algorithm for urban conditions. Consequently, changing the Site index between 1 and 3 will not affect the results.

Whereas varying any of the other input parameters will have an influence on the impact/damage estimates.

PM_{2.5} - Mortality YOLL [Pope 2002]

--- Health Impact ---

Pollutant: PM2.5

Emission: 99 tons/yr

Depletion velocity: 0.77 cm/s

Endpoint: PM2.5 - Mortality YOLL [Pope 2002]

ERF slope: 6.5100E-04 cases/(yr.person.ug/m3)

Impact type: Long-term mortality

Unit cost: 50000 €/case

--- Results ---

Impact: 1.301E+2 cases per year, of which the Local and Regional contributions are, respectively: 1.103E+02 and 1.973E+01 cases per year. The local impact is 84.8% of the Total.

Damage cost: 6.503E+6 € per year

(68% confidence interval = 2.168E+6, 1.0951E+7)

--- Estimation Code ---

Based on available input data, impacts and damages were calculated using the 'BEST Algorithm' in QUERI.

--- Data use ---

Of the available case study input data, these parameters were utilized: stack Height and Diameter; flue gas exhaust Temperature and Velocity; Site index; pollutant Emissions inventory and Depletion Velocities; Regional population density; detailed Local population statistics (5 by 5 km resolution); and detailed Meteorological parameters (hourly data).

--- Sensitivity analysis ---

Local concentrations were estimated using a Gaussian dispersion algorithm for urban conditions. Consequently, changing the Site index between 1 and 3 will not affect the results.

Whereas varying any of the other input parameters will have an influence on the impact/damage estimates.

PM2.5 - Chronic Bronchitis [Abbey 1995]

--- Health Impact ---

Pollutant: PM2.5

Emission: 99 tons/yr

Depletion velocity: 0.77 cm/s

Endpoint: PM2.5 - Chronic Bronchitis [Abbey 1995]

ERF slope: 6.5500E-05 cases/(yr.person.ug/m3)

Impact type: Morbidity

Unit cost: 169300 €/case

--- Results ---

Impact: 1.309E+1 cases per year, of which the Local and Regional contributions are, respectively: 1.110E+01 and 1.985E+00 cases per year. The local impact is 84.8% of the Total.

Damage cost: 2.215E+6 € per year

(68% confidence interval = 7.383E+5, 6.645E+6)

--- Estimation Code ---

Based on available input data, impacts and damages were calculated using the 'BEST Algorithm' in QUERI.

--- Data use ---

Of the available case study input data, these parameters were utilized: stack Height and Diameter; flue gas exhaust Temperature and Velocity; Site index; pollutant Emissions inventory and Depletion Velocities; Regional population density; detailed Local population statistics (5 by 5 km resolution); and detailed Meteorological parameters (hourly data).

--- Sensitivity analysis ---

Local concentrations were estimated using a Gaussian dispersion algorithm for urban conditions. Consequently, changing the Site index between 1 and 3 will not affect the results.

Whereas varying any of the other input parameters will have an influence on the impact/damage estimates.

PM2.5 - net Restricted activity days [Ostro 1987]

--- Health Impact ---

Pollutant: PM2.5

Emission: 99 tons/yr

Depletion velocity: 0.77 cm/s

Endpoint: PM2.5 - net Restricted activity days [Ostro 1987]

ERF slope: 3.3100E-02 cases/(yr.person.ug/m3)

Impact type: Morbidity

Unit cost: 110 €/case

--- Results ---

Impact: $6.612\text{E}+3$ cases per year, of which the Local and Regional contributions are, respectively: $5.609\text{E}+03$ and $1.003\text{E}+03$ cases per year. The local impact is 84.8% of the Total.

Damage cost: $7.274\text{E}+5$ € per year

(68% confidence interval = $2.425\text{E}+5$, $2.182\text{E}+6$)

--- Estimation Code ---

Based on available input data, impacts and damages were calculated using the 'BEST Algorithm' in QUERI.

--- Data use ---

Of the available case study input data, these parameters were utilized: stack Height and Diameter; flue gas exhaust Temperature and Velocity; Site index; pollutant Emissions inventory and Depletion Velocities; Regional population density; detailed Local population statistics (5 by 5 km resolution); and detailed Meteorological parameters (hourly data).

--- Sensitivity analysis ---

Local concentrations were estimated using a Gaussian dispersion algorithm for urban conditions. Consequently, changing the Site index between 1 and 3 will not affect the results.

Whereas varying any of the other input parameters will have an influence on the impact/damage estimates.

PM2.5 - Respiratory hospitalization [Dab 1996]

--- Health Impact ---

Pollutant: PM2.5

Emission: 99 tons/yr

Depletion velocity: 0.77 cm/s

Endpoint: PM2.5 - Respiratory hospitalization [Dab 1996]

ERF slope: $3.4600\text{E}-06$ cases/(yr.person.ug/m³)

Impact type: Morbidity

Unit cost: 4320 €/case

--- Results ---

Impact: $6.912\text{E}-1$ cases per year, of which the Local and Regional contributions are, respectively: $5.864\text{E}-01$ and $1.048\text{E}-01$ cases per year. The local impact is 84.8% of the Total.

Damage cost: 2.986E+3 € per year

(68% confidence interval = 9.953E+2, 8.958E+3)

--- Estimation Code ---

Based on available input data, impacts and damages were calculated using the 'BEST Algorithm' in QUERI.

--- Data use ---

Of the available case study input data, these parameters were utilized: stack Height and Diameter; flue gas exhaust Temperature and Velocity; Site index; pollutant Emissions inventory and Depletion Velocities; Regional population density; detailed Local population statistics (5 by 5 km resolution); and detailed Meteorological parameters (hourly data).

--- Sensitivity analysis ---

Local concentrations were estimated using a Gaussian dispersion algorithm for urban conditions. Consequently, changing the Site index between 1 and 3 will not affect the results.

Whereas varying any of the other input parameters will have an influence on the impact/damage estimates.

PM2.5 - Cerebrovascular hospitalization [Wordley 1997]

--- Health Impact ---

Pollutant: PM2.5

Emission: 99 tons/yr

Depletion velocity: 0.77 cm/s

Endpoint: PM2.5 - Cerebrovascular hospitalization [Wordley 1997]

ERF slope: 6.4200E-06 cases/(yr.person.ug/m3)

Impact type: Morbidity

Unit cost: 16730 €/case

--- Results ---

Impact: 1.283E+0 cases per year, of which the Local and Regional contributions are, respectively: 1.088E+00 and 1.945E-01 cases per year. The local impact is 84.8% of the Total.

Damage cost: 2.146E+4 € per year

(68% confidence interval = 7.153E+3, 6.438E+4)

--- Estimation Code ---

Based on available input data, impacts and damages were calculated using the 'BEST Algorithm' in QUERI.

--- Data use ---

Of the available case study input data, these parameters were utilized: stack Height and Diameter; flue gas exhaust Temperature and Velocity; Site index; pollutant Emissions inventory and Depletion Velocities; Regional population density; detailed Local population statistics (5 by 5 km resolution); and detailed Meteorological parameters (hourly data).

--- Sensitivity analysis ---

Local concentrations were estimated using a Gaussian dispersion algorithm for urban conditions. Consequently, changing the Site index between 1 and 3 will not affect the results.

Whereas varying any of the other input parameters will have an influence on the impact/damage estimates.

PM2.5 - Chronic cough, children [Dockery 1989]

--- Health Impact ---

Pollutant: PM2.5

Emission: 99 tons/yr

Depletion velocity: 0.77 cm/s

Endpoint: PM2.5 - Chronic cough, children [Dockery 1989]

ERF slope: 6.9100E-04 cases/(yr.person.ug/m3)

Impact type: Morbidity

Unit cost: 240 €/case

--- Results ---

Impact: 1.380E+2 cases per year, of which the Local and Regional contributions are, respectively: 1.171E+02 and 2.094E+01 cases per year. The local impact is 84.9% of the Total.

Damage cost: 3.313E+4 € per year

(68% confidence interval = 1.104E+4, 9.939E+4)

--- Estimation Code ---

Based on available input data, impacts and damages were calculated using the 'BEST Algorithm' in QUERI.

--- Data use ---

Of the available case study input data, these parameters were utilized: stack Height and Diameter; flue gas exhaust Temperature and Velocity; Site index; pollutant Emissions inventory and Depletion Velocities; Regional population density; detailed Local population statistics (5 by 5 km resolution); and detailed Meteorological parameters (hourly data).

--- Sensitivity analysis ---

Local concentrations were estimated using a Gaussian dispersion algorithm for urban conditions. Consequently, changing the Site index between 1 and 3 will not affect the results.

Whereas varying any of the other input parameters will have an influence on the impact/damage estimates.

PM2.5 - Congestive heart failure, elderly [Schwartz/Morris 1995]

--- Health Impact ---

Pollutant: PM2.5

Emission: 99 tons/yr

Depletion velocity: 0.77 cm/s

Endpoint: PM2.5 - Congestive heart failure, elderly [Schwartz/Morris 1995]

ERF slope: 4.3300E-06 cases/(yr.person.ug/m3)

Impact type: Morbidity

Unit cost: 3260 €/case

--- Results ---

Impact: 8.650E-1 cases per year, of which the Local and Regional contributions are, respectively: 7.338E-01 and 1.312E-01 cases per year. The local impact is 84.8% of the Total.

Damage cost: 2.820E+3 € per year

(68% confidence interval = 9.400E+2, 8.460E+3)

--- Estimation Code ---

Based on available input data, impacts and damages were calculated using the 'BEST Algorithm' in QUERI.

--- Data use ---

Of the available case study input data, these parameters were utilized: stack Height and Diameter; flue gas exhaust Temperature and Velocity; Site index; pollutant Emissions inventory and Depletion Velocities; Regional population density; detailed

Local population statistics (5 by 5 km resolution); and detailed Meteorological parameters (hourly data).

--- Sensitivity analysis ---

Local concentrations were estimated using a Gaussian dispersion algorithm for urban conditions. Consequently, changing the Site index between 1 and 3 will not affect the results.

Whereas varying any of the other input parameters will have an influence on the impact/damage estimates.

PM2.5 - Cough, adult asthmatics [Dusseldorp 1995]

--- Health Impact ---

Pollutant: PM2.5

Emission: 99 tons/yr

Depletion velocity: 0.77 cm/s

Endpoint: PM2.5 - Cough, adult asthmatics [Dusseldorp 1995]

ERF slope: 1.5680E-02 cases/(yr.person.ug/m3)

Impact type: Morbidity

Unit cost: 45 €/case

--- Results ---

Impact: 3.132E+3 cases per year, of which the Local and Regional contributions are, respectively: 2.657E+03 and 4.752E+02 cases per year. The local impact is 84.8% of the Total.

Damage cost: 1.410E+5 € per year

(68% confidence interval = 4.700E+4, 4.230E+5)

--- Estimation Code ---

Based on available input data, impacts and damages were calculated using the 'BEST Algorithm' in QUERI.

--- Data use ---

Of the available case study input data, these parameters were utilized: stack Height and Diameter; flue gas exhaust Temperature and Velocity; Site index; pollutant Emissions inventory and Depletion Velocities; Regional population density; detailed Local population statistics (5 by 5 km resolution); and detailed Meteorological parameters (hourly data).

--- Sensitivity analysis ---

Local concentrations were estimated using a Gaussian dispersion algorithm for urban conditions. Consequently, changing the Site index between 1 and 3 will not affect the results.

Whereas varying any of the other input parameters will have an influence on the impact/damage estimates.

PM2.5 - Bronchodilator use, adult asthmatics [Dusseldorp 1995]

--- Health Impact ---

Pollutant: PM2.5

Emission: 99 tons/yr

Depletion velocity: 0.77 cm/s

Endpoint: PM2.5 - Bronchodilator use, adult asthmatics [Dusseldorp 1995]

ERF slope: 7.6200E-03 cases/(yr.person.ug/m3)

Impact type: Morbidity

Unit cost: 40 €/case

--- Results ---

Impact: 1.522E+3 cases per year, of which the Local and Regional contributions are, respectively: 1.291E+03 and 2.309E+02 cases per year. The local impact is 84.8% of the Total.

Damage cost: 6.089E+4 € per year

(68% confidence interval = 2.030E+4, 1.827E+5)

--- Estimation Code ---

Based on available input data, impacts and damages were calculated using the 'BEST Algorithm' in QUERI.

--- Data use ---

Of the available case study input data, these parameters were utilized: stack Height and Diameter; flue gas exhaust Temperature and Velocity; Site index; pollutant Emissions inventory and Depletion Velocities; Regional population density; detailed Local population statistics (5 by 5 km resolution); and detailed Meteorological parameters (hourly data).

--- Sensitivity analysis ---

Local concentrations were estimated using a Gaussian dispersion algorithm for urban conditions. Consequently, changing the Site index between 1 and 3 will not affect the results.

Whereas varying any of the other input parameters will have an influence on the impact/damage estimates.

PM2.5 - Lower respiratory symptoms, adult asthmatics [Dusseldorp 1995]

--- Health Impact ---

Pollutant: PM2.5

Emission: 99 tons/yr

Depletion velocity: 0.77 cm/s

Endpoint: PM2.5 - Lower respiratory symptoms, adult asthmatics [Dusseldorp 1995]

ERF slope: 2.8400E-03 cases/(yr.person.ug/m3)

Impact type: Morbidity

Unit cost: 8 €/case

--- Results ---

Impact: 5.674E+2 cases per year, of which the Local and Regional contributions are, respectively: 4.813E+02 and 8.606E+01 cases per year. The local impact is 84.8% of the Total.

Damage cost: 4.539E+3 € per year

(68% confidence interval = 1.513E+3, 1.362E+4)

--- Estimation Code ---

Based on available input data, impacts and damages were calculated using the 'BEST Algorithm' in QUERI.

--- Data use ---

Of the available case study input data, these parameters were utilized: stack Height and Diameter; flue gas exhaust Temperature and Velocity; Site index; pollutant Emissions inventory and Depletion Velocities; Regional population density; detailed Local population statistics (5 by 5 km resolution); and detailed Meteorological parameters (hourly data).

--- Sensitivity analysis ---

Local concentrations were estimated using a Gaussian dispersion algorithm for urban conditions. Consequently, changing the Site index between 1 and 3 will not affect the results.

Whereas varying any of the other input parameters will have an influence on the impact/damage estimates.

PM2.5 - Cough, children asthmatics [Pope/Dockery 1992]

--- Health Impact ---

Pollutant: PM2.5r

Emission: 99 tons/yr

Depletion velocity: 0.77 cm/s

Endpoint: PM2.5 - Cough, children asthmatics [Pope/Dockery 1992]

ERF slope: 3.1200E-03 cases/(yr.person.ug/m3)

Impact type: Morbidity

Unit cost: 45 €/case

--- Results ---

Impact: 6.233E+2 cases per year, of which the Local and Regional contributions are, respectively: 5.287E+02 and 9.455E+01 cases per year. The local impact is 84.8% of the Total.

Damage cost: 2.805E+4 € per year

(68% confidence interval = 9.350E+3, 8.415E+4)

--- Estimation Code ---

Based on available input data, impacts and damages were calculated using the 'BEST Algorithm' in QUERI.

--- Data use ---

Of the available case study input data, these parameters were utilized: stack Height and Diameter; flue gas exhaust Temperature and Velocity; Site index; pollutant Emissions inventory and Depletion Velocities; Regional population density; detailed Local population statistics (5 by 5 km resolution); and detailed Meteorological parameters (hourly data).

--- Sensitivity analysis ---

Local concentrations were estimated using a Gaussian dispersion algorithm for urban conditions. Consequently, changing the Site index between 1 and 3 will not affect the results.

Whereas varying any of the other input parameters will have an influence on the impact/damage estimates.

PM2.5 - Bronchodilator use, children asthmatics [Roemer 1993]

--- Health Impact ---

Pollutant: PM2.5

Emission: 99 tons/yr

Depletion velocity: 0.77 cm/s

Endpoint: PM2.5 - Bronchodilator use, children asthmatics [Roemer 1993]

ERF slope: 9.0700E-04 cases/(yr.person.ug/m3)

Impact type: Morbidity

Unit cost: 40 €/case

--- Results ---

Impact: 1.812E+2 cases per year, of which the Local and Regional contributions are, respectively: 1.537E+02 and 2.749E+01 cases per year. The local impact is 84.8% of the Total.

Damage cost: 7.248E+3 € per year

(68% confidence interval = 2.416E+3, 2.174E+4)

--- Estimation Code ---

Based on available input data, impacts and damages were calculated using the 'BEST Algorithm' in QUERI.

--- Data use ---

Of the available case study input data, these parameters were utilized: stack Height and Diameter; flue gas exhaust Temperature and Velocity; Site index; pollutant Emissions inventory and Depletion Velocities; Regional population density; detailed Local population statistics (5 by 5 km resolution); and detailed Meteorological parameters (hourly data).

--- Sensitivity analysis ---

Local concentrations were estimated using a Gaussian dispersion algorithm for urban conditions. Consequently, changing the Site index between 1 and 3 will not affect the results.

Whereas varying any of the other input parameters will have an influence on the impact/damage estimates.

PM2.5 - Lower respiratory symptoms, children asthmatics [Roemer 1993]

--- Health Impact ---

Pollutant: PM2.5

Emission: 99 tons/yr

Depletion velocity: 0.77 cm/s

Endpoint: PM2.5 - Lower respiratory symptoms, children asthmatics [Roemer 1993]

ERF slope: 1.2020E-03 cases/(yr.person.ug/m3)

Impact type: Morbidity

Unit cost: 8 €/case

--- Results ---

Impact: $2.401\text{E}+2$ cases per year, of which the Local and Regional contributions are, respectively: $2.037\text{E}+02$ and $3.642\text{E}+01$ cases per year. The local impact is 84.8% of the Total.

Damage cost: $1.921\text{E}+3$ € per year

(68% confidence interval = $6.403\text{E}+2$, $5.763\text{E}+3$)

--- Estimation Code ---

Based on available input data, impacts and damages were calculated using the 'BEST Algorithm' in QUERI.

--- Data use ---

Of the available case study input data, these parameters were utilized: stack Height and Diameter; flue gas exhaust Temperature and Velocity; Site index; pollutant Emissions inventory and Depletion Velocities; Regional population density; detailed Local population statistics (5 by 5 km resolution); and detailed Meteorological parameters (hourly data).

--- Sensitivity analysis ---

Local concentrations were estimated using a Gaussian dispersion algorithm for urban conditions. Consequently, changing the Site index between 1 and 3 will not affect the results.