CISMOB
Interreg Europe

universidade de aveiro

Stockholm University

Technical paper 5

Estimating road traffic emissions and related costs in Sweden from 2000 to 2014

Authors E. Macedo, P. Tafidis

PP1, PP2

1. Introduction

Although there have been several improvements in vehicle technology and vehicle emission regulation across Europe [2], road transport sector is still responsible for significant contributions to emissions of Carbon Monoxide (CO), Carbon Dioxide (CO2), Nitrogen Oxides (NOX), Hydrocarbons, specially volatile organic compounds (VOC) and non-methane volatile organic compounds (NMVOC), and particulate matter (PM). In Sweden, this sector was responsible for approximately 20million tonnes of CO2 emissions in 2014 [4].

The present study is concerned with an analysis of major pollutant on-road emissions for all relevant road vehicle types from 2000 to 2014 based on Sweden car fleet data. It estimates emissions and costs, considering the contribution of each vehicle category to the total of emissions.

European Union
European Regional
Development Fund

The report is organized as follows:

- The second section presents the methodology and data source used in the study.
- The third section provides an analysis of emissions and associated costs in Sweden, a project partner in CISMOB project.

2. Methodology and data sources used

For obtaining the pollutant emissions the software COPERT v.4 [3] was used with the country-specific data of car fleet of Sweden.

To analyze and compare the environmental effects of different types of vehicles, we considered several pollutants, such as CO, CO2, VOC, NMVOC, NOX and PM2.5. SO2 emissions could not be estimated, since data misses information on annual fuel consumption, which is crucial for such estimation. Costs associated to the emissions of the pollutants PM 2.5, NMVOC and NOX are based in the damage costs of main pollutants from transport for 2010 mentioned in [2]. CO2 costs are based on the reference-value of 90€ per tonne [2].

The damage costs values for each country of the CISMOB consortium are displayed in the following table.

Country	CO2	NMVOC	NOX	PM 2.5		
				highway	rural	urban
Portugal	90	1048	1957	18371	49095	196335
Romania		1796	22893	56405	84380	231620
Spain		1135	4964	14429	48012	195252
Sweden		974	5247	14578	50210	197450

Table 1. Damage costs of main pollutants from transport, in € per tonne [2].

This report emission estimations are based on the results provided by the COPERT traffic emission model. Emissions were calculated using the COPERT v.4 software and COPERT database format. Swedish vehicle fleet and activity data with the latest official statistics was purchased in order to get access to information such as, population, mileage in km/year, percentage of activity on urban, rural and highway areas, …

Regarding the estimation of emissions in Sweden, emissions of several pollutants were computed and then, associated costs per km were calculated taking into account the values reported in Table 1.

3. Analysis of Sweden vehicle fleet emissions

3.1. Total Emissions and Costs

The following table shows the annual emissions of CO, CO2, VOC, NMVOC, NOX and PM2.5 for all types of vehicles of the Swedish fleet.

	2000	2001	2002	2003	2004	2005	2006	2007
CO	458782,35	421084,30	400520,18	372891,10	341586,33	322426,83	293450,65	262818,70
CO2	18224050,49	18528516,24	19219355,02	19588053,94	20165794,73	20488805,62	20601093,26	21124651,11
VOC	65469,05	59094,92	55549,60	51293,50	46758,00	43576,56	39400,94	34980,60
NMVOC	61200,51	55058,73	51630,64	47557,14	43223,87	40272,54	36350,78	32205,88
NOX	116613,07	107851,91	104620,41	100051,33	96748,10	93157,98	87454,28	81786,62
PM2.5	3792,83	3862,84	4108,15	4228,86	4332,71	4210,21	3949,77	3702,06

	2008	2009	2010	2011	2012	2013	2014
CO	228754,72	200983,52	178338,81	191126,69	157478,13	135488,55	120446,10
CO2	20798401,07	20503672,30	20896294,74	20652395,68	19855267,43	19831994,57	19831802,82
VOC	30383,16	26737,62	23531,75	27563,74	22801,79	19651,28	17439,13
NMVOC	27923,10	24454,06	21491,45	25402,68	20935,53	17993,77	15913,39
NOX	75247,34	67312,05	66806,67	76416,44	69039,84	65832,83	60651,02
PM2.5	3463,19	3118,82	3267,13	3799,55	3422,85	3194,01	2856,06

Table 2. Total emissions in Sweden in tonnes.

The CO2 emission is by far the most contributor to pollute the environment, presenting in 2014 more than 19,8 million tonnes. Comparing the values of the total amount of emissions of all pollutants between 2000 and 2014, we can see that there was an augment of almost 6%. A closer look to the total amount of CO, VOC, NMVOC, NOX and PM2.5 emissions (Figure 1) shows a decreasing tendency on the total emissions until 2010. In 2011, there was an augment, and CO and NOX are the most contributors to the augment. Specifically, there was an augment of approximately 7% and 14% for the total emissions of CO and NOX, respectively. There has been a decreasing in the total emission values since 2011.

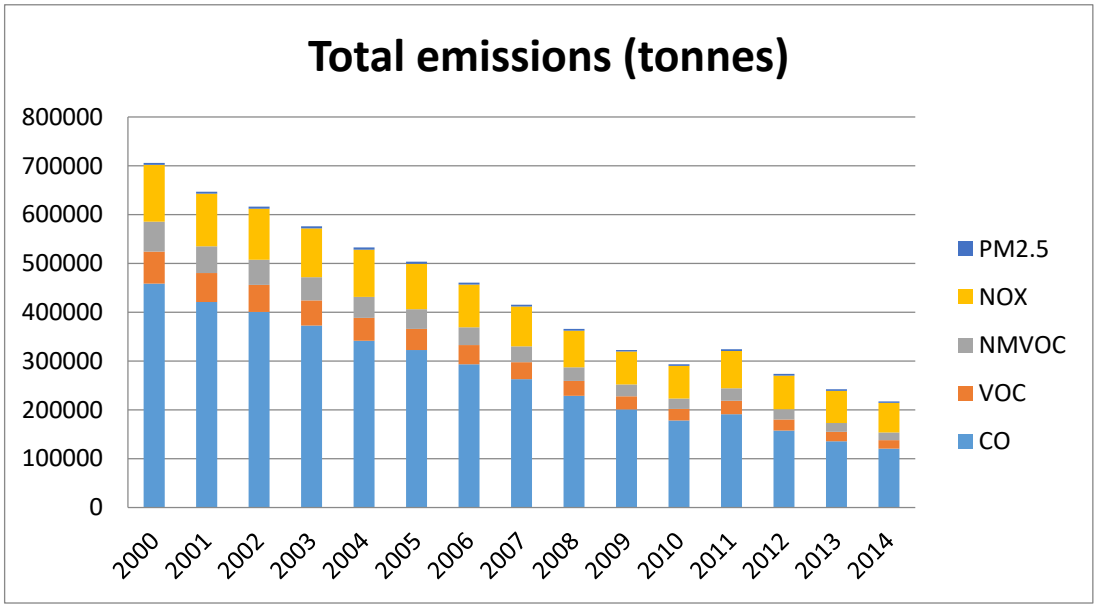

Figure 1. Total emissions of CO, VOC, NMVOC, NOX and PM2.5 (tonnes).

Table 3 presents the emission costs by each pollutant, given in Million Euros, and Figure 2 presents the total costs in Million Euros.

	2000	2001	2002	2003	2004	2005	2006	2007
CO2	1640,16	1667,57	1729,74	1762,92	1814,92	1843,99	1854,10	1901,22
NMVOC	59,61	53,63	50,29	46,32	42,10	39,23	35,41	31,37
NOX	611,87	565,90	548,94	524,97	507,64	488,80	458,87	429,13
PM2.5	434,67	442,84	472,77	487,08	497,60	481,80	451,08	425,01

	2008	2009	2010	2011	2012	2013	2014
CO2	1871,86	1845,33	1880,67	1858,72	1786,97	1784,88	1784,86
NMVOC	27,20	23,82	20,93	24,74	20,39	17,526	15,50
NOX	394,82	353,19	350,53	400,96	362,25	345,42	318,24
PM2.5	400,42	361,14	380,35	442,06	400,46	374,90	336,13

Table 3. Emission costs in Sweden in Million €.

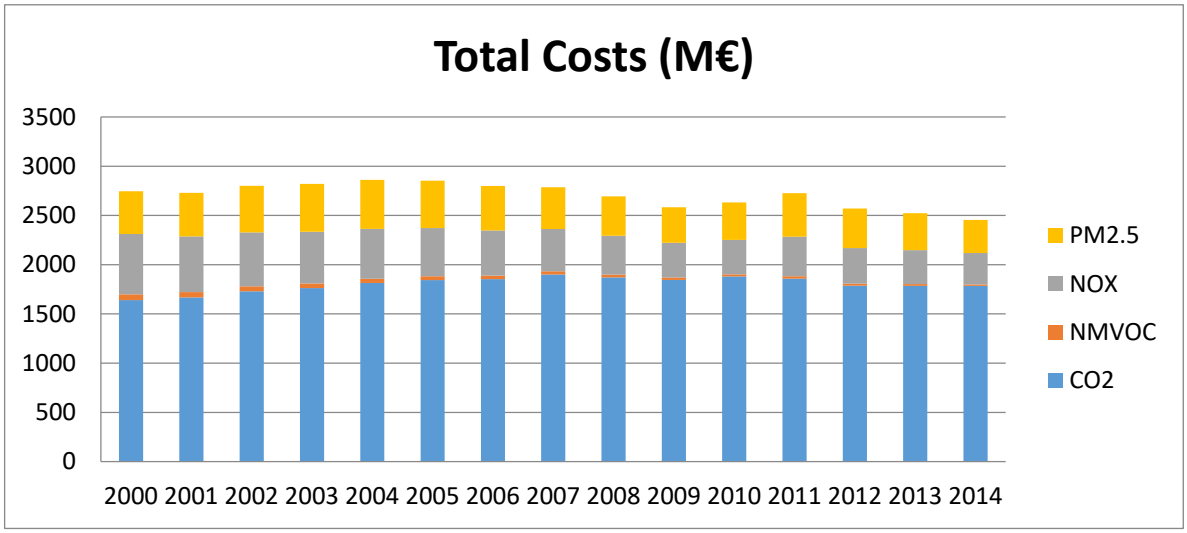

Figure 2. Total costs in Portugal in Million €.

From Table 3, it can be observed that the costs with CO2 have always been above 1640M€. In average, the CO2 costs are approximately 1802M€. The costs with NOX have been decreasing until 2010, reaching almost 351M€. In 2011, it augments at about 50M€ and then it tends to decrease. Comparing the values between 2000 and 2014, we can mention a reduction of almost 48%. With respect to the costs with NMVOC emissions, they have been decreasing until 2010, with an augment in 2011, and then they tend to decrease. The costs with PM 2.5 have been increasing until 2004, decreasing until 2009, and in 2010, there was again an augment. Since then, there can be observed a decreasing tendency in the costs with PM 2.5. Comparing the costs with NMVOC and PM 2.5 in 2000 and 2014, we can verify that there was reductions of almost 74% and 23%, respectively.

The following table and figure show the emission costs per km (€/km).

	2000	2001	2002	2003	2004	2005	2006	2007
CO2	0,02255	0,02258	0,02265	0,02265	0,02273	0,02259	0,02236	0,02205
NMVOC	0,00082	0,00073	0,00066	0,00060	0,00053	0,00048	0,00043	0,00036
NOX	0,00841	0,00766	0,00719	0,00675	0,00636	0,00599	0,00553	0,00498
PM2.5	0,00598	0,00600	0,00619	0,00626	0,00623	0,00590	0,00544	0,00493
	2008	**2009**	**2010**	**2011**	**2012**	**2013**	**2014**	
CO2	0,02183	0,02151	0,02146	0,02116	0,02090	0,02069	0,02043	
NMVOC	0,00032	0,00028	0,00024	0,00028	0,00024	0,00020	0,00018	
NOX	0,00460	0,00412	0,00400	0,00456	0,00424	0,00400	0,00364	
PM2.5	0,00467	0,00421	0,00434	0,00503	0,00468	0,00435	0,00385	

Table 4. Emission costs in Sweden in €/km.

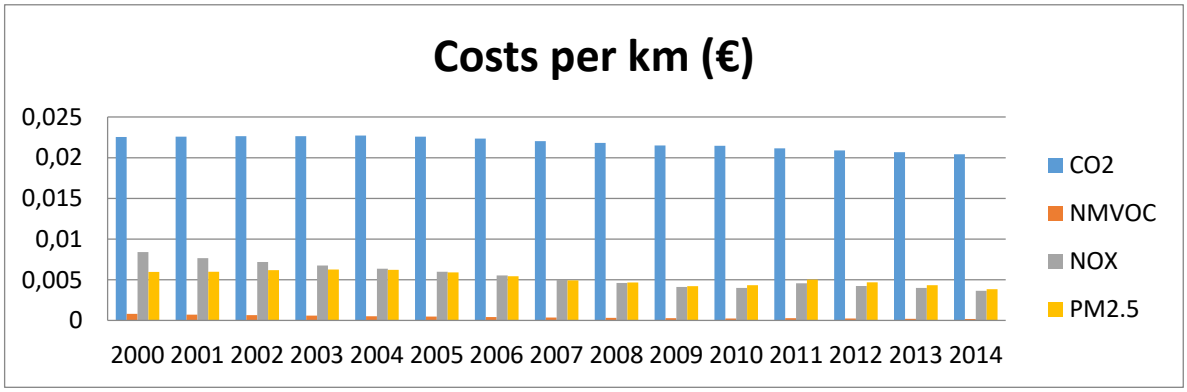

Figure 3. Costs per km (€).

It can be observed that in the studied period, CO2 presents the highest values, with values always above 0,02€, while NMVOC presents the lowest. Comparing the costs with CO2 in 2000 and in 2014, we can verify a reduction of only 9%. The costs per km of NOX and PM 2.5 are very close to each other over the years. The highest value of PM 2.5 was achieved in 2003. Since 2003, the costs with PM 2.5 have in general been decreasing until 2009. Then, there was an augmenting period until 2011, and a decreasing tendency followed, reaching 0,0038€ in 2014. Comparing the values of NOX between 2000 and 2014, we can observe a reduction around 57%.

3.2. Emissions by type of vehicles

The following figures are displayed using a logarithmic scale (to show magnitude) in order to emphasize the differences between the pollutant emissions.

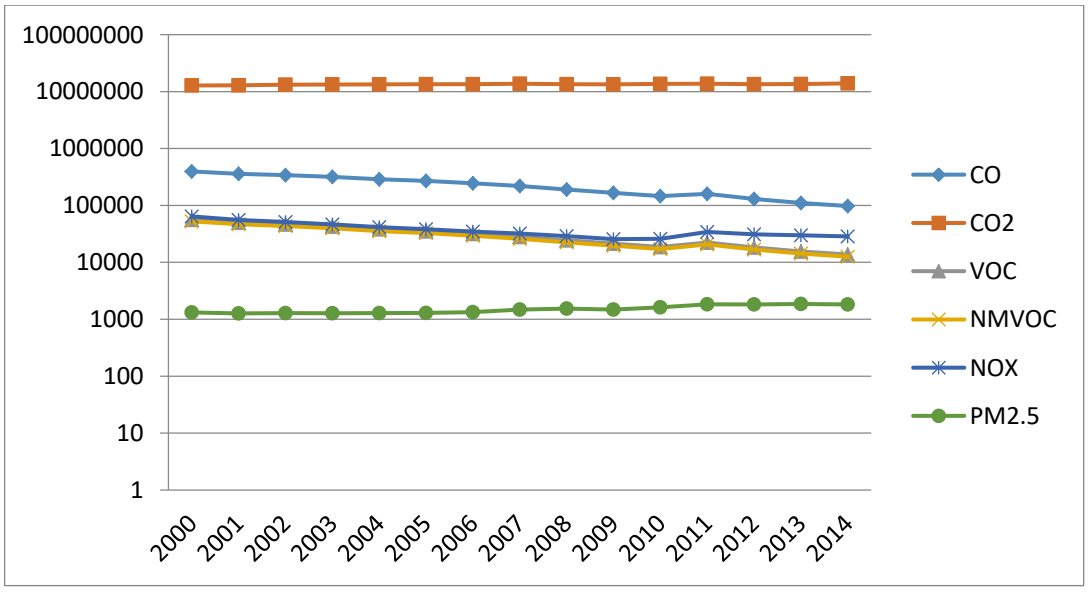

Figure 4. Passenger Cars – annual emissions in tonnes (logarithmic scale).

Regarding the emissions of pollutants by each type of vehicles, we can see from Figure 4 that the emissions of CO2 for the passenger cars (PC) are, in average, around 13,4 million tonnes. Comparing the CO2 emissions between 2000 and 2014, it can be verified an augment of almost 9%. With respect to CO, NOX, VOC and NMVOC, we can observe a decreasing tendency until 2010 (2009 for NOX), and then such values suffer an increase until 2011. Since 2011, the emissions of these pollutants tend to decrease, and comparing the values between 2000 and 2014, the emissions decreased around 75% (CO), 76% (VOC and NMVOC), 55% (NOX). We can see that since 2007, the PM 2.5 emissions were above 1450 tonnes. Comparing the values in 2000 and in 2014, we can verify an augment of approximately, 38%.

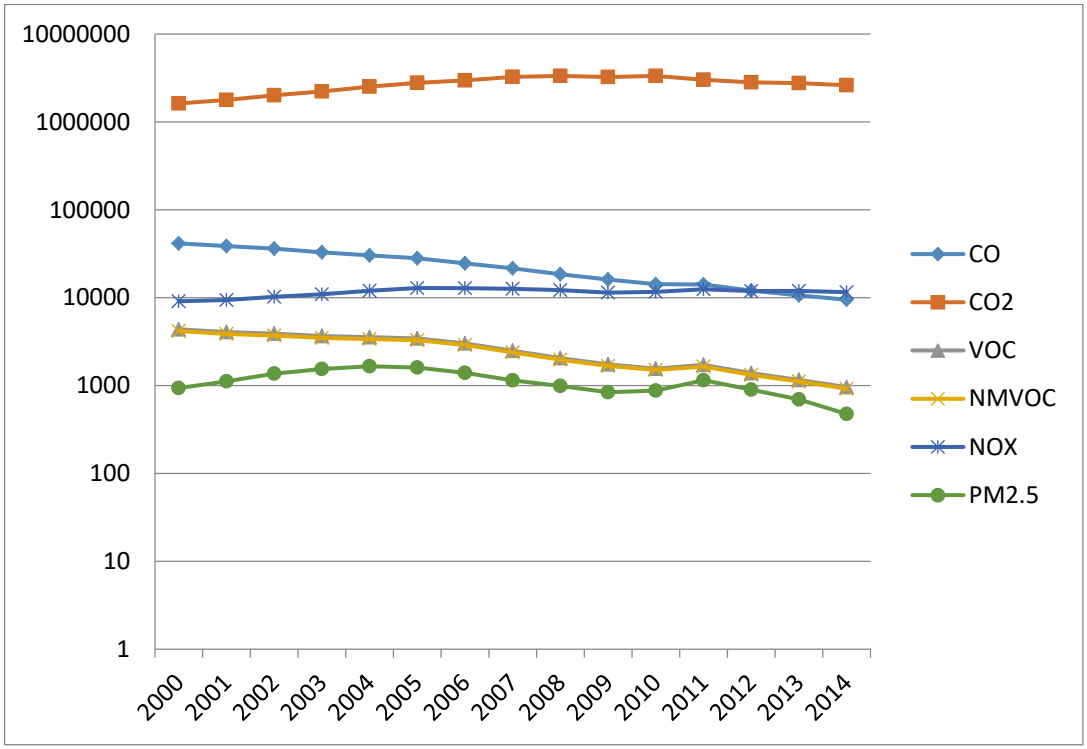

Figure 5. Light Commercial Vehicles – annual emissions in tonnes (logarithmic scale).

Concerning the emissions from LCV, no specific tendency can be pointed out. The highest value of CO2 was achieved in 2010 (almost 3,4 million tonnes). Comparing such value with that of 2014, we can verify a reduction of 22%. The emissions of CO, NMVOC and VOC have been in general decreasing until 2011, where an augment was registered. Then, the values tend to decrease, and comparing the emissions of such pollutants between 2000 and 2014, it can be verified a reduction of approximately, 77% for CO, 78% for NMVOC and VOC. Regarding the PM 2.5 emission we can observe an increasing behavior until 2004, then it decreases. There can be observed an increase in 2011 and then the decreasing tendency remains. Comparing the values between 2000 and 2014, we can see a reduction around 49%. It can be observed that since 2013, the emissions of NOX are greater than CO.

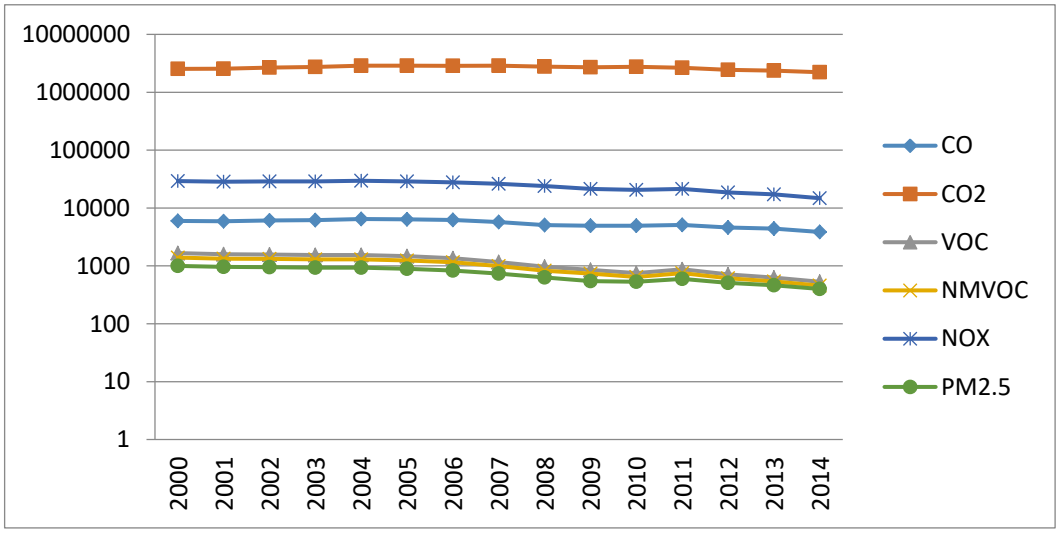

Figure 6. Heavy Duty Trucks – annual emissions in tonnes (logarithmic scale).

Annual total CO2 emissions increased, in general, between 2000 and 2005, where its maximum of almost 2,9 million tonnes was achieved. From Figure 6 we can see a slight tendency to a decrease of CO2 emissions since 2010. In the studied period, the average of CO2 emissions was around 2,7 million tonnes. Comparing the values between 2000 and 2014, there was a reduction around 13%. It can be observed that HDT produce many more NOX than CO emissions, when compared to PC and LCV. In average, the difference of NOX with CO emissions is 18894 tonnes. We can say that in general, there has been a more pronounced decreasing in the annual total emissions of VOC, NMVOC and PM 2.5. There can be verified a reduction in NOX, CO, VOC, NMVOC and PM 2.5 since 2011. Specifically, comparing such values with those obtained in 2014, there was a reduction around 31% for NOX, 24,5% for CO, 39,2% for VOC and NMVOC, and almost 33% for PM 2.5.

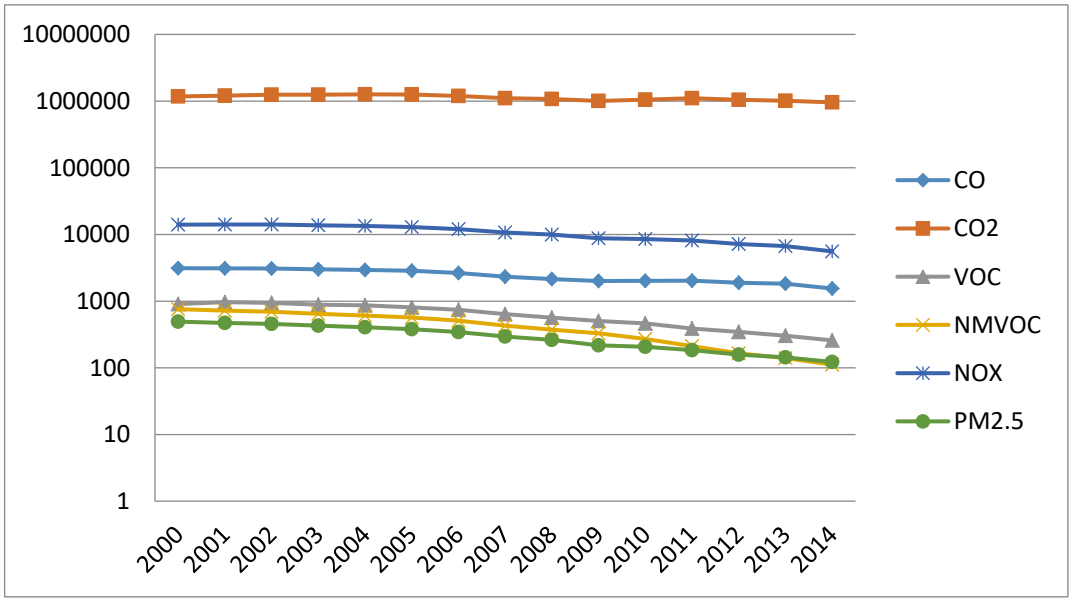

Figure 7. Buses – annual emissions in tonnes (logarithmic scale).

European Union
European Regional
Development Fund

Concerning the buses fleet, the above figure shows that CO2 emissions have a more homogeneous behavior, than the other pollutants, which exhibit, in general, a decreasing tendency since 2000. In average, the CO2 annual total emissions was 1,13 million tonnes. Once again, contrary to what PC and LCV data suggest, there is more NOX than CO emissions. In average, the difference of NOX with CO emissions was 8228 tonnes. Comparing the emissions of all pollutants between 2000 and 2014, there were reductions around 18%, 51%, 72%, 85%, 60% and 75%, for CO2, CO, VOC, NMVOC, NOX and PM 2.5, respectively.

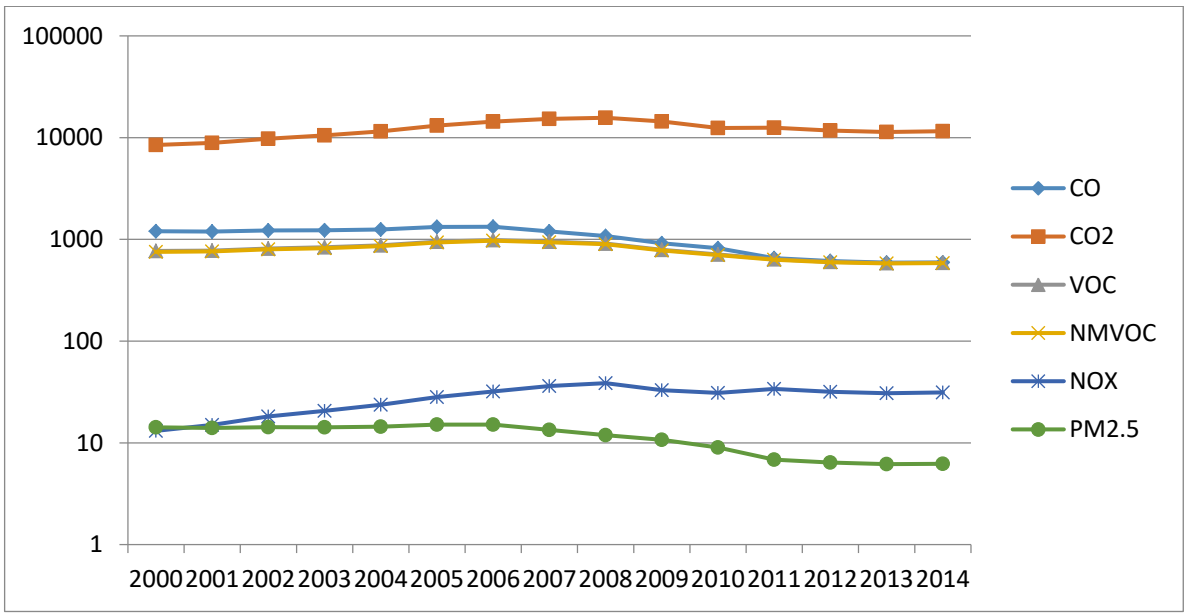

Figure 8. Mopeds – annual emissions in tonnes (logarithmic scale).

Regarding Mopeds, it can be observed an increased behavior of the CO2 emissions until 2008, where the maximum of 15665 tonnes was achieved. Since then, there can be observed, in general, a decreasing tendency. Comparing the values in 2000 and in 2014, there was an augment of more than 32% in the CO2 emissions. The annual total emissions of NOX have been presenting a similar behavior of increasing until 2008. It then tends to decrease, with a slight augment in 2011. Since then, the behavior is not stable. In particular, there was an increase between 2013 and 2014. The behavior of CO, VOC and NMVOC emissions over the years were very similar to each other, increasing until 2006, reaching the maximum values, and then, tend to decrease. Comparing the total annual emissions in 2000 and in 2014, we can point out reductions in the order of 51% for CO, 24% for VOC and 23% for NMVOC. With respect to the emissions of PM 2.5, it can be observed that the maximum was achieved in 2005, and was around 15 tonnes, and then it tends to decrease, reaching in 2014, its minimum value of 6,23 tonnes.

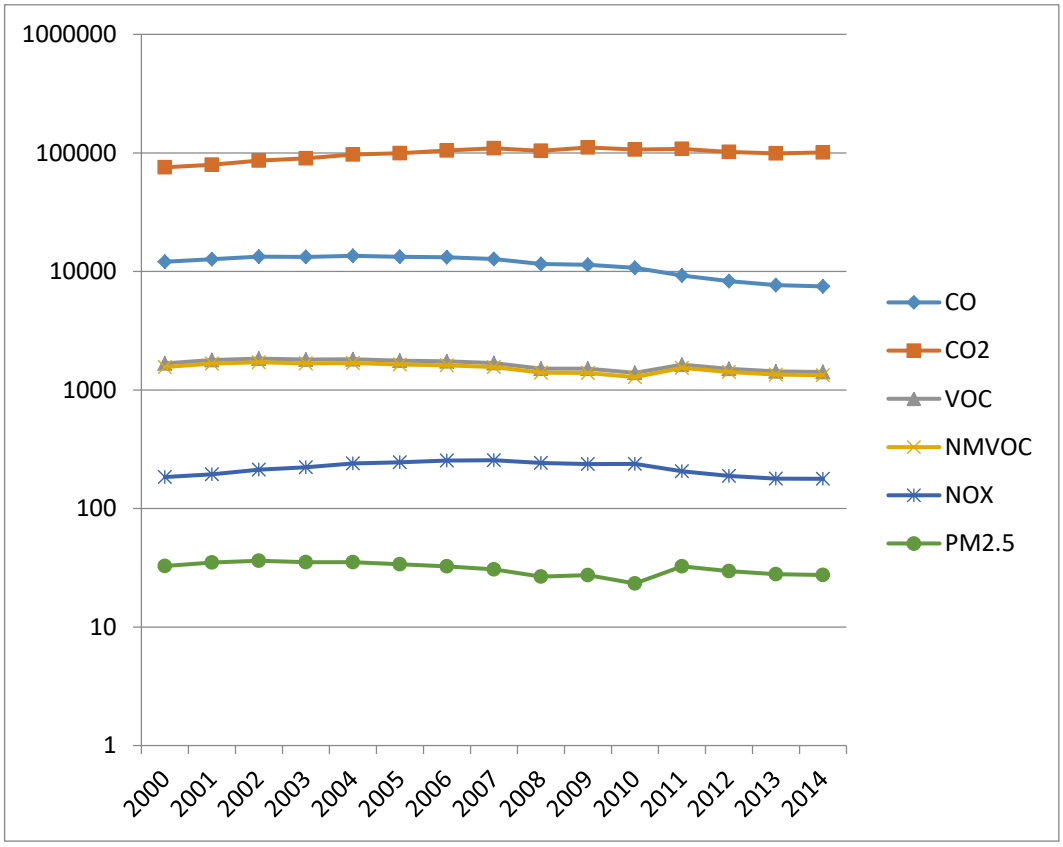

Figure 9. Motorcycles – annual emissions in tonnes (logarithmic scale).

From Figure 9, it can be observed that the annual emissions of CO2 have, in general, been increasing until 2009, reaching the maximum value of approximately, 111196 tonnes. Comparing the emissions in 2000 and 2014, there was an augment of 33%. The annual emissions of VOC, NMVOC and PM 2.5 presented a similar behavior over the years, achieving minimum values in 2010, increasing in 2011, and decreasing since then. There can be verified a reduction around 15%, 14,7%, and 16% for VOC, NMVOC and PM 2.5, respectively. Regarding the total emissions of CO, we can see that, in general, have been increasing until 2004, attaining the maximum of approximately, 13544 tonnes, and since then, have been decreasing to the minimum around 7477 tonnes. This represents a decrease of almost 45%. The NOX emissions increased between 2000 and 2007, and then tend, in general, to decrease. Comparing the values in 2000 and 2014, there can be pointed out a reduction of only 4%, approximately.

3.3. Analysis of Costs by technology – CO2

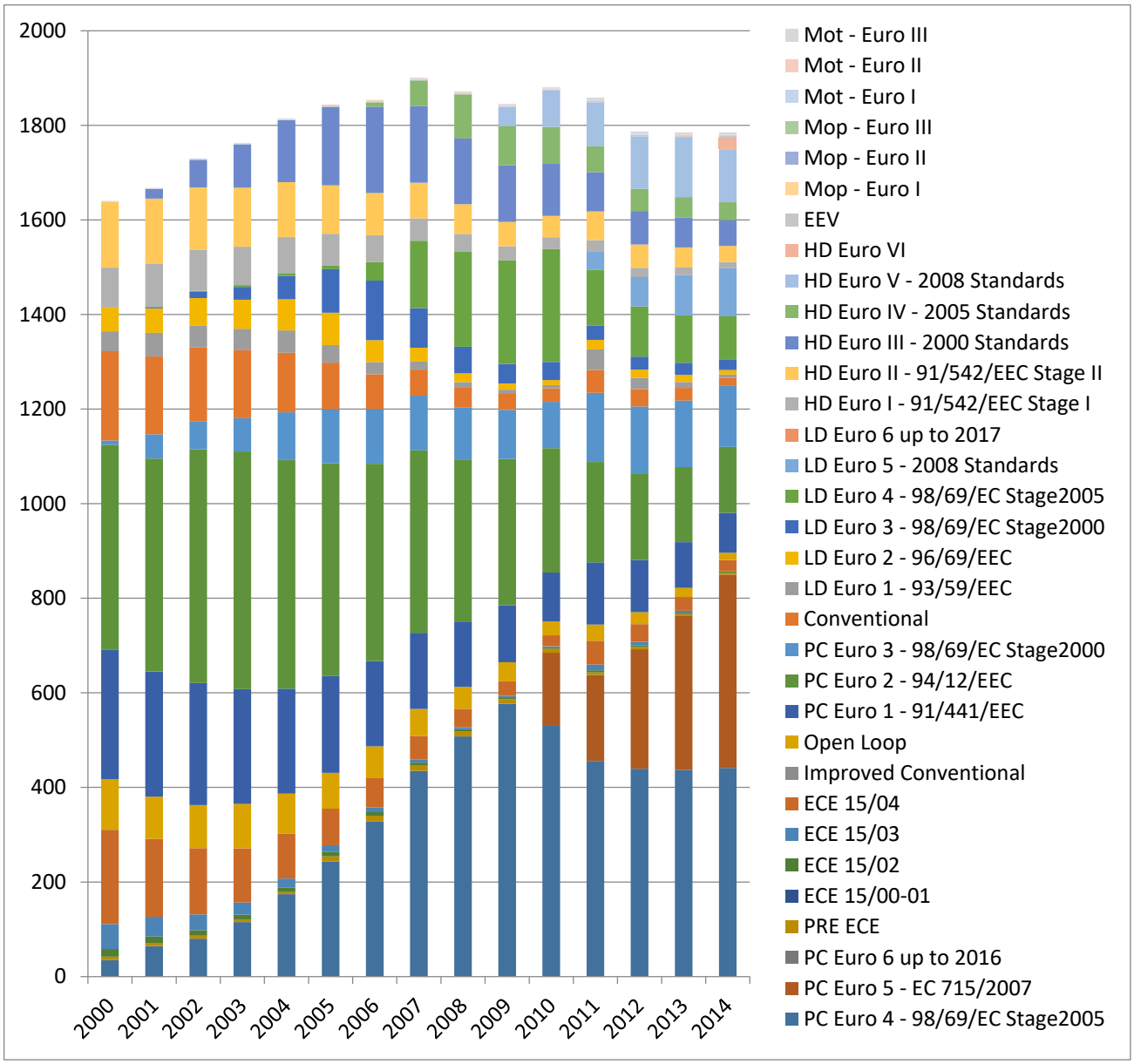

Figure 10. Total Costs of CO2 by technology in Million €.

From Figure 10, we can see that the total costs with CO2 emissions increased until 2007, and then some variations occurred to the end of the studied period. The highest cost was registered in 2007, and it was around 1901 million €. The costs in 2014 was approximately, 1785 million €, representing an augment of almost 9%, facing 2000. The most contributing technologies are PC Euro 2, PC Euro 1 and PC Euro 4. We can

also mention that PC Euro 5 had a contribution on the variation of costs, in particular since 2010, the costs with such vehicles tend to increase up to an augment of 164% in 2014. The costs with PC Euro 2 vehicles increased until 2003, with values around 503 million €. Then, the costs have been decreasing to 2014, presenting a reduction of more than 72%, facing the maximum in 2003. With respect to the PC Euro 1 vehicle technology, the costs have been decreasing since 2000, and comparing the values in 2000, with those in 2014, we can verify a reduction of 69%. The costs with PC Euro 4 vehicles have been increasing until 2009, and then tend to decrease. In 2014, there can be observed a slight augment in these costs. Comparing the highest value of 2009, with that of 2014, we can see a reduction of almost 24%.

3.4. Analysis of Costs by technology – NMVOC

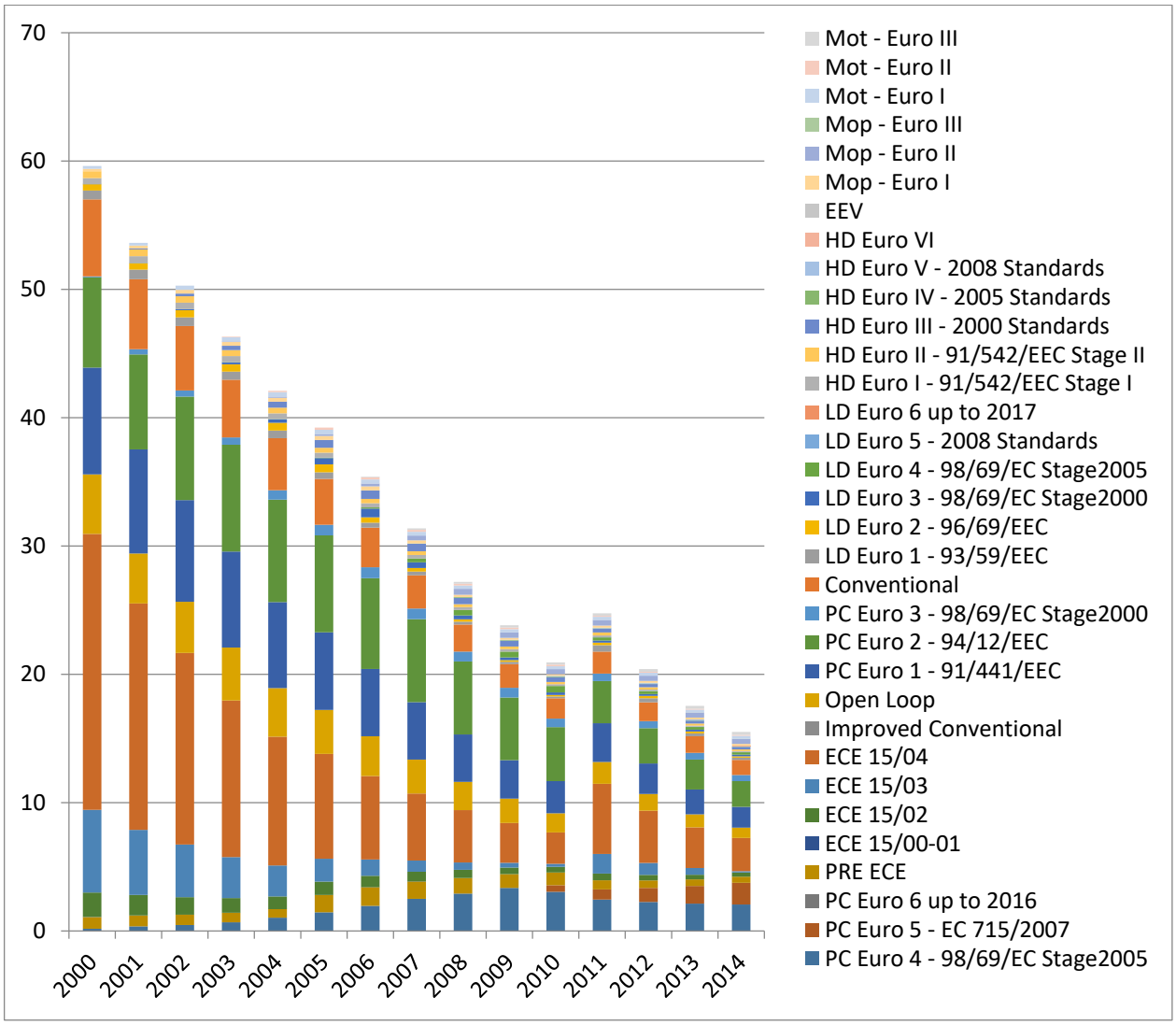

Figure 11. Total Costs of NMVOC by technology in Million €.

A first observation is that the costs with NMVOC emissions have been decreasing until 2011, where an augment was registered. Then, the costs tend to decrease. The highest value, almost 60M€, was registered in 2000. In 2014, the costs with NMVOC emissions presented a reduction of almost 74% facing 2000. The most contributing technologies for the decreasing tendency on the costs are ECE 15/04, PC Euro 1 and PC Euro 2. The norm ECE 15/04 is the major responsible for the decreasing behavior, but is also the responsible for the increasing in costs in 2011. There can be observed that the costs with the other two main technologies have been decreasing over the years.

3.5. Analysis of Costs by technology – NOX

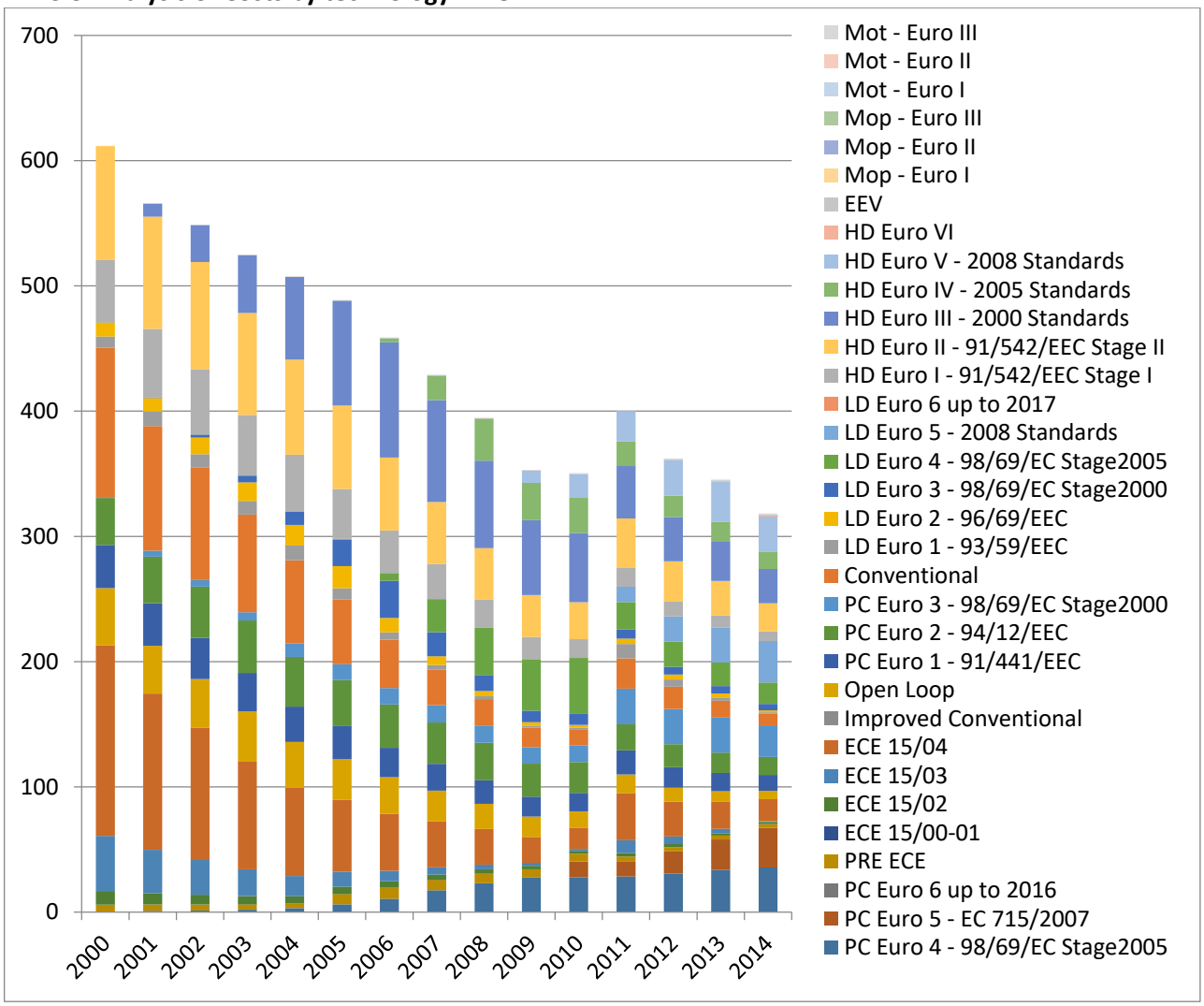

Figure 12. Total Costs of NOX by technology in Million €.

The total costs with NOX emissions achieved the maximum of almost 612M€ in 2000 and then, have been decreasing until 2010, presenting a reduction of almost 43% facing 2000. In 2011, there was registered an

augment around 14% facing 2010. Then, such costs tend to decrease and in 2014 the total costs were around 318M€. Comparing the costs between 2000 and 2014, there was a reduction of almost 48%. The most contributing technologies for the decreasing tendency on the costs are ECE 15/04 and Conventional. The norm ECE 15/04 is the major responsible for the decreasing behavior, but is also the responsible for the increasing in costs in 2011. Comparing the costs with ECE 15/04 vehicles between 2000 and 2014, it can be verified a reduction of more than 88%. There can be observed that the costs with Conventional technology vehicles have been decreasing over the years, but there was also registered an augment in 2011. Regarding the Conventional vehicles, it can be verified a reduction of more than 92% in the studied period.

3.6. Analysis of Costs by technology – PM 2.5

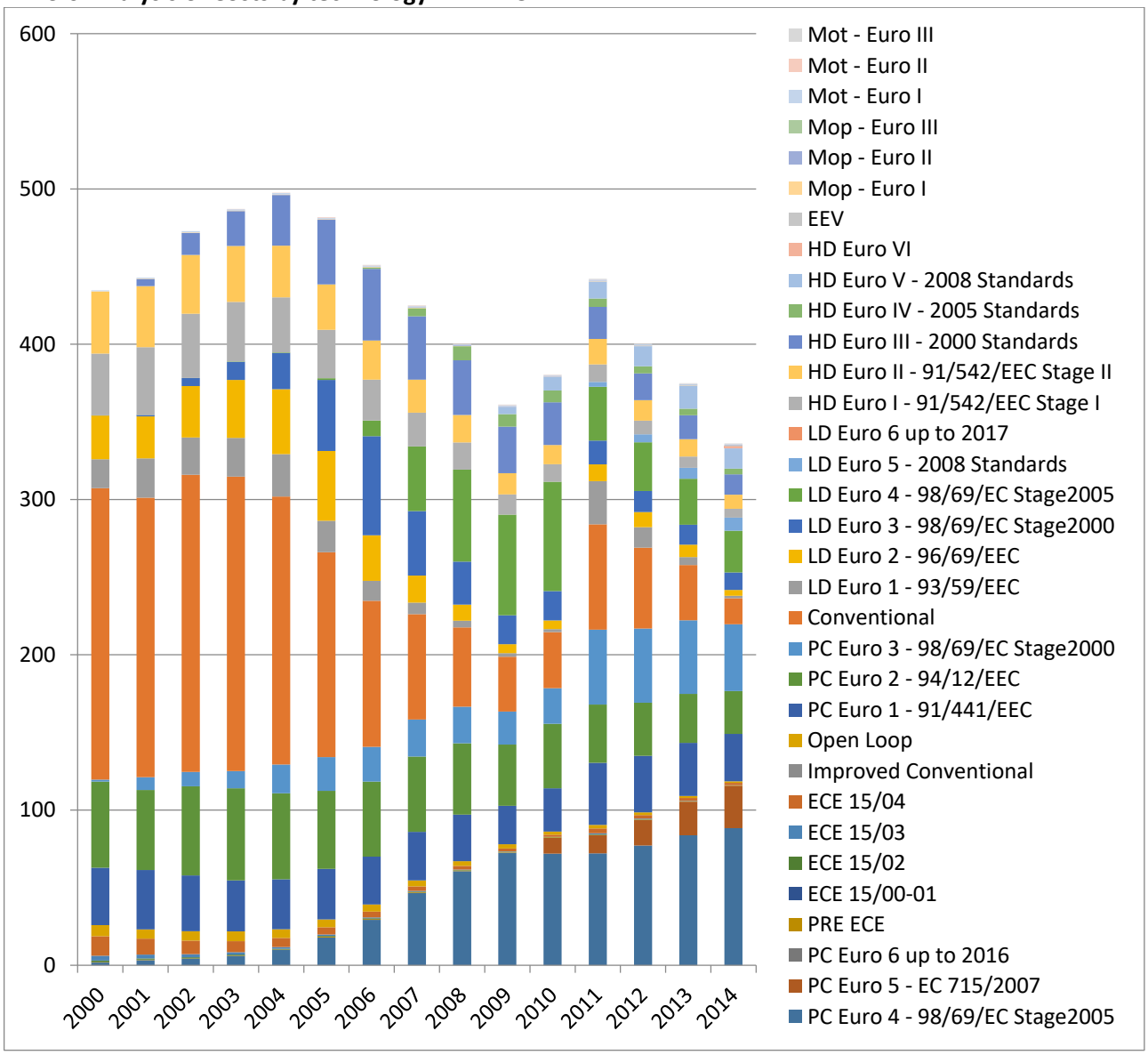

Figure 13. Total Costs of PM2.5 by technology in Million €.

A first observation is that the costs with PM 2.5 emissions have not been homogeneous in the studied period. In particular, we can observe that the costs have been increasing until 2004, where the maximum of almost 498M€ was registered. Then, the costs have been decreasing until 2009 and increasing until 2011. Since 2011, the costs with such emissions have been decreasing. Comparing the values between 2000 and 2014, there can be verified a reduction of almost 23%.

The most contributing technologies for the variations on the behaviour are Conventional and PC Euro 4. The costs with Conventional vehicles have been decreasing from 2000 to 2010, with reductions in the order of 81%. In 2011, the costs with such vehicles augment of almost 32M€, then decrease until 2014, with a reduction of more than 75%, facing 2011. Regarding the costs with PC Euro 4 vehicles, we can see that there have been increasing until 2009. Then, there was a slight reduction, and the costs have been increasing since 2010. In particular, when comparing the costs with such vehicles between 2000 and 2014, we can verify that there was an augment around 4926%.

References

[1] Agência Portuguesa do Ambiente, REA2016 - Relatório do estado do ambiente em Portugal, 2016, available at

http://sniamb.apambiente.pt/infos/geoportaldocs/REA/REA2016/REA2016.pdf

[2] EEA - European Environment Agency, *Explaining road transport emissions: A non-technical guide*, EEA Report, 2016, ISBN 978-92-9213-723-6, doi: 10.2800/71804, available at

https://www.eea.europa.eu/publications/explaining-road-transport-emissions

[3] European Commission, DG Mobility and Transport, Update of the Handbook of external costs of transport, Ricardo-AEA – Final Report, London, 2014, available at

http://ec.europa.eu/transport/sites/transport/files/themes/sustainable/studies/doc/2014-handbook-external-costs-transport.pdf

[4] Emisia, 2015, 'Copert 4' (http://emisia.com/copert).