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IMPROVED METHODOLOGY FOR ROAD EMISSIONS CALCULATION: THE CASE OF PORTUGAL

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ABSTRACT

A new national methodology to estimate road transportation emissions was developed with the main objective of improving emission estimates for those pollutants that are most dependent on the vehicle class and abatement technology. Emissions were estimated with a detailed level of disaggregation allowing the evaluation of measures aiming key source groups rather than road traffic in general. Those measures include reduction of speed limits, changes in fleet age or engine capacity, introduction of new technologies, among others. The methodology is coherent with the National Emission Inventory in terms of assumptions, activity data and emission factors.

Key Words: Road Transport, Emissions, Climate Change, Air Quality

1. INTRODUCTION

Emission estimates are required for various objectives. In first place, at national level, each country is required to submit emission estimates under the Convention on Long Range Transboundary Air Pollution (CLRTAP) and under the Framework convention on Climate Change (UNFCCC). The rapid increase in road traffic emissions in the last decade makes this sector one of the most important topics. In the other hand, the accomplishment of air quality at regional and city level involves the use of diagnosis and predictive models which require the elaboration of detailed emission inventories. Therefore, the emission inventories must be complete, reliable, and accurate.

Preferably the emission inventory for road sources should be based in knowledge of traffic flow and travelling conditions. However this information is usually limited to major roads. That is the case in Portugal where traffic monitoring is restricted to toll highways (about 2000 km in 2003), and some point survey in major non-toll highways and national roads. Given the incompleteness of these data, total emissions must be estimated from fuel consumption, i.e. coordinating a bottom-up approach together with a top-down approach. The proposed methodology to estimate

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emissions from road transportation uses a combination of country-specific and international methodologies and emission factors.

Transportation emissions from the analysed countries are responsible for similar shares from overall emissions, with the sole exception of Norway. Moreover, the share of road transportation within transport emissions is very high (most values greater than 90%).

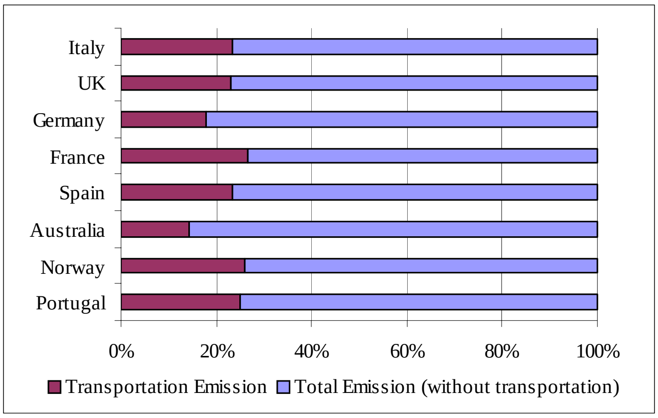

Figure 1. Share of transportation emissions (CO_2 equivalent) from the overall emissions (Source: UNFCCC, 2002).

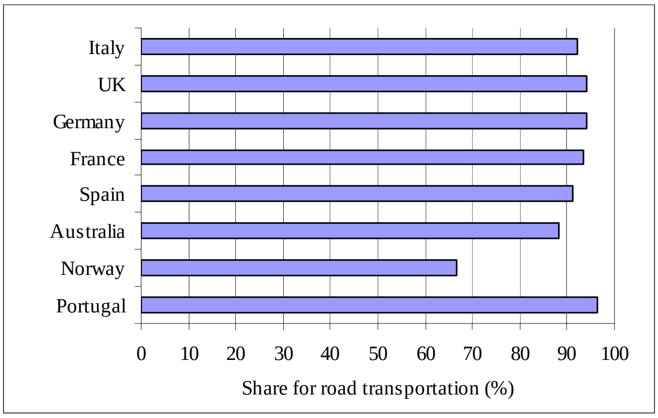

Figure 2. Share of road transportation emissions (CO_2 equivalent) from overall transport emissions (Source: UNFCCC, 2002).

2. METHODOLOGY

The model for exhaust emission estimate follows a country specific integrated methodology translated into a Visual Basic for Applications® (VBA) software tool linked with Microsoft Excel® spreadsheets. This model is compatible and based extensively in EMEP/CORINAIR Emission Inventory handbook (EEA,2002) and reproduces emission factors that were derived from the COPERT III Computer programme to calculate emissions from road transport (Ntziachristos and Samaras, 2000). Most of the countries under the UNFCCC which submitted annual inventories of greenhouse gas emissions by sources and removals by sinks used a combination of country-specific and IPCC methodologies and emissions factors. National emissions inventories from other countries show that COPERT model is commonly used among parties to estimate emissions from road transportation.

Data flow is summarized in Figure 3 from where several main steps may be identified as follows:

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- Estimate kilometres driven per vehicle type, driving conditions and vehicle technology;
- Estimate fuel consumption per vehicle type, driving conditions and vehicle technology (bottom-up approach);
- Correct fuel consumption using bottom-up approach in conjunction with top-down approach;
- Emission factors, corrected for hot and cold-start emissions;
- Determine emissions from kilometres driven or fuel consumption

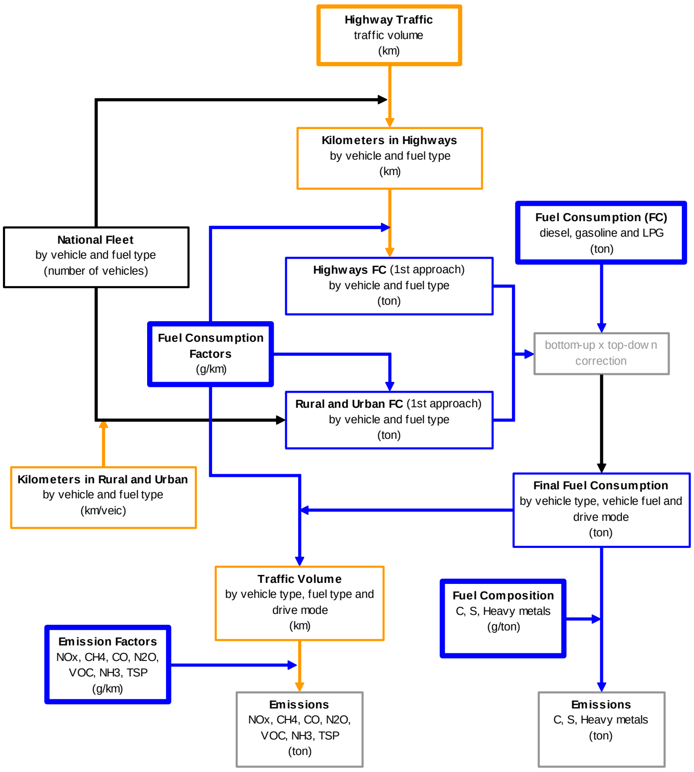


Figure 3. Methodology flow chart for road transport emission calculation.

The number of vehicles in active fleet was derived from sales and abatements statistics and adapted to EMEP/CORINAIR classification.

Table 1. Vehicle fleet.

	Vehicle Type	**1990**	**1995**	**2000**	**2003**
Light Vehicles	Passenger Cars	1,549,449	2,421,077	3,221,482	3,456,494
	Light Duty Vehicles	478,615	710,583	1,045,933	1,163,035
	Mopeds	834,692	708,016	581,340	505,335
	Motorcycles	51,394	111,836	175,957	200,735
	Sum of Light Vehicles	2,914,149	3,951,512	5,024,712	5,325,599
	% of Light Vehicles	96.4	96.6	97.0	96.9
Heavy Vehicles	Heavy Duty Vehicles	103,000	134,000	149,000	162,000
	Bus	1,132	1,355	1,482	1,616
	Coach	5,433	5,249	5,799	4,376
	Sum of Heavy Vehicles	109,565	140,604	156,281	167,992
	% of Heavy Vehicles	3.6	3.4	3.0	3.1
	TOTAL VEHICLES	**3,023,714**	**4,092,116**	**5,180,993**	**5,493,591**

Vehicle exhaust emissions and fuel consumption are strongly dependent on speed. Three driving modes where individualized in accordance with source categories SNAP97 from CORINAIR/EMEP methodology: urban, rural and highway. For each driving mode average speeds had to be set by vehicle type. Several information sources were used to establish average circulation speeds for each vehicle type.

Table 2. Assumed vehicle speeds by driving mode and vehicle type.

Driving Mode	**Vehicle Type**	**Assumed Speed (km/h)**	**Source**
Highway	Passenger Car (PassCar)	124	PNAC, 2003
	Light Duty Vehicles (LDV)	124	PNAC, 2003
	Heavy Duty Vehicles (HDV)	90	Maximum Legal Value
	Coaches	90	Maximum Legal Value
	Motorcycles	124	PNAC, 2003
Rural	Passenger Car (PassCar)	70	Maximum Legal Value
	Light Duty Vehicles (LDV)	70	Maximum Legal Value
	Heavy Duty Vehicles (HDV)	60	Maximum Legal Value
	Coaches	60	Maximum Legal Value
	Mopeds	40	Maximum Legal Value
	Motorcycles	70	Maximum Legal Value
Urban	Passenger Car (PassCar)	24.9	Gois et al., 2005
	Light Duty Vehicles (LDV)	24.9	Gois et al., 2005
	Heavy Duty Vehicles (HDV)	24.9	Gois et al., 2005
	Buses	14.8	Carris, 2005
	Coaches	24.9	Gois et al., 2005
	Mopeds	24.9	Gois et al., 2005
	Motorcycles	24.9	Gois et al., 2005

Fuel consumption under highway driving mode was estimated for each fuel using a bottom up approach based on estimates of distance driven in this driving mode.

$$Highway_{FC(f,y)} = \sum_{c}\sum_{t}\left[Highway_{Km(c,t,f,y)} \times FC_{(c,t,f,Hway)}\right] \times 10^{-6} \tag{1}$$

Where,

- $Highway_{FC(f,y)}$ = fuel consumption of fuel type f in highway driving mode by vehicles of all classes in year y (km/yr);
- $Highway_{km(c,t,f,y)}$ = total kilometres driven in highway net-road by vehicles of class c, with technology t, using fuel f in year y (km/yr);
- $FC_{(c,t,f,Hway)}$ = fuel consumption factor for vehicle type c, with technology t, using fuel f in highway driving mode (g/km);
- c = vehicle class or type: light passenger, LDV, HDV, etc;
- t = vehicle technology: PRE-ECE, ECE, Euro I, Euro II, etc;
- f = fuel type (gasoline, diesel or LPG);
- y = civil year.

Fuel consumption under urban and rural driving modes was estimated simply by subtracting fuel consumption estimated in highway mode from total fuel sales, at national level.

Individual fuel use under rural and urban driving conditions was finally determined from the number of vehicles, kilometres driven in urban and rural modes and, fuel consumption factors for all vehicle categories according with equation 3.

$$\begin{aligned}
Rural_{1stFC(c,t,f,y)} &= T_{class(c,t,f,y)} \times Km_{rural(c,f,y)} \times FC_{(c,t,f,s)} \times 10^{6} \\
Urban_{1stFC(c,t,f,y)} &= T_{class(c,t,f,y)} \times Km_{urban(c,f,y)} \times FC_{(c,t,f,s)} \times 10^{6}
\end{aligned} \tag{3}$$

Where,

- $Rural_{1stFC(c,t,f,y)}$, $Urban_{1stFC(c,t,f,y)}$ = first approach fuel consumption in rural and urban areas made by vehicles of class c, with technology t, using fuel f in year y (t);
- $T_{class(c,t,f,y)}$ = number of vehicles of class c, with technology t, using fuel f in year y;
- $Km_{rural(c,f,y)}$, $Km_{urban(c,f,y)}$ = rural and urban kilometres driven per vehicle of class c, using fuel f in year y (km/vehicle);
- $FC_{(c,t,f,s)}$ = fuel consumption factor for vehicles of class c, with technology t, using fuel f, at speed s (g/km).

Fuel adjustments are necessary because presently in the process of splitting total fuel among car types and fuel types not all class percentages add to unity. Therefore a correction must be made to make total fuel consumption equal original statistical data. Urban and rural fuel consumption estimates were corrected by the following factor for car type c, technology t, fuel f, driving mode d and year y.

$$Correc_{Factor(f,y)} = \frac{\left[Total_{FC(f,y)} - Highway_{FC(f,y)}\right]}{\sum_c \sum_t \left[Rural_{1stFC(c,t,f,y)} + Urban_{1stFC(c,t,f,y)}\right]} \tag{4}$$

Correction factors are later applied to the first approach fuel consumption under rural and urban driving conditions in the following manner:

$$\begin{aligned} Urban_{FC(f,y)} &= Correc_{Factor(f,y)} \times \sum_c \sum_t \left[Urban_{1stFC(c,t,f,y)}\right] \\ Rural_{FC(f,y)} &= Correc_{Factor(f,y)} \times \sum_c \sum_t \left[Rural_{1stFC(c,t,f,y)}\right] \end{aligned} \tag{5}$$

This correction guarantees that emission estimates are in accordance with good practices (IPCC, 2000; IPCC, 1996). Although emissions were derived from estimate of vehicle driven kilometres and from fuel consumption per kilometre (bottom-up approach), they where corrected for total national fuel sales (top-down correction).

Final activity, in kilometres, is estimated according with total fuel consumption in the following manner:

$$\begin{aligned} Km_{urban(c,t,f,y)} &= \frac{\left[Urban_{FC(c,t,f,y)} \times 10^6\right]}{FC_{(c,t,f,s)}} \\ Km_{rural(c,t,f,y)} &= \frac{\left[Rural_{FC(c,t,f,y)} \times 10^6\right]}{FC_{(c,t,f,s)}} \\ Km_{total(c,t,f,y)} &= Km_{highway(c,t,f,y)} + Km_{urban(c,t,f,y)} + Km_{rural(c,t,f,y)} \end{aligned} \tag{6}$$

Where,

- $Km_{total(c,t,f,y)}$, $Km_{highway(c,t,f,y)}$, $Km_{urban(c,t,f,y)}$, $Km_{rural(c,t,f,y)}$ = total driven distance under all driving modes estimated for vehicles of class c, with technology t, using fuel f in year y (km);
- $Urban_{FC(c,t,f,y)}$, $Rural_{FC(c,t,f,y)}$ = total fuel consumption allocated to vehicles of class c, equipped with technology t, using fuel type f, under urban and rural driving conditions in year y (t);
- $FC_{(c,t,f,s)}$ = fuel consumption factor for vehicles of class c, with technology t, using fuel f, at speed s (g/km).

3. RESULTS

Distance driven has increased steadily between 1990 and 2002. The increase in highway circulation, which has grown 7.8 times in twelve years, reflects not only the growth of the Portuguese highway road-net, but also an increase in intensity of road use. For the same period, rural and urban circulation has increased 2.0 and 1.6 times, respectively. Total road traffic activity has increased 110.7% since 1990. From 2002 to 2003 total road traffic activity registered a slight decrease of 0.47%, probably the result of an increase of oil prices in last years.

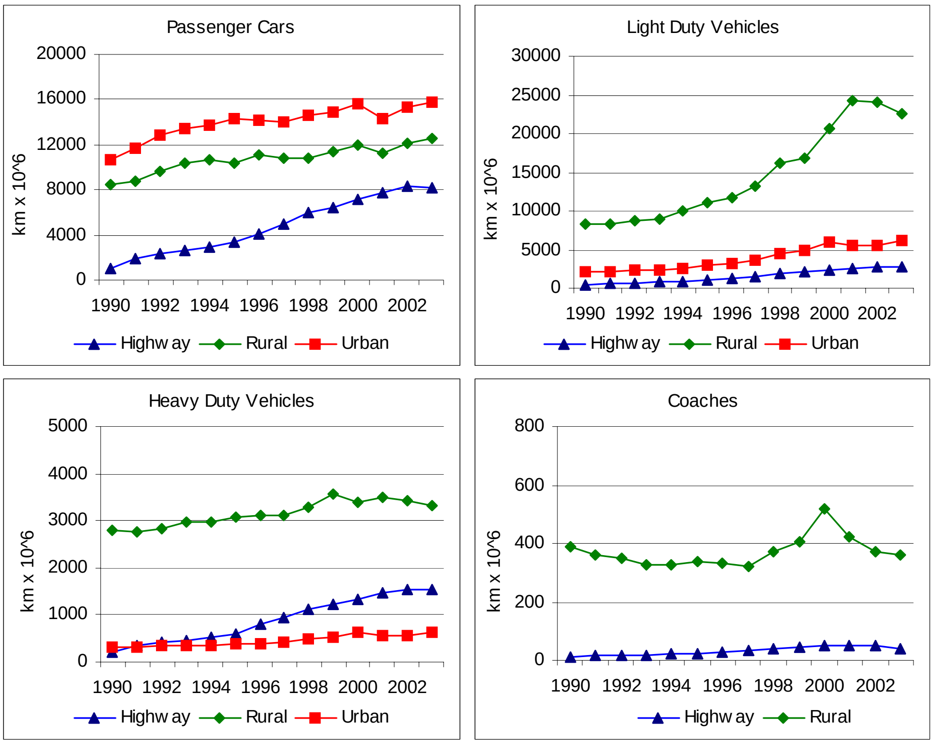
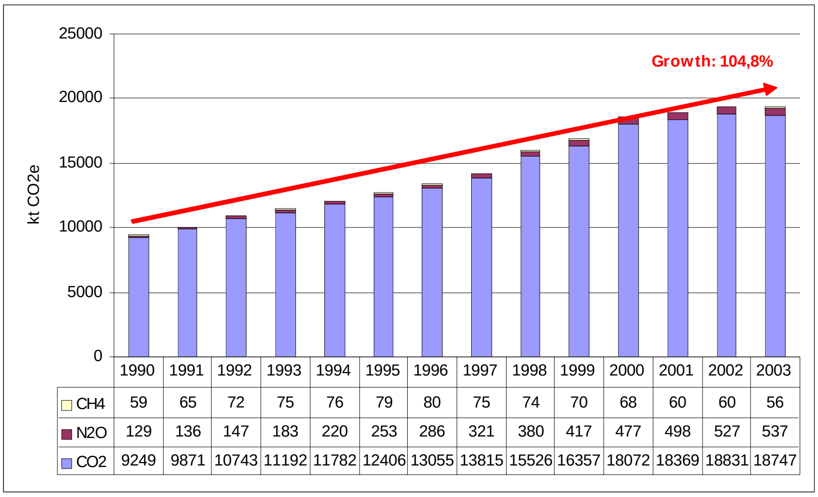


Figure 4. Distances travelled.

Exhaust greenhouse gases (GHG) emissions from road transportation were estimated about 19.3 Mt CO_2 equivalent in 2003 representing and increase of 104.8% compared to 1990 emission level estimated about 9.4 Mt CO_2 equivalent (Figure 5). Between 2002 and 2003 GHG emissions registered a slight decrease from 19.4 to 19.3 Mt CO_2 equivalent. Emissions of N_2O have increased by a factor of 4.2 since 1990 due to the introduction of catalytic converters. Some authors suggested that in some cases N_2O emissions could increase by as much as a factor of 10 (Wade et al.. 1994; de Soete and Sharp. 1991; Dasch. 1992). The introduction of catalytic converters brought also some disadvantages including the increase of CO_2 and NH_3 emissions which contribute to climate change and acid deposition. It is difficult to assess the extent to which CO_2 emissions have increased as a result of fitting catalytic converters, because improvements in fuel economy have been made at the same time as development of the engine management systems that are required to minimise NO_x and VOC emissions.



	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000	2001	2002	2003
□ CH4	59	65	72	75	76	79	80	75	74	70	68	60	60	56
■ N2O	129	136	147	183	220	253	286	321	380	417	477	498	527	537
■ CO2	9249	9871	10743	11192	11782	12406	13055	13815	15526	16357	18072	18369	18831	18747

Figure 5. Estimated emissions from road transportation.

Since 1992 that catalytic converters had contributed for major reductions of pollutants with special concern to urban air quality such as CO, NO_x, VOC and NMVOC (see Figure 6). Although NO_x absolute emissions has increased 22.7% since 1990 the emission factor given in mass of pollutant by fuel unit decreased from 14.9 $kgNO_x$/tep in 1990 to 4.6 $kgNO_x$/tep in 2003.

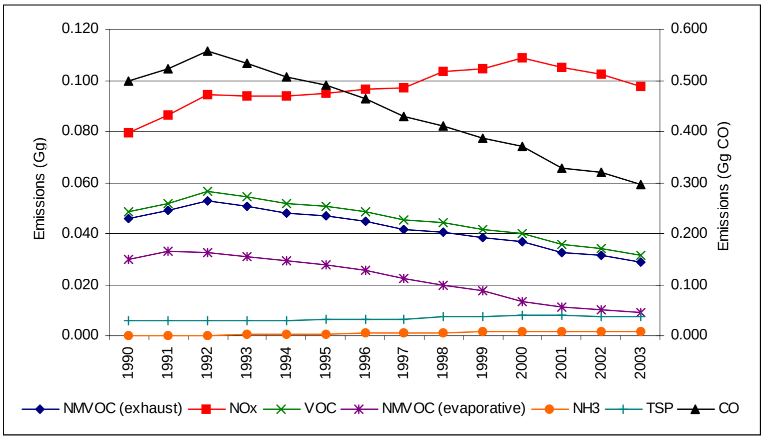
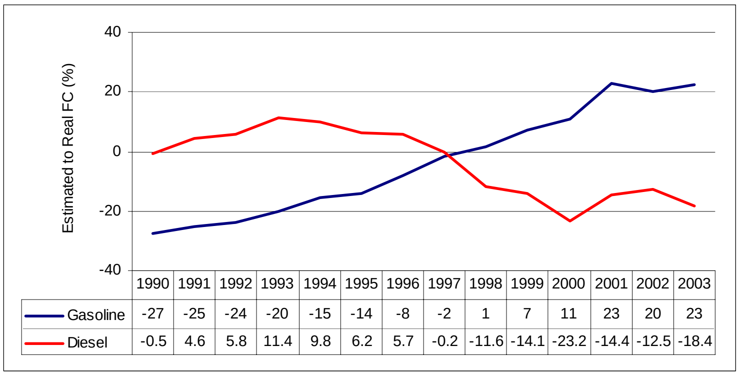


Figure 6. Non greenhouse gases emissions.

The model performance was evaluated by comparing the estimated fuel consumption (first approach bottom-up before top-down correction) with the real fuel consumption. Estimated fuel consumption varies within a maximum of ± 30% from real fuel consumption for all period of analysis. Very good estimations were performed for 1997 where gasoline and diesel differs from real values only by -2% and 0.2%, respectively.



	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000	2001	2002	2003
Gasoline	-27	-25	-24	-20	-15	-14	-8	-2	1	7	11	23	20	23
Diesel	-0.5	4.6	5.8	11.4	9.8	6.2	5.7	-0.2	-11.6	-14.1	-23.2	-14.4	-12.5	-18.4

Figure 7. Estimated to real fuel consumption.

The high level of disagreggation used in this inventory could be very useful to quantify emissions changes resulting from specific measures. It could be interesting to evaluate the impact of speed changes for each vehicle category and driving mode. The increase of average speed in urban areas could lead to a decrease in emissions. Obviously, this increase in average speed should be achieved by decreasing traffic jams instead of increasing the speed limit in urban areas. In highways, the decrease of the average speed could contribute to significant emission reductions particularly for light vehicles.

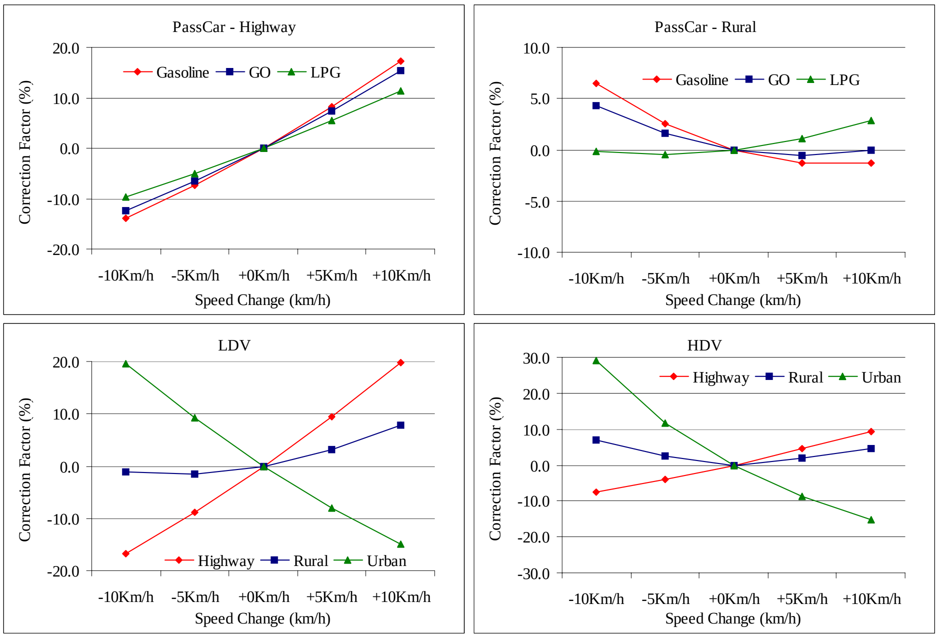


Figure 8. Emission correction as function of speed.

4. CONCLUSION

The use of the bottom up approach to estimate national emissions from road transportation should be considered a good approach given the similarity between the real and predicted total fuel consumption. Important results were achieved when considering the level of emission disagreggation within this sector.

However some problems were identified when scaling down the level of disagreggation in road transportation. This sector is one of the most complex sectors when overall emissions need to be calculated. The amount of variables and the data required for the calculation is scattered amongst several institutions and sometimes is simply inexistent. Therefore, many assumptions must be made increasing the model uncertainty. No specific calculations were performed to assess the model uncertainty however this subject is crucial to support the model output results.

Further work is needed to improve model accuracy and some topics for research were identified during the present study: use of a vehicle mileage correction factor; estimate emissions of ressuspended particulate matter from tyre and brake wear; use the road gradient correction factor; improve temporal allocation for line and are sources; apply quality assurance and quality control procedures; estimate model uncertainty. The model accuracy could still be improved by deriving the vehicle activity variable from the data acquired at the vehicle inspection centres which are under the authority of the *Direcção Geral de Viação*.

5. ACKNOWLEDGEMENTS

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REFERENCES

Gois, V., Maciel, H., Nogueira, L., Almeida, C., Torres, P., 2005. Spatial Allocation of Air Emissions From Mobile Sources Using Aerial Photography Data. Proceeding of the Urban Air Quality Conference, 29-31 March 2005, Valencia, Spain.

IPCC, 2000. Good Practice Guidance and Uncertainty Management in National Greenhouse Gas Inventories. Intergovernmental Panel on Climate Change. Accessed via internet @ http://www.ipcc-nggip.iges.or.jp/.

IPCC, 2001. Climate Change 2001: Impacts, Adaptation & Vulnerability. Contribution of Working Group II to the Third Assessment Report of the Intergovernmental Panel on Climate Change.

Ntziachristos. L., Samaras. Z., 2000. Speed-dependent representative emission factors for catalyst passenger cars and influencing parameters. Atmospheric Environment 34, 4611-4619.

PNAC, 2003. National Plan for Climate Change. Instituto do Ambiente. Accessed via internet @ www.iambiente.pt