Estimating Traffic Emissions Using Demographic and Socio-Economic Variables in 18 Chilean Urban Areas

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A macro-scale methodology for vehicle emissions estimation is described. The methodology is based on both correlations between activity level and PM, CO, THC and NO_x vehicle emissions and relationships between demographic and socio-economic variables and transportation activity level. First, pollutant emissions were correlated with transportation activity, expressed as vehicle-km/year, using existing data collected from mobile sources emission inventories in nine urban cities of Chile. Second, demographic and socio-economic variables were pre-selected from those that could intuitively be correlated with vehicle activity level and considering the data availability. Using the individual R^2 correlation coefficient as variable selection criterion, population, the number of vehicles, fuel consumption, gross domestic product, average family incomes and road kilometers were finally chosen. A different set of explicative variables was considered for different vehicle categories, based on the selection criterion above mentioned. Then, correlation functions between these variables and transport activity were obtained by non-linear Gauss–Newton least square method. This methodology was applied to eighteen provinces of the country obtaining total annual emission for mobile sources, divided into six main vehicles categories.

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INTRODUCTION

Most mobile sources emission estimations methodologies are based on emission factors and operational parameters representing real-world traffic flow conditions of the zone under analysis (Corvalán & Osses, 2002; Goyal & Rama Krishna, 1998; Lyons, Kenworthy, Moy, & Dos Santos, 2003; Reynolds & Broderick, 2000; Sharma & Khare, 2001; Sturm, Almbauer, Sudy, & Pucher, 1997; Zachariadis & Zamaras, 1999). Emission factors represent unit emissions as a function of the speed, obtained experimentally by transient tests conducted on chassis dynamometers. Emission factors are obtained using a representative sample of technologies and vehicle types present in the local fleet and using representative driving patterns (Corvalán & Urrutia, 2000; De Haan & Keller, 1999; Ntziachristos et al., 1999; US EPA, 1991). On the other hand, operational parameters involve flow densities by arc of the traffic network for different days of the week and hours of the day, average speed, and activity levels, expressed by vehicle-km/year. These operational parameters are normally obtained from transport models, traffic surveys, and vehicle fleet data bases (Cardelino, 1998; De Cea & Fernádez , 1993; Fernádez & De Cea, 1990; Kim, 2000).

Traffic emission can be related to technical and operational factors like vehicle technology, vehicle age and mileage, state of maintenance, fuel quality, existence of emission control devices, street flow density and average speed and accelerations. On the other hand emissions are also related to demographic and socio-economic factors. Several studies have demonstrated that changes in demographic and socio-economic factors can impact air pollution. Cole and Neumayer (2004), concluded that population increases are matched by proportional increases in CO_2 emissions which confirmed the previous findings of Dietz and Rosa (1997); York, Rosa, & Dietz, (2003), concerning elasticity of emissions of CO_2 with respect to population. Riley (2002) analyzed the influence of population growth, increases in urbanization, and economic development on the growth motor vehicles in China and their implications; one of which is the associated environmental impact.

In Chile, emission inventories of not only mobile sources but also stationary sources were developed for nine urban areas throughout the country, including the Metropolitan Region of the city of Santiago

(CENMA, 2000, 2002). Mobile sources inventories were constructed by applying the mobile source emission model, MODEM (Corvalán & Osses, 2002) and the local traffic model, ESTRAUS (De Cea & Fernández, 1993). MODEM calculates hourly pollutant production on each arc of the traffic network for each predefined vehicle category, using emission factors evaluated at hourly average flow speed obtained from the transport model ESTRAUS. Since the transport model estimates flow densities and average speed by arc for only on-peak and out of peak hours of the day, and considers two aggregated traffic flows (public transport and the rest vehicles categories), temporal expansion and characterization of traffic flow into vehicles categories by traffic surveys was needed at the overall urban areas where emission inventories were constructed. The emission factors used come from a local experimental test program for light duty gasoline passenger cars (Corvalán & Urrutia, 2000) and from international literature for the rest of vehicles categories (Ntziachristos et al., 1999). The emission factors experimental program involved chassis dynamometer tests that used driving cycles that represent the real-world driving patterns of the urban zone under analysis. The driving cycles were obtained by means of the driving of predefined circuits in the city with an instrumented vehicle. Strictly, this should be executed on each city where emission calculations are desired.

Despite the thoroughness of methodology above described, there are serious limitations on extending application to all of the urban areas of the country. The main restrictions are the required availability of an up to date transport model, emission factors representative of the technologies present in the local vehicles fleet and of the local driving patterns, and the characterization of traffic into categories for the local fleet. Normally emission calculations have a defined temporal period of validity which corresponds to period in which vehicle technologies and driving patterns do not change enough to introduce changes on emissions. Normally emission inventories are constructed for a temporal period of one year.

The analysis of these emission inventories allows local environmental authorities and policy makers to identify the relative contributions of different types of source and economic sectors on total criteria pollutant emissions. Processing and analyzing the data contained in the emission inventories makes possible to correlate emissions and activity level with demographic and socio-economic parameters. By using this correlation it is possible to estimate emission without the application of emission and traffic models, which are not available to most of the urban localities of the country.

GENERAL APPROACH

The methodology consists of two main steps. The first one is to correlate pollutant emission with mobile source activity levels, expressed as vehicle-kilometers per year, segregated into different vehicle categories present in urban fleets. The second step is first to identify demographic and socio-economic variables that can be linked with vehicle activity level and second to find multivariable correlations between them.

In order to correlate pollutant emissions with vehicle activity levels, data from mobile sources emission inventories corresponding to several urban areas of the country were used. These emission inventories were constructed by applying the emission and transport models mentioned above to the cities covered. Data concerning PM; CO; THC and NO_x vehicle emissions were correlated with vehicle-kilometers per year for the following vehicle categories: buses, trucks, light duty catalytic cars, light duty non-catalytic cars, commercial catalytic vehicles, commercial non-catalytic vehicles, and diesel commercial vehicles. Values of vehicle-kilometer per year come from transports models which were calibrated by data from automatic traffic measures network existing in the cities where transport models are available. These vehicle categories come from an aggregation of vehicle categories considered in emission inventories, where a finer distinction of technologies is done using the emission standards compliance of each one.

The correlations between vehicle activity level and demographic and socio-economic factors were obtained by identifying factors susceptible to be linked with emission of each pollutant considered for each vehicle category. Once variables were selected, multivariable correlations using the non-linear least square Gauss–Newton method was applied.

Finally, the application of both of the above steps permits the estimation of yearly emissions for each vehicle category and pollutant starting with the evaluation of demographic and socio-economic factors corresponding to the urban areas under analysis.

CORRELATIONS BETWEEN TRANSPORT ACTIVITY AND EMISSIONS

As was above mentioned, data from mobile sources inventories for nine urban areas of the country are available, including the Metropolitan Region of the city of Santiago. The MODEM emission model, was used for the calculation of atmospheric pollutant emissions produced by on-road vehicular activity in the mentioned urban areas. This vehicle emissions model uses as input traffic flows and average vehicle speeds modeled by the transportation strategic-allocation model ESTRAUS and emission factors to obtain emissions for several types of pollutants, all of which are determined for several categories of vehicles, with high levels of spatial and temporary desegregation. Activity levels come also from transport model, which estimates hourly vehicles flow densities (vehicles/hour) for each arc of predefined traffic networks, each of them with a known length (km). Table 1 shows vehicles-kilometer per year estimated for transport models for each vehicle categories in the cities considered in the emission inventories. Figure 1 represents aggregated results expressed as total activity level, considering all vehicles categories in each urban zone with existing emission inventories and its geographical location. Examining the figure it seems that Metropolitan Region of the city of Santiago has the highest transport activity level which reflects that this urban area concentrates 40% of the country's population and almost the 50% of the total vehicle fleet. This observation suggests that this urban area must be excluded in the correlations between emission and activity level; other wise, considerable distortions could be introduced onto the other urban areas. Table 2, shows pollutant emissions estimated for all the aggregated vehicle categories by the existing emission inventories, where remarkably higher emissions in Metropolitan Region of the city of Santiago are noted, which confirms the above observation concerning activity level.

In Figure 2, total emissions versus total activity considering all vehicle categories and the corresponding linear fit curves are plotted. Note the remarkable linearity between the variables, as is demonstrated by the R^2 correlation coefficient also shown on the figure. Data from Metropolitan Region was excluded in accordance to the above discussion. Table 3 shows the correlations obtained for each vehicle category and pollutant, with the corresponding correlation coefficient R^2. It seems that very high R^2 correlation coefficients are obtained except for THC from non-catalytic commercial vehicles and for all pollutants emitted by diesel commercial vehicles. No correlations have been proposed for gasoline PM emission which was assumed null for this vehicle category in comparison with diesel vehicles.

CORRELATION BETWEEN DEMOGRAPHIC AND SOCIO-ECONOMIC FACTORS AND TRANSPORT ACTIVITY

Preliminary analysis in order to select demographic and socio-economic variables which can be linked with vehicles activity was done.

TABLE 1

Activity Levels by Vehicle Categories, Estimated by Transport Models (veh-km/year)·10^3

	Cities								
Vehicle Type	Metropolitan Region	Concepción	Valparaíso	Rancagua	Temuco	Antofagasta	La Serena	Chillan	Osorno
Buses	1242611	223627	216378	26489	38577	54496	42141	16312	17082
Trucks	1157312	75365	95717	16057	19871	70873	45363	12748	20062
Catalytic light duty veh	7510825	314460	1075856	153266	90201	295428	127110	50041	58114
Non-catalytic light duty veh	3682930	245002	680210	137799	131591	156323	92638	60776	64073
Catalytic commercial veh	3283697	173129	258555	65089	38045	103100	45557	17173	28573
Non-catalytic commercial veh	1284072	109535	171681	42787	31670	51790	40553	28668	30577
Diesel commercial veh.	790027	43876	102594	9031	11190	32196	18284	9362	13284
Motorcycles	211944	1652	20063	3084	1183	5873	2687	2202	1749
	19163418	1186645	2621054	453602	362329	770079	414333	197282	233514

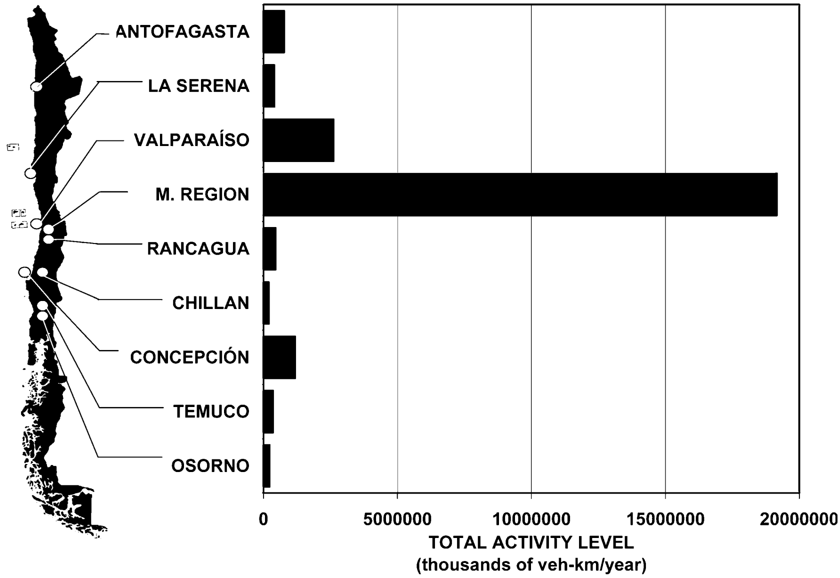

FIGURE 1. Total activity level by urban areas considered on existing emission inventories.

Several factors were considered and selection was made on the basis of individual correlations between factors and vehicle activity of each vehicle categories obtained from existing inventories. The following variables with

TABLE 2

Existing Emission Inventories

Urban Zones	PM Ton/year	CO Ton/year	THC Ton/year	NO_x Ton/year
Osorno	31	3479	349	685
Temuco	71	7371	1090	1283
Concepción	229	15989	2186	4273
Chillan	26	3425	352	603
Rancagua	44	7948	965	1013
Metropolitan Region	2425	174196	46180	24456
Valparaíso	210	37034	2739	5839
La Serena	56	4514	455	1230
Antofagasta	74	6751	736	1815

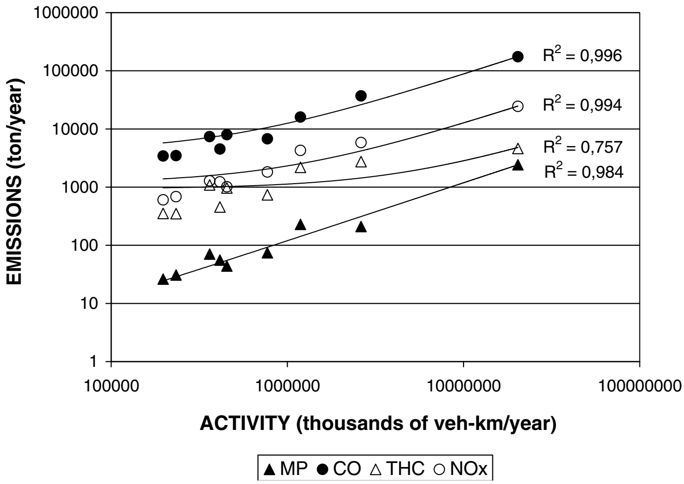

FIGURE 2. PM; CO; THC and NO_X emission v/s vehicle activity levels.

highest individual R^2 correlation coefficients were pre-selected: vehicle fleet (number of vehicles), fuel consumption, population, gross domestic product, average family incomes, kilometers of road and urban zone surfaces. The analysis established that the sets of explicative variables are not the same for different vehicle categories considered, that is to say, vehicle activity correlates with different variables concerning different vehicle categories. It is found that only a few variables (number of vehicles, fuel consumption, and population), correlate in reasonable terms for the overall vehicles categories.

An additional criterion to be considered in the explicative variables selection is the feasibility of access to the corresponding data for the zones under analysis. The variables pre-selected on this work can be evaluated by accessing the following information resources: *Number of vehicles of each category* which compose the fleets of different urban areas can be obtained by the analysis and processing of data base and statistics coming from the I/M programs (periodical technical revision which are obligatorily conducted for vehicles in order to verify safety and emission aspects) and also from data bases of municipal vehicle registers. *Fuel Consumption* is obtained from regional fuel sells statistics, assuming averages fuel performances of each vehicle category. *Regional and city population data* are available from demographic data bases provided by National Statistics Institute. *Regional Domestic Gross Products* are available from Central Bank databases. *Average Family Incomes* can be obtained from data administrated by the

TABLE 3

Correlation between Annual Emission (ton/year) and Activity Level x (veh-km/year)

Vehicle Types	Pollutant	Emissions as a Function of Activity Level, x	R^2
Buses	CO	$3.4 \cdot 10^{-3}\ x + 35.22$	0.99
	THC	$1.3 \cdot 10^{-3}\ x + 7.25$	0.98
	NO_X	$1.2 \cdot 10^{-2}\ x - 77.52$	0.99
	PM	$7.0 \cdot 10^{-4}\ x - 8.49$	0.98
Trucks	CO	$1.9 \cdot 10^{-3}\ x + 9.70$	0.98
	THC	$1.1 \cdot 10^{-3}\ x + 5.32$	0.95
	NO_X	$5.4 \cdot 10^{-3}\ x + 16.62$	0.98
	PM	$5.0 \cdot 10^{-4}\ x + 1.34$	0.99
Catalytic Light Duty Vehicles	CO	$2.6 \cdot 10^{-3}\ x + 10.10$	0.98
	THC	$3.0 \cdot 10^{-4}\ x + 11.52$	0.99
	NO_X	$5.0 \cdot 10^{-4}\ x + 20.06$	0.97
Non-Catalytic Light Duty Vehicles	CO	$4.2 \cdot 10^{-2}\ x + 454.99$	0.99
	THC	$2.0 \cdot 10^{-3}\ x + 160.45$	0.81
	NO_X	$2.0 \cdot 10^{-3}\ x + 2.44$	0.99
Catalytic Commercial Vehicles	CO	$5.3 \cdot 10^{-3}\ x - 52.20$	0.82
	THC	$4.0 \cdot 10^{-4}\ x + 2.71$	0.96
	NO_X	$5.0 \cdot 10^{-4}\ x - 1.93$	0.99
Non Catalytic Commercial Vehicles		$1.9 \cdot 10^{-2}\ x + 177.39$	0.89
	THC	$2.3 \cdot 10^{-3}\ x + 79.27$	0.42
	NO_X	$2.9 \cdot 10^{-3}\ x + 25.15$	0.91
Diesel Commercial Vehicles	CO	$5.0 \cdot 10^{-4}\ x + 3.96$	0.74
	THC	$1.0 \cdot 10^{-4}\ x + 2.92$	0.50
	NO_X	$1.0 \cdot 10^{-3}\ x + 11.93$	0.63
	PM	$1.0 \cdot 10^{-4}\ x + 1.18$	0.55

TABLE 4

Demographic and Socio-economics Variables Selected

Variable	Units	Public Transport	Cargo Vehicles	Commercial Vehicles	Private Light Duty Vehicles
Vehicle Quantity	Units	√	√	√	√
Fuel Consumption	m^3/year	√	√	√	√
Population	inhabitants	√	√	√	√
Regional Internal Gross Product	NM$	√	√	√	
Average Family Incomes	NM$	√		√	√
Kilometers of Roads	km		√	√	√
Urban Zone Surface	km^2		√		

local Planning and Development Ministry. *Kilometers of Road* can be estimated from data provided by Public Works Ministry. Table 4 indicates the demographic and socio-economic variables finally selected for each vehicle category.

Determination of vehicle activity functions was done correlating the selected variables by means of a non-linear model adjusting parameters in iterative form in order to attain convergence to known vehicle activity values coming from existing emission inventories. The model proposed is of the type shown on the following equation:

$$Y = f(\chi, \beta, c) \tag{1}$$

where: Y is the vector representing the known vehicle activity (veh-km/year); χ, is the matrix of variables considered and β and c, are coefficients to be determined. Coefficient β and c are adjusted so that the set of the known variables lead to the estimations of vehicle activity. In order to carry out this adjustment, vector Y contains the set of vehicle activity values for a vehicle category done at the cities where this parameter is known. Using the simplest Gauss–Newton methods for non-linear squares least regressions it is possible to find functions of the form:

$$y_i = f_i(\chi, \beta) \tag{2}$$

The adjustment is carried out by taking a matrix with columns containing the independent variables χ which define the problem analyzed and their corresponding response or objective vector, Y. The method requires an initial value β^0 to start the iterations. On each iteration β^k, a first order approximation of the ith function is done around of iteration point β^k, obtaining the following equation:

$$f_i(\beta) \approx f_{\text{linear},i}(\beta) = f_i\left(\beta^k\right) + \nabla f_i\left(\beta^k\right)^T\left(\beta - \beta^k\right) \tag{3}$$

then, the sum of the square of linear residues are minimized obtained the following iteration point β^{k+1} (equation (4)). The problem is considered solved when this sum is less than and predefined tolerance ϵ.

$$\min_\beta = \sum_i \left(f_{\text{linear},i}(\beta) - y_i\right)^2 \tag{4}$$

Numerically it is possible to face the problem of getting the partial derivates with respect to the parameter to be determined in the f_i functions and then iterate the matrix equations (5) and (6):

$$b = \left(D^t D\right)^{-1} D^t Y \tag{5}$$

$$g_{n+1} = g_n + b \qquad n \geq 0 \tag{6}$$

where g, is the refined estimations matrix; b, is the estimation changes rate, Y, is the error matrix (y–$f(\chi,\beta)$) and D is the partial derivates matrix. The iteration processes are done until the square of residues is less than and predefined tolerance ϵ.

In order to carry out the methods above described, equation (1) takes the form:

$$Y = \sum_i^n c_i \chi_i^{\beta_i} \tag{7}$$

The model assigns to each independent variable χ_i the parameters c_i and β_i resulting from the non-linear square least method above described. In order to carry out the iterations leading to the correlations a Matlab program was written. Table 5 presents coefficients c_i and β_i obtained for each explicative variable and vehicle category. Note that vehicle categories were segregated into sub-categories taking into account specific technologies defined by the emission standards compliances. In an Appendix, the description of vehicular sub-categories is included.

TABLE 5

Coefficients *c* and *β*

Categories	Sub-categories	Coefficients	KM of road	Veh. Fleet	Fuel Consumption	Population	Gross Internal Product	Average Family Income	Regional Area
Public Transport	Bus type 1	c_i	–	0.3988	0.2509	2.4726	–	−0.1602	–
		β_i	–	1.4082	0.1049	1.6236	–	−0.5246	–
	Bus type 2	c_i	–	2.0640	−0.5821	0.2829	–	−0.5806	–
		β_i	–	1.1482	1.9500	1.1474	–	0.0057	–
	Bus type 3	c_i	–	0.5512	1.0900	0.3083	–	−0.0282	–
		β_i	–	1.9308	2.4951	2.1046	–	0.8150	–
Trucks	Trucks type 1	c_i	−0.0150	0.0683	0.2044	–	0.0539	0.0000	−0.0027
		β_i	0.7471	0.5334	2.0284	–	1.5916	0.0000	−0.4432
	Trucks type 2	c_i	−0.0057	1.0838	0.6187	–	0.4863	0.0000	0.0476
		β_i	0.3953	4.6021	1.5625	–	6.5754	0.0000	2.2454
Commercial Vehicles	Catalytic	c_i	−0.0079	7.6511	0.9114	4.3022	1.9931	0.0006	–
		β_i	1.2364	2.8352	1.7289	6.4396	5.8009	10.6374	–
	No catalytic	c_i	−0.0012	0.1625	0.2972	0.0603	0.0499	0.0432	–
		β_i	−1.2951	0.7945	1.3977	3.9242	5.3312	4.8698	–
	Diesel	c_i	−0.0012	0.1625	0.2972	0.0603	0.0499	0.0432	–
		β_i	−1.3931	3.6990	1.9342	4.0428	5.3556	3.0208	–
Light Duty Vehicles	Catalytic private cars	c_i	−0.0121	0.2855	0.2197	−0.0181	–	0.0107	–
		β_i	1.0148	0.9958	2.5813	−0.1649	–	−0.6055	–
	No catalytic private cars	c_i	−0.1237	0.0917	0.5281	−0.3617	–	0.0220	–
		β_i	0.1408	5.9987	1.2643	5.9147	–	0.5938	–
	Catalytic taxis	c_i	–	1.3057	0.6472	1.7516	–	0.0559	–
		β_i	–	3.4457	5.5907	2.4255	–	6.6026	–
	No cat. taxis	c_i	–	0.0647	0.4335	2.1834	–	0.7445	–
		β_i	–	0.1549	0.2263	8.4092	–	0.2811	–

RESULTS OF ACTIVITY LEVEL AND EMISSION ESTIMATIONS

The methodology described above was applied to 18 urban areas in the country where data of demographic and socio-economic parameters involved were available. Chile is politically and administratively divided into 13 regions, each of them divided into provinces with a variable amount of cities. Since most of demographic and socioeconomic data are of the regional type, the urban zones considered in this work correspond to a provincial geographic definition where data of socio-economic variables were estimated by interpolation of regional data using population as interpolation criteria. Figure 3 shows the total coverage achieved considering urban zones with existing emission inventories and provinces in which emission inventories were estimated with the methodology developed in the present work.

By applying the model of non-linear regression to obtain vehicle activity from demographic and socio-economic factors identified on Table 4 using coefficients c and β shown on Table 5, vehicle activity functions are obtained for each vehicle category. Using the corresponding data for variables for each province analyzed, predicted vehicle

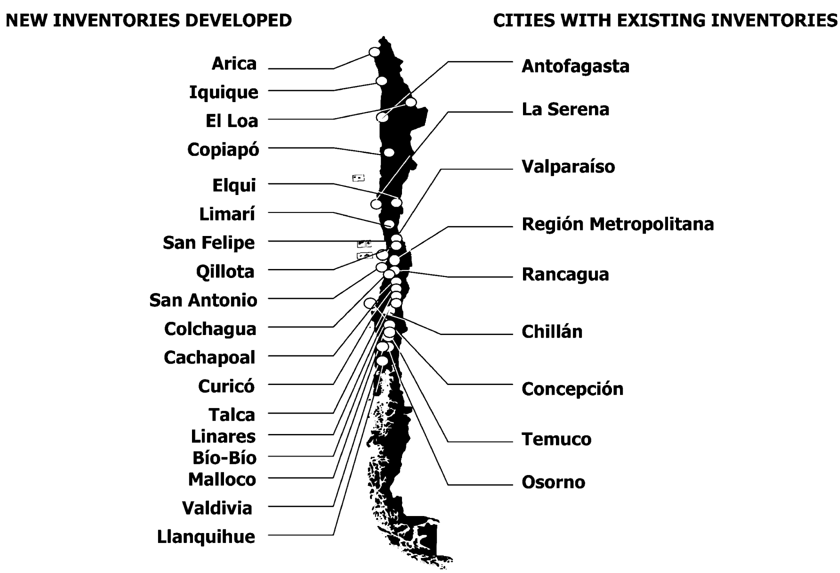

FIGURE 3. Total encourage achieved with the application of proposed methodology.

activity levels shown on Table 6 with the percentage distribution by vehicle categories shown on Figure 4 are finally achieved. It is noted that the distribution of non-catalytic vehicle activity is almost homogeneous in the overall provinces analyzed but has a higher dispersion than the other vehicle categories activity. Variables like population, average family income and regional internal gross product define the division of transport type which results in different distribution of vehicle categories activity.

Introducing the vehicles activity values on correlations of Table 3, the predicted pollutant emissions shown on Tables 7–10, for each province and vehicle categories are obtained. Figure 5 shows the PM, CO, THC, and NO_x total emissions in the provinces analyzed. The maximum CO emission is detected in the province of Cachapoal which can be explained by the highest total vehicle activity and highest non-catalytic vehicle activity calculated for this province. Graphs of Figure 6 represent the contribution of each vehicle categories on total emissions of the four pollutants considered. Great dispersion of contributions of PM emission is noticed due mainly to the relative activity distribution of buses and trucks, as can be observed on Figure 4. In regard to gaseous pollutants a more homogeneous distribution of contributions to total emission from different vehicle categories is observed except for buses which can be explained by the same argumentation presented above in the activity analysis.

In order to verify the predicted results obtained, a comparison between ''predicted'' and ''observed'' values of activity level and emissions was done. Results of application of the conventional emission model, MODEM, using transport model and emission factors was available for four urban zones inserted on provinces modeled by the present methodology. Table 11 shows the predicted and observed results of activity level and total emissions of PM; CO and THC, and Table 12 shows the percent variations referred to predicted values. Positive figures indicate that predicted values are greater than observed and negative figures mean that methodology predict values lower than observed. The percent differences are in the range of −32% to 71.4% which could be considered high but these differences seem reasonable for an aggregate macro-scale methodology, taking into account that observed results come from detailed modeling of traffic activity in an specific urban zone and the utilization of emission factor for each vehicle technologies for each vehicle category present on the fleet, and predicted results come from a correlation between explicative variables of the provincial basis and activity level.

TABLE 6

Predicted Vehicle Activity on Cities Where Methodology was Applied (Thousands of veh-km/year)

Provinces	Buses	Trucks	Catlytic Light Duty Vehicles	Non Catalytic Light Duty Vehicles	Catalytic Commercial Vehicles	Non Catalytic Commercial Vehicles	Total
Llanquihue	89713	50160	49295	77867	49081	65233	381349
Valdivia	102373	38178	62299	80865	50099	63864	397678
Malleco	43203	52797	15143	42009	11730	44114	208996
Bío Bío	76719	44969	29553	82813	23912	58872	316837
Linares	41460	69839	14820	64995	20181	46547	257842
Talca	93603	57885	50533	93318	47923	54378	397640
Curico	74053	62574	33775	74458	52953	45665	343477
Cachapoal	188276	91536	71862	158037	73249	69533	652493
Colchagua	19555	34230	23221	64434	27709	36205	205354
San Antonio	130446	70038	78065	57902	98971	33166	468589
Quillota	69961	37680	48124	76672	58629	42420	333485
San Felipe	26248	31063	24202	53493	37667	31332	204004
Limarí	54394	26432	4377	39264	3800	30134	158400
Elqui	108036	41470	53399	81855	45402	47548	377710
Copiapó	51174	35261	25249	55574	25003	42704	234965
El Loa	89718	49519	47236	70099	58584	52824	367979
Iquique	126159	73441	3283	79729	30201	37463	350277
Arica	107928	31121	3447	66035	11516	36264	256311

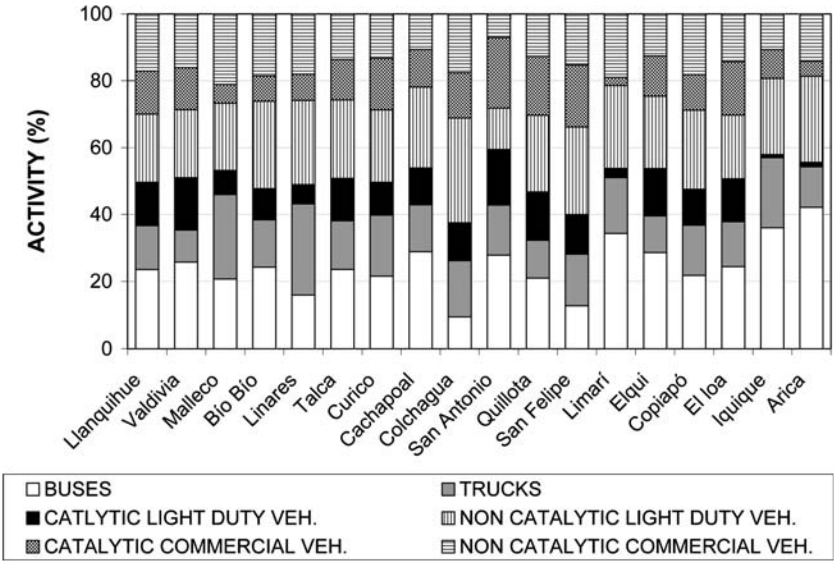

FIGURE 4. Vehicle activity distribution by categories on provinces where methodology was applied.

DISCUSSION AND CONCLUSION

The methodology described above constitutes a macro-scale alternative model to estimate transport emissions in urban areas without regard to output of sophisticated transport and emission models which are not always possible to apply to any region of the country. As an example of application, results concerning a set of the important urban zone of the country, in terms of population and vehicle fleet sizes, where it was possible the recompilation of reliable data of explicative variables were presented and analyzed. One advantage of the methodology proposed is the fact that socio-economic variables, in general terms, change slower than parameters involved in methodologies based on transport and emissions models which suggest that validity of results lasts for a longer time.

Geographic segregation of emissions estimated by the methodology depends on the type of demographic and socio-economic information available. In the application presented provincial information was obtained by using interpolation of regional available data, and as a result the emissions estimated correspond to this geographical unit. Nevertheless, accuracy of calculation can be improved if original data from smaller areas, for

TABLE 7

Predicted PM Emissions (ton/year)

Provinces	Buses	Trucks	Total
Llanquihue	21	24	46
Valdivia	24	19	43
Malleco	10	26	35
Bío Bío	18	22	40
Linares	9	34	43
Talca	22	28	50
Curico	17	30	47
Cachapoal	46	44	90
Colchagua	4	17	20
San Antonio	31	34	65
Quillota	16	18	35
San Felipe	5	15	21
Limarí	12	13	25
Elqui	26	20	46
Copiapó	12	17	29
El Loa	21	24	45
Iquique	30	35	66
Arica	26	15	41

example province or individual urban cities, is available. Then, one of the most important limitation of the methodology is the fact that socio-economical and demography variables data are normally available on de provincial basis, and these variables are correlated with activity level corresponding to specific urban areas.

Comparisons of predicted and observed results of activity level and emissions for four urban zone denote that, despite the lower precision of methodology compared to those based on transport and emission model, it is good enough to estimate order of magnitude of total emission in an urban zone and even to determine the relative contribution of different vehicle categories to the total transport emissions.

In general terms, emission of pollutants analyzed correlates very well with vehicle activity, except the emissions of THC for non catalytic and diesel commercial vehicles and PM emissions from diesel commercial vehicles. Nevertheless, considering the overall vehicle categories, THC and PM emissions correlate significantly better with R^2 equal to 0.77 and 0.98 respectively. The lower correlation detected could originate from inaccuracies in input data coming from existing emission inventories and vehicle

TABLE 8

Predicted CO Emissions (ton/year)

Provinces	Buses	Trucks	Catalytic Light Duty Vehicles	Non Catalytic Light Duty Vehicles	Catalytics Commercial Vehicles	Non Catalytic Commercial Vehicles	Total
Llanquihue	1161	99	63	1832	78	967	4198
Valdivia	1308	77	79	1907	79	950	4400
Malleco	621	104	20	932	18	706	2401
Bío Bío	1010	89	38	1956	37	888	4018
Linares	601	134	19	1509	31	736	3031
Talca	1206	113	64	2219	76	833	4510
Curico	979	121	43	1746	84	725	3698
Cachapoal	2305	174	91	3842	116	1020	7547
Colchagua	346	70	30	1495	43	609	2592
San Antonio	1634	135	99	1331	157	571	3927
Quillota	931	76	61	1802	93	685	3648
San Felipe	424	64	31	1220	59	549	2347
Limarí	751	56	6	864	5	534	2215
Elqui	1374	83	68	1932	72	749	4277
Copiapó	713	72	32	1273	39	689	2818
El Loa	1161	98	60	1637	93	814	3862
Iquique	1584	141	5	1878	47	624	4279
Arica	1372	64	5	1535	18	609	3603

TABLE 9

Predicted THC Emissions (ton/year)

Provinces	Buses	Trucks	Catalytic Light Duty Vehicles	Non Catalytic Light Duty Vehicles	Catalytics Commercial Vehicles	Non Catalytic Commercial Vehicles	Total
Llanquihue	104	50	6	129	5	105	399
Valdivia	118	40	7	134	5	104	408
Malleco	51	53	2	69	1	82	259
Bío Bío	89	46	4	137	3	98	376
Linares	50	68	2	108	2	85	315
Talca	108	57	6	155	5	93	425
Curico	86	62	4	123	6	84	365
Cachapoal	215	88	9	262	8	110	691
Colchagua	25	36	3	107	3	74	248
San Antonio	150	68	9	96	10	71	405
Quillota	82	39	6	127	6	81	341
San Felipe	32	33	3	89	4	69	229
Limarí	64	29	1	65	1	68	227
Elqui	124	43	6	136	5	86	399
Copiapó	60	37	3	92	3	81	276
El Loa	104	50	6	116	6	92	374
Iquique	145	71	0	132	3	75	427
Arica	124	33	0	109	1	74	342

TABLE 10

Predicted NO_x Emissions (ton/year)

Provinces	Buses	Trucks	Catalytic Light Duty Vehicles	Non Catalytic Light Duty Vehicles	Catalytics Commercial Vehicles	Non Catalytic Commercial Vehicles	Total
Llanquihue	428	292	20	169	19	118	1045
Valdivia	491	221	25	176	19	116	1048
Malleco	197	307	5	88	5	79	681
Bío Bío	363	261	11	180	9	107	931
Linares	188	408	5	140	8	84	832
Talca	447	337	20	204	18	98	1125
Curico	350	365	13	161	20	82	991
Cachapoal	917	536	29	351	28	126	1987
Colchagua	80	198	9	139	11	64	500
San Antonio	630	409	32	124	37	59	1290
Quillota	330	218	19	166	22	76	832
San Felipe	113	179	9	114	14	55	484
Limarí	523	152	1	82	2	53	811
Elqui	519	241	21	178	17	85	1061
Copiapó	237	204	9	118	10	76	655
El Loa	428	288	19	151	22	95	1004
Iquique	609	429	0	173	12	67	1290
Arica	518	180	0	142	4	64	909

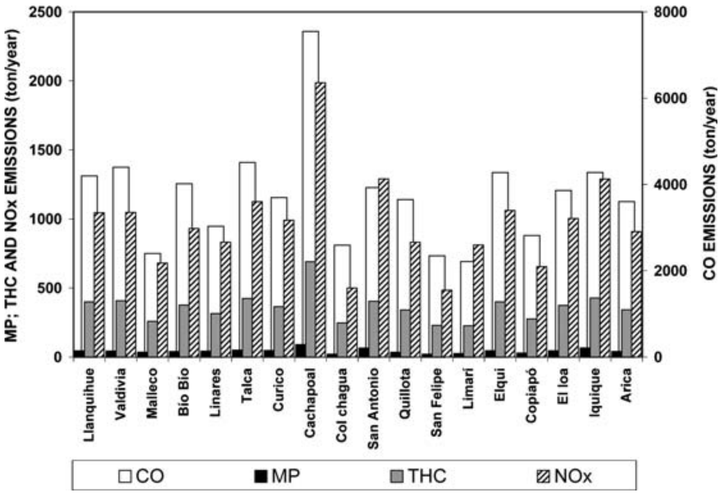

FIGURE 5. Estimated emission for provinces considered.

activity determined by transport model which were extrapolated from the original coverage (urban cities) to provinces which were sometimes interpolated from regional data using linear population proportionality.

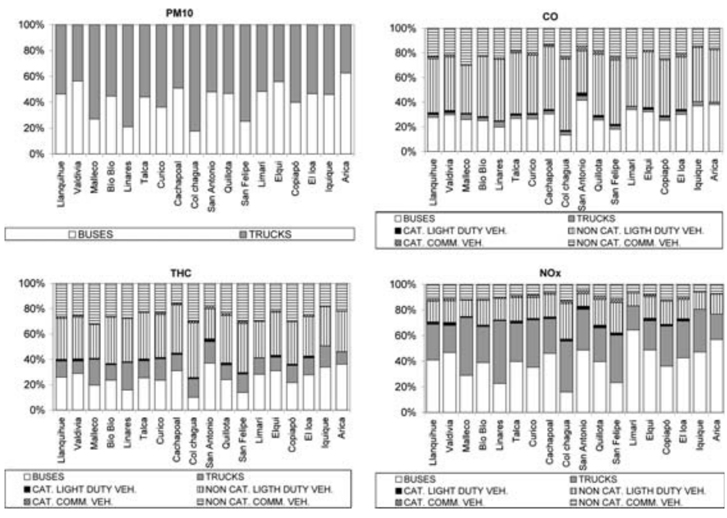

FIGURE 6. Responsibility of each vehicle categories on total emissions of the four pollutants considered, on the each province analyzed.

TABLE 11

Predicted and Observed Results of Activity Level and Emission for Five Provinces

	Activity Level (veh-km/year)·10^3		PM (ton/year)		CO (ton/year)		HC (ton/year)	
Provinces	Observed	Predicted	Observed	Predicted	Observed	Predicted	Observed	Predicted
Copiapó	285662	234965	20.4	28.8	2316.2	2817.5	236.1	275.6
Talca	435425	397640	19.1	50.1	5136.8	4510.3	553.6	424.5
Bío-Bío	454054	316837	11.4	39.7	5303.7	4018.0	330.6	376.3
Valdivia	262458	397678	12.3	43.0	1883.8	4399.7	179.7	407.7

TABLE 12

Percent Variations Referred on Predicted Values

Province	NA %	PM %	CO %	HC %
Copiapó	−21.6	29.2	17.8	14.3
Talca	−9.5	61.9	−13.9	−30.4
Bío-Bío	−43.3	71.3	−32.0	12.1
Valdivia	34.0	71.4	57.2	55.9

The selection of summation functions in order to correlate vehicle activity with socio-economic and demographic variables instead other approaches, like product functions, is based on quicker convergence of Gauss–Newton method, despite a more reasonable sensitivity that can be reached with the type of functions selected. For each vehicle categories, different sensitivities are obtained with vehicle fleet, fuel consumption and average family incomes being the most influential variables, which appear to be a very reasonable result.

The methodology presented here can be used effectively to create mobile sources emission inventories and extend them to a national coverage. Nevertheless it is not appropriate to design and evaluate specific emission reduction measures and strategies mainly because socio-economic and demographic variables are not sensitive to typical environmental management measures, like implementation of new and in-use vehicles emission standards, inspection-maintenance programs, improvement of fuel quality, rationally car use, and others. In this context, the vehicles emission determination by the use of traffic and emission models must to be continued and efforts must to be directed to the micro-scale analysis of specific urban areas and even the implementation of more accurate methods like on road emissions.

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APPENDIX

Vehicles Categories and Sub-categories Considered

Vehicle Categories	Vehicle Sub-categories	Year Model	Emission Standards Compliance
Buses	Bus type 1	Before 1993	No emission standard
	Bus type 2	1993–1996	EPA91 or EURO1
	Bus type 3	After 1996	EPA94 or EURO2
Trucks	Trucks type 1	Before 1993	No emission standard
	Trucks type 2	After 1993	EPA 91
Commercial	Non Catalytic	Before 1992	No emission standard
Vehicles	Catalytic	After 1992	EPA 94
	Diesel	All	
Light Duty	Non Catalytic	Before. 1992	No emission standard
Vehicles	Catalytic	After 1992	EPA 94
	Motorcycles	All	
	Non catalytic taxis	Before 1992	No emission standard
	Catalytic taxis	After 1992	EPA 94

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