H14-291
TOP-DOWN VS. BOTTOM-UP APPROACH IN DELINEATING TRAFFIC ROLE IN AIR QUALITY SCENARIOS

L. Pallavidino[1], R. Prandi[1], M. P. Costa[2], A. Nanni[2], A. Bertello[3], E. Bracco[3], F. Pavone[3]

[1]Simularia *Srl, via Principe* Tommaso 39, Torino - Italy
[2]Arianet Srl, via Gilino 9, Milano - Italy
[3]Provincia di Torino, Servizio Qualità dell'Aria e Risorse Energetiche, C.so Inghilterra 7, Torino - Italy

Abstract
In regional emission inventories road transport contribution is often evaluated by adopting a top-down methodology, which is based on the choice of large scale variables (for example fuel sold or consumed) then conveyed to smaller scale by using proxy variables (for example resident population or registered fleet).
While this approach is the most effective for the compilation of national databases of emissions, since it allows to obtain a geographically complete and methodologically homogeneous set of information, when it comes to the assessment of air quality and to the evaluation of measures in alternative scenarios the bottom-up strategy could prove to be preferable. The amount of pollutants released by traffic networks is in this latter case estimated starting from site-specific data such as traffic flow, vehicles speed, vehicle categories and local fleet technical features (fuel supply, weight, etc.). The bottom-up approach is clearly affected by the amount and quality of information available, but it allows the estimate of emission data with a greater spatial and temporal detail.
In this paper, we present a comparison of the results obtained by the application of the two approaches in evaluating road transport emissions in the metropolitan area of Torino, in which 1 350 000 inhabitants on average travel 8.5 km a day. Traffic flow data are available on an hourly basis on a network consisting of 5125 links, part of a larger road monitoring system. On site surveys have been used to differentiate vehicle categories on highway, rural and urban roads.
Even if both methodologies are based on Copert IV, the quantitative comparison of estimated traffic emissions enlightens differences which are not negligible for some pollutants.
In order to fully assess pros and cons of the two methodologies, emissions have been used to feed an air quality modelling system, based on the Eulerian chemical transport model FARM, on a 1 km horizontal spatial resolution square grid (51 x 51 km^2), using a regional simulation on a 4 km grid as one-way boundary conditions. The results emphasize a good description of the pattern distribution of pollution caused by the road network, treated as a linear source in the bottom-up approach, and show the appropriateness of using such an approach when proposed measures for abatement of traffic-related pollution need to be assessed.

INTRODUCTION
The Directive 2008/50/EC, in accordance with the previous European Directives, requires Member States to develop air quality plans in order to comply with air quality standards in the most effective and timesaving way.
A reliable and updated estimation of emission sources is thus a crucial factor in the definition of effective air quality plans and related abatement measures.

Emission inventories are usually based on a top-down methodology. They rely on information that must be homogeneously available for large territories. In the case of road transport, the fuel consumption is commonly used for the estimate of regional emissions and proxy variables, like resident population or registered vehicles fleet, are used to estimate road transport emissions on smaller administrative levels.

The definition of effective measures and the assessment of their effects on air quality can require an extremely detailed knowledge of emissions: in these cases a bottom-up approach can be preferable whenever local information are collected in a consistent way, both in quantity and in time.

In this paper we present a comparison between top-down (Regione Piemonte, 2008) and bottom-up approaches in evaluating road transport emissions in the metropolitan area of Torino, in the North-Western part of the Po Valley. This is one of the most polluted area in Europe, mainly due to road transport which is the most relevant atmospheric pollutant source, and the air quality plans already in force include specific actions aimed at the abatement of traffic emissions.

ESTIMATE AND COMPARISON OF ROAD TRANSPORT EMISSIONS
The Piemonte Region is divided in seventeen air quality zones. The agglomeration of Turin, labeled as IT0103 according to directive 2008/50/EC reporting requirements. encompasses besides Torino other ten smaller cities with a total of about 1'350'000 inhabitants. The IT0103 zone is characterized by a poor air quality: this is the combined result of a heavy load of emissions, due to the high density of population, roads and factories, and the typical meteorology of Po Valley, often affected by very stable atmospheric conditions. Since 2006, in the metropolitan area of Torino is active a real time traffic control system, based on around 1000 sensors feeding a traffic assignment model, capable of estimating traffic flows and velocities on 6150 links every hour. The following analysis is limited to the 5125 links falling in the zone IT0103, while the extension to the whole regional network is under investigation.

Top-down methodology
Top-down emissions are reported in IREA, the official emission inventory of the Piemonte Region (Regione Piemonte, 2008). IREA is released every two years and it contains an estimate of pollutants emitted by all the activities potentially relevant for the assessment of atmospheric pollution, geographically partitioned among the 1206 municipalities. A well-established methodology, shared by eight regions in Italy and mostly based on the INEMAR database (Arpa Lombardia) is employed to calculate emissions. The road transport module was developed according to Copert IV (Ntziachristos L. and Z. Samaras, 2009): road transport emissions of the whole Piemonte region are calculated starting from few traffic data (on the

main highways and roads), from the amount of fuel sold in the area and from the vehicles fleet technical features. As a first step, the emissions of highways and rural roads are calculated using the traffic flow data, while an estimate of the associated fuel consumption is obtained. Consequently, from the amount of fuel sold, the residual fuel is distributed among all Piedmont Region municipalities using as a proxy variable the vehicles fleet composition as derived from the municipal registers. To better reproduce the features of the circulating fleet as opposed to the registered one, the annual mean distance covered by each Copert category has been exploited as a weighting parameter. The emissions of all pollutants is then calculated.

The Piemonte Region emission inventory has been recently enforced by the quantification of PM_{10} and $PM_{2.5}$ emissions due to particulate resuspension from the roads surface, according to the formula suggested by EPA (EPA, 2006).

$$EF = [k(SL/2)^{0.65}(W/3)^{1.5} - C](1-1.2\,P/N) \quad (1)$$

where:

EF is the particulate emission factor, expressed in g/(V*km);
k is the particle size multiplier for particle size range, 4.6 g/(V*km) for PM_{10}, 1.1 g/(V*km) for $PM_{2.5}$;
SL is the road surface silt loading, varying in the Piedmont inventory from 0.02 g/m^2 and 0.25 g/m^2;
W is the average weight (tons) of the vehicles traveling the road (1.13 for cars, 3.35 for light duty vehicles, 13 for heavy-duty vehicles, 0.3 for two wheelers);
C is the emissions of PM_{10} (unit g/(V*km)) from exhaust, brake wear and tyre wear;
P is the number of hours with at least 0.254 mm of precipitation;
N is the number of hours in the averaging period.

Bottom-up methodology

The bottom-up emissions have been calculated using the traffic flow data of a network consisting of 5125 links by employing the software TREFIC (Nanni A., P. Radice and P. Smith, 2009) that implements Copert IV emission factors for most of pollutants and the emission factors provided by IIASA (IIASA, 2002) for PM_{10} and $PM_{2.5}$. Since the IIASA emission factors include exhaust and wear emissions but do not take into account the resuspension of PM_{10}, this contribution has been calculated by using the EPA formula recently published in 2011 (EPA, 2011).

$$EF = [k(SL)^{0.91}(W)^{1.03}](1-1.2\,P/N) \quad (2)$$

This equation (2) gives an estimate of resuspended particulate matter using the same parameters of equation (1), but it is based on a wider set of experimental data. Besides different values of the fitting exponents, the new formula does not require to subtract the contribution of exhaust, brake wear and tyre wear, while the k coefficient is now set to 0.62 g/(V*km) for PM_{10} and 0.15 g/(V*km) for $PM_{2.5}$. For the sake of the present analysis, the silt loading parameter, SL, has been set equal to 0.03 g /m^2, the smallest value among those suggested by EPA. The local traffic management company (5T s.r.l). has provided traffic flow data for all the hours in year 2008. For each link, the hourly mean flow and the mean speed of vehicles have been calculated. The hourly mean flow has then been split into the flow of four vehicle types: two wheelers, passenger cars, light duty vehicles, heavy duty vehicles. The splitting rule was different for highways, rural and urban roads, being based on specific site surveys or published studies (traffic flow measurements, highways toll payment data, mobility report...)(Comune di Torino, 2002; Agenzia Mobilità Metropolitana Torino, 2004).

Table 6. Splitting percentage among vehicle types for different type of roads.

Vehicle type	Urban roads split of vehicle flow	Turin city center split of vehicle flow	Rural roads split of vehicle flow	Highway split of vehicle flow
two wheeler	6%	6%	6%	4%
passenger car	85.8%	87%	84.8%	78%
light duty vehicle	5.8%	5.8%	4.8%	9%
heavy duty vehicle	2.4%	1.2%	4.4%	9%

The TREFIC software requires also the input of the fleet for the splitting of each vehicle type flow into COPERT categories. The fleet is defined using the dataset provided by Regione Piemonte and employed for the compilation of the top-down inventory IREA.

Other input parameters include the annual mean temperature, set to 13.5°C on the basis of the measurements of Giardini Reali station, and the average trip length has been set to 8.5 km on the basis of Turin Metropolitan Area Mobility Report (Agenzia Mobilità Metropolitana Torino, 2004).

Using, traffic flow data, fleet data and the other input parameters the hourly mean emission of each link has been calculated and then the yearly emission due to private transport on the road network has been calculated.

For the assessment of evaporative emissions from parked vehicles it has assumed that one million of vehicles were hypothetically positioned along the considered network and a daily average temperature ranging from 8.5°C to 18.5°C has been considered.

In Table 2 the yearly emissions for the main atmospheric pollutants are reported, as estimated in the bottom-up approach.

Table 7. Emissions calculated for road network in zone IT0103 (Turin Metropolitan Area) in bottom-up approach.

	CO (t/y)	CO_2 (kt/y)	NMVOC (t/y)	NO_X (t/y)	PM_{10} (t/y)	SO_2 (t/y)
Private road network emission (including stationary evaporative emissions) – zone IT0103	15226.5	1232.8	1753.3	5240.7	657.5	30.1
GTT public buses road network emissions (including stationary evaporative emissions) – zone IT0103	175.8	64.9	89	626.4	40.1	0.1
Total emissions of road network – zone IT0103	15402.3	1297.7	1842.3	5867.1	697.6	30.2

The emissions caused by circulating buses of the local public transport company (GTT) have been separately calculated using the total fuel consumption, the vehicle fleet composition and the average commercial speed (17.5 km/h). These data were retrieved in the annual report of GTT (Gruppo Torinese Trasporti) and in the annual report about mobility in the metropolitan area (Agenzia Mobilità Metropolitana Torino, 2008).

Top-down vs. bottom-up: comparison between the results

Even if dense, the road network employed by the 5T traffic model does not include all the urban streets of the Turin metropolitan area. Not surprisingly CO_2 emissions estimated in the bottom-up approach corresponds only to the 63% of CO_2 reported in Piedmont inventory for the same area. Since the emissions assigned to highways and rural roads in the two approaches are approximately the same, a share of CO_2 (760.3 kt) has been associated to bottom-up diffuse urban emissions, in order to keep the total amount of CO_2 emitted by road transport the same in the two approaches. Consequently, a share of emissions for all the other pollutants has been estimated using the ratio between each pollutant and CO_2 calculated in the bottom-up approach for the subset of urban links. In Table 3 the emissions estimated in the bottom-up approach for the road network are reported, including public buses and diffuse urban emissions. In Table 4 the emissions estimated by Piemonte Region using a top-down approach are reported.

Table 8. Sum of road network emissions and urban diffuse emissions in zone IT0103 (Turin Metropolitan Area) in bottom-up approach.

	CO (t/y)	CO_2 (kt/y)	NMVOC (t/y)	NO_X (t/y)	PM_{10} (t/y)	SO_2 (t/y)
Total emissons of road network + LPT– zone IT0103	15402.3	1297.7	1842.3	5867.1	697.6	30.2
Diffuse urban emissions – zone IT0103	10085.9	760.5	1664.3	2710.1	368.2	18.5
BOTTOM-UP approach Road transport emissions - zone IT0103	25488.2	2058.2	3506.6	8577.2	1065.8	48.7

Table 9. Emissions in zone IT0103 (Turin Metropolitan Area) in top-down approach (Piemonte Region Inventory).

	CO (t/y)	CO_2 (kt/y)	NMVOC (t/y)	NO_X (t/y)	PM_{10} (t/y)	SO_2 (t/y)
TOP-DOWN approach Road transport emissions, Piemonte Region inventory - zone IT0103	30060.9	2058.1	5520.3	8916.9	2111.7	342.2

The results obtained by using the two approaches show some considerable differences. When compared with top-down, the bottom-up road transport estimate accounts for 96.2% of NO_X emissions, 84.8% of CO emissions, 63.5% of NMVOC emissions, 50.5% of PM_{10} and 14.2% of SO_2, while the CO_2 is constrained to be the same, as explained before.

The macroscopic difference in the SO_2 amounts is easily explained: in TREFIC the fuel sulphur content is set to 40 ppm for both gasoline and diesel, in agreement with Copert methodology, while in Piemonte Region Inventory the sulphur content is set to 130 ppm for gasoline and 300 ppm for diesel, an outdated standard not yet revised.

The difference in PM_{10} emissions is mainly due to resuspension, a phenomenon highly dependent by the parameters choice, even if also the emission factors for exhaust, wear emissions are different in two approaches (IIASA vs. COPERT).

In order to elucidate the overall underestimate which seems to be associated with the bottom-up approach, even if the same set of emission factors have been employed and a comparable set of input data used in the two calculation flows, in Figure 1 and in Figure 2 is shown the apportionment of CO_2 among urban roads, rural roads and highways and the apportionment of CO_2 among the vehicle types for each road type. CO_2 emissions are directly related to the fuel consumption and give an immediate picture of the traffic features, depending on the number of circulating vehicles and on the lengths of trips. By looking at Figure 1 and in Figure 2 it becomes evident that the main difference resides in the share of emissions associated to urban roads: in the top-down approach the contribution of passenger cars travelling on urban roads accounts just for the 52% of the total as opposed to 80% for the bottom-up approach. Since passenger cars are characterized by lower emission factors, the emissions of all pollutants is lower for the bottom-up methodology.

The comparable NO_X emissions found in the two approaches are due to the fact that in the bottom-up case the share emissions of CO_2 of highways is higher with a higher percentage of heavy duty vehicles, which are characterized by very high emission factors of this pollutant.

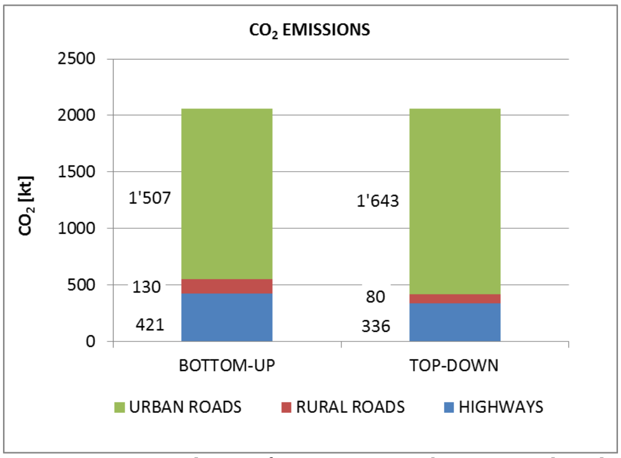

Figure 21. Apportionment among road types of CO_2 emissions in bottom-up and top down approaches.

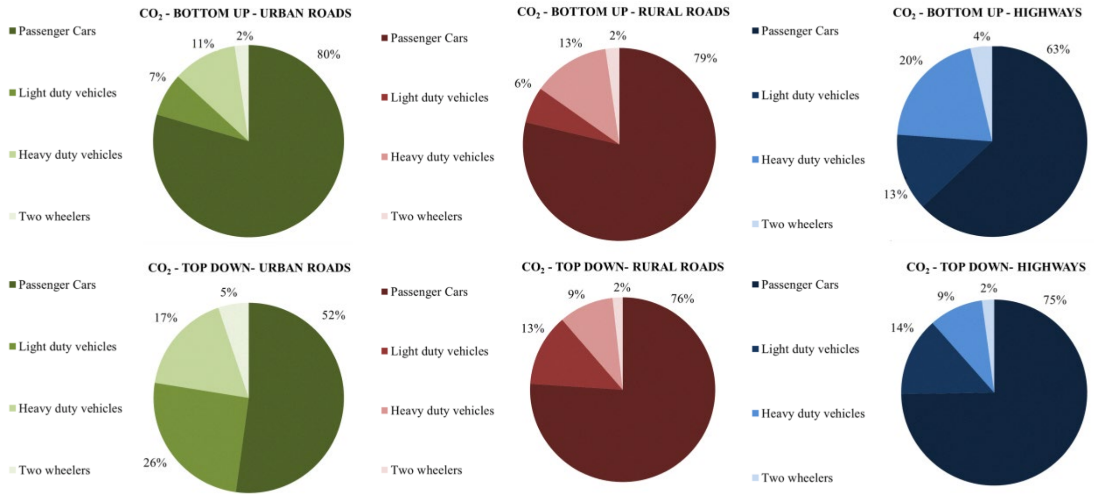

Figure 22. Apportionment among vehicle types of CO_2 emissions assigned to urban roads, rural roads and highways in bottom-up and top-down approaches.

The ex-post picture of traffic features is the result of the intrinsic characteristics of each methodology. In the bottom-up approach, emissions are calculated for each road (classified as urban/rural/highway) on the basis of the available flow data, and the splitting into vehicle types and Copert categories is derived from measurements and local evaluation. On the contrary, in the top-down methodology the pollutant emissions attributed to urban roads are calculated starting from CO_2 emissions, with CO_2 apportionment among the Copert categories only based on the registered vehicular fleet weighted with the annual mean distance travelled, distinguished between urban and rural/highway. Since the emission factors of different Copert categories have a wide spread, the different apportionment of CO_2 among the categories can lead to big differences in the total pollutants emissions.

POLLUTANTS CONCENTRATION

In order to assess the effectiveness of the bottom-up approach in the description of air quality, pollutant's concentration has been calculated by using the eulerian chemical transport model FARM (Calori e Silibello, 2009). Arpa Piemonte has provided three dimensional meteorological fields with 4 km of horizontal resolution for the months of January and February of 2008, and the corresponding concentration fields of pollutants, with a hourly frequency, calculated with FARM, starting from emissions of the top-down inventory of Piemonte Region (Muraro et al., 2009). The meteo dataset has been obtained with the mass-consistent model Swift/Minerve (Aria Technologies, 2001) and it is based on local wind and temperature measures (ground and profiles) and ECMWF analysis.

The dispersion simulation with bottom-up road transport emissions has been performed with a horizontal resolution of 1 km on a square grid of 51 x 51 km^2. Three-dimensional meteorological fields have been downscaled from the original dataset at 4 km resolution by applying the same mass-consistent model Swift/Minerve, while the turbulence parameters and the deposition velocities by using Surfpro3 (Silibello C., 2006).

Besides road transport emissions, all the other emission sources have been selected from the inventory of Piemonte Region and modulation profiles and cartographic layers were also provided by Arpa, except for industrial emissions and diffuse urban road transport. As for the time-modulation of linear road transport emissions, specific daily, monthly and yearly profiles have been derived from the original set of 5T data.

In Figure 3 the two-month average NO_2 concentration field is mapped showing a pattern resembling the road network depicted in the cartography below. When compared with monitoring data, the simulated values (in red) show very good agreement in the town centre, except for the south-west, probably because of a noticeable industrial source which needs to be outdated. A general underestimate is evident in the coronal monitoring sites, this is probably due to the fact that the road graph used by traffic model is less established than in the city centre.

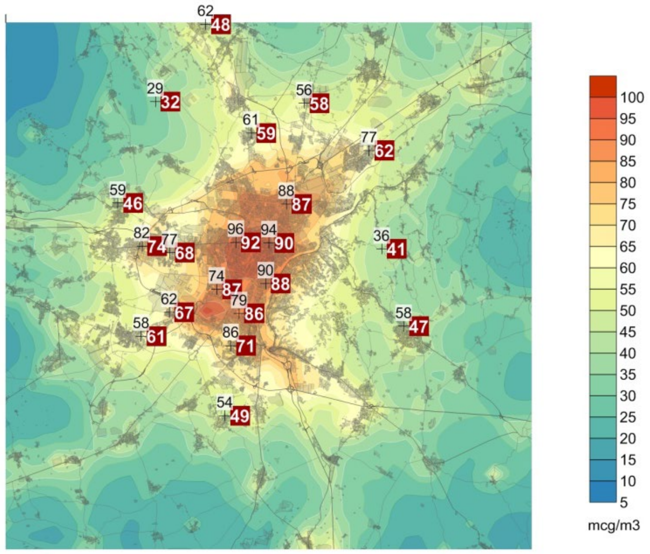

Figure 23. Average NO_2 concentration field of January and February 2008. Simulated values in red and monitoring data in black

CONCLUSIONS

In this paper we have compared top-down vs. bottom-up methodology for estimating the road transport emissions in the metropolitan area of Torino, where the road network traffic data available allow the estimate of the main share of road transport emissions.

The quantitative analysis has shown considerable differences. The use of local flow data and proxy variables lead to a different apportionment of CO_2 emissions among urban roads, rural roads and highways and among the vehicle types. As a consequence, total emissions of all pollutants are lower for the bottom-up methodology compared to top-down, except for nitrogen oxides. Even so, the bottom-up methodology provides a more reliable tool for the development of effective air quality plans in metropolitan areas, where road transport usually is a significant cause of atmospheric pollution, since it allows an explicit apportionment among road types and Copert categories that better fits the reality and a more detailed spatial description of road transport emissions. While time-consuming due to the large amount of traffic data that need to be treated, the bottom-up approach proves an essential step in the elaboration of firm mobility scenarios, capable of including detailed and precise measures only applied to a subset of roads or vehicles.

ACKNOWLEDGMENTS

The authors would like to thank ARPA Piemonte (Area Previsione e Monitoraggio Ambientale), 5T s.r.l., Piemonte Region, CSI and ATIVA for having kindly provided the data required.

REFERENCES

Agenzia Mobilità Metropolitana Torino, 2004 e 2008: Indagine sulla mobilità delle persone e qualità dei trasporti, *http://www.mtm.torino.it/it/dati-statistiche/imq2008.pdf*

Aria Technologies, 2001: Minerve Wind Field Models version 7.0, General Design Manual. ARIA Report, May 2001.

Arpa Lombardia: INEMAR, INventario EMissioni ARia, *http://www.inemar.eu/xwiki/bin/view/InemarWiki/Moduli.*

Calori G. and C. Silibello, 2009: FARM (Flexible Air quality Regional Model) Model formulation and user manual. Rapporto ARIANET R2009.23

Comune di Torino, 2002: Piano Urbano del Traffico della Mobilità delle Persone 2001. *Torino, Deliberazione del Consiglio Comunale 19 giugno 2002 (http://www.comune.torino.it/put2001/)*

EPA, 2006: AP 42 Section 13.2.1 Paved Roads, November 2006.

EPA, 2011: AP 42 Section 13.2.1 Paved Roads, Update January 2011.

Gruppo Torinese Trasporti, 2008: Il Bilancio di sostenibilità, gestione ambientale 2008. *http://www.comune.torino.it/gtt/gruppo/bil_sost/06_ambientale.pdf*

IIASA, 2002. Modelling Particulate Emissions in Europe. Interim Report IR-02-076.

Muraro M., M. Giorcelli, S. Bande, A. D'Allura, S. Finardi, 2009: Sistema modellistico multiscala per la simulazione di dispersione di inquinanti in atmosfera. Proceedings of the conference "Controllo ambientale degli agenti fisici: nuove prospettive e problematiche emergenti", Vercelli, 2009.

Nanni A., P. Radice and P. Smith, 2009: "TREFIC (Traffic Emission Factors Improved Calculation) User's guide". Rapporto ARIANET R2009.19

Ntziachristos L. and Z. Samaras, 2009: Exhaust emissions from road transport, EMEP/EEA emission inventory guidebook.

Regione Piemonte, 2008: Inventario Regionale delle Emissioni in Atmosfera – Anno 2007, *http://www.sistemapiemonte.it/ambiente/irea/*.

Silibello C., 2006 "SURFPRO (SURrface-atmosphere interFace PROcessor) User's guide". Rapporto ARIANET R2006.06