Journal of Earth Sciences and Geotechnical Engineering, vol.7, no. 1, 2017, 175-190
ISSN: 1792-9040 (print version), 1792-9660 (online)
Scienpress Ltd, 2017

Combining microscopic traffic modelling and 3 pollutant emission modellings to assess modifications of traffic supply and demand

Anne-Laure Badin[1], Aurore Clavel[1], Thérèse Vittoz[1], Caroline Sorand[1], Delphine Lejri[2], Ludovic Leclerc[2] and Xavier Olny[1]

Abstract

Traffic management definition and assessment strategies rely on results from successive stages of modelling: from traffic to air pollution concentrations. The objective of this study was to improve this modelling process. Combining microscopic traffic modelling and 3 pollutant emission modellings was performed: two using aggregated traffic estimates (HBEFA, Copert) and the other using vehicle trajectory (Phem). The studied area is part of the Lyon urban area (6,2 km², 2091 road sections). Traffic and emissions were simulated for 16 scenario resulting from modifications of supply or demand (traffic calibration on the afternoon rush hour). Copert and HBEFA estimations show many similarities and differences with Phem. Ranking of scenarios on the basis of their variation to the reference was performed and analysed. Copert and HBEFA provide the same ranking. To focus on the analysis of two scenarios, difference of NOx emissions per link were maped (only the higher variations). The relevance of dealing with both the network and the links spatial scales to assess the impact of the scenario was clearly shown.

Keywords: dynamic traffic modelling, traffic management, emissions, scenario, sensitivity

1 Introduction

Health impact of air pollution is largely referenced; road traffic is one of the main source of some pollutants (NOx, particulate matter) (Pascal et Medina 2012). Local air quality results from the combination of regional air quality and local emissions of pollutants. As road traffic is a major source of pollution, policies

---

[1] Cerema CE, Bron, 69500, Bron
[2] COSYS-LICIT, IFSTTAR, ENTPE, Université de Lyon, 69000, France

aiming at improving air quality target it. Pollutants emissions from road traffic depend in particular on volumes of traffic, vehicle fleet and vehicle dynamic. Thus policies aim at having an impact on these parameters, by improving car fleet renewal, promoting public transport and car sharing, and implementing traffic management. Implementation of traffic management and promotion of public transport and car sharing could be efficient more rapidly than car renewal. In order to define operational policies and measures impacting traffic, their efficiency needs to be assessed. Stakeholders require this assessment to base their decision on it. Analysis and ranking of scenarios regarding their impact on air pollution and health therefore has to be performed.

In France, these assessments are commonly conducted on the basis of results of traffic static modelling; these studies are performed to assess the impact of a new road on air quality. Temporal and spatial precisions of those modellings are quite insufficient to assess the impact of traffic management measures. Thus it is needed to develop some methods using dynamic traffic modelling as input of emissions modellings. The mid term aim of our work is to define a methodology to assess traffic management strategies regarding their environmental impacts.

We have performed couplings of results from a microscopic dynamic modelling with pollutant emissions modellings. Different modifications of traffic supply and demand were modeled and analyzed in terms of traffic and environmental impacts. Some analyses of these results are presented in this paper.

2 Methods

The studied area

The studied area is part of the Lyon urban area (6,2 km^2, 2091 road sections). It is considered as an urban area. Speed limits are, respectively, 50, 30 and 70 km/h, for 89, 10 and 1% of the links.

The microscopic traffic simulations

The microscopic traffic simulations were modeled with Aimsun (Transport Simulation System, s. d.) for 1 hour (the traffic was loaded 15 min before the beginning of the simulation, on an empty network). Real data of the 5-6 PM period were used for the calibration. The reference simulation was sufficiently stabilized to allow the assessment of the sensitivity to supply and demand variations. Its own variability was assessed (10 runs performed).

The studied scenarios

To assess sensitivity of the joint modellings, 16 scenarios of modified traffic supply and demand were simulated (table 1).

The following mean traffic parameters were recorded: flow (veh/h), density (veh/km), total run distance (km). Microscopic traffic simulation is stochastic, so in order to qualify the variability of the estimated traffic parameters, the simulation of the reference was repeated 10 times with a random seed pace (sec/km), total run time (h), mean speed (km/h). Results are presented in the table 2.

The modelling of pollutant emissions

The configuration of the emission modellings benefited from previous works: i, the development of an information system called TRAPS (Trafic Related Air Pollution Simulator), that establishes the link between modellings of traffic and emissions, ii, TRAPS calibration with appropriated fleet composition and traffic situation iii, sensibility analyses that settled an optimal time aggregation of 15 min, and the use of mean spatial speed.

Pollutant emissions were calculated using: Copert IV, HBEFA and PHEM (Hausberger, Stefan). Only exhaust emissions were calculated, and cold start excess emissions were not taken into account. Fuel consumption (FC) and the following pollutants: CO, NOx, hydrocarbons (HC) were considered.

As any aggregated emission model, Copert IV uses mean driving speed and total travelled distance for a given time period to predict the related exhaust emissions. The total emissions are calculated as the product of the travelled production (vehicle.distance) and the unitary emission factors (expressed in g.km−1). Unitary emission factors consist of speed-continuous functions that have been constructed over driving cycles of about 6mn-length, which are representative of encountered traffic conditions. These unitary emission functions are defined for each vehicle technology. The unitary emission functions of a specific vehicle category (passenger cars, light commercial vehicles, heavy duty vehicles or buses) are obtained by operating a weighted average of the vehicle technologies that compose the category.

Table 1: description of the simulated scenarios

Simulation	Description	Named as
Reference		Ref
Supply modification	Capacity of the street called *bvd du 11 novembre* was reduced to 400 vehicles/hour (instead of 1300)	O11nov
	The street called *rue Francis de Pressensé* was settled as a one way street; journeys from west to east were made impossible	OPr
Modification of the overall matrix of demand: for all the O-D the number of journeys increase / decrease in the given proportion	- 30%	Dm30MG
	- 20%	Dm20MG
	- 10%	Dm10MG
	+ 10%	Dp10MG
	+ 20%	Dp20MG
	+ 30%	Dp30MG
Modification of part of the matrix of demand	Demand modification of the O-D submatrix constituted from the O-D that use the streets called *bvd Stalingrad* and *bvd du 11 novembre*	Dm20S11
	- 20%	Dm10S11
	- 10%	Dp10S11
	+ 10%	Dp20S11
	+ 20%	
Modification of part of the matrix of demand	Demand modification of the O-D submatrix constituted from the O-D that use the streets called *bvd Emile Zola* and *rue Francis de Pressensé*	
	- 20%	Dm20ZP
	- 10%	Dm10ZP
	+ 10%	Dp10ZP
	+ 20%	Dp20ZP

Table 2: traffic parameters mean and SD for 10 replicates of the reference scenario

	Unit	Mean value	Standard deviation
Traffic flow	veh/h	13747	156
Density	veh/km	8,0	0,4
Traveled total distance	km	29588	522
Mean speed	km/h	25,1	0,6

Copert IV (Ntziachristos et al., 2009) has been widely used in most European Countries to elaborate the national emission inventories, but it is also extensively used for network emission modelling (Borge et al., 2012; Samaras, Christos et al., 2014). However, its use at spatial scales lower than the driving cycles is subject to questions, since the speed distribution might differ and lose representativeness over too small samples or specific traffic conditions (e.g. in the vicinity of intersections).

HBEFA is another aggregated emission model. It provides emission factors, i.e.

the specific emission in g/km for all current vehicle categories (PC, LDV, HDV, buses and motor cycles), each divided into different technologies segments, for a wide variety of traffic situations. Traffic situations were not provided by the microscopic traffic modelling. Thus, a conversion method was defined to estimate the traffic situation from the mean speed occurring on the links and some characteristics of the link. Then, emissions are calculated with the HBEFA methodology.

PHEM (Passenger Car and Heavy Duty Emission Model) calculates the fuel consumption and emissions of vehicles based on the vehicle longitudinal dynamics and on-engine emissions maps, with a 1s time resolution. The model provides an estimate of the engine power of a vehicle at each time step (1s), based on its speed time series and road gradient. The engine speed is estimated based on the transmission ratios and a gear shift model. The model also includes transient correction functions, and a cold start tool, to finally provide the evolution with time of fuel consumption and emissions of CO, CO2, HC, NOx, NO, particle mass (PM). Cold start emissions will be however disregarded in this paper.

PHEM has been coupled with dynamic traffic platforms at several occasions, in order to test the impact on emissions of road traffic strategies that modifies the vehicle kinematics behavior. However, the inadequacy between its required high traffic data resolution and the available dynamic traffic model outputs, which are much less refined, is subject to debate.

Data analysis has been performed using Rdata project (R Core Team, 2015) and Qgis (QGIS Development Team).

3 Results

Comparison of emission modellings

Ranges of pollutant emissions and fuel consumption differ between emission modellings as illustrated on figure 1. Range of Phem estimated emissions is much larger than ranges of emissions calculated with mean speed models. Moreover Phem estimates are always higher than Copert and HBEFA estimates: from 1.4 to 2 times the Copert estimates, and from 1.5 to 2.8 the HBEFA estimates.

A better consideration of the diversity of speeds by Phem could explain part of the variability of estimated environmental parameters.

The higher estimations of environmental parameters with Phem could result from the vehicle accelaration calibration of of the traffic modelling. Indeed, the modelling may not necessarily be well clibrated for environmental impact assessment. This was identified in the CoERT-P project.

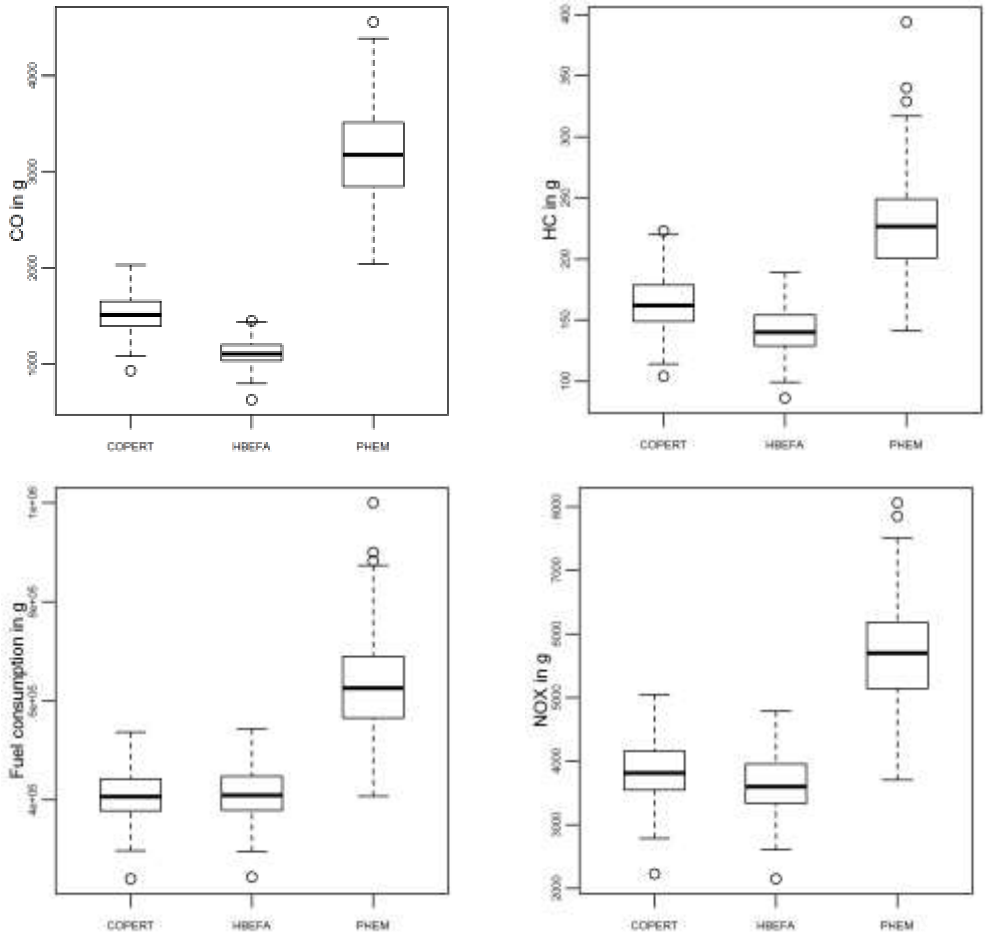

Figure 1: boxplot of the environmental parameters calculated with the different emission modellings for all the scenarios for the 4 periods of 15 min aggregated at the network scale

Table 3: global traffic estimates for the reference and all the scenarios

Scenario	Production in 1h (veh.km)	Production relative to ref	Spatial mean speed in m/s (over the 4 periods) (range)
ref	29 240	-	5~~,~~.2-5~~,~~.9
O11nov	28 230	-3%	3~~,~~.9-5~~,~~.2
OPr	29 010	-1%	5~~,~~.1-5~~,~~.6
Dm30MG	22 130	-24%	6~~,~~.5-7~~,~~.6
Dm20MG	24 987	-15%	6~~,~~.2-6~~,~~.8
Dm10MG	26 789	-8%	5~~,~~.7-6~~,~~.1
Dp10MG	31 100	6%	4~~,~~.2-5~~,~~.1
Dp20MG	33 370	14%	3~~,~~.9-4~~,~~.3
Dp30MG	25 570	-13%	1~~,~~.3-3~~,~~.6
Dm20S11	28 550	-2%	5~~,~~.3-5~~,~~.7
Dm10S11	28 370	-3%	5~~,~~.2-6~~,~~.8
Dp10S11	30 520	4%	4~~,~~.7-5~~,~~.4
Dp20S11	30 780	5%	4~~,~~.6-5~~,~~.0
Dm20ZP	28 150	-4%	5~~,~~.3-5~~,~~.7
Dm10ZP	27 290	-7%	5~~,~~.3-6~~,~~.6
Dp10ZP	30 160	3%	4~~,~~.6-5~~,~~.3
Dp20ZP	30 910	6%	4~~,~~.6-5~~,~~.3

Comparisons of all the scenarios at the network scale

The table 3 presents the traffic global estimates. Traffic production varies from 22 130 to 33 370 veh.km for two scenarios that impact the global OD matrix, respectively the Dm30MG and the Dp20MG scenario. Surprisingly, the scenario that impacts the most the demand (Dp30MG) do not show the greater production; mean speeds are much lower than for other scenarios: 1.3 to 3.6 m/s. In this scenario, grid lock occured, no more vehicle could enter the network. Thus this scenario was considered to be out of the traffic legitimate domain we do not further consider it in this study. Regarding all the other scenarios, mean speed ranges from 3.9 m/s for both O11nov / Dp20MG to 7.6 m/s for the Dm30MG scenario.

Comparison of scenarios is first performed using the aggregation of environmental parameters on the overall network; the relative difference to the reference scenario is considered.

Relative difference of scenario to the reference ranges from -35% to 49%, respectively for HC Dm30MG and HC Dp10MG scenarios, both being Phem estimates. The ranking of scenarios from the less emissive to the more emissive is similar whatever environmental parameters is considered when considering HBEFA and Copert estimates, and it is the same regarding the Phem NOx estimates: Dm10ZP, O11nov, Dm10S11, OPr, Dp10ZP, Dp10S11, Dp20ZP, Dp20S11, Dp10MG, Dp20MG.

Whereas Phem NOx estimates rank scenarios as all Copert and HBEFA environmental estimates, Phem estimates of HC, fuel consumption or CO rank differently the scenarios (figure 2). The HC and FC appear to evolve in the same way whereas CO evolves differently. As an example, Dp10MG is the most emissive scenario regarding HC (+48%) and is expected to lead to the higher fuel consumption (+42%), whereas it leads to only +5% of CO emissions.

Whatever method is used for emissions estimations, pollutant emissions and fuel consumption are significantly (more than 5% of difference relative to the reference values) higher in the followings scenarios, from the higher to the lesser increase: Dp20MG, Dp10MG, Dp20S11, Dp20ZP, Dp10S11, and significantly lower in the following scenarios, from the higher to the lesser decrease: Dm30MG, Dm20MG, Dm10MG, Dm20ZP, Dm20S11.

Minor relative differences are noticed for the following scenarios: Dm10ZP (-4% whatever the parameters and emissions modelling used), O11nov (from -3 to 4%), Dm10S11 (from -6 to –2%), OpR (from -1 to 0%), Dp10ZP (from 3 to 9%).

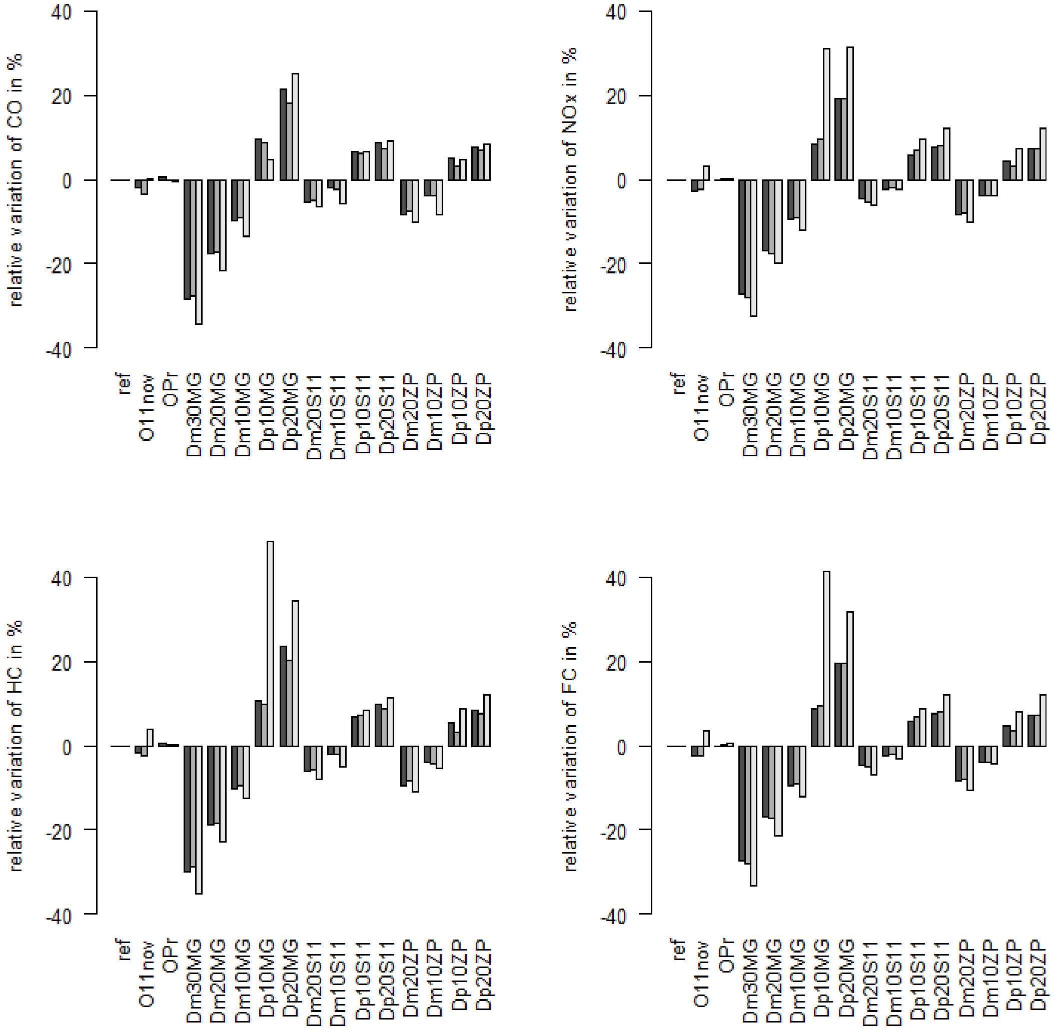

Figure 2: relative variation of the environmental parameters calculated for each scenario to the reference scenario. The darker grey: Copert, medium grey: HBEFA, light grey: Phem estimations.

Analysis of two scenarios on the basis of the difference of NOx emission between scenario and reference over the 2091 links

Focus was directed on the analysis of NOx emissions in the following analysis. We have chosen to further analyze two scenarios that have presented moderate variations of emissions at the network scale: Dm20ZP and the O11nov scenarios. Their variations of environmental parameters rank from -8 to -11% and -3 to +4% to the reference scenario, respectively. Both are quite realistic scenarios that could be analyzed as part of a transport local policy.

Maps are presented in the figures 3 and 4. As to highligth the major trends, a selection of the links that show the higher difference in NOx emissions between scenario and reference was performed. D is defined as D=NOx emissions of the scenario – NOx emissions of the reference. Figured links have absolute value of D > 10 g of NOx / h/ link. This means that Positive D means more emissions (figured in solid line); negative D means less emissions (dashed line). All links and nodes are included in the analysis, whereas only links are figured. Details of the distribution of D regarding the threshold of 10 g and the quantiles 0.05 and 0.95 are provided in table 4.

Figure 3: impact of the O11nov scenario on the estimated NOx emissions. NOx emissions of the reference scenario is figured in ligth grey, major differences of O11nov to the reference in dark. More explanations of method in the text.

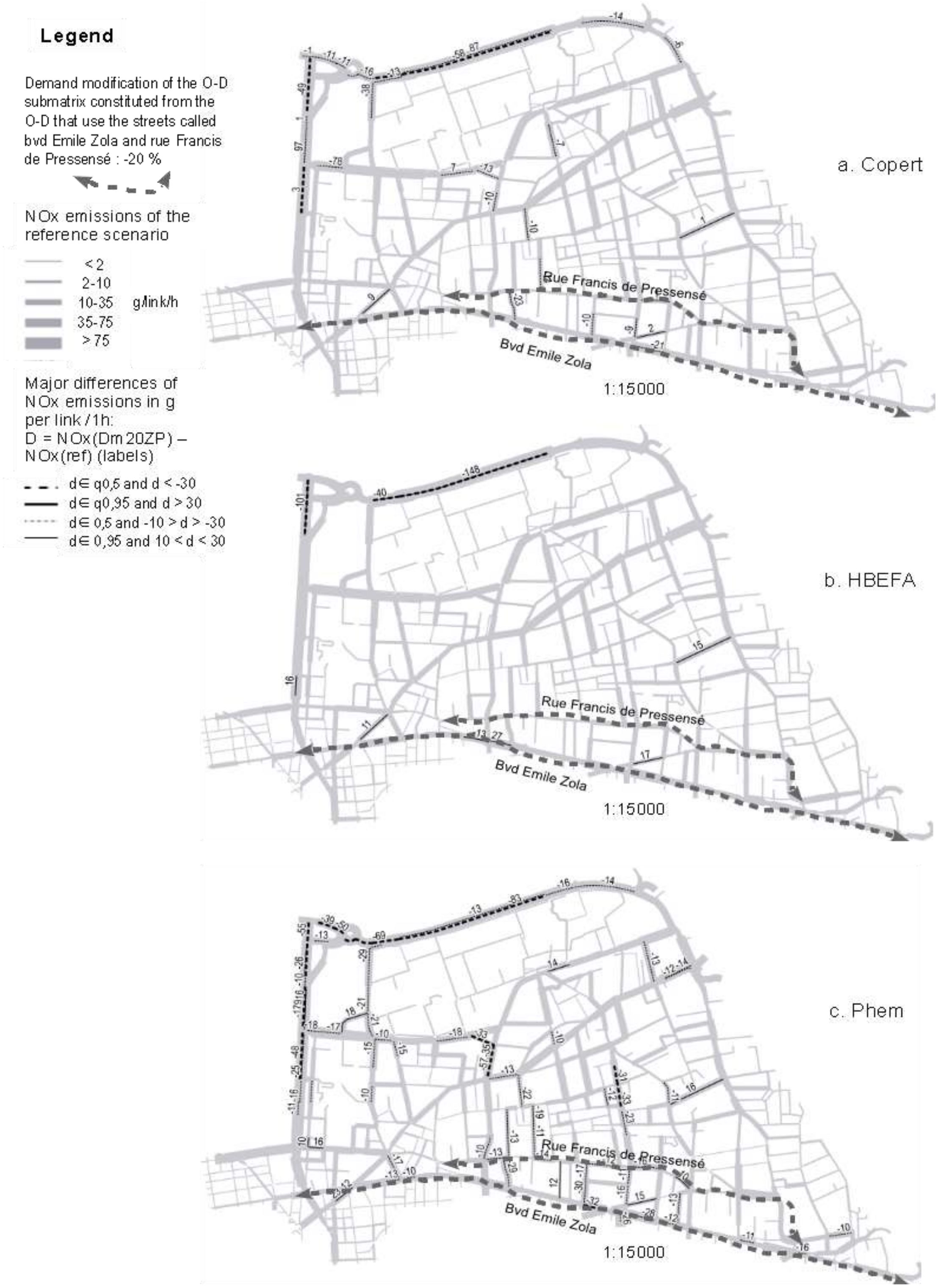

Figure 4: impact of the Dm20ZP scenario on the estimated NOx emissions. NOx emissions of the reference scenario is figured in ligth grey, major differences of O11nov to the reference in dark. More explanations of method in the text.

Table 4: absolute differences of NOx emissions between scenarios and reference taken into account in different subsets of data, q0.05 and q0.95 are quantiles of the differences (D) of emissions of the 2091 links and nodes. a, NOx emissions are summed over the different subsets of links (in g / h); b, percents are given relatively to the sum of negative and positive differences of emissions; c, number of links per subsets

			Sum of NOx emissions differences in the following subsets						Values of difference of NOx emissions per link (in g/h)	
			D < -10	D < q0.05	D < 0	D > 0	D > q0.95	D > 10	Quantile 0.05	Quantile 0.95
Dm20ZP – ref	Copert	a	-625	-1072	-1698	428	318	47	-3.67	1.14
		b	37%	63%	100%	100%	74%	11%		
		c	29	106	921	515	105	4		
Dm20ZP – ref	HBEFA	a	-666	-1090	-1661	474	368	98	-3.54	1.17
		b	40%	66%	100%	100%	78%	21%		
		c	29	106	919	514	106	7		
Dm20ZP – ref	Phem	a	-1732	-2007	-3078	742	542	171	-7.30	1.90
		b	56%	65%	100%	100%	73%	23%		
		c	73	106	932	516	106	13		
O11Nov – ref	Copert	a	-1271	-1622	-2301	1899	1457	1101	-5.10	4.07
		b	55%	70%	100%	100%	77%	58%		
		c	56	106	766	681	106	51		
O11Nov – ref	HBEFA	a	-1215	-1637	-2289	1915	1508	1150	-5.22	4.18
		b	53%	72%	100%	100%	79%	60%		
		c	48	106	771	672	106	51		
O11Nov – ref	Phem	a	-2197	-2357	-3423	4135	3189	3094	-8.81	9.17
		b	64%	69%	100%	100%	77%	75%		
		c	89	106	769	698	106	96		

The table 4 shows the quantities of NOx emissions that are generated or avoided thanks to the scenarios over different subsets of links. Regarding the two studied scenarios, quantiles 0.05 and 0.95 of NOx differences are very similar for Copert and HBEFA resulting estimates (maximal difference of 0.13), whereas absolute values of these quantiles are higher for Phem. The distribution of differences of NOx emissions is thus more dispersed. Phem calculations result in more frequent large differences between scenarios and reference.

The proportions of links with less emissions (ie negative D) over the links with supplementary emissions (ie positive D) are different for the two studied scenarios: 1.8 for the Dm20ZP and 1.1 for the O11nov (ratio similar whatever emissions modelling used).

At least 63% of the emissions variation are taken into account when considering 5% of the links included in one of the tails of the distritbution of D (with values of difference inferior to quantile 0.05, or superior to quantile 0.95). It reaches 79% for the O11Nov scenario estimated with HBEFA. More than 200 links are considered (2*0.05*2091 links and nodes).

More than 200 links represented on the map may result in a confusing map, thus we have applied a threshold at 10 g/link on D. When applying this threshold value, the number of links is reduced to 33 to 185 and the representativeness of these links as supporting a large amount of NOx variation is also reduced up to 11%. The two scenarios present noticeable differences: i, in terms of number of links having a D > 10 (33 to 86 for Dm20ZP, 99 to 185 for O11Nov), ii, the representativeness of the subset is more reduced in the case of Dm20ZP (11% to 23% of the positive emissions, and 37% to 56% of the negative emissions) than in the case of O11Nov, in which the reduction due to the threshold still represents more than the half of the emission variations. These differences must result from the scenario design. One is a very local operation, O11Nov, resulting in high local variation of emissions. The Dpm20ZP scenario induced a much more global variation; indeed it affects two very long and travelled roads of Villeurbanne. It must trigger an impact on the overall urban area but with less intense variation per link than the O11Nov scenario (ie less links showing differences > 10).

The analysis of maps (figures 3 and 4) show some similarities and some dissimilarities. As previously presented, more links are figured for the O11Nov than the for the Dm20ZP. More links are figured when Phem was the modelling used. Each modelling highlights some links that do not appear in the other. For each scenario, some links are figured whatever the emissions modelling is used. The larger solid and dashed dark lines highlight the difference of emissions that are higher than 30 g. For instance, this helps to identify the links that would support major variation of pollution, especially noticeable on the Op11nov map (figure 3).

4 Discussion

Several environmental parameters were calculated with 3 different emissions modellings on the basis of a microscopic dynamic modelling of a French urban network. As far as we know, very few studies reported that kind of data (Borge et al., 2012).

Investigating various spatial scales

Air quality results from phenomena that occur at different spatial scales. Emissions from traffic are local, but emitted pollutants can be transported far away from their sources. This supports the idea of analysing scenarios with different levels of spatial aggregation.

Interestingly, the analysis of the two selected scenario is very different at the two considered scales. At the network scale, no clear conclusion could been drawn for the O11nov scenario. But when hightlighting the links that represent the higher variations, impact of the O11nov scenario could be clearly noticed on some roads whose emissions were largely modified. . No aggregation was performed at the road scale, the two directions of traffic were considered. So, for some roads emissions increase on the links of one direction, and decrease on the links of the opposite direction. Aggregation has to be performed to provide better clarity concerning the variation of the emissions in a given road. Dispersion phenomena, largely influenced by the weather, and population allocation must also be taken into account in the future methodology.

Does the choice of the modelling of pollutants influence the scenario ranking?

Whereas estimations of emissions largely differ between the two aggregated modellings (Copert and HBEFA) and the instantaneous modelling (Phem), the differences of scenario emissions relative to the reference emissions are much less significant.

As a stakeholder could procede, we have conduced an analysis by ranking the scenarios from the less emissive to the more emissive one. Rankings based on fuel consumption and pollutant estimates were performed. Whatever environmental parameter considered, the two aggregated modellings provided the same ranking of scenarios. Part of the rankings based on Phem estimates could be similar or different depending on the environment parameters considered (HC and FC *vs* CO *vs* NOx).

As Phem considers vehicle trajectories and speed, it might be more sensitive to variations of traffic condition and speed variation. Further investigations of the traffic dynamic in those scenarios would provide explanations, but has not been performed yet.

Combining a dynamic traffic modelling and emissions modellings

This study is one stage of development of a much longer line of modelling that goes from the traffic characterization to the health impact assessment. The analysis of the microscopic simulation results would allow to further characterize the traffic conditions.

Comparisons between emissions modellings were made possible because ensuring consistency of emissions factors, vehicle fleets and other hypothesis were performed previously in the CoERT-P project. To improve the combining of dynamic traffic modelling and emissions modelling, other developments are needed: integration of the fleet of heavy duty vehicles, and calculation of cold start excess emissions. These developments would integrate the TRAPS interface.

A weak representativness of accelerations for the traffic simulation is suspected to explain the high values of Phem estimates. The mean speed used for Copert and HBEFA calculations might be more realistic. Previous work have already discussed the relevance of combining microscopic traffic simulation with estimations of environmental parameters (Vieira da Rocha et al, 2015).

Ranking of scenarios on the basis of relative difference to the reference is often used. However, accurate estimations of real pollutant emissions are needed because they enter the calculations of pollutant concentrations. Monitoring air pollution can only be performed on pollutants concentrations.

In order to valuate the emissions estimations and their trends, comparisons with measures would be necessary. Following this idea, experimentations could be designed on the basis of the results of modelling. Locations for the measuring apparatus and period of observation could be defined thanks to modelling results.

This is one perspective of this work.

Dynamic traffic modellings are usually made for dealing with rush hours and their constraints. However, pollutant emissions in each hour of the day contribute to the air quality. Thus, methodologies of traffic modellings have to evolve to also take into account environmental requirements and not only traffic management ones.

Acknowledgments

This work was supported by the PREDIT IV fund of the French ministry of environment and transport (Medde). The authors are grateful to F. Golay for preliminary work, to M. André, and O. Charnay for useful help for data analysis, and L. Chauvin for proofreading.

References

[1] Borge R., I. de Miguel, D. de la Paz , J. Lumbreras, J. Pérez & E. Rodríguez (2012): Comparison of road traffic emission models in Madrid (Spain). Atmospheric Environment, 62, p 461–471.
[2] Ntziachristos L., D. Gkatzoflias, K. Chariton & Z. Samaras (2009): COPERT: A European Road Transport Emission Inventory Model - In “Information Technologies in Environmental Engineering”, Ioannis N Athanasiadis Andrea E Rizzoli Pericles A Mitkas et Jorge Marx Gómez, Berlin, 491 504.
[3] Samaras C., L. Ntziachristos & Z. Samaras (2014): COPERT Micro : a tool to calculate the vehicle emissions in urban areas, Paris, France, 14-17 April, 2014, Transport Research Arena, 10.
[4] COPERT 4 (version 4.10) (2012): Emisia. http://emisia.com/copert.
[5] Hausberger S (s. d.): PHEM (version 11.2.17): Graz University of Technology.
[6] HBEFA (version expert version 3.1v5) (2014): Infras: http://www.hbefa.net/e/index.html.
[7] QGIS Development Team (2016): QGIS Geographic Information System, Open Source Geospatial Foundation.
[8] R Core Team (2015): R: A language and environment for statistical computing, Vienna, Austria: R Foundation for Statistical Computing.
[9] Transport Simulation System (s. d.): Aimsun, Transport Simulation System: https://www.aimsun.com/
[10] Vieira da Rocha T., L. Leclercq, M. Montanino, C. Parzani, V. Punzo, B. Ciuffo & D. Villegas (2015): Does traffic-related calibration of car-following models provide accurate estimations of vehicle emissions?, Transportation Research Part D, 34(c), 267–280.