Session 7: Mobile sources

Development of road traffic emission inventories for urban air quality modeling in Madrid (Spain)

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OUTLINE

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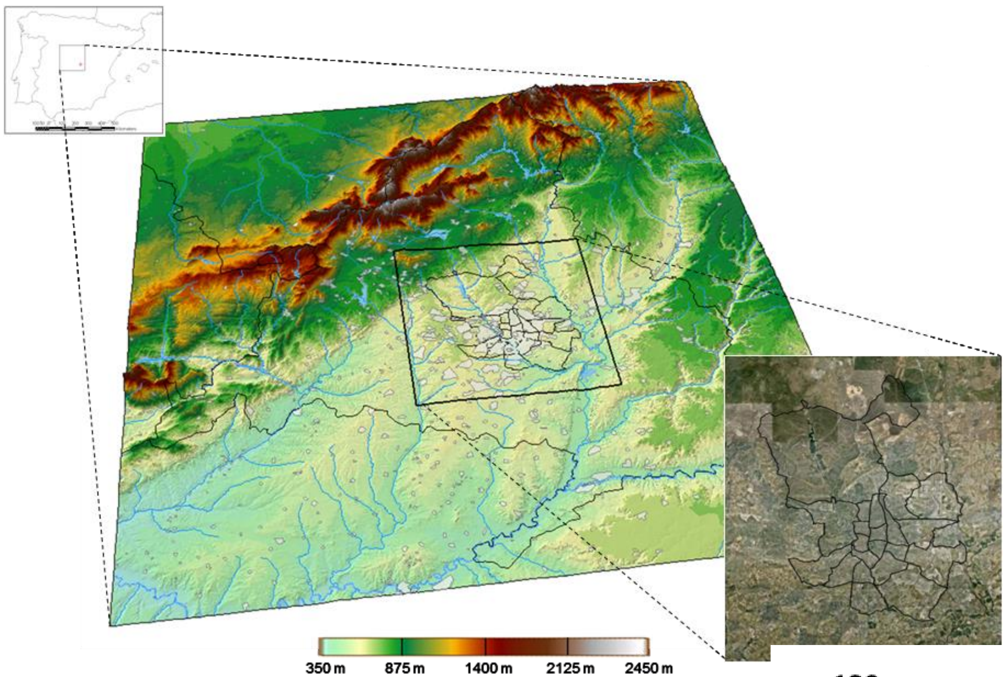
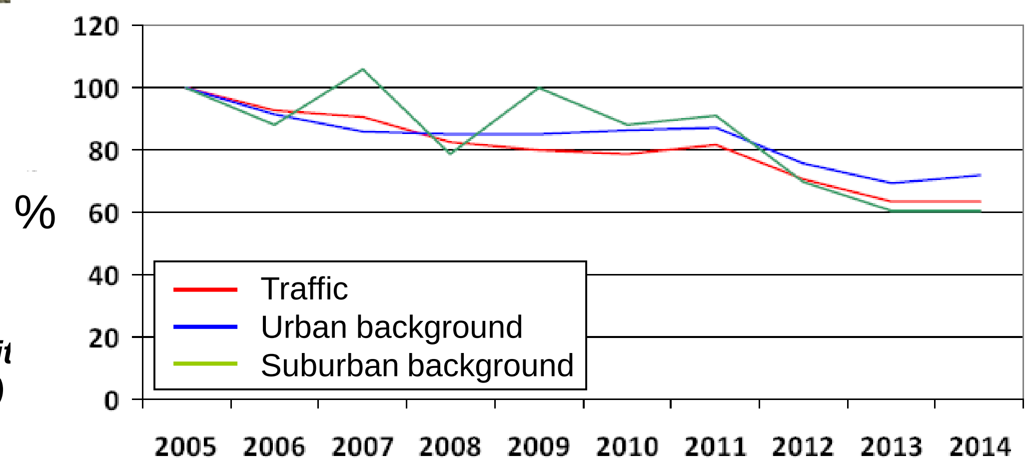
1. INTRODUCTION

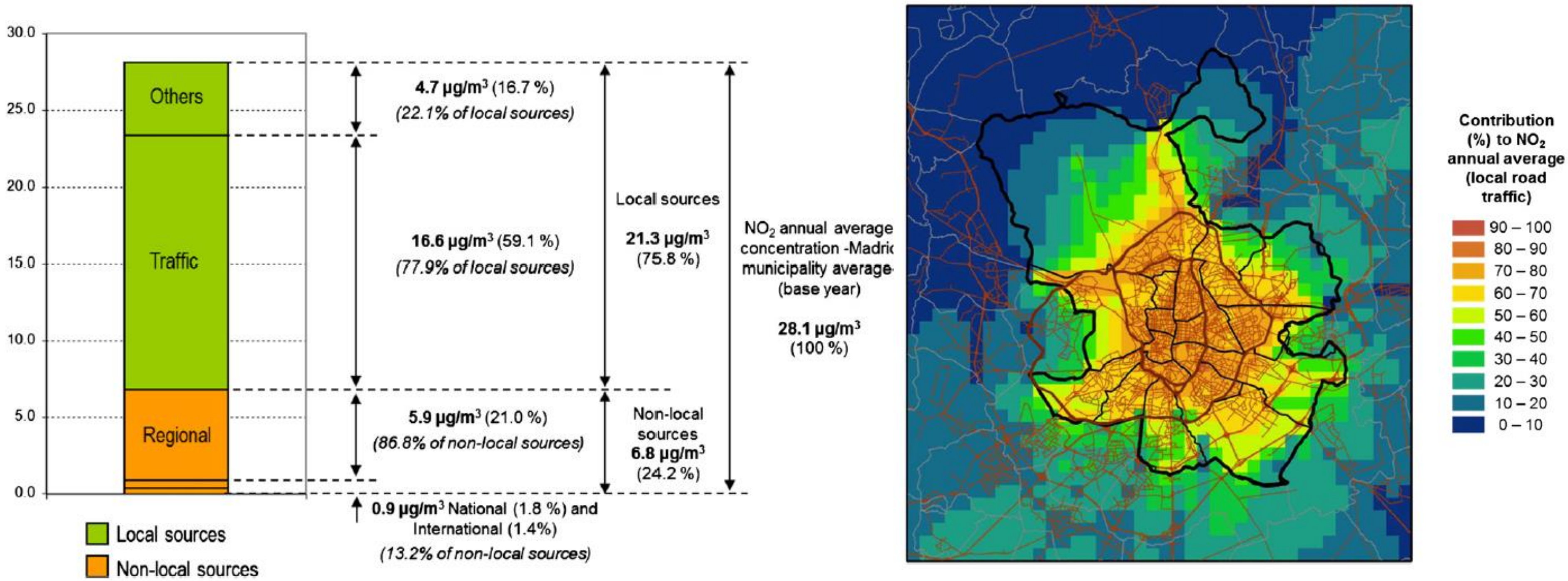


- Madrid city (Spain): 3.2 million inhabitants in the city, more than 5 million people in the metropolitan area

- Positive trend of AQ in the city. Remaining issues: NO_2



Annual evolution of NO_2 levels in Madrid cit
(average by station type; relative to 2005)

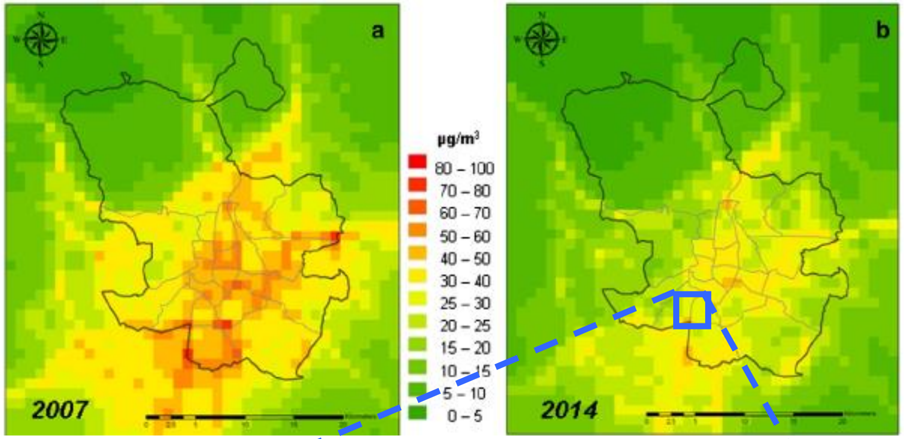


Figures from Borge et al., 2014 (STOTEN)

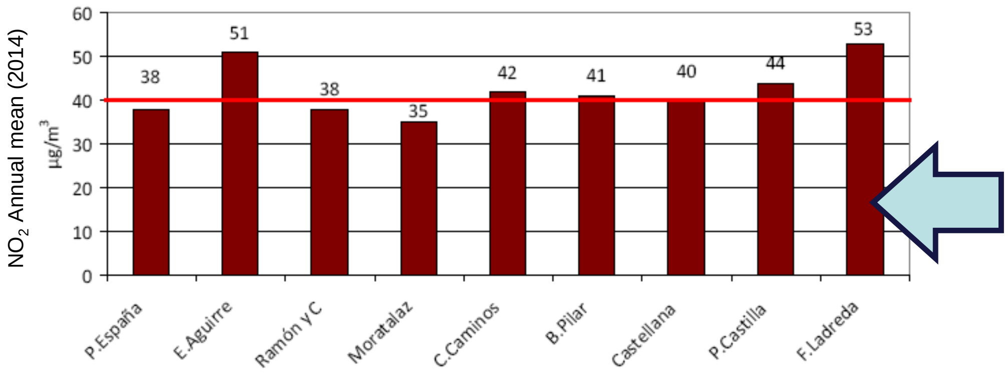
- The main responsible to high NO_2 ambient air concentration values is road traffic

Accurate and updated road traffic emission inventories are needed to define and simulate abatement measures

- Emission inventories have been developed to support the simulation of city-scale measures, but also complementary local measures to deal with particular issues in specific hot-spots such as Fernandez Ladreda (FL) square



FL air quality monitoring station



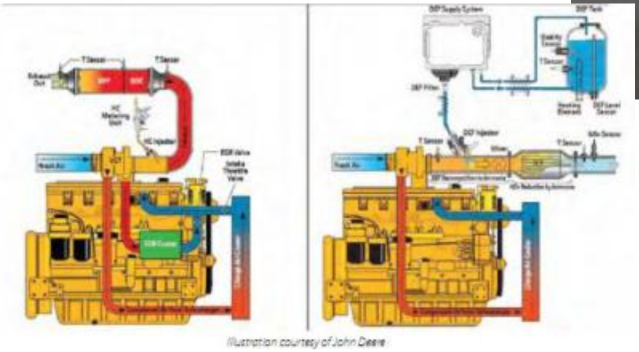
Traffic stations in the Madrid City Council Air Quality Network

2. METHODOLOGY

2.1. Emission models

- The development of emission inventories for on-road mobile sources is particularly complex, since emissions depend on multiple factors:

  - road type and traffic conditions
  - vehicle type, age and maintenance conditions
  - driving patterns / driving stage
  - meteorology



- There are many emission models based on alternative approaches for emission computation; according to Smit (2009):

  -'Average-speed' models (e.g. COPERT, MOBILE, EMFAC) – macroscopic description

  -'Traffic-situation' models (e.g. HBEFA, ARTEMIS) – link level

  -'Traffic-variable' models (e.g. TEE, Matzoros model) – traffic flow variables defined by macro or microscale traffic models

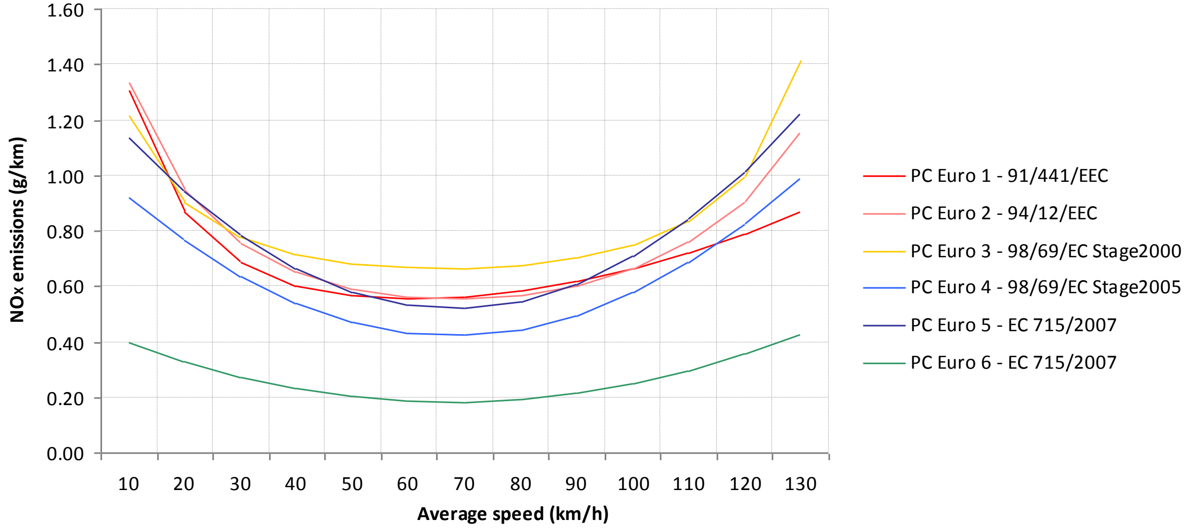
  -'Cycle-variable' models (e.g. MEASURE, VERSIT+) – individual vehicle driving patterns

  -'Modal' models – engine operation, also microscale approach

- The choice of the modeling approach would depend on the purpose of the computation (detail needed, scale of interest, etc)

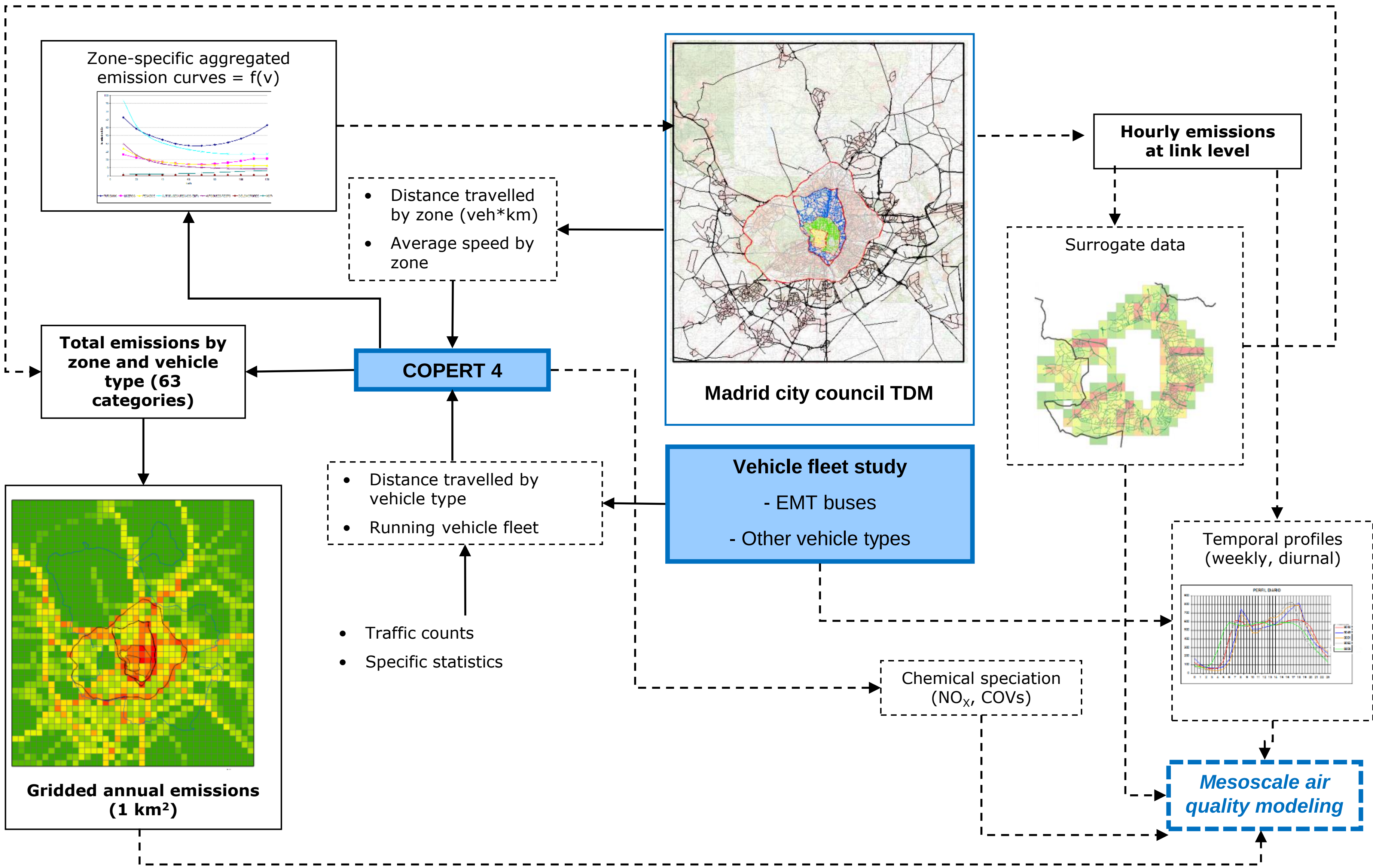
- The COPERT model (COmputer Programme to calculate Emissions from Road Transport) (currently v.4.11) is the reference model according to the EMEP/EEA methodology for the computation of road traffic emission inventories in Europe

- Average speed model, more than 100 vehicle categories



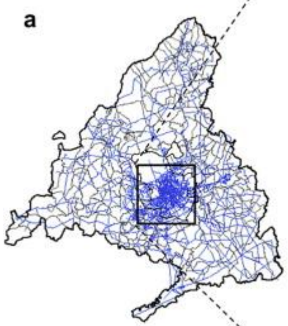
- It has been integrated with the regional traffic model (TDM) for emission computation at link level

Mesoscale road traffic emission computation scheme

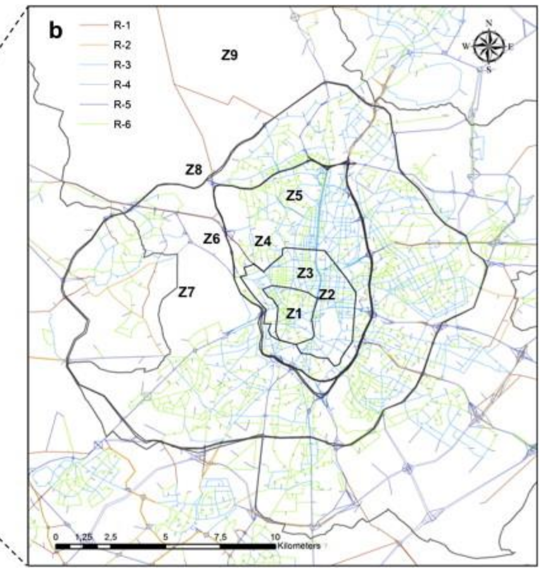


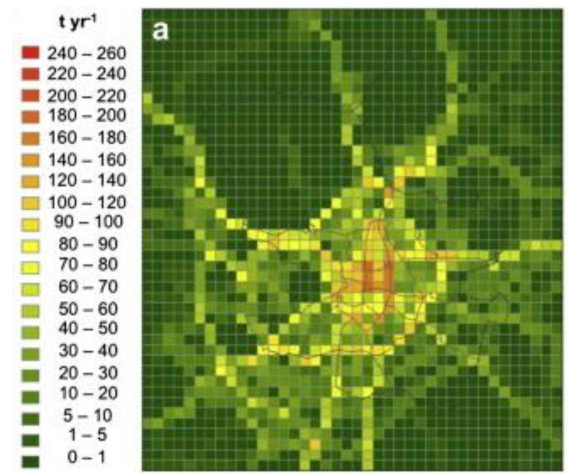
- Link-level, 1h intensity and speed from a macroscopic traffic model

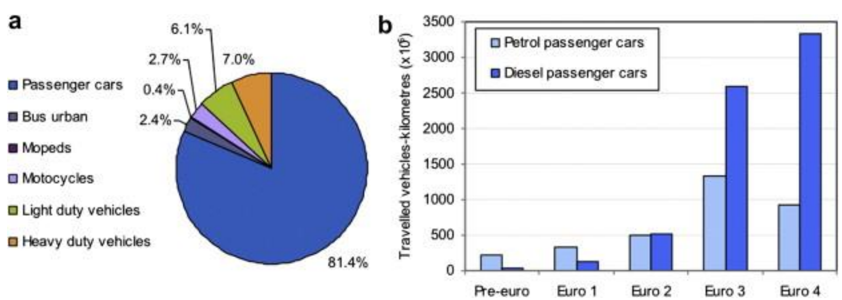
- Fleet composition and age from field campaigns (characterization study)



15 000 links aprox.





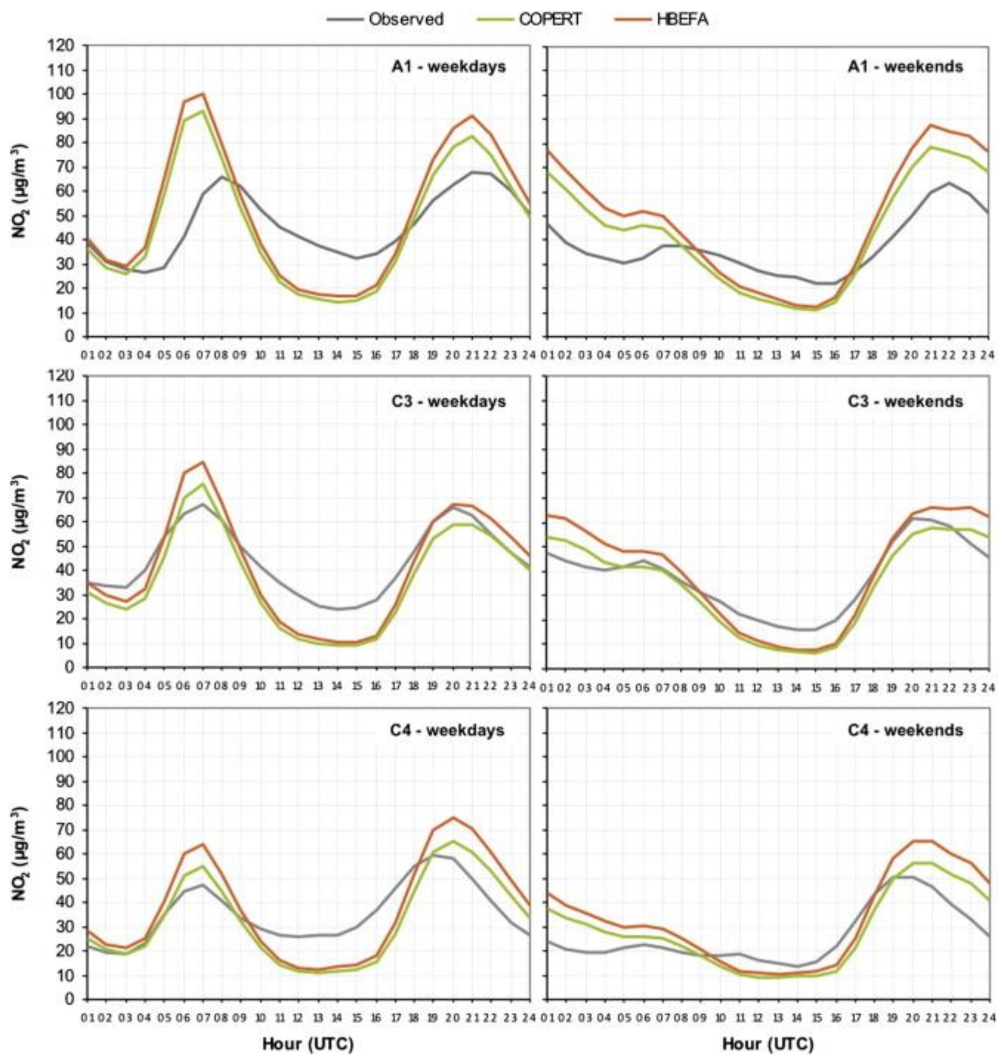


Figures from Borge et al., 2012 (AtmosEnv)

- Fleet composition is a key input for emission computation and also from the policy making perspective

- Outputs from COPERT are routinely used for the compilation of the Madrid emission inventory and mesoscale modeling activities (e.g. Madrid's Air Quality Plan)

- It has been found to perform reasonably well and similar to traffic-situation models (HBEFA)

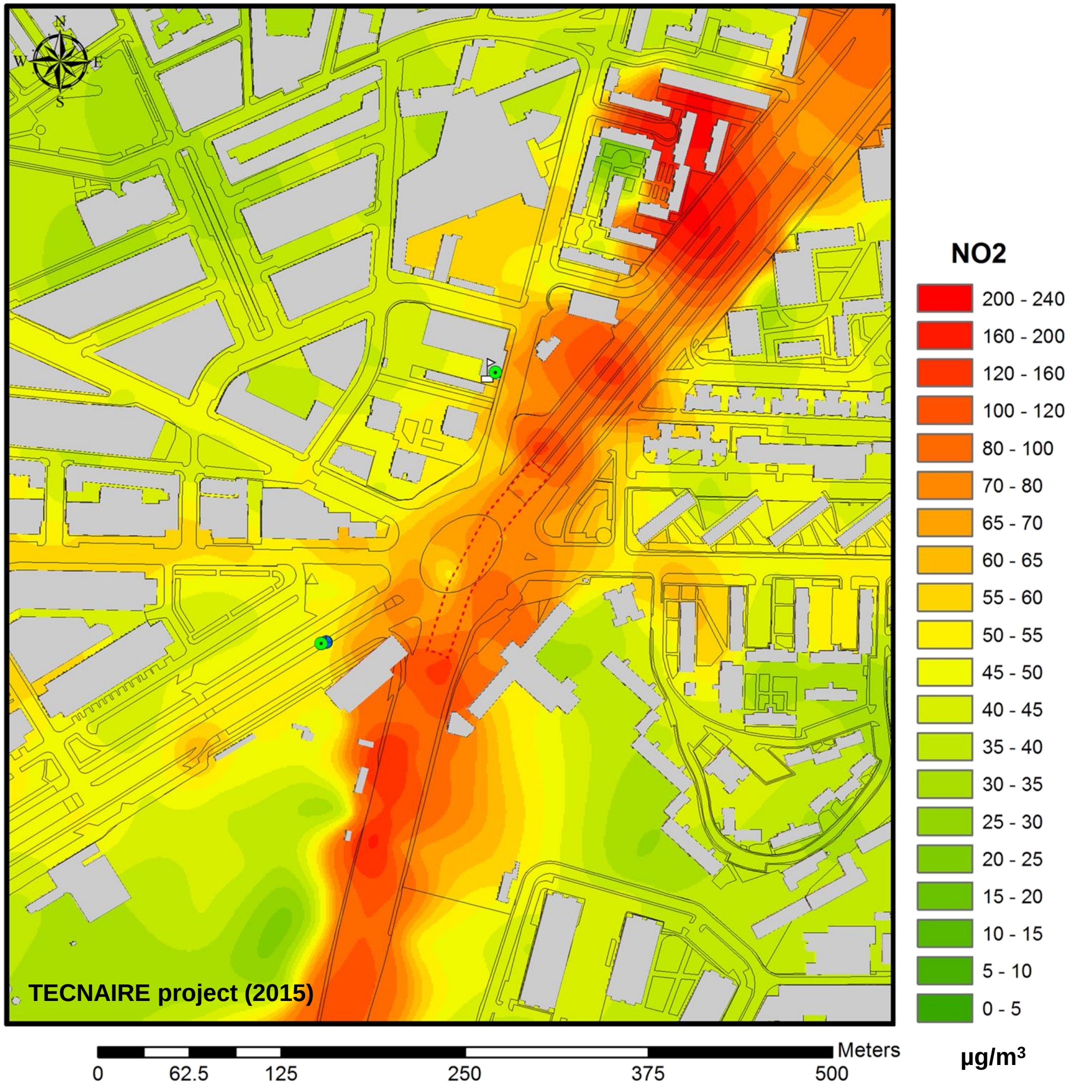


Figures from Borge et al., 2012 (AtmosEnv)

Microscale emission computation

- Further computation detail is needed to understand pollution dynamics in urban hot-spots (e.g. FL square; a heavily-trafficked roundabout)

- High temporal and spatial resolution emissions from cycle-variable models are needed to simulate air quality at this scale



- Computation of microscale emissions require additional information to describe the behaviour of single vehicles to produce individual braking-acceleration patterns

- The PTV VISSIM 6.00-19 microscale traffic flow model was selected to generate realistic traffic data

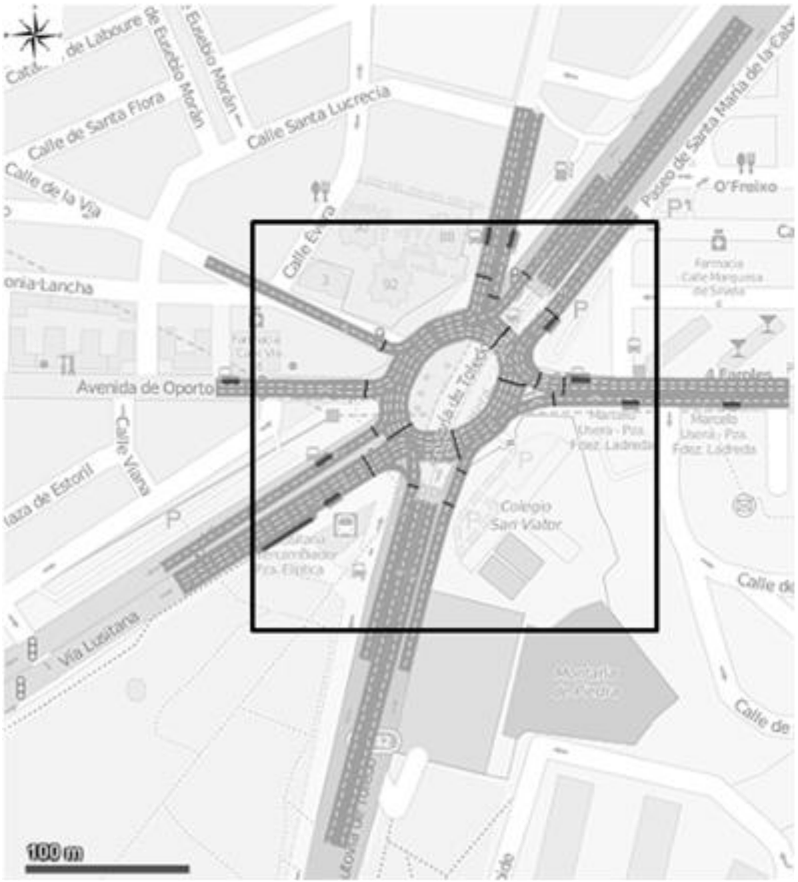
- In addition to fleet composition this model needs information on:

  - Detailed network definition

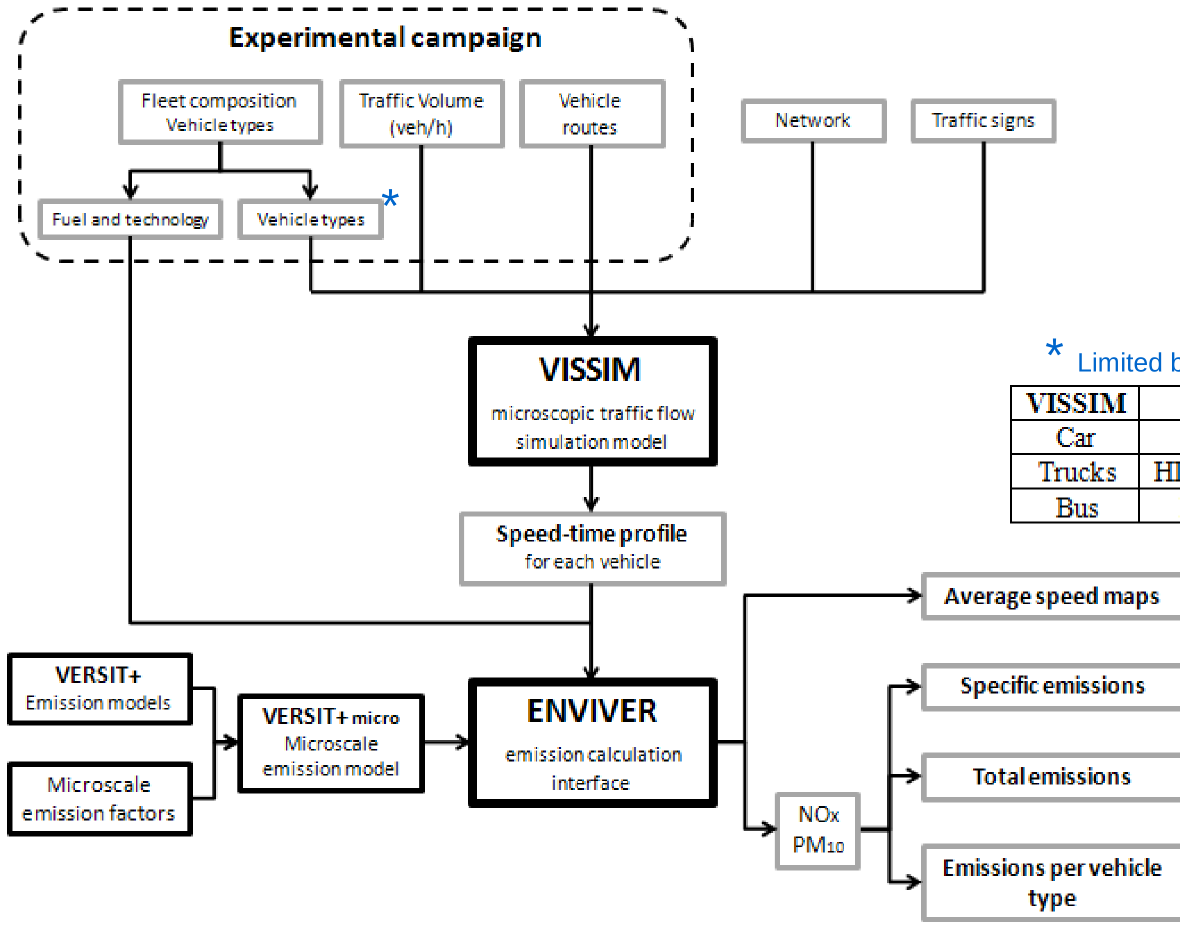
  - Vehicle fluxes and routes within the modeling domain

  - Traffic signs

  - Traffic lights phases



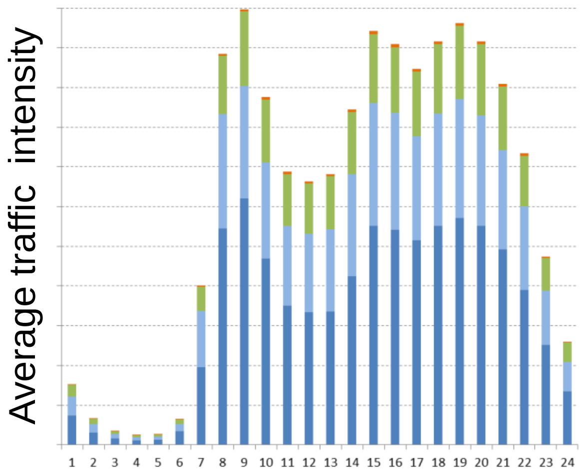
- Emissions are computed through VERSIT+ emission factors
- The link between traffic variables and emission factors is done by the ENVIVER interface



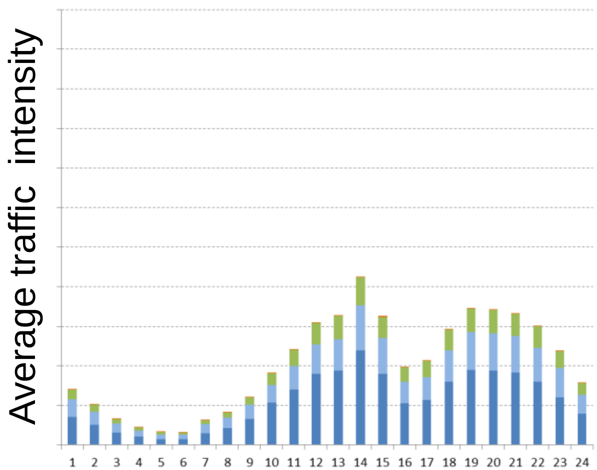
* Limited by VERSIT+ classes

VISSIM	VERSIT+
Car	LD_City_2013
Trucks	HD_Medium_City_2013
Bus	HD_Bus_City_2013

- 12 scenarios were selected to perform 1-h length simulations
- Representative of working and weekend days, peak and valley hours



Week days



Weekends

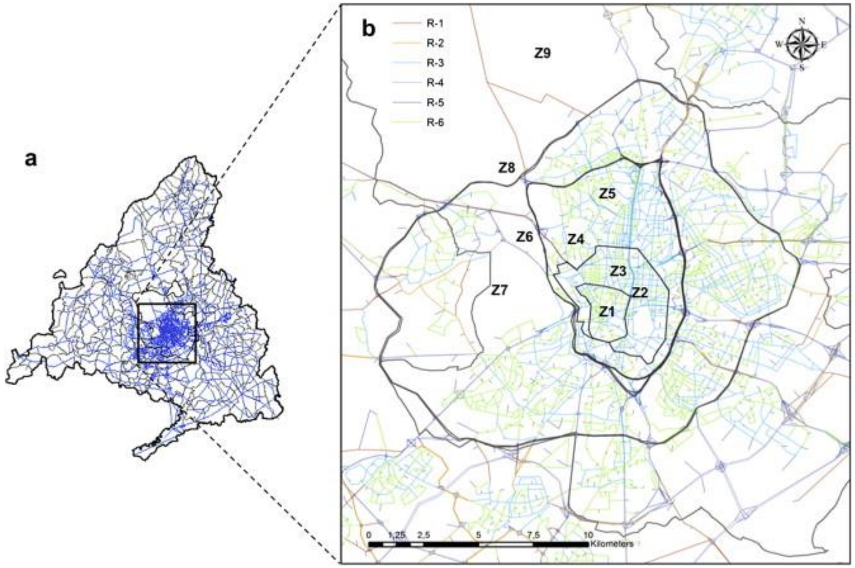
Day	Hour	Scenario
Wednesday 22/05/2013	4:00-5:00	E1
	8:00-9:00	E2
	14:00-15:00	E3
	19:00-20:00	E4
Friday 24/05/2013	4:00-5:00	E5
	8:00-9:00	E6
	14:00-15:00	E7
	19:00-20:00	E8
Sunday 26/05/2013	4:00-5:00	E9
	8:00-9:00	E10
	14:00-15:00	E11
	19:00-20:00	E12

Madrid municipality
Other provinces
Madrid Greater Region - others
Unknown

2.2. Measurement campaign

•A 10-day field campaign (May 22-June 2, 2013) was carried out to:

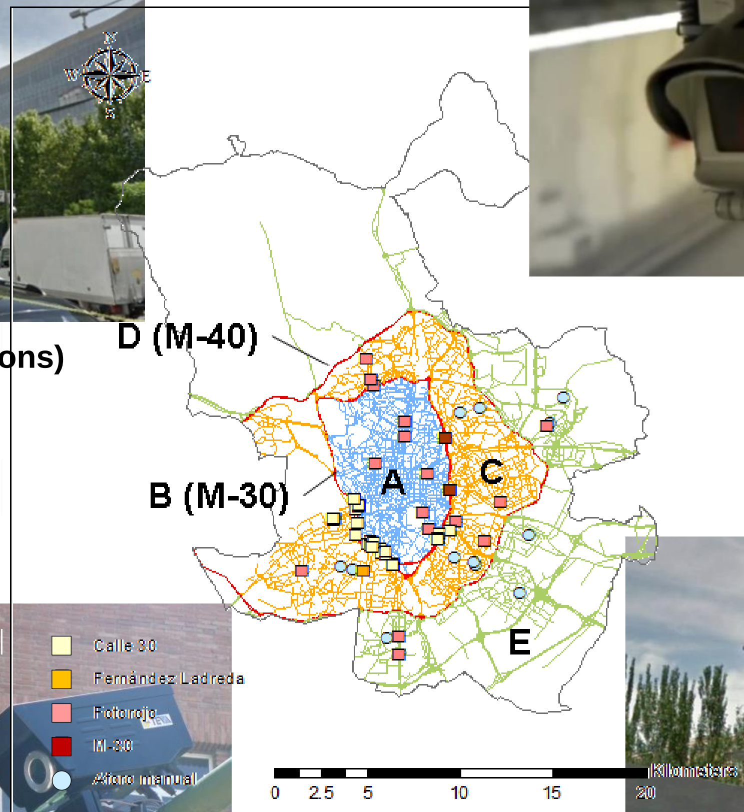
- update vehicle fleet characterization in Madrid and in FL specifically
- detailed traffic flows within the microscale modeling domain



•The sampling points were selected to be representative of each of the areas defined in the TDM (merged into 5: A to E)

• Already available equipment was used as much as possible

• Additional cameras were only deployed in FL



Red-light cameras (17 locations)

Calle 30 cameras (tunnels) (34 loc.)

Manual sampling (13 locations)

M-30 cameras (2 locations)

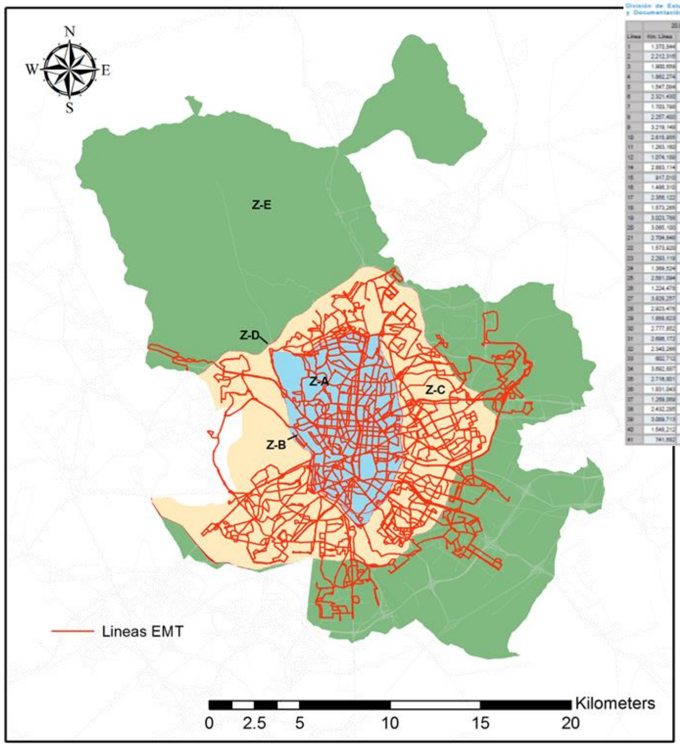
FL cameras (2 locations)

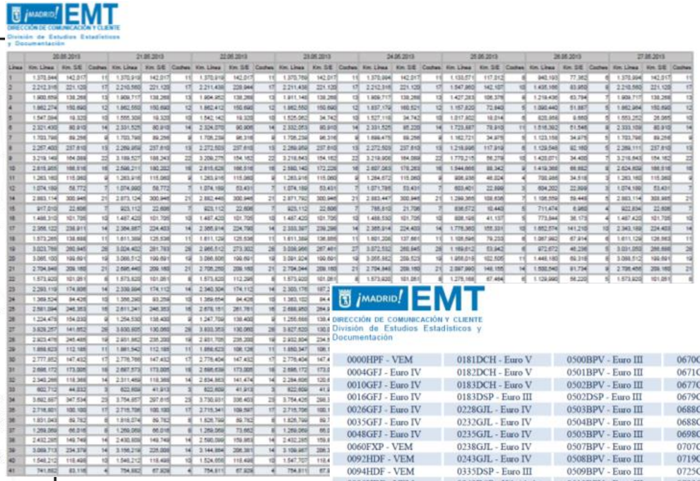
- Public buses were excluded. This information was provided by the Municipal Transport Company (EMT):

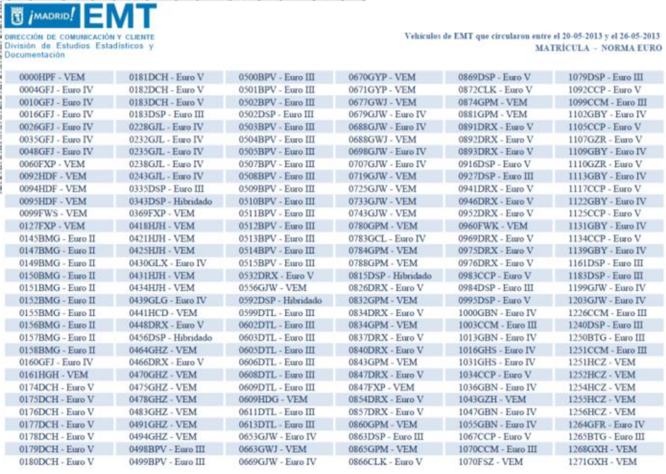
    - number and mileage of buses on each line

    - detailed routes and frequency in each line

    - plate number and characteristics of each bus







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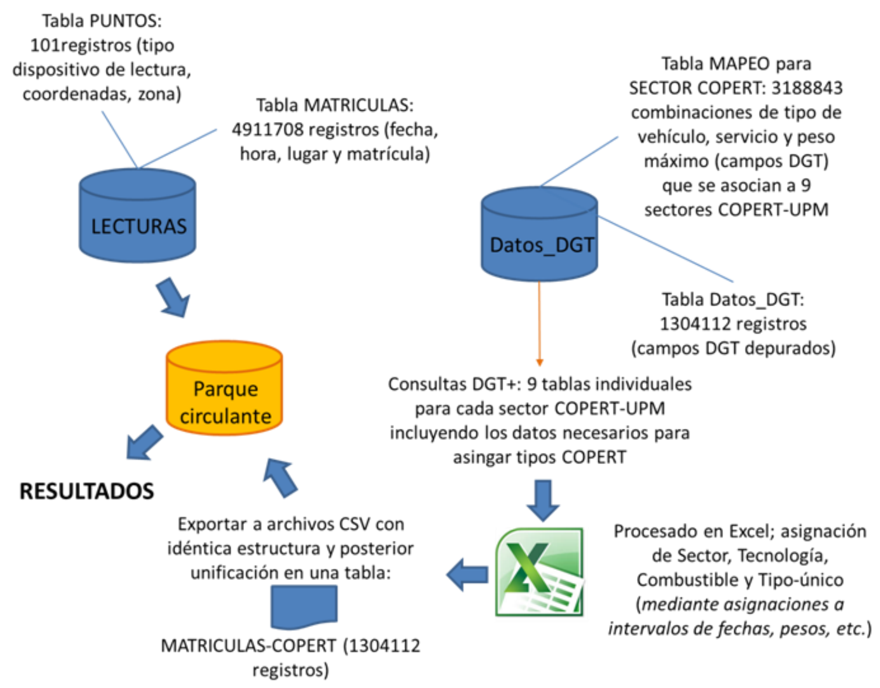
Vehículos de EMT que circularon entre el 20-05-2013 y el 26-05-2013
MATRÍCULA - NORMA EURO

0000HPF - VEM	0181DCH - Euro V	0500BPV - Euro III	0670GYP - VEM	0869DSP - Euro V	1079DSP - Euro III
0004GFJ - Euro IV	0182DCH - Euro V	0501BPV - Euro III	0671GYP - VEM	0872CLK - Euro V	1092CCP - Euro V
0010GFJ - Euro IV	0183DCH - Euro V	0502BPV - Euro III	0677GWJ - VEM	0874GPM - VEM	1099CCM - Euro III
0016GFJ - Euro IV	0183DSP - Euro III	0502DSP - Euro III	0679GJW - Euro IV	0881GPM - VEM	1102GBY - Euro IV
0026GFJ - Euro IV	0228GJL - Euro IV	0503BPV - Euro III	0688GJW - Euro IV	0891DRX - Euro V	1105CCP - Euro V
0035GFJ - Euro IV	0232GJL - Euro IV	0504BPV - Euro III	0688GWJ - VEM	0892DRX - Euro V	1107GZR - Euro V
0048GFJ - Euro IV	0235GJL - Euro IV	0505BPV - Euro III	0698GJW - Euro IV	0893DRX - Euro V	1109GBY - Euro IV
0060FXP - VEM	0238GJL - Euro IV	0507BPV - Euro III	0707GJW - Euro IV	0916DSP - Euro V	1110GZR - Euro V
0092HDF - VEM	0243GJL - Euro IV	0508BPV - Euro III	0719GJW - VEM	0927DSP - Euro III	1113GBY - Euro IV
0094HDF - VEM	0335DSP - Euro III	0509BPV - Euro III	0725GJW - VEM	0941DRX - Euro V	1117CCP - Euro V
0095HDF - VEM	0343DSP - Hibridado	0510BPV - Euro III	0733GJW - VEM	0946DRX - Euro V	1122GBY - Euro IV
0099FWS - VEM	0369FXP - VEM	0511BPV - Euro III	0743GJW - VEM	0952DRX - Euro V	1125CCP - Euro V
0127FXP - VEM	0418HJH - VEM	0512BPV - Euro III	0780GPM - VEM	0960FWK - VEM	1131GBY - Euro IV
0145BMG - Euro II	0421HJH - VEM	0513BPV - Euro III	0783GCL - Euro IV	0969DRX - Euro V	1134CCP - Euro V
0147BMG - Euro II	0425HJH - VEM	0514BPV - Euro III	0784GPM - VEM	0975DRX - Euro V	1139GBY - Euro IV
0149BMG - Euro II	0430GLX - Euro IV	0515BPV - Euro III	0788GPM - VEM	0976DRX - Euro V	1161DSP - Euro III
0150BMG - Euro II	0431HJH - VEM	0532DRX - Euro V	0815DSP - Hibridado	0983CCP - Euro V	1183DSP - Euro III
0151BMG - Euro II	0434HJH - VEM	0556GJW - VEM	0826DRX - Euro V	0984DSP - Euro III	1199GJW - Euro IV
0152BMG - Euro II	0439GLG - Euro IV	0592DSP - Hibridado	0832GPM - VEM	0995DSP - Euro V	1203GJW - Euro IV
0155BMG - Euro II	0441HCD - VEM	0599DTL - Euro III	0834DRX - Euro V	1000GBN - Euro IV	1226CCM - Euro III
0156BMG - Euro II	0448DRX - Euro V	0602DTL - Euro III	0834GPM - VEM	1003CCM - Euro III	1240DSP - Euro III
0157BMG - Euro II	0456DSP - Hibridado	0603DTL - Euro III	0837DRX - Euro V	1013GBN - Euro IV	1250BTG - Euro III
0158BMG - Euro II	0464GHZ - VEM	0605DTL - Euro III	0840DRX - Euro V	1016GHS - Euro IV	1251CCM - Euro III
0160GFJ - Euro IV	0466DRX - Euro V	0606DTL - Euro III	0843GPM - VEM	1031GHS - Euro IV	1251HCZ - VEM
0161HGH - VEM	0470GHZ - VEM	0608DTL - Euro III	0847DRX - Euro V	1034CCP - Euro V	1252HCZ - VEM
0174DCH - Euro V	0475GHZ - VEM	0609DTL - Euro III	0847FXP - VEM	1036GBN - Euro IV	1254HCZ - VEM
0175DCH - Euro V	0478GHZ - VEM	0609HDG - VEM	0854DRX - Euro V	1043GZH - VEM	1255HCZ - VEM
0176DCH - Euro V	0483GHZ - VEM	0611DTL - Euro III	0857DRX - Euro V	1047GBN - Euro IV	1256HCZ - VEM
0177DCH - Euro V	0491GHZ - VEM	0613DTL - Euro III	0860GPM - VEM	1055GBN - Euro IV	1264GFR - Euro IV
0178DCH - Euro V	0494GHZ - VEM	0653GJW - Euro IV	0863DSP - Euro III	1067CCP - Euro V	1265BTG - Euro III
0179DCH - Euro V	0498BPV - Euro III	0663GWJ - VEM	0865GPM - VEM	1070CCM - Euro III	1268GXH - VEM
0180DCH - Euro V	0499BPV - Euro III	0669GJW - Euro IV	0866CLK - Euro V	1070FSZ - VEM	1271GXH - VEM

- A total of 4,911,708 plate readings was made during the campaign
- Up to 1,304,112 different plates were identified (after data cleaning and duplicates removal)
- Vehicle information was retrieved from the vehicle registration database managed by the national traffic authority (DGT):
  - date of first registration
  - brand and model
  - vehicle type (segment)
  - service (public / private)
  - number of seats / weight
  - engine size
  - propulsion technology
  - hybrid indicator (yes/no)
  - ZIP codes (vehicle & owner)



- Vehicles were mapped into COPERT categories (plus some others interesting for policy purposes; e.g. taxis)

- 199 vehicle type in this study

COPERT Sector	Fuel/ Propulsion	Emission standards	European Emission Standard time frame			
Light commercial vehicles	Gasoline	Conventional	- 1992			
< 3.5t		Euro 1 - 93/59/EEC	1993 – 1996			
		Euro 2 - 96/69/EC	1997 – 1999			
		Euro 3 - 98/69/EC S 2000	2000 – 2004			
		Euro 4 - 98/69/EC S 2005	2005 – 2010			
		Euro 5 - 715/2007/EC S 2011	2011 – 2014			
		Euro 6 - 715/2007/EC S 2015	2015 -			
	Diesel	Conventional	- 1992			
		Euro 1 - 93/59/EEC	1993 – 1996			
		Euro 2 - 96/69/EC	1997 – 1999			
		Euro 3 - 98/69/EC S 2000	2000 – 2004			
		Euro 4 - 98/69/EC S 2005	2005 – 2010			
		Euro 5 - 715/2007/EC S 2011	2011 – 2014			
		Euro 6 - 715/2007/EC S 2015	2015 -			
Heavy-duty trucks	Gasoline	Conventional				
> 3.5t	Diesel		<=7.5t	7.5t- 16t	16t - 32t	>32t
		Conventional	- 1991	- 1991	- 1991	- 1991
		Euro I - 91/542/EEC S I	1992 - 1994	1992 - 1994	1992 - 1994	1992 - 1994
		Euro II - 91/542/EEC S II	1995 - 1999	1995 - 1999	1995 - 1999	1995 - 1999
		Euro III - 1999/96/EC S I	2000 - 2004	2000 - 2004	2000 - 2004	2000 - 2004
		Euro IV - 1999/96/EC S II	2005 – 2007	2005 – 2007	2005 – 2007	2005 – 2007
		Euro V - 1999/96/EC S III	2008 -	2008 -	2008 -	2008 -
		Euro VI – not proposed				
Buses	Diesel		Urban		Coaches	
		Conventional	- 1991		- 1991	
		Euro I - 91/542/EEC S I	1992 – 1994		1992 - 1994	
		Euro II - 91/542/EEC S II	1995 – 1999		1995 - 1999	
		Euro III - 1999/96/EC S I	2000 – 2004		2000 - 2004	
		Euro IV - 1999/96/EC S II	2005 – 2007		2005 – 2007	
		Euro V - 1999/96/EC S III	2008		2008	
		Euro VI – not proposed				
	Gas natural	Euro I - 91/542/EEC S I	1992 – 1994			
		Euro II - 91/542/EEC S II	1995 – 1999			
		Euro III - 1999/96/EC S I	2000 – 2004			
		Euro IV - 1999/96/EC S II	2006 -			
		Euro V - 1999/96/EC S III	2009 -			
		EEV – 1999/96/EC	2000 -			
Mopeds < 50cm³	Gasoline	Conventional	- 1998			
		Euro 1 - 97/24/EC S I	1999 - 2001			
		Euro 2 - 97/24/EC S II	2002 -			
		Euro 3 - Proposed				
Motorcycles	Gasoline		2-stroke > 50cm³	4-stroke 50–250cm³	4-stroke 250–750cm³	4-stroke > 750cm³
		Conventional	- 1998	- 1998	- 1998	- 1998
		Euro 1 - 97/24/EC	1999 - 2002	1999 – 2002	1999 – 2002	1999 - 2002
		Euro 2 - 2002/51/EC S I	2003 - 2005	2003 – 2005	2003 – 2005	2003 - 2005
		Euro 3 - 2002/51/EC S II	2006 -	2006 -	2006 -	2006 -

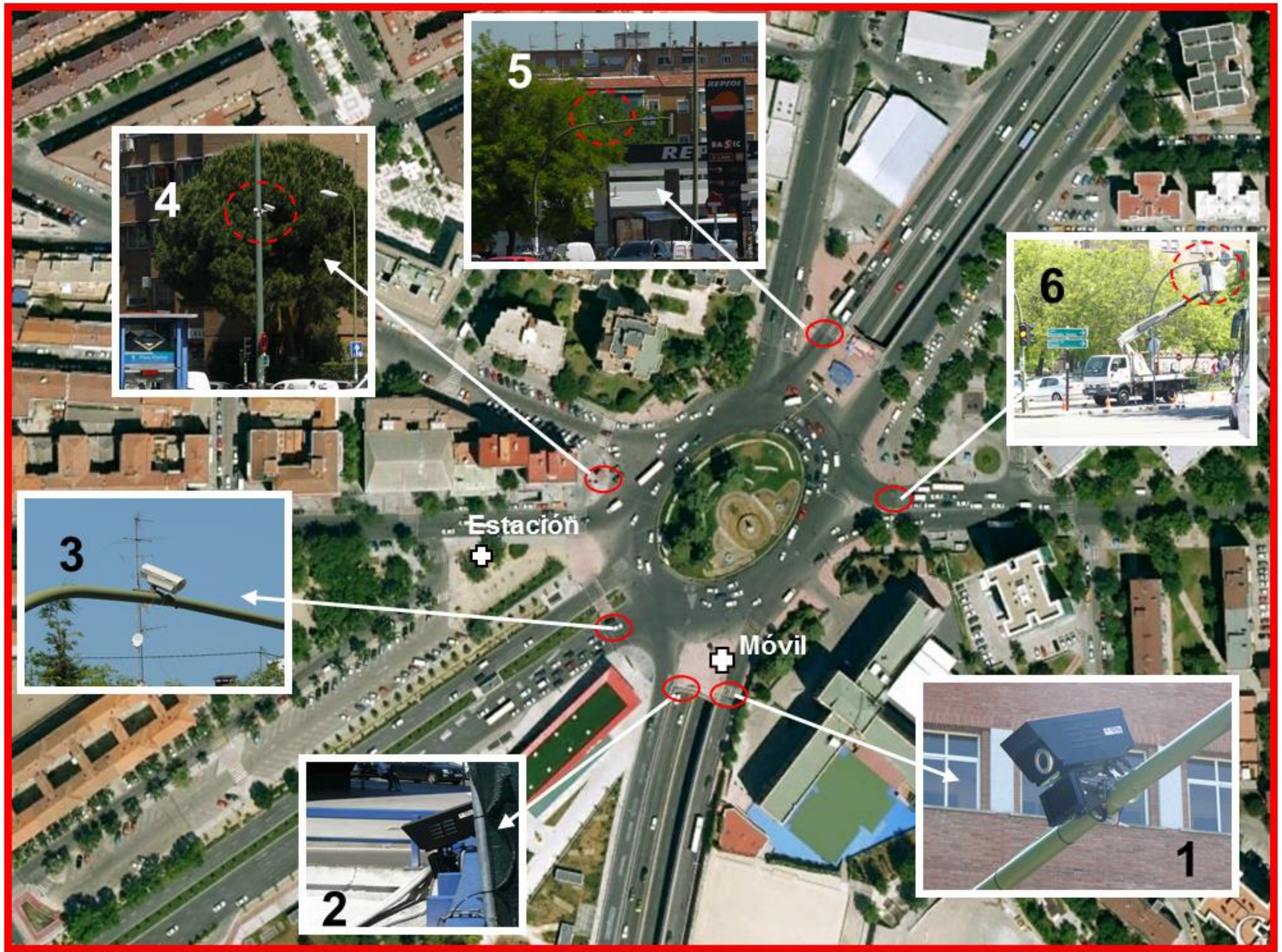
COPERT Sector	Fuel/ Propulsion	Emission standards	European Emission Standard time frame		
Passenger cars	Gasoline		< 1.4l	>=1.4l y <=2.0l	> 2.0l
		PRE ECE	- 1971	- 1971	- 1971
		ECE 15/00-01	1972 – 1977	1972 - 1977	1972 - 1977
		ECE 15/02	1978 – 1979	1978 - 1979	1978 - 1979
		ECE 15/03	1980 – 1984	1980 - 1984	1980 - 1984
		ECE 15/04	1985 – 1992	1985 - 1992	1985 - 1989
		Euro 1 - 91/441/EEC	1993 – 1996	1993 - 1996	1990 - 1996
		Euro 2 - 94/12/EC	1997 – 1999	1997 - 1999	1997 - 1999
		Euro 3 - 98/69/EC S 2000	2000 – 2004	2000 - 2004	2000 - 2004
		Euro 4 - 98/69/EC S 2005	2005 – 2010	2005 – 2010	2005 – 2010
		Euro 5- 715/2007/EC S 2011	2011 – 2014	2011 – 2014	2011 – 2014
		Euro 6 - 715/2007/EC S 2015	2015 -	2015 -	2015 -
		2-stroke engine			
	Diesel		<=2.0l		> 2.0l
		Conventional	- 1992		- 1992
		Euro 1 - 91/441/EEC	1993 – 1996		1993 – 1996
		Euro 2 - 94/12/EC	1997 – 1999		1997 – 1999
		Euro 3 - 98/69/EC S 2000	2000 – 2004		2000 – 2004
		Euro 4 - 98/69/EC S 2005	2005 – 2010		2005 – 2010
		Euro 5 - 715/2007/EC S 2011	2011 – 2014		2011 – 2014
		Euro 6 - 715/2007/EC S 2015	2015 -		2015 -
	LPG	Conventional	- 1992		
		Euro 1 - 91/441/EEC	1993 - 1996		
		Euro 2 - 94/12/EC	1997 - 1999		
		Euro 3 - 98/69/EC S 2000	2000 - 2004		
		Euro 4 - 98/69/EC S 2005	2005 -		
	Hybrid	Euro 4 - 98/69/EC S 2005	2005 -		

- Individual readings were merge by vehicle type and zone to get a "standard vehicle" by zone

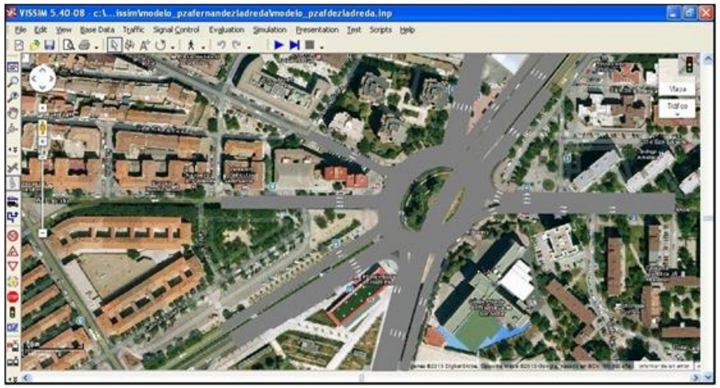
- Total mileage in each zone was not estimated but taken from the TDM

Additional data for the microscale simulation

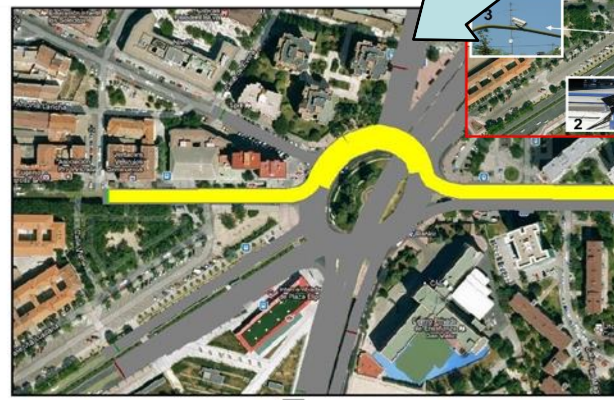
- Video cameras (don't read plates) to account for vehicle fluxes in each possible route in the area of interest (FL square): movements



Detailed network (lanes):
19 links, 22 connectors



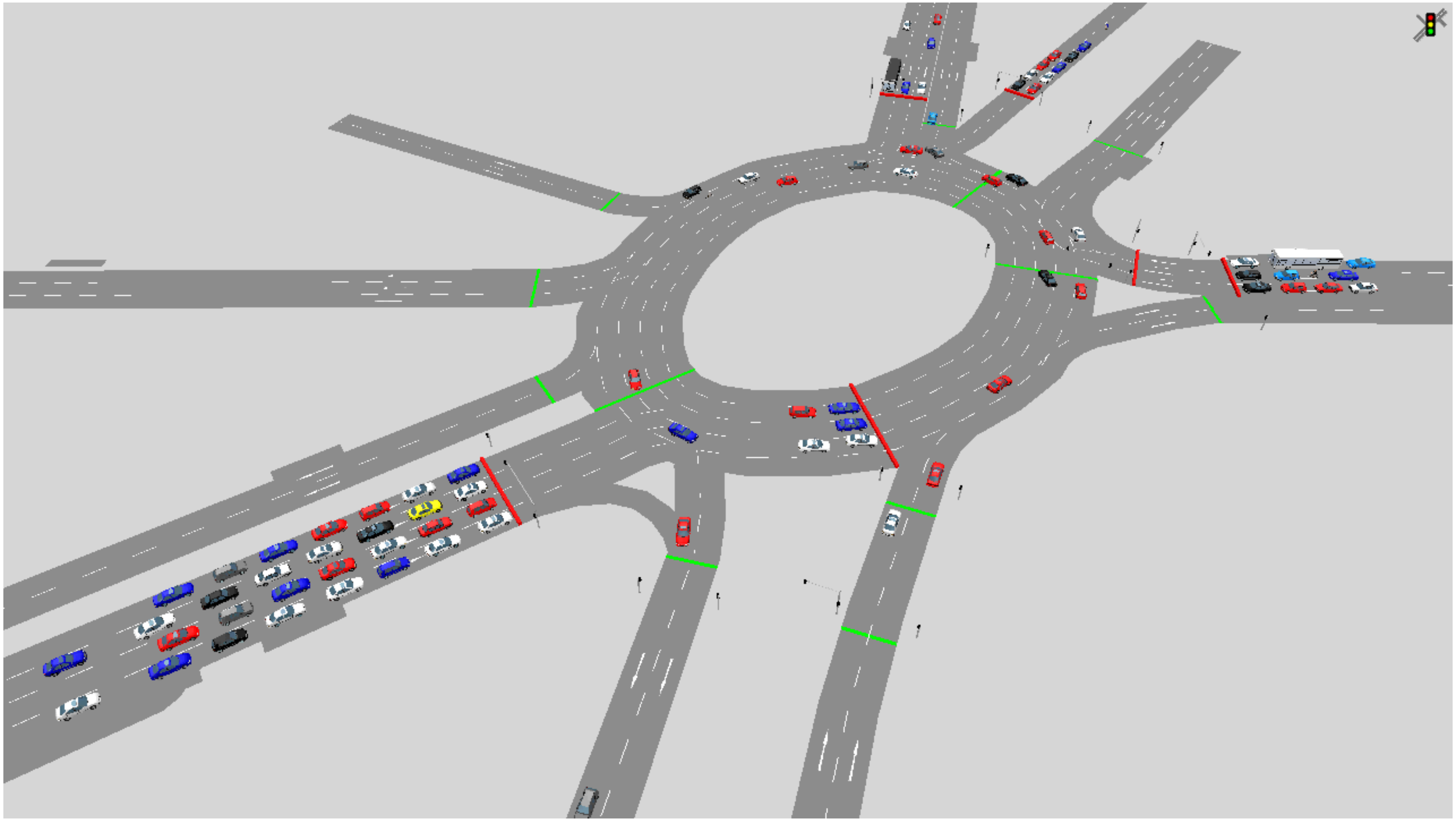
Movements



No	Signal group	Signal sequence						
1	Signal group 1	Red-	95	16				3
2	Signal group 2	Red-	97	19				3
3	Signal group 3	Red-	49	19				3
4	Signal group 4	Red-	73	19				3
5	Signal group 5	R	63	46			10	3
6	Signal group 6	R	63	48			9	3
7	Signal group 7	Red-	25	43				3
8	Signal group 8	Red-	20	89				3
9	Signal group 9	Red-	25	83				3
10	Signal group 10	Red-	25	86				3
11	Signal group 11	Red-	25	91				3
12	Signal group 12	R	14	97			10	3
13	Signal group 13	Red-	49	63				3
14	Signal group 14	R	63	36			8	3
15	Signal group 15	Red-						
16	Signal group 16	Red-						
17	Signal group 17	R						
18	Signal group 18	Red-						
19	Signal group 28	R						

EMT buses

Traffic lights location and phases



3. RESULTS AND DISCUSSION

Fleet composition and emissions in Madrid

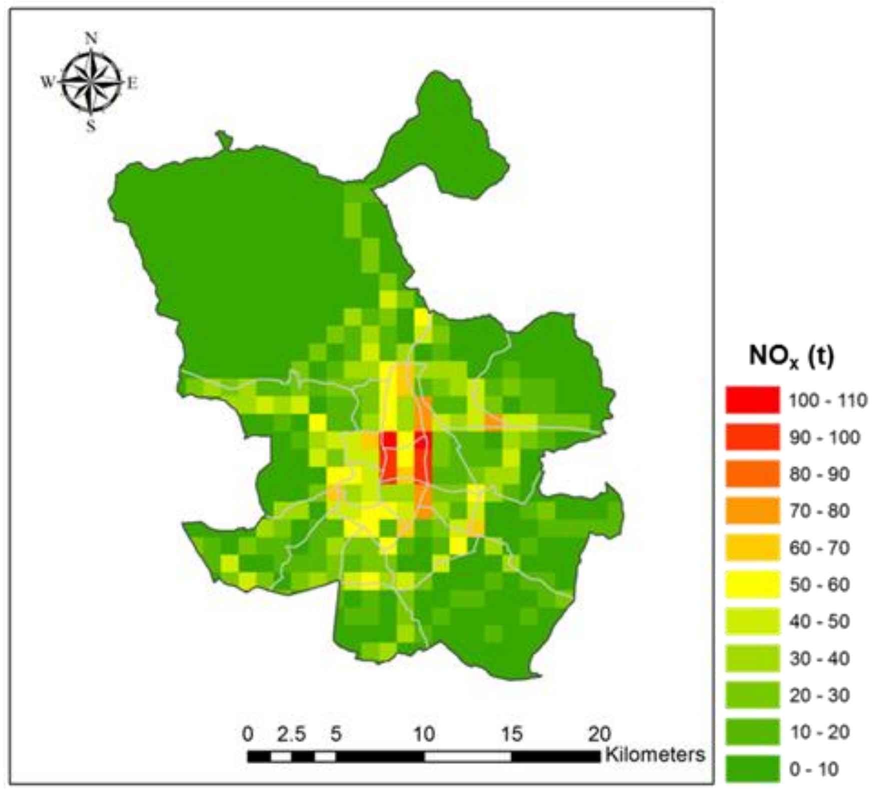
- Despite a decreasing tendency, road traffic is still the main contributor of emissions in Madrid city (year 2013):

  - 56.3 % of NO_X

  - 65.1 % of $PM_{2.5}$ (exhaust)

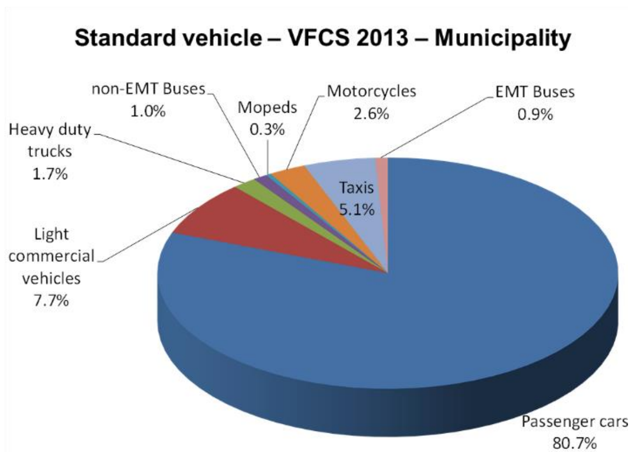
  - 40.6 % of CO_2

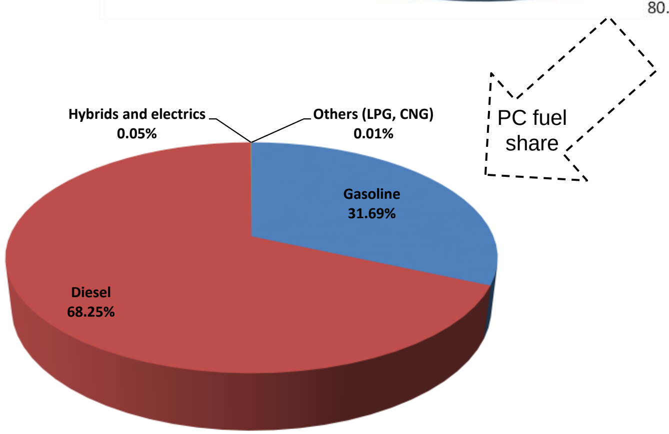
Pollutant	Emission	Unit
CH_4	170	t
CO	6,524	t
CO_2	2,339	kt
COVNM	2,532	t
N_2O	79	t
NH_3	134	t
NO_x	7,992	t
PM_{10}	624	t
$PM_{2.5}$	473	t
SO_2	14	t



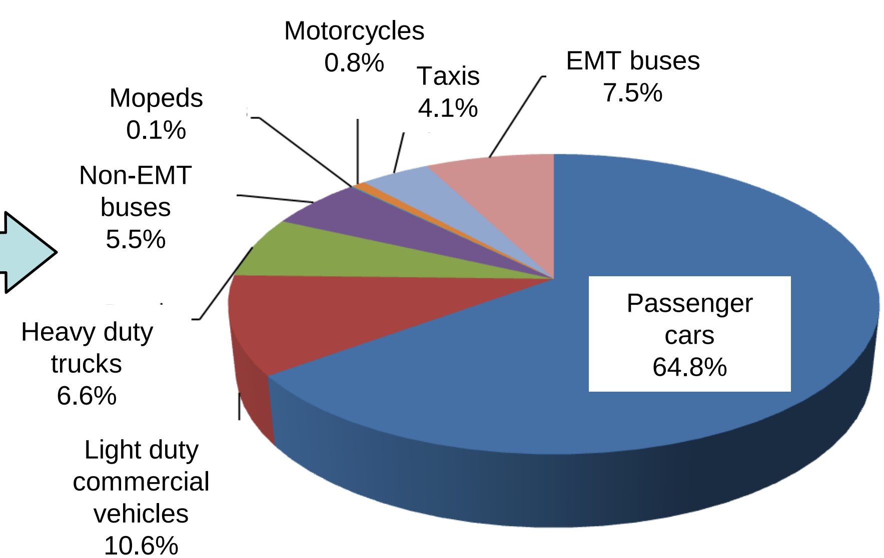
- Fleet composition and emissions dominated by diesel passenger cars:

Mileage distribution

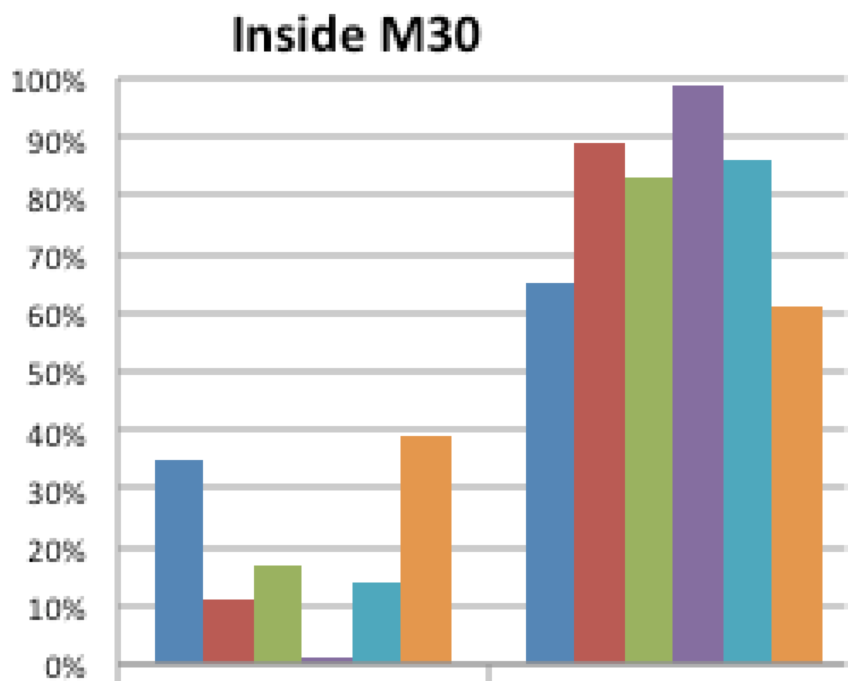




NOx emissions - Municipality



- NO_X emissions are driven, basically, by diesel vehicles (89%) (99% of NO_2)
- PM emissions are also generated by diesel vehicles (86%)
- Gasoline influence on CO_2 emissions is higher than corresponding mileage share (39%)



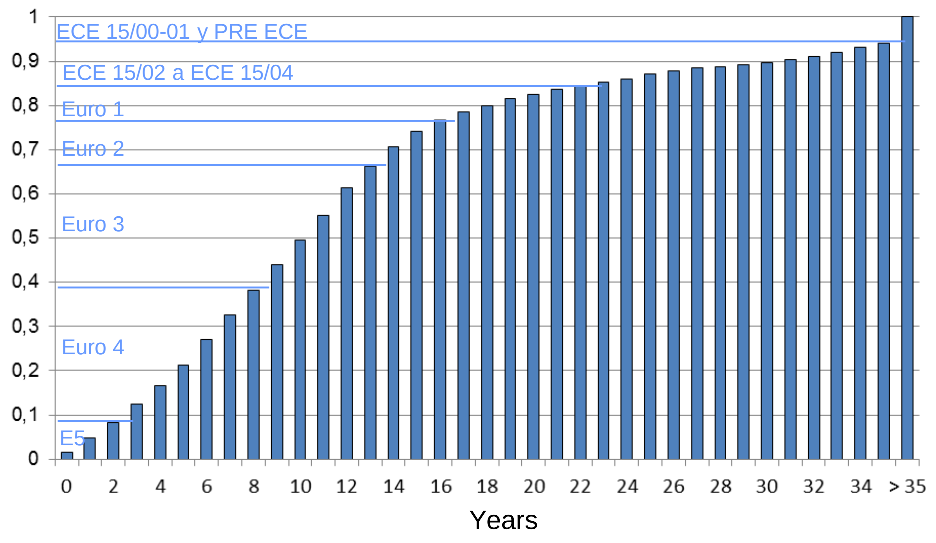
	Petrol	Diesel	Hybrid & Electric	Other
Mileage	34,74%	65,16%	0,08%	0,02%
NOx	11,01%	88,99%	0,00%	0,00%
NO	17,00%	82,99%	0,00%	0,00%
NO2	1,03%	98,97%	0,00%	0,00%
PM exhaust	13,94%	86,04%	0,02%	0,01%
CO2	38,79%	61,17%	0,03%	0,01%

Source: Lumbreras et al., 2014

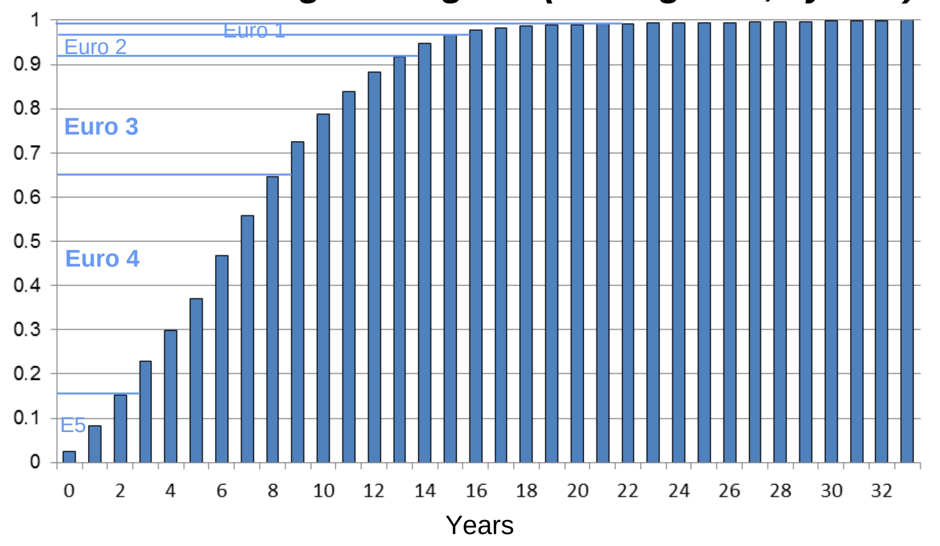
- Average age has considerably increase (from the last, pre-crisis, fleet characterization study)

	Average age (years)	*Previous study (2009)*
Passenger cars	9.3	*5.7*
Light commercial vehicles	10.0	*5.1*
Heavy-duty trucks	10.8	*6.8*
Buses	8.1	*6.2*
Motorcycles	9.8	*3.1*
Taxis	4.4	*-*

Gasoline cars age histogram (Average = 13,0 years)

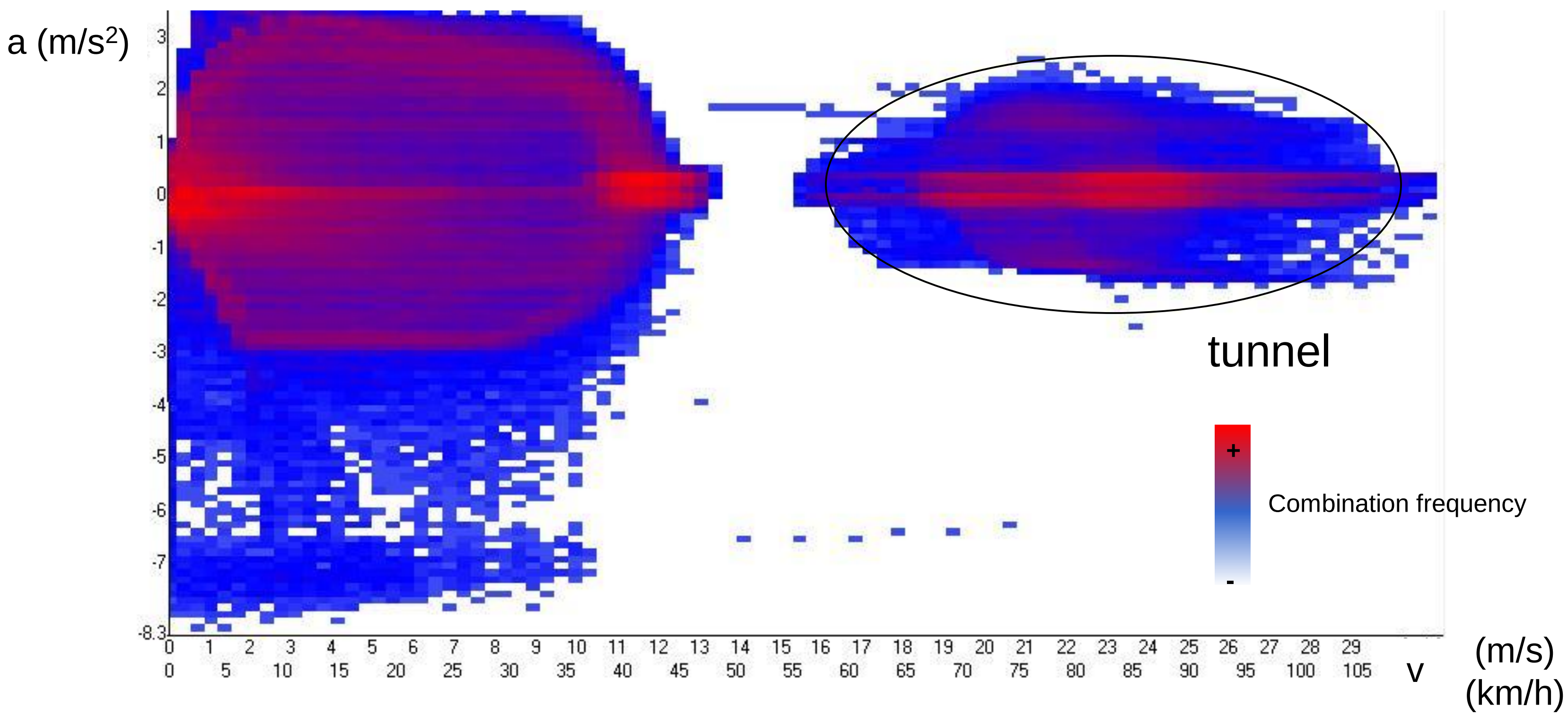


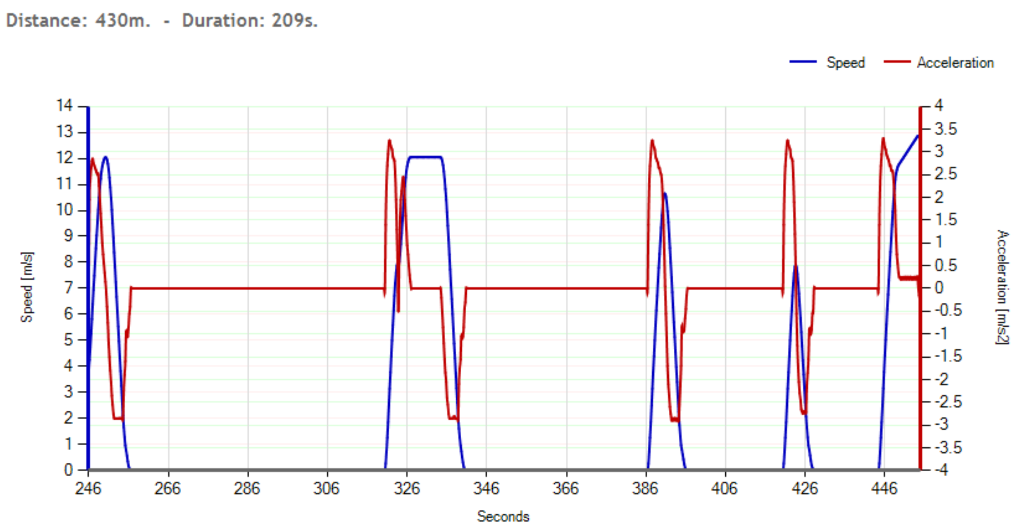
Diesel cars age histogram (Average = 7,2 years)



Microscale emission simulation in Fernández Ladreda square

- The 12 simulations were successfully performed
- The model produces individual speed and acceleration patterns for every vehicle trip with a 0.2 sec. resolution

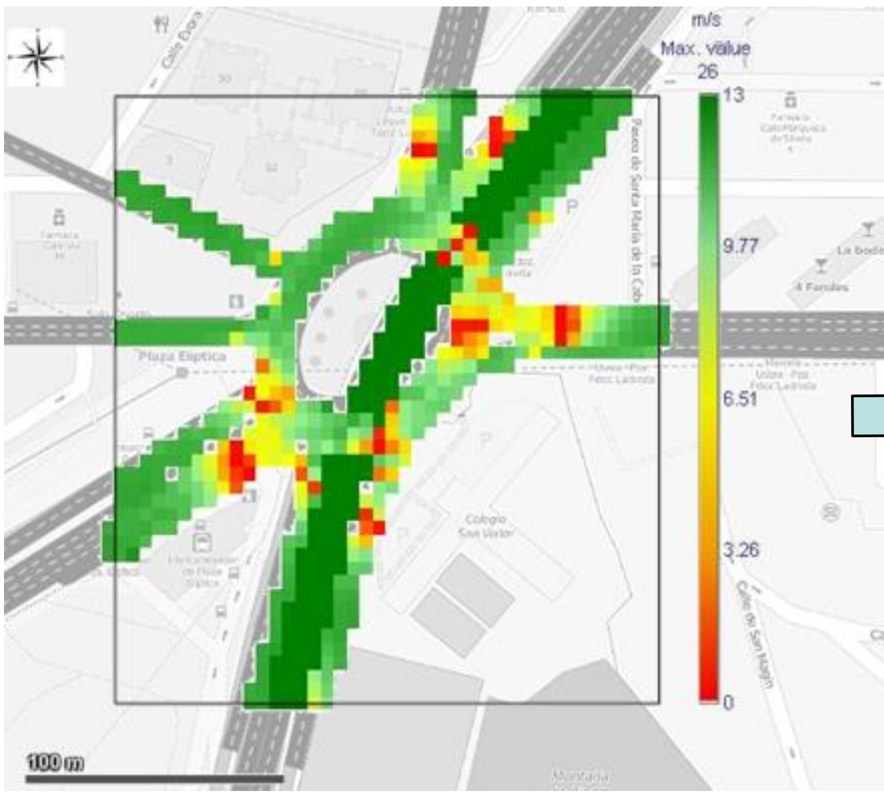




Result example: speed-acceleration graphic of a passenger car for a given trip in the E9 scenario

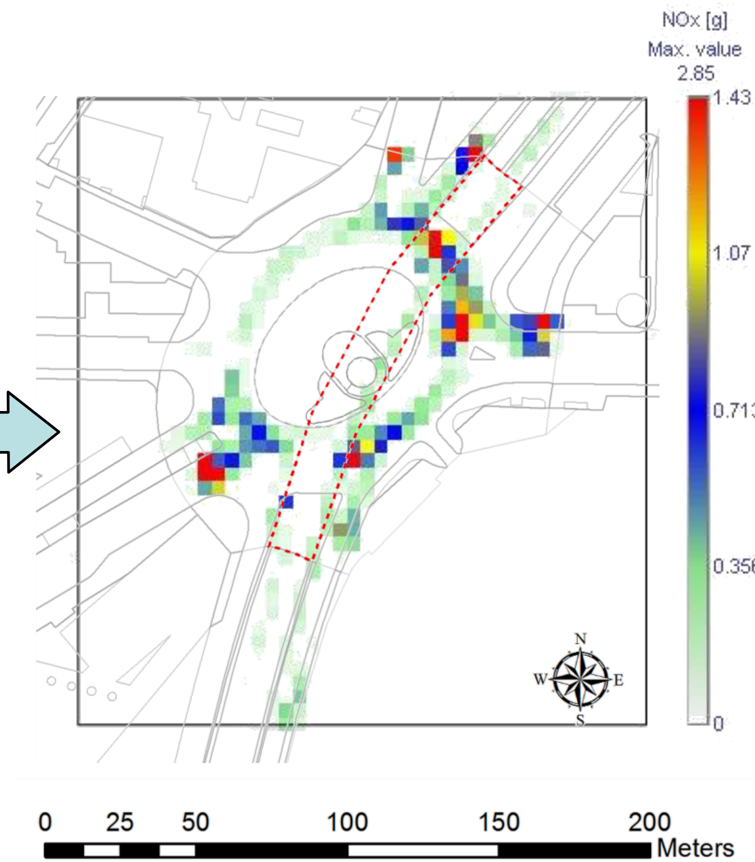
- This information is processed by ENVIVER to produce very high resolution emissions
- The result need to be aggregated in time as needed (requirements of the air quality model to be coupled)
- Emissions for every trip in each scenario were computed and the results were aggregated for the whole hour period for comparison (and 5 m horizontal resolution)

- Hourly average speed was also computed in order to compare the results with COPERT



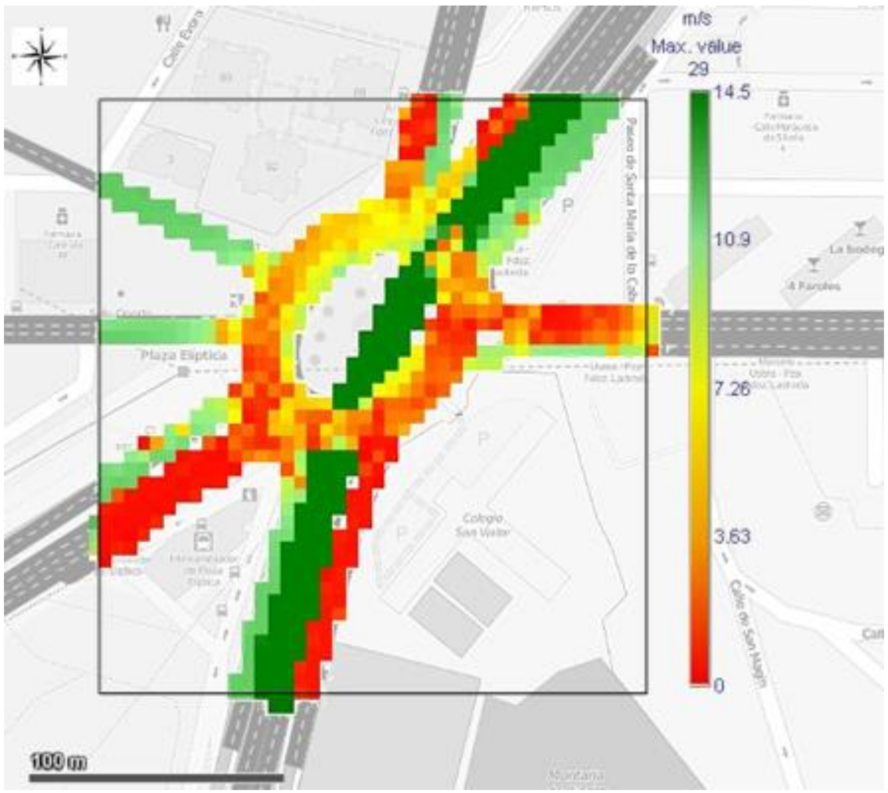
Average speed (E1): low traffic intensity, freeflow (Wednesday 4:00-5:00 AM)

NO_X emissions (E1): 111 gr/h

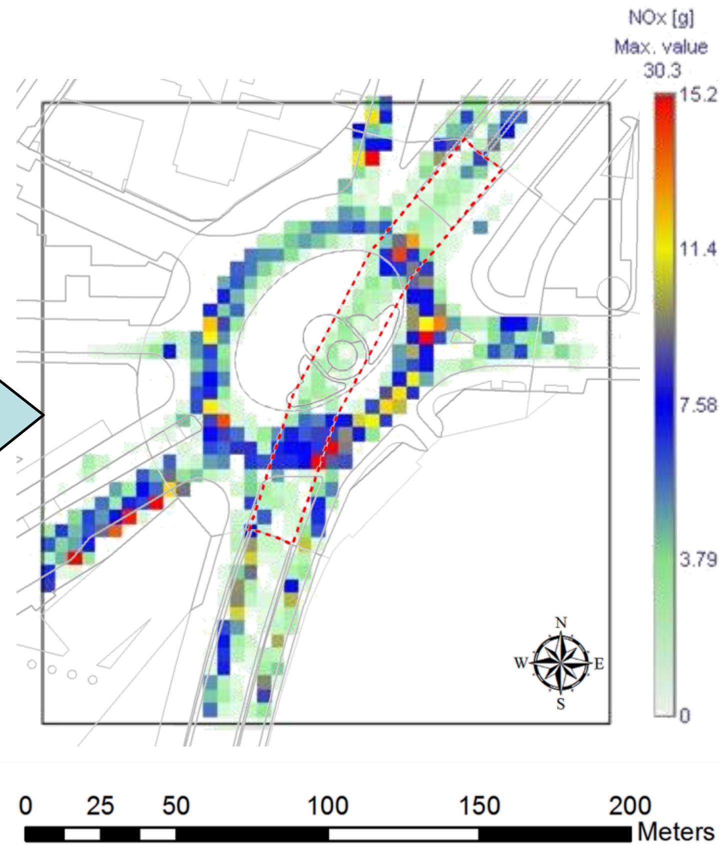


- The inverse relationship between average speed and emission is clearly reproduced by the microscale model

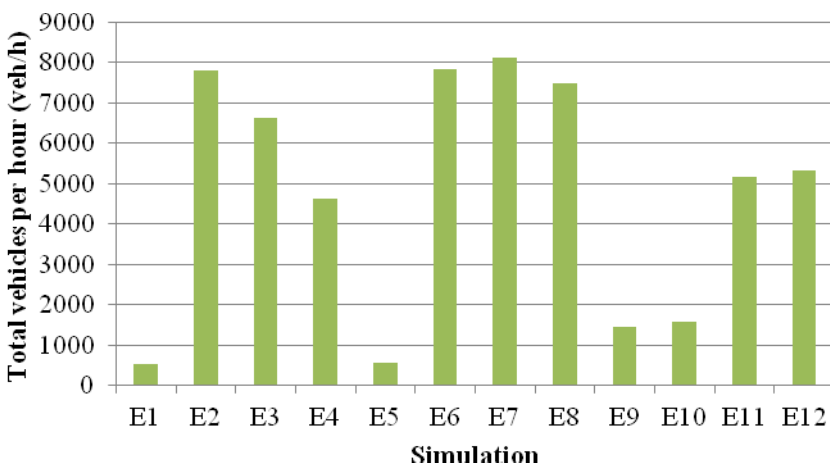
NO_X emissions (E2): 1721 gr/h

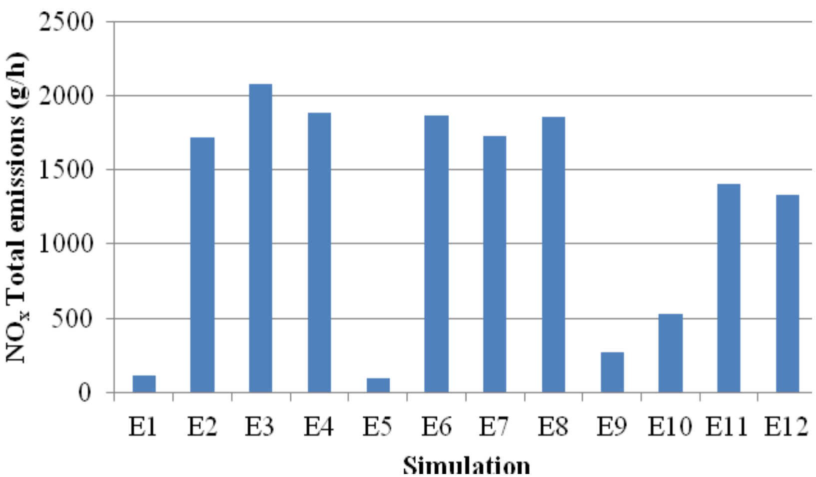


Average speed (E2): high traffic intensity, saturated (Wednesday 8:00-9:00 AM)



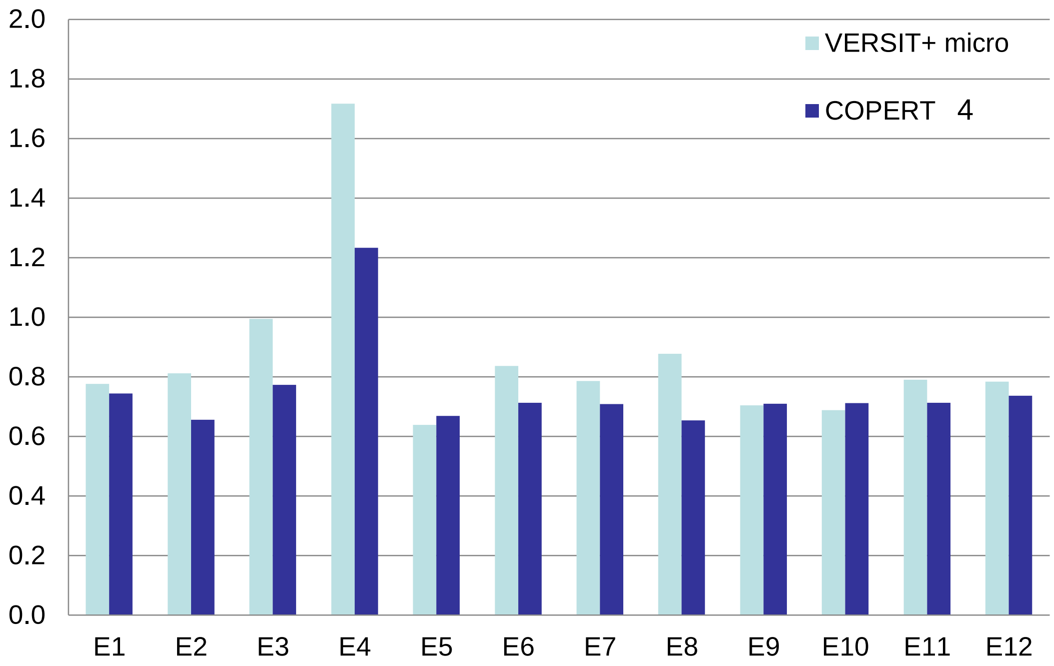
- NO_X hourly emissions in the square range from 100 to more than 2000 grams
- Maximum emissions (afternoon peak hour) do not correspond to maximum traffic intensity
- There is a significant variation in emissions per vehicle and distance travelled throughout the day / week
- Vehicle type emission contribution (not shown) also varies considerably





- Secondary emission factors as a function of speed have been computed for each scenario and compared with the corresponding outputs of the mesoscale model

COPERT IV and VERSIT+ micro NOx emissions factors (g/km) for passenger car



- Mean normalized bias error = 15.5% (taking COPERT as a reference)
- Deviations of VERSIT+ at scenario level range between -5% and 40%

4. CONCLUSIONS

- Road traffic is the main emitting sector in Madrid
- The methodology applied to compute emissions at microscale shows promising results
- Good agreement with well-known average speed algorithms used for mesoscale modeling
- According to the results, complementary local measures in hot spots may play a relevant role in future air quality policies

Next steps (microscale emission modeling)

- Apply the methodology to other hot spot configurations (junctions, street canyons, etc.)
- Better understanding and refinement of emission computation algorithms to expand the vehicle type categories available and make full use of the data provided by the fleet characterization study
- Enhance emission results exportability and other issues for postprocessing and integration with CFD codes (numerical results, grid cell size) for hot-spot air quality modeling

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Thank you for your attention!

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