The assessment of road traffic air pollution by means of an average emission parameter

The assessment of road traffic air pollution by means of an average emission parameter

Concettina Marino, Antonino Nucara*, Matilde Pietrafesa, Alfredo Pudano

Department DIIES -"Mediterranea" University of Reggio Calabria

* e-mail: antonino.nucara@unirc.it, Tel. +39 0965 875 411, Fax +39 0965 875 202,

ABSTRACT

This work proposes a simple methodology to assess pollution loads discharged by road traffic within a specific temporal and spatial domain, in the case that detailed disaggregated data about vehicle fleet composition are not available at local scale. The adopted methodology starts by defining a useful specific emission function that allows easy calculation of the total amount of pollutant emissions in a year. The function, called Yearly Average Vehicle (YAV), is representative of the annual average emission factor of a homogeneous category of vehicles. The employment of the YAV permits easy assessment of different scenarios and allows the analysis of the influence of different items that could alter the global amount of pollutant emissions released by road traffic, such as improvements of emissive characteristics of vehicles, changes in the transportation demand and variations of traffic flow path lengths.

The procedure has been applied to the urban area of the Italian city of Messina, where public administration has recently adopted a measure aimed at alleviating the load of the traffic pollution inside the urban area.

KEYWORDS

Air Pollution Assessment; Emission factors; Transport Policy; Road Traffic

1 INTRODUCTION

In recent years, the maintenance of a high standard of living and services in urban areas resulted in a progressive deterioration of air quality, primarily due to the high emission rates connected to the use of fossil fuels. Therefore, air quality in urban areas is strongly affected by the presence of several pollutants, most of which originates from road traffic.

According to IPCC [1], greenhouse gas (GHG) emissions need to be reduced by 50%-80% by 2050 to limit the evolving climate changes. The transport sector is a large source of GHG emissions and in Europe it contributes approximately one quarter of all greenhouse gas outputs, with a growing trend for both the near and distant future [2].

Amid transport systems, road vehicles are acknowledged to be sources of a range of pollutants that have significant impacts on both global and local scales [3]. Indeed, an estimated 10% of the global pollution is generated by road vehicles which are furthermore accountable for 20% of the European anthropogenic CO2 emissions [4], while and local impact of various air pollutants generated by road traffic, such as CO, NOx SO2 and PM10, has been documented [5-7].

Furthermore transport emissions have been constantly increasing for the last twenty years due to the rapidly rising traffic needs around the world. For example, it has been estimated that CO2 emissions from road traffic worldwide will increase by 92% between 1990 and 2020 [8]. In Europe this issue has been largely surveyed [9] and several studies addressing road transport emission projections up to 2020 have estimated that, even though the technological improvements linked to European Legislation (Euro Standards) has often an effective impact on emission reduction, especially on a per vehicle-km basis [6], CO2 emissions are, in some instance, expected to increase due to large mobility enhancement [10].

Policy development, therefore, needs to address road transport growth, if absolute reductions in greenhouse gas emissions and air quality improvements are to be achieved.

Planning the land of urban areas and optimizing urban mobility have been acknowledged to be effective measures to reach this goal and lower the environmental stress on urban centres [11], more than often affected by poor air quality. With this aim several studies have been also conducted to evaluate the effect on air quality and human health [12], while other research has been aimed at the analysis of the correlation among traffic parameters (flows, queues length, occupancy degree, and travel time) and pollutant concentration [13], in order to help the planning strategies to be developed and effectively applied.

Therefore, undivided attention is presently being paid world-wide towards the building-up of simple evaluation models, capable of singling out the quantities of gaseous pollutants emitted by the transportation means in an assigned urban area.

As a matter of fact, transport policy assessment models have been developed in Europe to analyze the effects of alternative planning strategies on transport system emissions [14-18]. These models were mainly used to assess the efficiency of several fiscal and regulation policies in reducing the gaseous emissions discharged by cars and road traffic [19,20].

To specifically analyze the effectiveness of tax and fiscal policies on emission rates, transport models were developed even outside of Europe [21] and applied on urban context [22].

Nevertheless, different type of technical transport models, exploitable to assess the impact of more general policies not only involving fiscal and tax strategies, are also nowadays available. They are analytical models assessing, for example, the effect of a polluting activity (driving a car) for which there is a fixed demand [23-25], or address the effect of technical progress of the vehicle fleet on emission rates [26], or alternatively are transport network models based on transport demand forecast [27].

Several emission monitoring and inventorying models are also available, such as MOVES [28], MOBILE [29], ARTEMIS [30], VERSIT [31]. In this context the COPERT methodology [32], which is part of the EMEP/EEA air pollutant emission inventory guidebook [26] for the calculation of air pollutant emissions and which is consistent with the 2006 IPCC Guidelines [33], is a tool used to calculate road transport emissions.

In particular the EMEP/EEA provides three different approaches (Tiers) in relation to the type of available data.

The Tier 1 approach utilizes mean emission factors, expressed in grammes of pollutant per fuel consumption, for each vehicle category (Passengers Cars, Light Duty Veichles, etc.); the Tier 2 utilizes mean emission factors expressed in grammes of pollutant per vehicle-kilometre, distinguishing vehicle technology (PRE ECE, ECE, EURO, etc.), vehicle category (Passengers Cars, Light Duty Veichles, etc.), fuel and displacement or weight of vehicles; finally, the Tier 3 approach utilizes a detailed procedure to assess the vehicle hot emissions, in which the emission factors, referred to the same vehicle categories defined by the Tier 2 method, are determined as a function of the vehicle speed.

The COPERT methodology, that may be considered a standard in regards to vehicle emission estimation across Europe, is consistent with Tier 3 approach and is the most commonly used computer code to calculate emissions from road transport within the European Union. It is the select tool of studies analyzing the effects of road transport strategies addressing pollution problems [34,35] and allows the calculation of vehicle emissions in accordance with the requirements of international conventions and protocols and EU legislation, taking into account the vehicle speeds and distances travelled.

The models mentioned above are often based on emission factors. The assessment of road-traffic-related pollutant emission factors is usually based on exhaust gas measurements of vehicles on test bench over various driving cycles. These tests, indeed, do not necessarily reflect the real on-road driving conditions and the level of maintenance of the actual vehicle fleet [36].

Therefore, there is a need for on-road emission estimates of air pollutants from actual vehicles under real driving conditions.

Recent studies [37] carried out by means of portable emission measuring systems (PEMS) demonstrated, for examples, that, as far as NOx emission is concerned, diesel vehicles seem to comply with the corresponding emission standard over the European type-approval driving cycle (NEDC), but they constantly exceed the specified limit when tested under real-world driving conditions.

NOx levels of two tested Euro 5 diesel passenger cars, in particular, demonstrated consistently higher in urban, rural, and highway driving conditions than those of the corresponding emission standard and the COPERT emission factor.

Moreover, in this context, the role of weather data should be also taken into account, assuming a significant importance [38].

These observations raise concerns regarding the assessment of actual emissions of modern vehicles, especially because the impact of road vehicle flows on urban air-quality could be appreciably underestimated. Therefore this fact should be considered when emission assessments are carried out and the prevision of possible future evolution of emission scenario should conservatively take the issue into account.

However, the listed models are usually regarded as useful tools for local administrations, called into action in developing urban mobility policies in the aim of successfully selecting optimal alternatives to satisfy transportation demand in town and in order of suitably pursuing sustainability and less environmental impacts in urban context. But, in that case, the drawback lies in the fact that often these models are not easy to deal with and results are not immediately interpretable, especially by not experts; furthermore, they need input data not always available.

In order to address this issue, this study proposes an analysis procedure based upon a new specific emission function that allows feasible assessments of the total amount of pollutant emissions discharged by the traffic flows circulating in assigned spatial and temporal domains.

Assuming a temporal domain of one year, the parameter, called Yearly Average Vehicle (YAV), represents the annual average emission factor of a specific category of vehicles; it is computed for each pollutant and is referred to a specific year.

The proposed methodology was applied to a case study, namely the urban area of the Italian city of Messina.

Messina, located on the Sicilian cost nearby the Italian peninsula, in addition to the traffic loads related to the local human activities, is also subjected to traffic flows due to vehicles coming from the continent and directed towards other Sicilian centres. The vehicles, as a matter of fact, are carried on ferries across the Strait of Messina, that separates the Italian Peninsula from the isle of Sicily, and are disembarked at the harbor of Messina located near the city centre.

With the aim of alleviating the load of the traffic pollution, affecting particularly the centre of the city, the public administration of Messina has adopted a measure that consists of rerouting the ferry activity occurring in the Strait of Messina from the harbour of Messina to the one of Tremestieri, a small suburban district in the south of the city.

In order to assess the effectiveness of the adopted measure, this study reports the results of an analysis aimed at evaluating the variation in the emission rates of those major pollutants discharged by the traffic activity.

In the study YAVs have been calculated for passenger cars and light and heavy duty vehicles using emission data from EMEP/EEA emission inventory guidebook 2009 [26] and vehicle fleet consistency data from the Italian Transportation Plan [39]. Calculations were carried out for two different years, corresponding to the pre and post-operam conditions.

The implementation of the YAV has allowed easy different scenario assessments, taking into account different items that could affect results, such as improvements of emissive characteristics of vehicles, changes in the transportation demand and variations of traffic flow path lengths.

It has been proved to be a feasible tool to assess urban mobility policies and select the most effective measure.

2 METHODOLOGY

2.1 Emission of a vehicular fleet

The global emissions of the vehicular fleet, in an assigned context, do depend on the specific emissions of the emissive classes in which the fleet can be split up.

An emissive class is a set of vehicles which have a homogeneous behavior in terms of emission rates and type of pollutants discharged into the air.

Generally, the specific emissions of a vehicular emissive class are expressed by means of the emission factors, that represent the amount of pollutants emitted by the average vehicle representative of a given class per unit length of the journey.

Indeed, each emission factor is referred to a specific pollutant, so that there are as many emission factors as the types of pollutants discharged into the air by the considered emissive class of vehicles; furthermore, it is often expressed as a function of the journey average speed.

As far as the European region is concerned, emission factors can be evaluated by means of the methodology reported in the EMEP/EEA air pollutant emission inventory guidebook 2009 [26], where vehicles are suitably classified by type (cars, heavy vehicle, motorcycles, etc.), by fuel, by age and by engine capacity or, with regard to commercial vehicles exclusively, by weight.

In this methodology the age of the vehicle is used to identify the technical legislation (namely the European Emission Standard) ruling the emission rates when the vehicle was registered. Emission factors, as a matter of fact, strongly depend on the reference technical legislation.

During the last decades several emission standards have been enacted and each of them has a term of validity.

Comparing the vehicle age to the boundaries of these validity terms, the emission standard the vehicle must comply with may be identified.

Moreover, since every Emission Standard is considered to identify a legislation emissive class, the age of each vehicle is actually used to determine the specific legislation emissive class the vehicle belongs to.

Therefore, assessing the vehicle age with respect to the issuing date of the European Emissions Standard that the vehicles must comply with, the emission factors are evaluated, for each homogeneous emissive category and for each pollutant, by means of equations that could differ in the functional dependence of the involved parameters, but that, in many instances, assume the following form:

$$EF_{ijhkl} = \frac{a_{ijhkl} + c_{ijhkl}v + e_{ijhkl}v^2}{1_{ijhkl} + b_{ijhkl}v + d_{ijhkl}v^2} \qquad (1)$$

where v is the journey average speed (km/h) of vehicle, i represents the i-th pollutant, j the vehicle type, h the fuel, k the engine volume or vehicle weight and l the legislation emissive class identified by the age of the vehicle. The emission factor is expressed in grams of pollutant per vehicle and per kilometer (g vehicle^{-1} km^{-1}) and the values of the coefficients a, b, c, d, and e are derived from EEA [26].

Thus, pollutant emissions of a given class of the vehicle fleet circulating in a studied context, E_{ijhkl} (g), can be expressed with the following equation:

$$E_{ijhkl} = EF_{ijhkl} \times N_{jhkl} \times L_{jhkl} \qquad (2)$$

where EF_{ijhkl} (g vehicle^{-1} km^{-1}) is the pertinent emission factor, N_{jhkl} (vehicle) is the number of vehicles belonging to each homogeneous emitting class of the analyzed fleet and L_{jhkl} (km) is the average length of the typical travel of the case under examination.

Therefore the total amount of the emissions of pollutant i in the analyzed context, $E_{i,tot}$, is given by:

$$E_{i,tot} = \sum_j \sum_h \sum_k \sum_l EF_{ijhkl} \times N_{jhkl} \times L_{jhkl} \qquad (3)$$

2.2 The Yearly Average Vehicle

The application of the equation (3) is strongly limited by the level with which the number of vehicles for each of the emitting class, N_{jhkl}, is generally known.

In order to overcome this limitation, it is relevant to observe that the overall number of vehicles circulating in the studied context is easier to be determined than the number of vehicles belonging to each single emission class. This data, indeed, can be, at least, evaluated from the total transportation demand which is usually a known information.

Moreover, data regarding class distribution of the national fleet, circulating in an assigned year, are generally available. These types of road traffic consistency data can be, usually, derived from statistical surveys or transportation plans that are typically led by national administrations and that generally report records about the numbers of vehicles registered on an annual base and their characteristics such as type, fuel, displacement or weight. These data can be feasibly processed to obtain the fleet distribution by age over a period of time that includes less recent years, not directly covered by the published records. The distribution by age, then, can be used to obtain the distribution of the running fleet by legislation emissive class.

Therefore the percentages of the global amount of vehicles belonging to each class which vehicular fleet can be split into (namely type class, fuel class, age-legislation class and displacement or weight class), is generally easier to be determined than the number of vehicles belonging to each single emission class, .

Assuming the hypothesis of stochastic independence, for a selected year, vehicle distribution in terms of emitting classes can be obtained as joint distribution and, therefore, equal to the product of marginal distributions:

$$p_{jhkl}\Big|_y^c = p_j\Big|_y^c \times p_h\Big|_y^c \times p_k\Big|_y^c \times p_l\Big|_y^c \qquad (4)$$

where the c-apex points out the transportation category (for instance passengers or freight), subscript y stands for year, j, h, k, l point out type class (cars, heavy vehicles, motorcycles), fuel class (gasoline, diesel, LPG), displacement or weight class and legislation emissive class respectively, while p stands for percentage of vehicles.

This consideration leads to the definition of an useful parameter that would represent the average emission factor of a transportation category, and not of a specific class. By referring it to a year, this index has been then called "Yearly Average Vehicle" (YAV).

It can be considered as an extension of an index previously introduced by some of the present authors (Nucara et al., 1999; 2001) and, referring to a specific transportation category, c, it is provided by:

$$YAV_i\Big|_y^c = \frac{\sum_j \sum_h \sum_k \sum_l EF_{ijhkl} \times N_{jhkl}\Big|_y^c}{N_{tot}\Big|_y^c} = \sum_j \sum_h \sum_k \sum_l EF_{ijhkl} \times p_{jhkl}\Big|_y^c \qquad (5)$$

where: $p_{jhkl}\Big|_y^c = \frac{N_{jhkl}\Big|_y^c}{N_{tot}\Big|_y^c}$

This average emitting vehicle strictly refers to a specific pollutant and it should be computed for each year of the studied period of time, due to the continuous evolution of the circulating fleet. The procedure leading to eq. (5) is schematically reported in Fig. 1.

The YAV is an emission factor function with an analytical structure similar to the emission factor functions of the Tier 3 method of the EMEP/EEA procedure. But, differently from Tier 3 method, it is referred to a more aggregated group of vehicles. In particular the aggregation level used in the proposed model is similar to the one utilized in Tier 1 approach.

This allows to keep the precision level of Tier 3, limiting the number, typology and detail of data that should be managed.

In other words, once YAVs for different vehicle types (i.e. cars, tracks, etc), or transport category (i.e. passenger vehicle, freight, etc.) are known, a number of data comparable with those requested by Tier 1 approach can be managed, although emission factors variable with velocity can be still taken into account like in Tier 3.

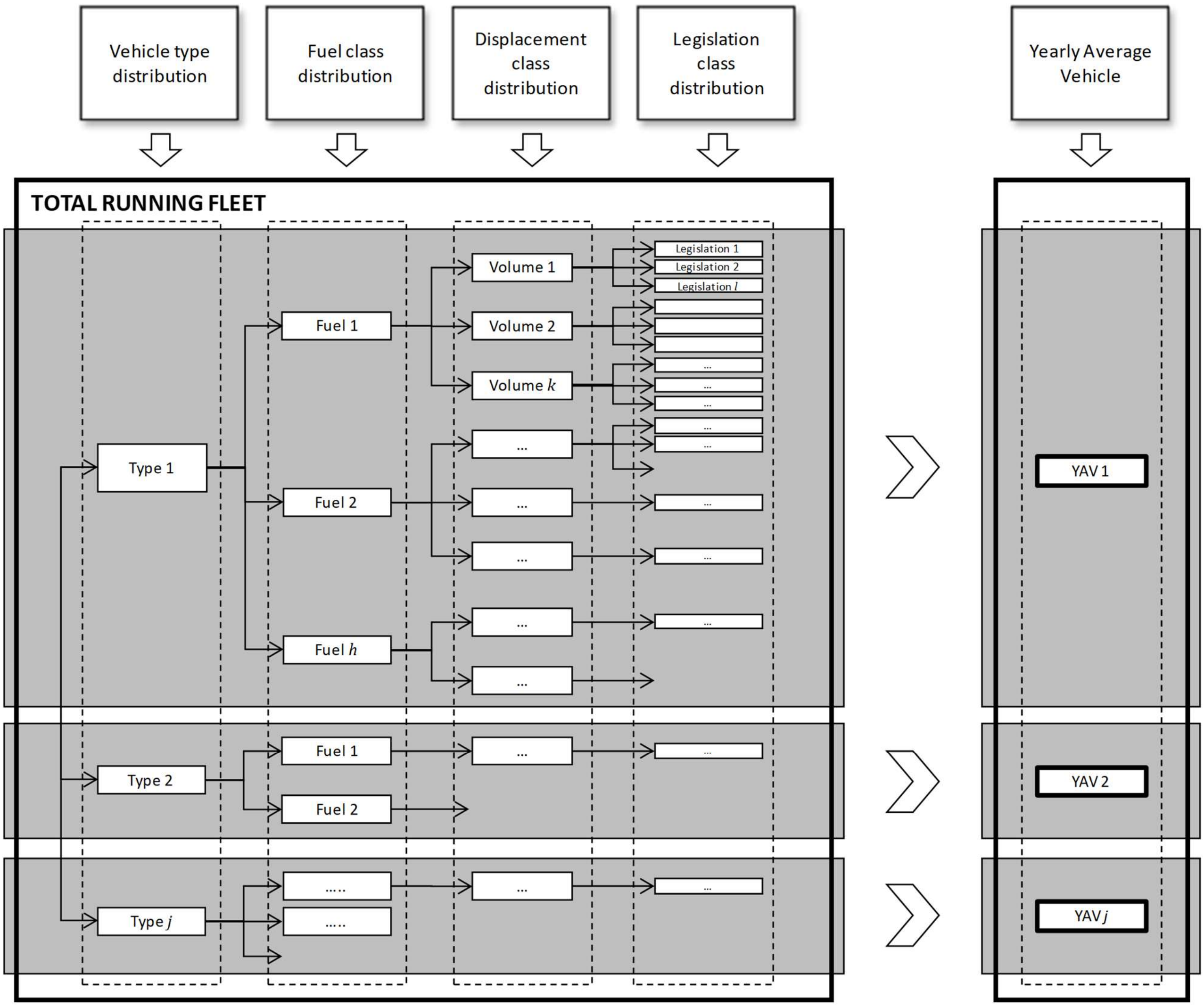

Fig. 1 Procedure for the assessment of the Yearly Average Vehicle

YAV, therefore, is an indicator describing the emission characteristics of a whole specific vehicle fleet and it is referred to a specific year.

The defined parameter allows easy appraisal of the emission characteristics of a specific vehicle fleet. The sense of this statement may be more thoroughly understood if the following Fig. 2 is considered.

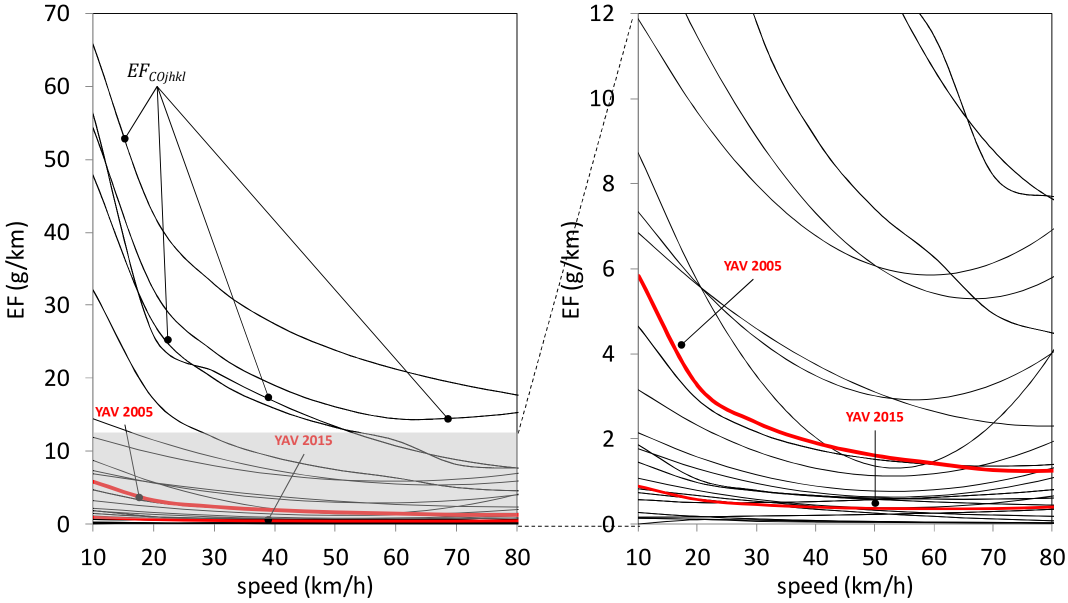

Fig. 2 CO emission factor versus vehicle speed for passenger cars and YAVCO for the years 2005 and 2015

Besides YAV trend for an example vehicle fleet, it reports the graphs of the emission factors versus the vehicle speed as they may be calculated by means of the EEA methodology [26] for the same fleet; the two reported graphs differs for the y-axis scale only, being the second one reported to make the lines characterized by values lower than 12 g/km more distinguishable. Obviously each emission factor is referred to a specific vehicle class, so that the application of the methodology will yield as many lines as the number of the classes the studied vehicle fleet may be split into. This makes the appraisal of the pollution load of the running fleet scarcely clear. Furthermore, difficulties enhance when comparisons among different scenarios have to be made, because emission factors give no information on this subject and, therefore, the total amount of pollutant emissions must be evaluated to reach this goal.

The defined YAV, conversely, makes the pollution load connected to a specific vehicle fleet immediately appreciable, because it comprise all the emission factors in a single function and, therefore, characterize the running park from the standpoint of pollutant emission amount.

Moreover comparisons among different scenarios are really feasible through YAV calculations. Fig. 2, as a matter of fact, reports YAV trends for two different years (2005 and 2015). Comparing the two curves the reduction of pollution loads, which takes place because of the improvement of the vehicle emission characteristics implemented from 2005 to 2015, is clearly deducible.

Global pollution loads released by the running fleet are also evaluable once YAVs have been calculated.

Starting from the knowledge of the yearly average vehicle and assuming that reasonably the journey average length is the same for all the vehicles belonging to a specific category, the total amount of the *i*-th pollutant emissions, $E_i\big|_{Ty}^{c}$, for the c-th category of transportation in the period T_y of the year y, can be easily computed by means of the equation:

$$E_i\big|_{Ty}^{c} = YAV_i\big|_{y}^{c} \times N_{tot}\big|_{Ty}^{c} \times \overline{L}^c \tag{6}$$

where $N_{tot}\big|_{Ty}^{c}$ is the total number of circulating vehicles of the *c*-th transportation category in the period T_y of the year y and $\overline{L}^c$ is the journey average length of the c-th transportation category.

Finally, this overall average emitting vehicle allows an easy appraise of the global amount of pollutants emitted by the whole vehicular fleet, in a specific period of the year y:

$$E_i\big|_{Ty} = \sum_c YAV_i\big|_y^c \times N_{tot}\big|_{Ty}^c \times \overline{L}^c \qquad (7)$$

where i identify the *i*-th pollutant.

Therefore the emission amount can be simply assessed by multiplying YAV values by the total number of the vehicle composing the running fleet in every context. Once YAV is known, the mean emission factor of the running fleet is known and, thus, it can be used for emission assessment in different context, even if data regarding the number of vehicles belonging to each emission categories is not known.

YAV determination could be entrusted to a recognized institution (e.g. municipality, state administrations, etc.) and its values, depicting the actual emission average characteristic of the running fleet, might be used as a reference parameter to compare homogeneously the effects on emissions of different mobility policies (e.g. transportation policies causing variation of vehicle speeds).

The presented method, is quite simple and, once defined the YAV, it can be considered, within the limits of the adopted hypotheses, as a manual method, comparable to Tier 1 of the EMEP/EEA methodology. It can be easily handled by the local authorities, so they may adopt a flexible tool exploitable, for example, for evaluation of regulatory policies aimed at reducing urban pollution caused by road vehicles.

The method has been structured so that it may be used when detailed data about vehicle fleet composition are not known. When such a case occurs, YAV calculated with reference to a different territorial domain might be used for all the regions which are reasonably characterized by similar vehicle distribution among fleet components.

The proposed index, for example, allows the assessment of the emissions discharged by a local fleet assuming that its composition is analogous to the one pertaining to a larger territorial context (e.g. a national scale) whose data are well known.

Obviously this approach entails a lower accuracy with respect to the more detailed methods; nevertheless its allows the emission assessment when the only available data about the running fleet is the global number of vehicles.

An example of such a case is reported in the following section.

3 A CASE STUDY

The methodology and the indicator previously described have been utilised to assess the evolution of the pollutant emission scenario in the Italian city of Messina as a result of the implementation of a measure stated by the Harbor Planning Scheme [40] that has been recently issued by the local Urban Administration.

Messina, in fact, is located on the Sicilian coast, nearby the Italian peninsula (Fig. 3), and because of that position, its urban area has been experiencing a progressive deterioration of air quality due to pollutant emissions mainly discharged by traffic flows coming from the continent and directed towards other Sicilian centres. Actually the vehicles coming from the Continent are carried to the Sicilian cost by means of ferries crossing the Strait of Messina that separates the Italian Peninsula from the isle of Sicily.

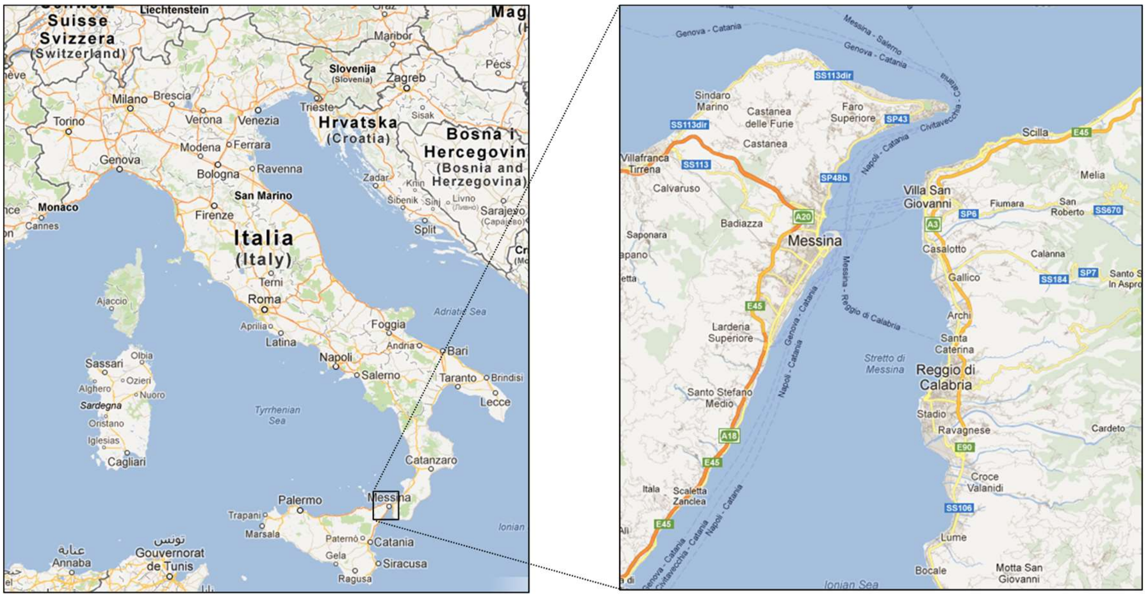

Fig. 3 Location of the studied city

Currently the ferry activity carrying the road vehicles exploits three docking sites: S. Francesco, Maritime Station and Tremestieri that harbors heavy vehicles exclusively and is located outside the city centre area (Fig. 4).

Fig. 4 Location of the three docking areas of Messina

The characteristics of the paths separating the docking areas from the nearest highway junction, the principal destination of the studied traffic flows mainly headed to and coming from centers located outside the urban district, are reported in Table 1.

Table 1 Characteristics of the transport system

Docking	Nearest highway junction	Trip length (km)	Mean speed (km/h)
S. Francesco	Messina Boccetta	4.0	20
Maritime station	Messina Centre	4.5	20
Tremestieri	Messina Sud – Tremestieri	1.8	40

Trying to lower the traffic loads affecting the city centre of Messina, the Municipal Administration has planned to reroute the whole ferrying activity in the Strait of Messina from the docks of both S. Francesco and Maritime station to the one of Tremestieri, the small suburban district in the south of the city. This measure is to be completely realized in 2015.

The present analysis tries to assess the evolution of pollutant emissions loads ante and post-operam through a set of phases that respectively allow to determine:

- the composition of the vehicle fleet and transportation demand in 2005, before the intervention, and in 2015, after the intervention;

- the yearly average vehicle for each pollutant in 2005 and 2015;
- the global amount of each pollutant emitted by the whole vehicular fleet in 2005 and 2015.

Data supporting the analysis were derived from:

- the Urban Mobility Plan of the City of Messina [41];
- the Harbor Planning Scheme of the City of Messina [40];
- the Italian National Transport and Infrastructure Plan [39];
- the EMEP/EEA emission inventory guidebook 2009 [26], as regards as the pollutants emission functions.

3.1 Fleet composition and vehicle flows.

The average daily number of vehicles composing the flows between the two shores of the Strait of Messina in 2005 has been deduced from both the Urban Mobility Plan [41] and the Harbor Planning Scheme of the city of Messina [40].

Two categories of mobility demand are present in the area: passengers and freight. Moreover passenger transportation is realized by means of light cars exclusively, the percentage of heavy vehicle and motorcycle being negligible in that case.

Freight transportation, on the other hand, involves both heavy and light duty vehicles and the corresponding weight class distribution is derived from the Italian National Transport and Infrastructure Plan [39].

Data from this last document has also allowed the construction of vehicle fleet and distribution in terms of age, fuel and power, in 2005.

To construct the vehicle flow in 2015, prevision data from the Urban Mobility Plan [41] and the Harbor Planning Scheme [40] have been utilized.

Moreover, in order to foresee the composition and distribution of the fleet in 2015, an extrapolation of data related to the period spanning from 1980 to 2005 has been carried out, for both passenger cars and commercial goods vehicles, under the following hypothesis:

- age class distribution of passenger cars is constant from 2005 to 2015;
- age and weight class distribution of commercial goods vehicles is constant from 2005 to 2015.

These hypotheses could be considered reliable on the basis of the analysis of the fleet composition trend in the past years [42].

As far as age class distribution is concerned, it must be stressed that the application of the methodology reported in [26] for emission factor evaluations, requires a further elaboration to identify the legislation emissive category of every vehicle. The latter, in fact, is defined by the specific European Emission Standard that vehicles must comply with, and, therefore can be obtained connecting the vehicle registration date to the validity term of each Emission Standard. Following this procedure the distribution by legislation emissive class was able to be determined.

Considering the directives currently in force and that, in addition, EURO 6 will be adopted from 2014, the identified classes for passenger cars and for freight vehicles are reported respectively in Table 2 and Table 3.

Table 2 Legislation emissive classes for passenger cars

Legislation class		Validity term
PRE EURO	PRE ECE	Up to 1971
	ECE-15.00, ECE-15.01	1972 to 1977
	ECE-15.02	1978 to 1980
	ECE-15.03	1981 to 1985
	ECE-15.04	1985 to 1992
EURO	EURO 1 - 91/441/EEC	1993 to 1996
	EURO 2 - 94/12/EC	1997 to 2001
	EURO 3 - 98/69/EC Stage 2000	2002 to 2005
	EURO 4 - 98/69/EC Stage 2005	2006 to 2009
	EURO 5 - EC 715/2007	2010 to 2013
	EURO 6 - EC 715/2007	After 2014

Table 3 Legislation emissive classes of freight vehicles

Legislation class		Validity term
PRE EURO	PRE EURO	Up to 1992
EURO	EURO I - 91/542/EEC Stage I	1993 to 1995
	EURO II - 91/542/EEC Stage II	1996 to 1999
	EURO III - 1999/96/EC Stage I	2000 to 2004
	EURO IV - 1999/96/EC Stage II	2005 to 2007
	EURO V - 1999/96/EC Stage III	2008 to 2013
	EURO VI - COM (2007) 851	After 2014

Utilizing the data derived from the Italian National Transport and Infrastructure Plan [39] for the period spanning from 1980 to 2005, the evolutionary trend up to 2015 of the fleet distributions in terms of legislation emissive class, fuel, displacement or weight, for both passengers cars and freight vehicles, was determined. So, two fleet configurations have been considered for comparison purposes: the one assessed in 2005 and the one to be expected in 2015.

For passenger cars, the distribution by legislation emissive class is reported in Fig. 5, while distributions by fuel and displacement are shown in Fig. 6 and Fig. 7 respectively.

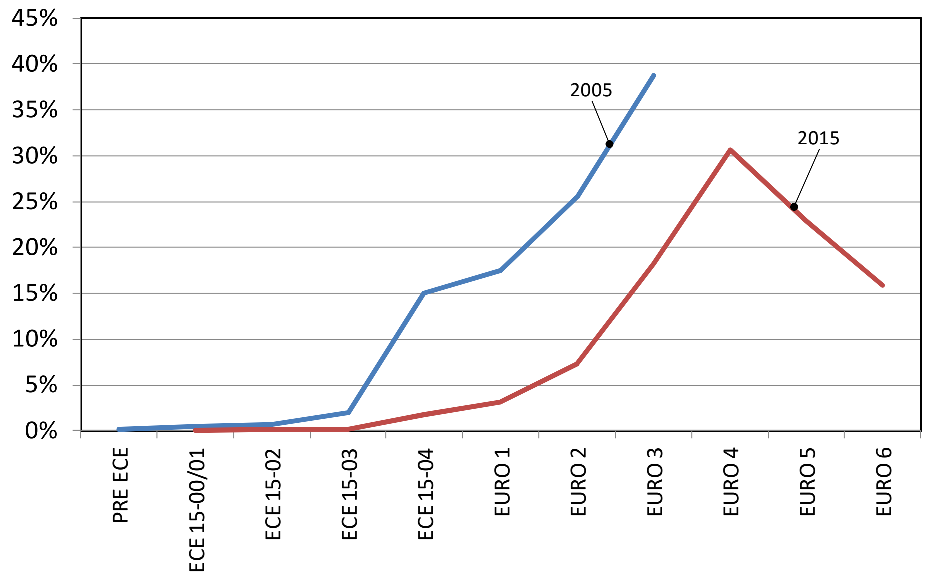

Fig. 5 Passenger cars distribution by legislation emissive class

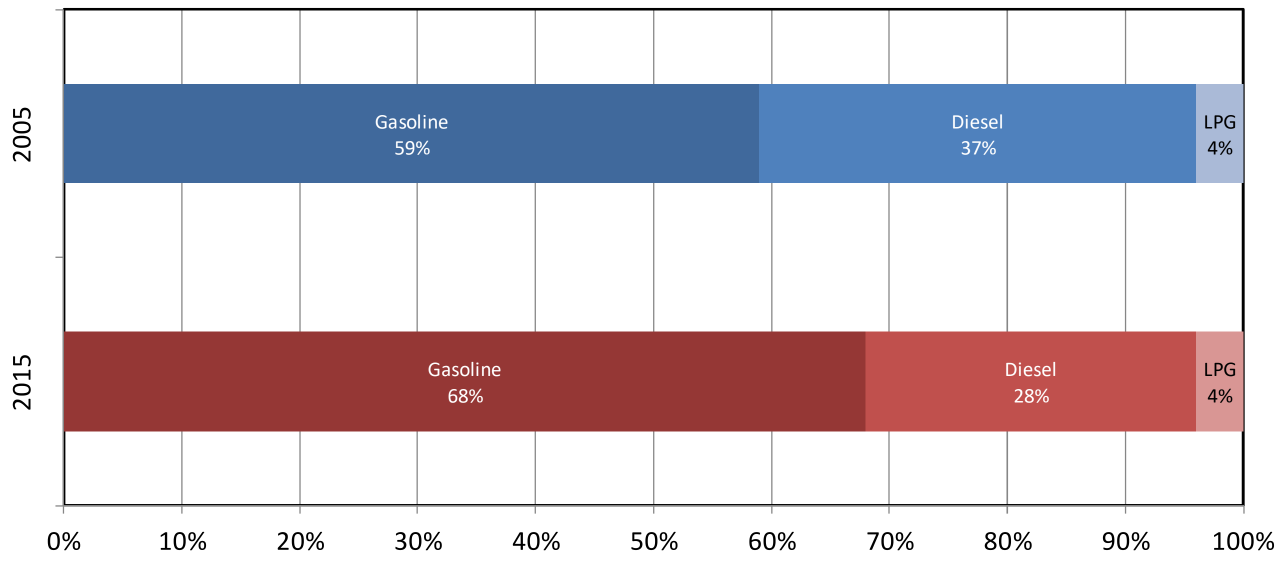

Fig. 6 Passenger cars distribution by fuel

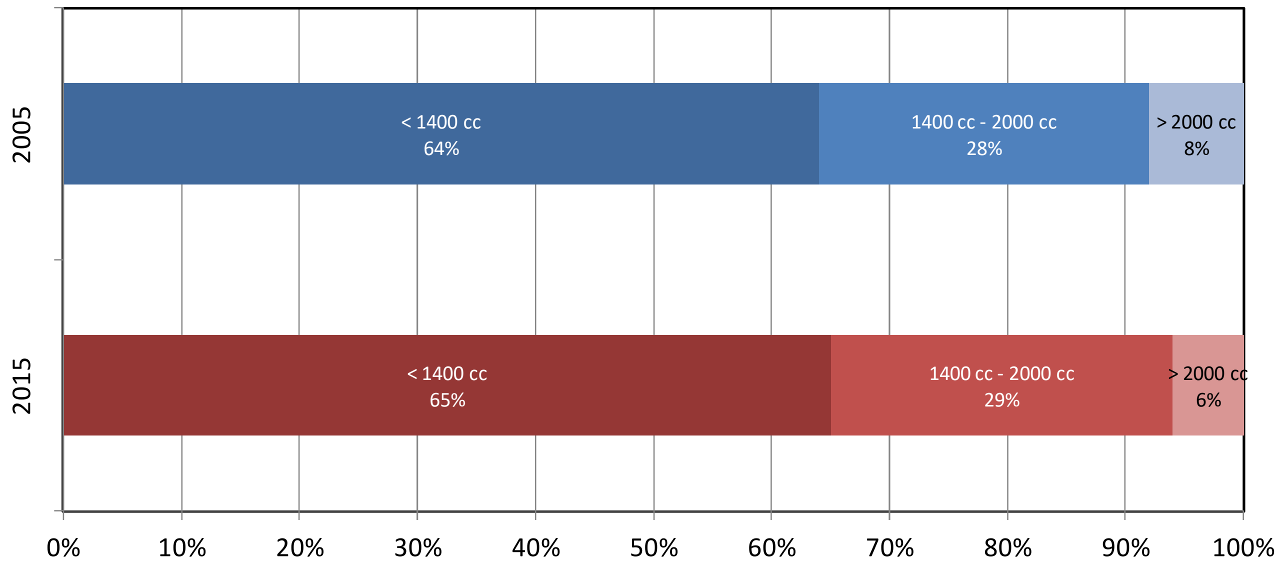

Fig. 7 Passenger cars distribution by displacement

The distribution by legislation emissive class for freight vehicles is, instead, reported in Fig. 8. As regards the weight distribution, it was assumed constant from 2005 to 2015 (Fig. 9), while as far as fuel distribution is concerned, it was assumed that all freight vehicles are powered by diesel which is a truthful hypothesis for the specific studied case.

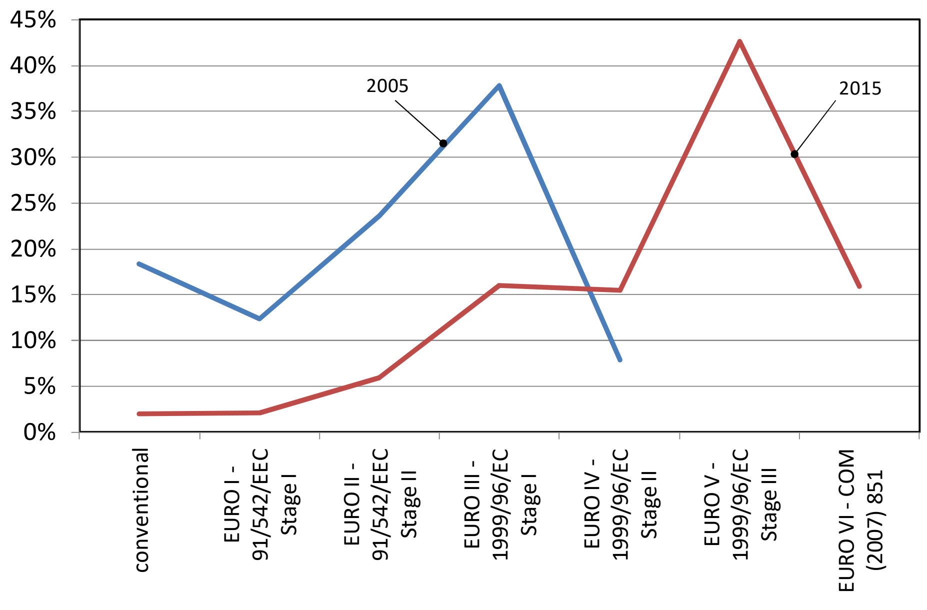

Fig. 8 Freight vehicle distribution by legislation emissive class

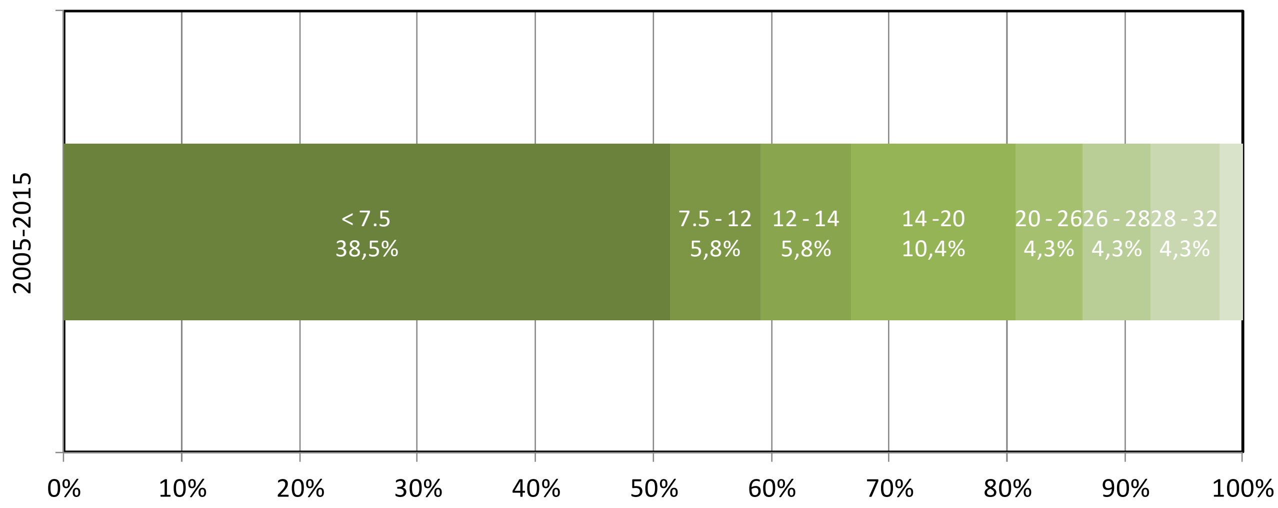

Fig. 9 Freight vehicle distribution by weight

Once the marginal distributions were determined, utilizing eq. (4) the joint distribution p_{jhkl} was assessed. As an example, the result for passenger cars, referred to the year 2015, is reported in Table 4.

Table 4 Passenger cars distribution by legislation emissive categories referred to the year 2015

Vehicle type	Fuel	Displacement	Legislation class	Vehicle distribution		
Passenger cars	Gasoline	<1400 cc	PRE EURO	0,4%		
			EURO 1	0,8%		
			EURO 2	2,7%		
			EURO 3	6,5%		
			EURO 4	6,9%		
			EURO 5	14,6%		
			EURO 6	6,5%		
		Total <1400 cc			38,4%	
		>2000 cc	PRE EURO	0,0%		
			EURO 1	0,1%		
			EURO 2	0,2%		
			EURO 3	0,6%		
			EURO 4	0,6%		
			EURO 5	1,3%		
			EURO 6	0,6%		
		Total >2000 cc			3,5%	
		1400 cc - 2000 cc	PRE EURO	0,2%		
			EURO 1	0,3%		
			EURO 2	1,2%		
			EURO 3	2,9%		
			EURO 4	3,1%		
			EURO 5	6,5%		
			EURO 6	2,9%		
		Total 1400 cc - 2000 cc			17,1%	
	Total Gasoline					59,0%
	Diesel	All displacement	PRE EURO	0,4%		
			EURO 1	0,7%		
			EURO 2	2,6%		
			EURO 3	6,3%		
			EURO 4	6,7%		
			EURO 5	14,0%		
			EURO 6	6,3%		
		Total			37,0%	
	Total Diesel					37,0%
	GPL	All displacement	PRE EURO	0,0%		
			EURO 1	0,1%		
			EURO 2	0,3%		
			EURO 3	0,7%		
			EURO 4	0,7%		
			EURO 5	1,5%		
			EURO 6	0,7%		
		Total			4,0%	
	Total GPL					4,0%
Total Passenger cars				100,0%	100,0%	100,0%

3.2 Yearly average vehicle in 2005 and 2015

As stated before, the Yearly Average Vehicle (YAV) represents the average emission factor of a whole category of transport. It is referred to an year and is provided by eq. (5).

In the studied case transportation system is made up of two category, namely passenger cars (PC) and freight (F), while four types of pollutants have been considered: CO, NOx, VOC and PM.

Furthermore, scenarios of two years (2005 and 2015) have been analyzed so that, in the end, 16 YAVs have been calculated. The results are shown in Fig. 10 which reports the YAV trends with the vehicle average speed.

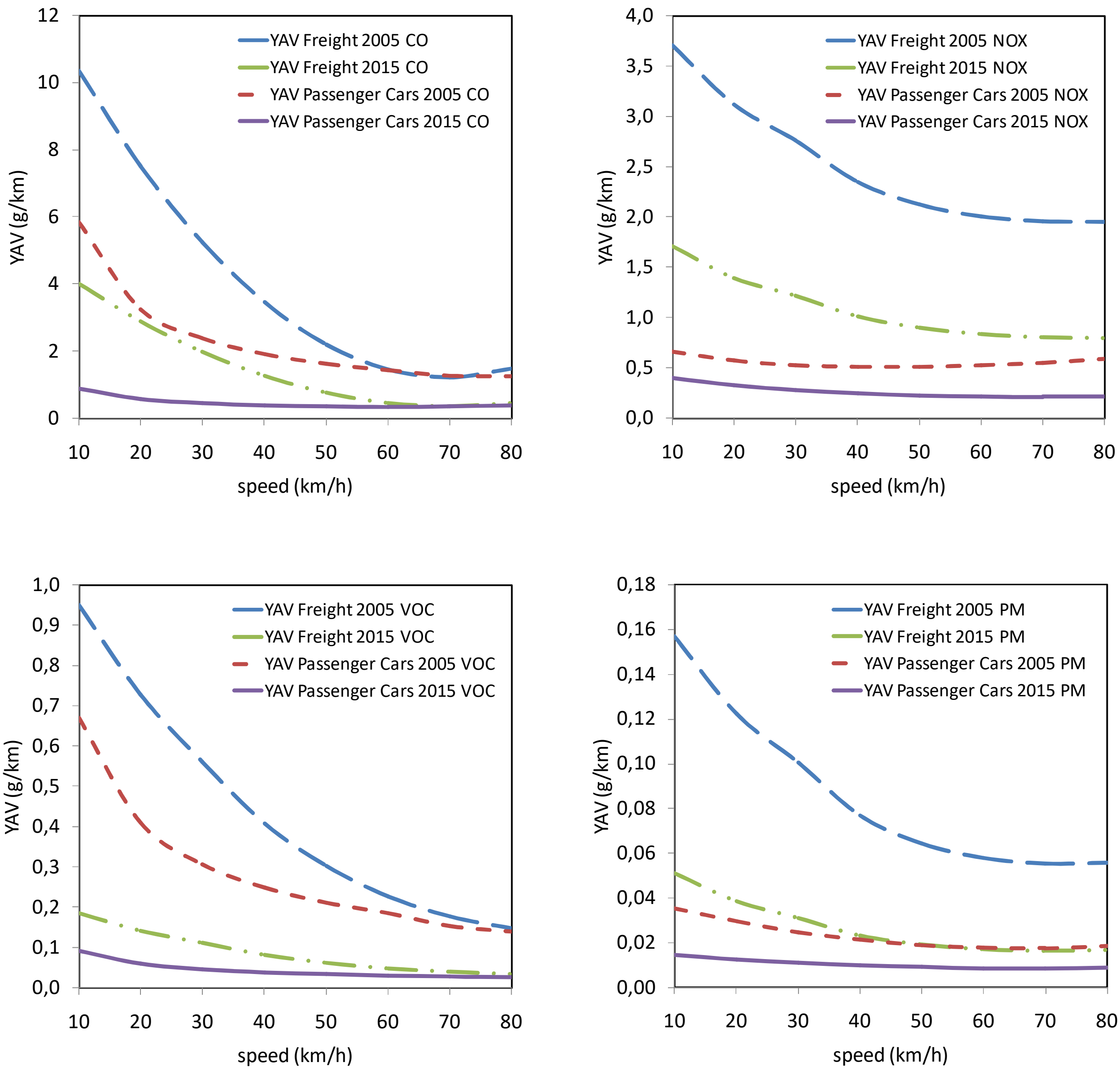

Fig. 10 Yearly average vehicles as a function of vehicle speed

In the analyzed cases, the journey average speed that is consistent with the characteristics of the paths developing inside the urban area to the nearest highway junction (Table 1), principal destination of the studied road traffic flow, has been estimated to assume two values: 20 km/h and 40 km/h. Table 5 reports YAVs calculated in correspondence of these two values.

Table 5 Values of YAVs, for vehicle speeds of 20 and 40 km/h

Year	Pollutant	YAV (g/km)			
		Passenger Cars		Freight	
		v = 20 km/h	v = 40 km/h	v = 20 km/h	v = 40 km/h
2005	CO	3.259	1.910	7.523	3.452
	NOx	0.570	0.512	3.120	2.345
	PM	0.029	0.021	0.122	0.077
	VOC	0.410	0.248	0.728	0.407
2015	CO	0.570	0.388	2.887	1.264
	NOx	0.326	0.247	1.395	1.014
	PM	0.013	0.010	0.039	0.023
	VOC	0.059	0.038	0.142	0.081

The simple observation of both the previous Fig. 10 and Table 5 does denote the effectiveness of the YAV indicator in interpreting the environmental feature of a given transportation system and its evolution with time.

It allows, for instance, an easy and rapid quantification of the effects of policies aimed at changing the traffic flow characteristics such as the average speed.

3.3 Emission assessment

By means of eq. (5) and (6), the YAV indicator allows easy evaluations of pollutant emission loads discharged by a specific transportation system, even in correspondence of several hypothetical scenarios in turn correlated to different values of $N_{tot}\big|_{Ty}^{c}$ and $\bar{L}^{c}$.

In the studied case, in order to effectively evaluate the environmental consequence of the measure to be adopted by the Municipal Administration and consisting in the displacement of the whole ferrying activity to the Tremestieri docking area, four scenarios have been considered. They are reported in the following, while traffic flows corresponding to the four different scenarios are reported in Table 6 and Fig. 11.

Scenario 0. It is the basic scenario with vehicle flows and fleet distribution as in 2005, passenger cars headed to and coming from S. Francesco and Maritime Station docks, light and heavy duty vehicles loaded and unloaded at Tremestieri.

Scenario 1. It considers the evolution of both vehicle flows and fleet class distributions up to 2015, but the ratio among vehicular flows headed to and coming from the three docks is maintained as in 2005.

Scenario 2. It considers the evolution of both vehicle flows and fleet class distributions up to 2015 as in Scenario 1, but the displacement measure is partially adopted, abandoning S. Francesco dock and assuming that traffic loads affecting Maritime Station dock remain as in 2005.

Scenario 3. It considers the evolution of both vehicle flows and fleet class distributions up to 2015, but the displacement measure is totally adopted with the discarding of both S. Francesco and Maritime Station docks.

Table 6 Daily traffic flows in the different scenarios

Scenario	Reference year	Transportation category	Traffic flow (vehicle/day)		
			S. Francesco	Tremestieri	Maritime station
Scenario 0	2005	Passenger Cars	4096	0	1531
		Freight	0	2936	0
Scenario 1	2015	Passenger Cars	4710	0	1760
		Freight	0	3685	0
Scenario 2	2015	Passenger Cars	0	4939	1531
		Freight	0	3685	0
Scenario 3	2015	Passenger Cars	0	6470	0
		Freight	0	3685	0

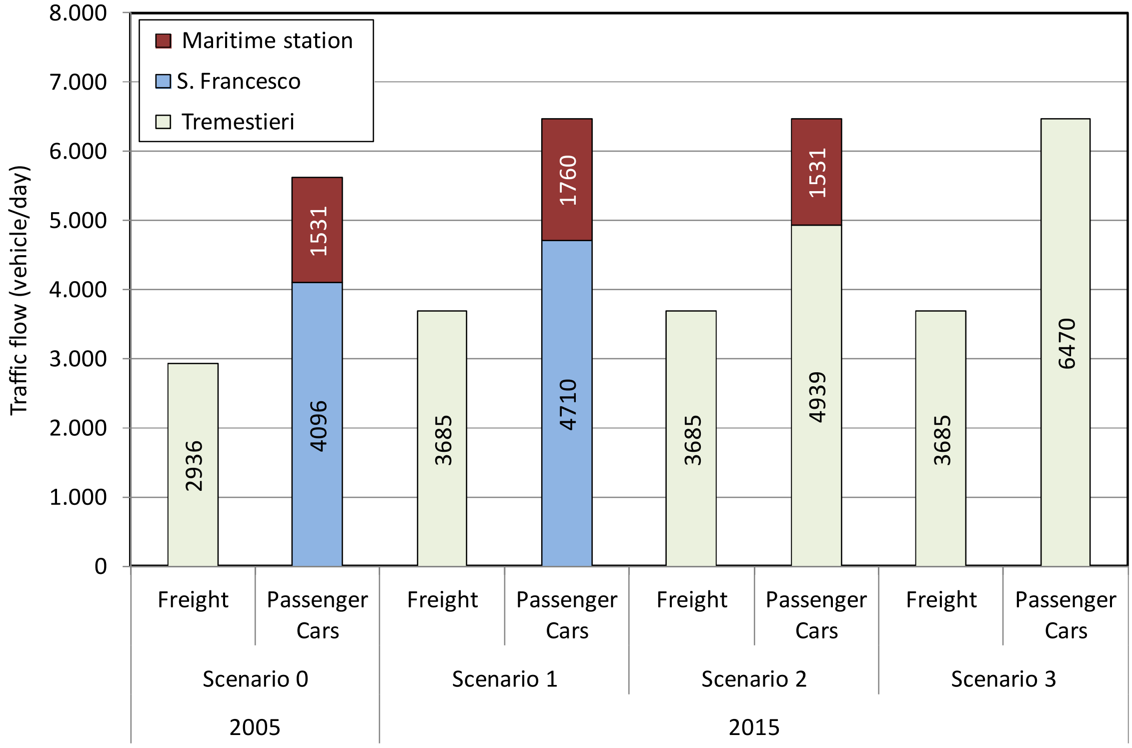

Fig. 11 Daily traffic flows in the different scenarios

3.4 Result and discussion

Fig. 12, that reports the results of the analysis in terms of pollutant emissions corresponding to the four considered scenarios, gives an account of the outcomes regarding the three docking sites (S. Francesco, Maritime Station and Tremestieri); instead, Fig. 13 reports the result referred to the entire urban area.

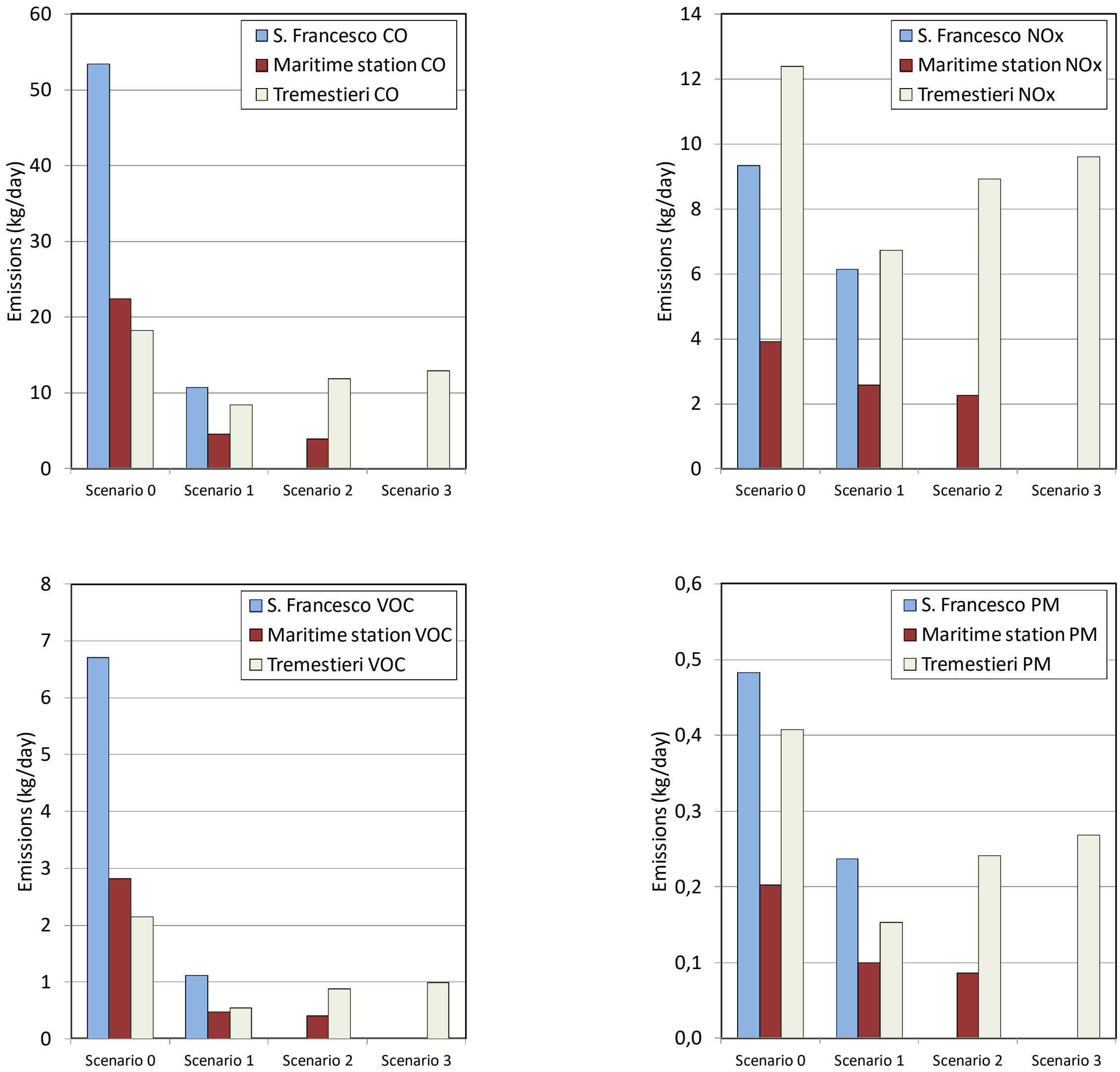

Fig. 12 Daily pollutant emissions in the docking sites of S. Francesco, Tremestieri and Maritime Station

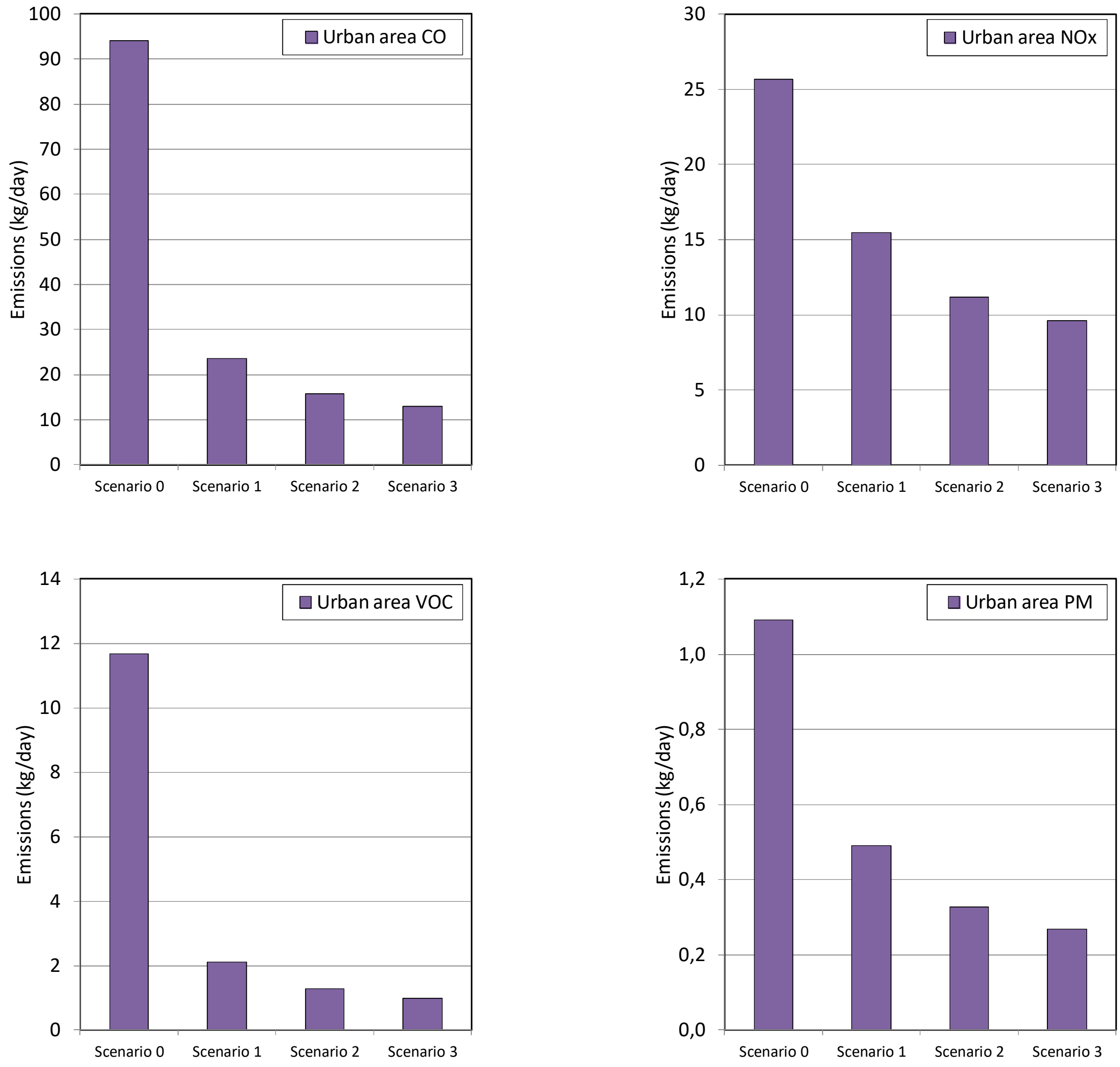

Fig. 13 Daily pollutant emissions in the entire urban area

As a first result, it must be stressed that even the mere evolution of the fleet (Scenario 1), involving an improvement of the emissive classes of vehicles with time, causes a remarkable drop of the pollution loads in each of three docking sites and in the urban area too. This reduction comes off notwithstanding the traffic flow growth that takes place from 2005 to 2015 and that, therefore, is highly compensated by the enhanced emissive quality of the running fleet.

As a matter of fact, comparing results for Scenario 1, which only takes into account the evolution of both vehicle flows and fleet class distribution, with the reference Scenario 0, it can be noted a decrease of the vehicle emissions that, in the urban area, ranges from 35% to 82% depending on the specific pollutant.

The closure of the dock of S. Francesco (Scenario 2) and the corresponding displacement of traffic loads enhance the emissions affecting Tremestieri area in Scenario 1 (Fig. 12) and so does the closure of Maritime Station (Scenario 3). More evidence of these circumstances can be found comparing data reported in Table 7.

Table 7 Daily pollutant emission in the Tremestieri area in the different scenarios

Scenario	Emissions in the Tremestieri area (kg/day)			
	CO	NOx	VOC	PM
Scenario 0	18.24	12.39	2.15	0.41
Scenario 1	8.39	6.72	0.54	0.15
Scenario 2	11.84	8.92	0.88	0.24
Scenario 3	12.91	9.60	0.98	0.27

Nevertheless, the whole urban area seems to receive further relief by the global rerouting of the ferry activity to Tremestieri; in fact pollutant emissions affecting the urban area in Scenario 3 are noticeably lower than in Scenario 1 and Scenario 2 (Fig. 13 and Table 8).

Table 8 Daily pollutant emission in the urban area in the different scenarios

Scenario	Emissions in the urban area (kg/day)			
	CO	NOx	VOC	PM
Scenario 0	94.10	25.66	11.69	1.09
Scenario 1	23.64	15.46	2.12	0.49
Scenario 2	15.76	11.17	1.28	0.33
Scenario 3	12.91	9.60	0.98	0.27

This is due to the modification of vehicle paths which, in fact, implies a reduction of the trip length and an enhancement of the average speed.

4 CONCLUSIONS

Nowadays land planning of urban areas and urban mobility optimization have been commonly acknowledged to be effective measures in order to reduce greenhouse gas emissions and improve air quality, even on a local scale.

Therefore, local administration are, more than often, called into action in developing planning policies addressing mobility problems and transport system organizations with the aim of lowering environmental impacts and pursuing sustainability. But to reach this goal they need suitable tools in order to assess the real effectiveness of the alternative measures they could adopt.

Through this study a simple model devoted to the evaluation of pollutants released in urban contexts by the transportation sector has been presented and a new indicator of the average emissions of the transportation system, the Yearly Average Vehicle, YAV, has been singled out. It is to be evaluated for every pollutant and has an annual time domain, but represents the emission characteristics of the fleet running in a specific context, so that comparison among its values, calculated for different years, makes the appraisal of the quality evolution of the vehicle fleet with time more practical.

The YAV, indeed, allows easy different scenario assessments, taking into account different items that could affect results, such as improvements of emissive characteristics of vehicles, changes of the transportation demand and traffic flow path length variation.

If the scenarios are referred to the same year, without variation of the vehicular fleet distribution, it is possible to quickly evaluate several different policies implying variation of traffic flow parameters.

Therefore this indicator could represent a very useful aid for local administrations with the aim of both selecting optimal alternatives that satisfy the transportation demand in towns and addressing urban policies to pursue sustainability and less environmental impacts.

The indicator has been tested by using an application regarding the Southern Italy Town of Messina, located on the Sicilian cost nearby the Italian peninsula, that is affected by heavy pollution loads generated by road traffic which is fed by both local human activities and vehicle flows coming from the continent and directed towards other Sicilian centres.

In order to assess the effectiveness of a measure adopted by the public administration of the city, this study reports the results of an analysis aimed at evaluating the variation in the emission rates of those major pollutants discharged by the traffic activity.

The proposed indicator has proved to be a reliable tool in order to reach this goal and has allowed easy assessment of four different pollutant emissions scenarios of the urban traffic system.

NOMENCLATURE

E	pollutant emission (g)
EF	pollutant emission factor (g km^{-1} $vehic^{-1}$)
N	number running vehicles (vehic)
L	mean length of the travel (km)
v	vehicle velocity (km/h)
p	vehicle statistical distribution (%)
YAV	Yearly Average Vehicle (g km^{-1} $vehic^{-1}$)
a, b, c, d, e	constants

Subscripts

i	pollutant
j	vehicle type
h	fuel
k	engine volume or vehicle weight
l	vehicle age
y	reference year
T	period of time

Apex

c	category of transportation

REFERENCES

1. IPCC (2007). Climate Change 2007: Synthesis Report. Geneva, Switzerland: Intergovernmental Panel on Climate Change.

2. EEA (2009). Transport at a crossroads. TERM 2008: indicators tracking transport and environment in the European Union. *Technical report 3/2009*. Copenhagen, Denmark: European Environmental Agency.

3. Metz, N. Contribution of Passenger Cars and Trucks to CO_2, CH_4, N_2O, CFC and HFC Emissions. In *2001 Environmental Sustainability Conference & Exhibition, Graz, November 2001 2001*

4. Nejadkoorki, F., Nicholson, K., Lake, I., & Davies, T. (2008). An approach for modelling CO_2 emissions from road traffic in urban areas. *Science of the Total Environment, 406*(1-2), 269-278.

5. Delfino, R. J., Chang, J., Wu, J., Ren, C., Tjoa, T., Nickerson, B., et al. (2009). Repeated hospital encounters for asthma in children and exposure to traffic-related air pollution near the home. *Annals of Allergy, Asthma & Immunology, 102*(2), 138-144.

6. Kousoulidou, M., Ntziachristos, L., Mellios, G., & Samaras, Z. (2008). Road-transport emission projections to 2020 in European urban environments. *Atmospheric Environment, 42*(32), 7465-7475.

7. Castell, N., Mantilla, E., Stein, A. F., Salvador, R., & Millàn, M. (2011). Simulation and Evaluation of Control Strategies for Ozone Reduction in a Complex Terrain in Southwestern Spain. *Environmental Modeling & Assessment, 16*(6), 565-576.

8. Gorhan, R. (2002). Air pollution from ground transportation. An assessment of causes, strategies and tactics, and proposed actions for the internal community. Division for Sustainable Development Department of Economic and Social Affairs, United Nations.

9. EPA (2010). Ireland's Greenhouse Gas Emissions in 2009. Wexford, Ireland: Environmental Protection Agency.

10. Lumbreras, J., Valdés, M., Borge, R., & Rodrìguez, M. E. (2008). Assessment of vehicle emissions projections in Madrid (Spain) from 2004 to 2012 considering several control strategies. *Transportation Research Part A, 42*(4), 646-658.

11. EEA (2010). Towards a resource-efficient transport system. TERM 2009: indicators tracking transport and environment in the European Union. *Technical report 2/2010*. Copenhagen, Denmark: European Environmental Agency.

12. Johansson, C., Burman, L., & Forsberg, B. (2009). The effects of congestions tax on air quality and health. *Atmospheric Environment, 43*(31), 4843-4854.

13. Galatioto, F., Zito, P., & Migliore, M. (2009). Traffic Parameters Estimation to Predict Road Side Pollutant Concentrations using Neural Networks. *Environmental Modeling & Assessment, 14*(3), 365-374.

14. De Borger, B., Ochelen, S., Proost, S., & Swysen, D. (1997). Alternative transport pricing and regulation policies: a welfare analysis for Belgium in 2005. *Transportation Research Part D: Transport and Environment, 2*(3), 177-198.

15. EC (2002). Fiscal measures to reduce CO_2 emissions from new passenger cars main report. *Report 4/2002*. Brussels, Belgium: European Commission's Directorate-General for Environment.

16. EC (2007). TREMOVE Final Report. Brussels, Belgium: European Commission's Directorate-General for Environment.

17. Jansen, H., & Denis, C. c. (1999). A welfare cost assessment of various policy measures to reduce pollutant emissions from passenger road vehicles. *Transportation Research Part D: Transport and Environment, 4*(6), 379-396.

18. Barbieri, D., Nucara, A., Pietrafesa, M., Rizzo, G. (1995). Energy and environmental issues as choosing elements for selecting options in the transportation sector aimed at reducing CO 2 emissions: An application to the Italian case. *Studies in Environmental Science, 65*(PART B), 1193-1196.

19. Fu, M., & Andrew Kelly, J. (2012). Carbon related taxation policies for road transport: Efficacy of ownership and usage taxes, and the role of public transport and motorist cost perception on policy outcomes. *Transport Policy, 22*, 57-69.

20. Giblin, S., & McNabola, A. (2009). Modelling the impacts of a carbon emission-differentiated vehicle tax system on CO_2 emissions intensity from new vehicle purchases in Ireland. *Energy Policy, 37*(4), 1404-1411.

21. Hayashi, Y., Kato, H., & Teodoro, R. V. R. (2001). A model system for the assessment of the effects of car and fuel green taxes on CO_2 emission. *Transportation Research Part D: Transport and Environment, 6*(2), 123-139.

22. Hensher, D. A. (2008). Climate change, enhanced greenhouse gas emissions and passenger transport - What can we do to make a difference? *Transportation Research Part D, 13*(2), 95-111.

23. Calthrop, E., & Proost, S. (2003). Environmental pricing in transport. In D. A. Henscher, Button, K.J. (Ed.), *Handbook of Transport and The Environment* (pp. 1827 - 2003): Elsevier.

24. Proost, S. (2011). Theory of external costs. In A. de Palma, Lindsey, R., Quinet, E., Vickerman, R. (Ed.), *A Handbook of Transport Economics*: Elgar.

25. Proost, S., & Van Dender, K. (2012). Energy and environment challenges in the transport sector. *Economics of Transportation, 1*(1-2), 77-87.

26. EEA (2009). EMEP/EEA air pollutant emission inventory guidebook 2009. *Technical report 9/2009*. Copenhagen, Denmark: European Environmental Agency.

27. de Jong, G., Gunn, H., & Ben-Akiva, M. (2004). A meta-model for passenger and freight transport in Europe. *Transport Policy, 11*(4), 329-344.

28. EPA (2012). Motor Vehicle Emission Simulator (MOVES). United State Environmental Protection Agency.

29. EPA (2003). MOBILE 6 Vehicle Emission Modeling Software. United State Environmental Protection Agency.

30. André, M. (2004). The ARTEMIS European driving cycles for measuring car pollutant emissions. *Science of the Total Environment, 334-335*, 73-84.

31. Smit, R., Smokers, R., & Rabé, E. (2007). A new modelling approach for road traffic emissions: VERSIT+. *Transportation Research Part D, 12*(6), 414-422.

32. Gkatzoflias, D., Kouridis, C., Ntziachristos, L., & Samaras, Z. (2012). COPERT 4 Computer programme to calculate emissions from road transport. Copenhagen, Denmark: European Environmental Agency, European Topic Centre on Air and Climate Change (ETC-ACC).

33. IPCC (2006). 2006 IPCC Guidelines for National Greenhouse Gas Inventories. Hayama, Japan: Intergovernmental Panel on Climate Change, Institute for Global Environmental Strategies (IGES).

34. Int Panis, L., Beckx, C., Broekx, S., De Vlieger, I., Schrooten, L., Degraeuwe, B., et al. (2011). PM, NO_X and CO_2 emission reductions from speed management policies in Europe. *Transport Policy, 18*(1), 32-37.

35. Soylu, S. (2007). Estimation of Turkish road transport emissions. *Energy Policy, 35*(8), 4088-4094.

36. Palmgren, F., Hansen, A. B., Berkowicz, R., & Skov, H. (2001). Benzene emission from the actual car fleet in relation to petrol composition in Denmark. *Atmospheric Environment, 35*(1), 35-42.

37. Kousoulidou, M., Fontaras, G., Ntziachristos, L., Bonnel, P., Samaras, Z., & Dilara, P. (2013). Use of portable emissions measurement system (PEMS) for the development and validation of passenger car emission factors. *Atmospheric Environment, 64*, 329-338.

38. Cannistraro, G., Giaconia, C., Pietrafesa, M., & Rizzo, G. (1995). Reduced weather data for building climatization and application to 29 European locations. *Energy, 20*(7), 637-646.

39. MIT (2005). Conto Nazionale dei Trasporti e delle Infrastrutture, Anno 2005. Roma, Italy (in italian): Ministero delle Infrastrutture e dei Trasporti, Istituto Poligrafico e Zecca dello Stato.

40. APM (2007). Piano Regolatore Portuale. Messina, Italy (in italian): Autorità Portuale di Messina.

41. MM (2006). Piano Urbano della Mobilità. Messina, Italy (in italian): Messina Municipality.

42. MIT (2000-2010). Conto Nazionale dei Trasporti e delle Infrastrutture, Anni 2000-2010. Roma, Italy (in italian): Ministero delle Infrastrutture e dei Trasporti, Istituto Poligrafico e Zecca dello Stato.