# The ECODRIVE Project: controlling and managing traffic for reducing noise from private road transport

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In order to meet the current pressure from the European Commission on the Member States, in last decades, innovative solutions have been proposed to improve the sustainability of human activities on the territory. In this context, the ECODRIVE Project aims at reducing atmospheric pollution and noise generated by private road transport through the implementation of specific traffic management and control policies, which can encourage users towards more sustainable driving behaviours. In order to demonstrate the effectiveness of these policies, and with the aim of focusing the analysis on the acoustic part of the project, the effects of some policies based on the application of increasingly restrictive speed limits were illustrated. The results showed how careful traffic management can guarantee environmental benefits. In the future, however, it will also be necessary to take into account the side effects of the application of these policies, such as the increase in travel times, which is one of the main disadvantages for road users.
**Keywords:** sustainability, noise pollution, noise emissions

**Il progetto ECODRIVE: controllo e gestione del traffico per ridurre il rumore del trasporto privato su strada**

Per far fronte alle attuali pressioni della Commissione Europea sugli stati membri, negli ultimi decenni sono state proposte soluzioni innovative per migliorare la sostenibilità delle attività umane sul territorio. Il progetto ECODRIVE si inserisce in questo contesto, con l'obiettivo di ridurre le emissioni inquinanti in atmosfera e il rumore generato dal trasporto privato su strada, mediante l'implementazione di apposite politiche di gestione e controllo del traffico che possano spingere gli utenti verso comportamenti di guida più sostenibili. Al fine di mostrare l'efficacia di tali politiche e con l'obiettivo di focalizzare l'analisi sulla parte acustica del progetto, sono stati illustrati gli effetti di alcune politiche basate sull'applicazione di limiti di velocità sempre più restrittivi. I risultati hanno mostrato come la gestione del traffico in modo oculato possa garantire benefici ambientali. In futuro, però, sarà necessario tenere conto anche degli effetti collaterali dell'applicazione di tali politiche, come, ad esempio, l'incremento dei tempi di viaggio, che rappresenta uno dei principali svantaggi per gli utenti della strada.
**Parole chiave:** sostenibilità, inquinamento acustico, emissioni acustiche

## 1 | Introduction

The rapid development of society occurred in recent times has affected all human activities, leading to the economic growth, the increase in the welfare of population, as well as an overall increase in population. In the transportation field this resulted in an increasing demand for mobility among people, who began to prefer car as the mean of transport that best suits their needs. Automotive industries, planners and Public Administrations tried to deal with these changing requirements of population, with continuous advancements in cars' technology, the expansion of road infrastructures, and the development of communication and monitoring systems to improve road circulation. This widespread usage of cars, however, has negative consequences on congestion, road safety, and, more importantly, on the environmental impact of the private road transport. The latter is central to an ongoing debate regarding the measures to be taken to achieve the objectives of the European Green Deal [1], that is pressing Member States to take specific actions to reach the "Zero Emission Target". The transport sector is primarily involved in achieving this goal, as it is one of the major contributors to pollutant emissions in atmosphere, especially GHG, coming from burning fossil fuels, and to noise production. Noise is known as the "unseen pollutant" [2] and its long-term effects can be very harmful to human health, environment, and ecosystems. In fact, according to what is reported in the last quinquennial Report on the Implementation of the Noise Directive [3], it is the second most important environmental disease factor in the EU, after air pollution, and proper actions must be taken to reduce by 30% (compared with 2017) the number of people chronically exposed to traffic noise by 2030, as mandated by the European Greed Deal. However, the predictions of the European Environmental



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Agency (EEA) are not so optimistic [4]. According to these estimates, in 2017 about 18 million people in Europe were suffering from long-term exposure to road, rail and aircraft noise and this datum has remained relatively constant until today. The same report [4] argues that the 30% reduction of people exposed is unlikely to be achieved within the time limit set by the European Commission, unless significative resources will be spent on more efficient transport planning, better management of transport systems, and significative reductions in road traffic. In this context, the ECODRIVE project takes place, aiming at reducing both pollutant emissions and noise due to private road transport by managing and controlling traffic flows, with proper policies. These actions, involving the main traffic variables, e.g. speed limits or road's capacity, force users to take less aggressive and more sustainable driving behaviours. The project will be the topic of this paper, which will be divided as follows: in the next section (Section 2), the theoretical framework and the literature review will be reported, while in Section 3 the main aspects of the project will be presented. In Section 4, the main results from the speed-based tests conducted on a real network will be exhibited and discussed. The last paragraph (Section 5) will be devoted to the conclusions and the potential future developments of the project.

## 2 | Literature review

Noise pollution is the introduction into the environment of any unwanted, unintentional, and disturbing sound producing disturbance or annoyance in humans, daily activities, and ecosystems [2]. The main noise sources, due to human activities on the territory can be identified in: domestic activities, social events, commercial, industrial and craft activities, and transportation [5]. The latter is one of the major causes of noise pollution, especially in urban areas, and it can be attributable to three different noise sources: road, rail, and aircraft noise. Although railway noise and aircraft noise, especially during the taking-off and landing phases, reach significative values, they are discontinuous and only cause nuisance in the areas neighbouring stations and airports, while road traffic noise is present throughout the entire territory and affects urban, suburban, and residential areas.

For the assessment of road traffic noise, different models were developed over the years [6], [7], [8]. These models have become more accurate over time, as detection techniques have been refined, but they all consider the same fundamental variables, albeit related in different ways:

- $Q$: traffic volumes [veh/h], as it is known that noise levels increase for larger numbers of vehicles [9];
- $v_m$: traffic mean speed [km/h], as data indicates a linear relationship between noise and speed [10]. Speed is known for being the variable that has the greatest impact on noise;
- $d$: distance from the source [m], since the noise reduces as the distance between the source and the receiver increases, due to the propagation phenomenon [11].

In addition to the variables used in calculation, there are several other factors that influence the noise emitted by vehicles. These factors can be classified as follows [9]:

- *Traffic factors* that, in addition to traffic volumes and mean speeds, also include vehicle composition, the percentage of heavy vehicles within the fleet, and the presence of congestion or bottlenecks;
- *Road factors* which concern the characteristics of the infrastructure, such as pavements, grade, geometry, presence of intersections, and installation of noise barriers;
- *Vehicle factors*, that mainly relate to vehicle features, e.g. type of engine, type of fuel, age and state of maintenance of the vehicle;
- *Human factors* which include behaviour, habits, and experience of drivers.

In the last years, the European Union tried to provide a unique methodology for the assessment of noise emissions form transportation, to standardize the calculation procedures of all Member States. This has led to the entry into force of the Commission Directive (EU) 2015/996 of 19 May 2015 [12], which describes CNOSSOS-EU model [13], for the assessment of noise from transportation systems. The model allows to estimate traffic noise as a combination of propulsion noise (Eq. 1), that generates from the engine of the vehicle, and the roll-ing noise (Eq. 2), that is caused by the movement of tyres on the road surface.

$$L_{WP\,f,m} = A_{P\,f,m} + B_{P\,f,m} \cdot \left(\frac{v_m - v_{ref}}{v_{ref}}\right) + \Delta L_{WP\,f,m}(v_m) \qquad (1)$$

$$L_{WR\,f,m} = A_{R\,f,m} + B_{R\,f,m} \cdot log\left(\frac{v_m}{v_{ref}}\right) + \Delta L_{WR\,f,m}(v_m) \qquad (2)$$

Where:

- $L_{WPf,m}$ is the propulsion noise sound power level, in the frequency $f$, for a vehicle of class $m$ [dB];
- $L_{WRf,m}$ is the rolling noise sound power level, in the frequency $f$, for a vehicle of class $m$ [dB];
- $v_m$ is the traffic mean speed [km/h];
- $v_{ref}$ is the reference speed, equal to 70 km/h;
- $A_{pf,m}$, $B_{Pf,m}$, $A_{Rf,m}$, and $B_{Rf,m}$ are coefficients differentiated for each octave band and for each vehicle class $m$, for a reference speed $v_{ref}$ [12];
- $\Delta L_{pf,m}$, $\Delta BL_{Rf,m}$ are the sums of corrective factors, that consider conditions which differ from those of the base calculation [12].

The Environmental Noise Directive 2002/49/EC [14] has laid down several rules to be followed by all EU Member States in designing and implementing targeted actions for noise reduction. These actions are known as “noise mitigation measures” and they are usually classified into three categories: at the source, on the propagation path, and on the receivers [15]. At-source measures are the most efficient noise mitigation strategies [16] and they are thought to act on the different components of road traffic noise. In fact, incentivizing the pur-



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chase of electric vehicles, or encouraging users towards more moderate driving behaviours can allow to reduce the propulsion noise, while abatements in rolling noise can be achieved through interventions on tyres and road surfaces, as well as through variations in road speed limits. Targeted measures on mobility, such as reductions of traffic volumes, restrictions on speed limits and vehicle compositions, as well as incentives for sharing mobility, and adoption of toll schemes, can also help to reach good results in terms of noise pollution reduction. When at-source measures are not sufficient and interventions on propagation paths are needed, the installation of noise barriers is recommended, being the most effective actions, even if the performance of each barrier depends on the characteristics of the site where it is placed [15]. When interventions at the source or along the propagation paths are insufficient, too complicated, or too expensive, interventions on the receivers are taken into account. These actions consist in modifications and improvements on buildings and façades, to reduce the negative effects of the noise.

The ECODRIVE Project, which is the subject of this paper, involves the application and test of some traffic management and control policies, to encourage users to adopt more sustainable driving behaviours, thereby reducing emissions from road transport. For this reason, these policies can be classified as at-source measures, where the sources of noise are the individual vehicles moving in the network.

## 3 | The ECODRIVE Project

In compliance with European regulations, noise levels in areas adjacent to road infrastructure must be kept below certain thresholds. Therefore, if the noise caused by vehicle traffic exceeds the legal limits, targeted actions must be taken to reduce it. The ECODRIVE Project is aimed at designing and applying several policies for managing and controlling traffic, to reduce the overall emissions from road traffic. These policies, acting on the main traffic flow variables, such as mean speeds, vehicles composition, road capacity, etc… aim at influencing road users' behaviours towards milder and more sustainable driving styles. For these reasons, the measures tested under the ECODRIVE Project can be considered as "at-source" measures. However, the road noise reduction is not the only goal of the project, but it is also meant to reduce pollutant emissions from vehicle exhaust pipe. The Project follows a simulation approach and consists of three phases, with the first two already concluded and the final phase still ongoing. The first part of the project was fully devoted to the building of a theoretical framework, which includes all the fundamental models to be integrated within the simulation tool. The second phase focused on the building and calibration of the test network. Preliminary tests were also run in this phase. The last phase involves laboratory tests to determine the traffic configurations that best minimize the environmental impact of road traffic.

### 3.1 | Methodology

The ECODRIVE project follows a simulation approach. The methodology employed in the project is reported in Fig. 1.

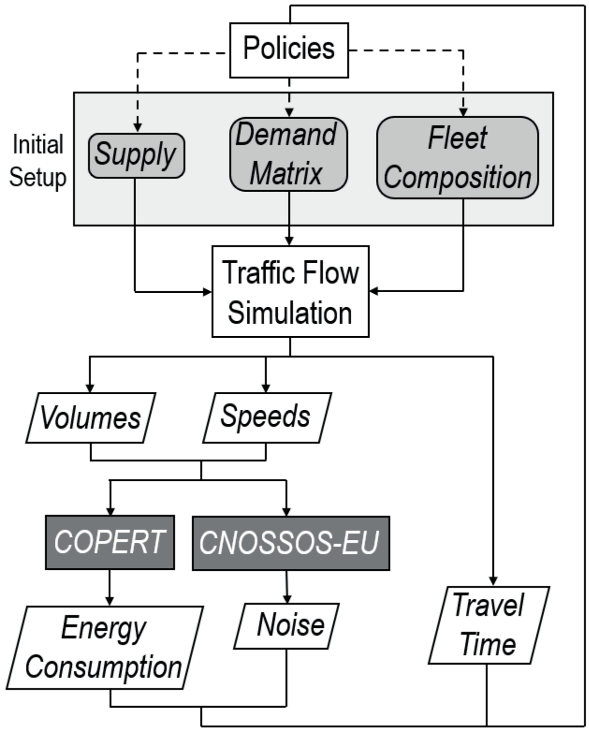


**Fig. 1 – Methodology of the project**
***Metodologia del progetto***

The starting configuration comprises a supply system, a demand matrix, and the characteristics of vehicle fleet. The supply system includes not only the road network with its geometrical characteristics, and centroids, but also speed limits, priority rules and potential restrictions on the circulation of different vehicle classes (which may involve closing one or more lanes to specific vehicle types). The demand matrix represents all the movements between origins and destinations throughout the network, for a specific time interval. The fleet composition mainly refers to the share of heavy vehicles and the distribution of car emission classes according to EURO standards. These three components of the initial setup are the input for the traffic flow simulation. In the specific case of the project, the IT tools chosen for running the simulation was PTV Vissim™ [17], which, for its microscopic nature that, although generates complexities in the model, allows to differentiate actions per lanes, per segments, per vehicle classes, etc., seemed to be the software that best suited the objectives of the project. At the end of the simulation process, several outputs are obtained; among them, traffic volumes and traffic mean speeds are the two key variables for feeding the emission models. As mentioned before, the ECODRIVE project is aimed at the reduction of the overall emissions from road traffic. For this reason, two different emission models are involved: COPERT methodology [18, 19] is used for esti-



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mating the energy consumption of the traffic stream, while CNOSSOS-EU model is applied for noise assessment. Energy consumption is assessed as a proxy variable for pollutant emissions. This choice is based on the fact that cars with different technologies, developed many years apart, are compared. Moreover, if it is necessary to evaluate scenarios that are far apart in time, the automotive industry can advance its technological development. Using energy consumption instead of emissions, allows for the comparison of emission values from different vehicle classes equipped with more or less advanced technologies. This decision based on the strict correlation between energy consumption and certain pollutants, such as $CO_2$, which follow a similar trend except for a constant factor (the emission factor EF) [20]. Both energy consumption and noise contribute to determine the environmental impact of the system. Another simulation output is Travel Time, that is important for the estimation of the performances of the network, as each policy applied should be meant to reduce air and noise pollution, without worsening the level of service of the road. Once energy consumption, noise, and travel time have been estimated, traffic management and control policies are applied. These measures can indifferently act on any of the three components of the initial setup, modifying one or more elements. The policy's choice can be autonomously made from the modeller or influenced by the simulation results. The representation of policies being freely applicable in any system component and having the ability to act differently is shown in Fig. 1 by dotted lines. Once the policy has been applied, the procedure is repeated, until an acceptable reduction of emissions is achieved.

## 3.2 | Test network

The road segment chosen for the tests is the South-Eastern Quadrant of the Freeway A90 in Rome, commonly known among Italian inhabitants as GRA (Grande Raccordo Anulare), a ring-shaped freeway that surrounds the Italian Capital. Freeway A90 is the main collector of movements of the city of Rome and its South-Eastern part, being the main connection between the most important generation and attraction poles of the city of Rome, turns out to be the busiest part of the road, with traffic volumes that can reach 5000 veh/h during morning rush hour [21]. Probably due to the high volumes of traffic or to the road's geometry, with a junction every 2 km, the GRA is often affected by congestion and road accidents, which are troublesome for viability, social and economic costs, and environmental impact. Limiting the analysis to a single quadrant, which is the most problematic, allows to localize the interventions and their effects. The GRA and the section chosen for the tests are reported in Fig. 2. The network under exam is made up of two main trunks, one in ascendant direction, which coincides with the internal carriageway, and the other in the opposite direction, which is the external carriageway, with the main exits and entries in the right part. Both the directions are characterized by three lanes, and, in some stretches, a shoulder lane is also present, that is used in case of forced stops of users, vehicles breakdowns, or for passing the rescue and emergency vehicles.


**Fig. 2 – Freeway A90. In red is highlighted the South-Eastern Quadrant chosen for the tests, with its main junctions**

***L'autostrada A90. In rosso è evidenziato il Quadrante sud-est scelto per i test, con i suoi principali svincoli***

## 3.3 | The noise reduction acceptability criteria

As reported in 3.1 | the procedure is repeated, testing new policies, until an acceptable reduction of noise is achieved. For the road segment in exam, described in 3.2 |a single section was chosen and the corresponding values of volumes, recorded by ANAS detectors [21], were considered. Keeping the volume values constant, traffic mean speed was variated, from 5 km/h to 130 km/h and the noise was assessed with the CNOSSOS-EU model. It is important to notice that the Freeway A90 in Rome is paved with draining asphalt, which is expected to reduce noise by 3 dB compared to normal asphalt. The corrective factors for the draining asphalt [12] were used for assessing rolling noise (Eq. 2). The assessed values of noise are reported in Tab. 1.

In Tab. 1, noise levels for speeds below 20 km/h have been assessed and reported only for computational completeness, but they will not be considered in the subsequent evaluations and comparisons. In fact, as reported in the Commission Directive (EU) 2015/996 [12], for speed values lower than 20 km/h, the sound power level is the same defined by the formula applied for 20 km/h. Actually, the rising values of noise levels recorded for the lowest speeds, should not be considered as a trend reversal, but as a consequence of the fact that the model does not typically applies for speeds lower than 20 km/h. As the values of Tab. 1 are assessed in standard conditions, for real traffic volumes, with no traffic disruptions of limitations, with varying speed, any noise reduction achieved through speed limit reduction that is similar, equal or greater than the values reported in Tab. 1, is considered acceptable.



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**Tab. 1 – Values of noise with varying speed, for constant traffic volumes, for each vehicle class**

***Valori del rumore al variare della velocità, per volumi di traffico costanti, per ciascuna classe veicolare***

| *Speed [km/h]* | *Cars Noise [dB]* | *Heavy Vehicles Noise [dB]* | *Motorbikes Noise [dB]* | *Total Noise [dB]* |
|---|---|---|---|---|
| *130* | 88.8 | 89.6 | 67.4 | 92.2 |
| *125* | 88.6 | 89.3 | 66.8 | 92.0 |
| *120* | 88.3 | 89.0 | 66.2 | 91.7 |
| *115* | 88.0 | 88.8 | 65.6 | 91.4 |
| *110* | 87.7 | 88.5 | 65.0 | 91.2 |
| *105* | 87.5 | 88.3 | 64.5 | 90.9 |
| *100* | 87.2 | 88.0 | 63.9 | 90.6 |
| *95* | 86.9 | 87.7 | 63.4 | 90.4 |
| *90* | 86.6 | 87.5 | 62.9 | 90.1 |
| *85* | 86.2 | 87.3 | 62.4 | 89.8 |
| *80* | 85.9 | 87.0 | 62.0 | 89.5 |
| *75* | 85.6 | 86.8 | 61.5 | 89.2 |
| *70* | 85.2 | 86.6 | 61.1 | 89.0 |
| *65* | 84.9 | 86.4 | 60.8 | 88.7 |
| *60* | 84.5 | 86.2 | 60.4 | 88.4 |
| *55* | 84.1 | 86.0 | 60.1 | 88.2 |
| *50* | 83.7 | 85.9 | 59.9 | 87.9 |
| *45* | 83.3 | 85.8 | 59.7 | 87.7 |
| *40* | 82.8 | 85.7 | 59.6 | 87.5 |
| *35* | 82.4 | 85.8 | 59.5 | 87.4 |
| *30* | 81.9 | 85.9 | 59.6 | 87.4 |
| *25* | 81.6 | 86.1 | 59.7 | 87.4 |
| *20* | 81.3 | 86.5 | 60.1 | 87.7 |
| *15* | 81.2 | 87.3 | 60.8 | 88.2 |
| *10* | 81.6 | 88.5 | 61.9 | 89.3 |
| *5* | 83.4 | 91.1 | 64.4 | 91.8 |

## 4 | Speed tests

Being a Freeway, according to Italian Traffic Laws [22], the speed limit in GRA is equal to 130 km/h for cars and motorbikes, and 80 km/h for heavy vehicles, which are also prohibited from passing on the third lane, located on the left of the carriageway. Several laboratory tests were conducted, based on the progressive reduction of speed limits. The choice of applying speed-based policies is since, as aforesaid in paragraph 2, speed is the variable that most influences noise emissions, but, as the ECO-DRIVE Project is aimed at reducing the overall emissions from private road transport, it has a considerable influence also on vehicles energy consumption. Three different sets of tests were carried out. In the first set, speed limits were gradually reduced for all the vehicles in the network, as reported in Tab. 2. As the simulation tool does not automatically adjust the speed limit of vehicles if it is lower than the imposed one, heavy vehicles, which travel at 80 km/h, are affected by the speed reduction only when the limit is posed equal to 70 km/h.

**Tab. 2 – First set of speed-based policies: same reduced speed limit for all vehicle classes**

***Primo set di politiche: stesso limite di velocità ridotto per tutte le classi veicolari***

| *Policy ID* | *Cars Speed Limit [km/h]* | *Heavy Vehicles Speed Limit [km/h]* | *Motorbikes Speed Limit [km/h]* |
|---|---|---|---|
| P01 | 130 | 80 | 130 |
| P02 | 120 | 80 | 120 |
| P03 | 110 | 80 | 110 |
| P04 | 100 | 80 | 100 |
| P05 | 90 | 80 | 90 |
| P06 | 80 | 80 | 80 |
| P07 | 70 | 70 | 70 |

Tab. 3 summarizes the second set of tests, where the limits' differentiation is based on the vehicle class, while Tab. 4 reports a synthesis of the last set of policies, where speed restrictions were imposed on a per-lane basis. As regards Tab. 3, five different vehicle classes were defined:

**Tab. 3 – Second set of speed-based policies: reduced speed limit differentiated for all vehicle classes**

***Secondo set di politiche: limite di velocità ridotto differenziato per le varie classi veicolari***

| *Policy ID* | *LE Cars Speed Limit [km/h]* | *ME Cars Speed Limit [km/h]* | *HE Cars Speed Limit [km/h]* | *Heavy Vehicles Speed Limit [km/h]* | *Motorbikes Speed Limit [km/h]* |
|---|---|---|---|---|---|
| P08 | 130 | 130 | 120 | 80 | 130 |
| P09 | 130 | 120 | 120 | 80 | 120 |
| P10 | 120 | 120 | 110 | 80 | 120 |
| P11 | 120 | 110 | 110 | 80 | 120 |
| P12 | 110 | 110 | 100 | 80 | 110 |
| P13 | 110 | 100 | 100 | 80 | 110 |
| P14 | 100 | 100 | 90 | 80 | 110 |
| P15 | 100 | 90 | 90 | 80 | 100 |
| P16 | 90 | 90 | 80 | 80 | 90 |
| P17 | 90 | 80 | 80 | 80 | 90 |
| P18 | 80 | 80 | 70 | 80 | 80 |
| P19 | 80 | 70 | 70 | 80 | 80 |

**Tab. 4 – Third set of policies: limit restrictions imposed on a per-lane basis**

***Terzo set di politiche: limiti di velocità differenziati per corsia***

| *Policy ID* | *Shoulder Lane Speed Limit [km/h]* | *Right Lane Speed Limit [km/h]* | *Central Lane Speed Limit [km/h]* | *Left Lane Speed Limit [km/h]* |
|---|---|---|---|---|
| P20 | 110 | 110 | 120 | 130 |
| P21 | 100 | 100 | 110 | 120 |
| P22 | 90 | 90 | 100 | 110 |
| P23 | 80 | 80 | 90 | 100 |
| P24 | 70 | 70 | 80 | 90 |



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High-Emitting cars (HE Cars) include EURO 0, EURO 1, EURO 2, and EURO 3 vehicles; Medium-Emitting cars (ME Cars) encompasses EURO 4 and EURO 5 vehicles, while Low-Emitting cars are composed by EURO 6 vehicles. Heavy Vehicles and Motorbikes are the other two vehicle classes considered during simulations.

The simulation period lasts 7800 seconds and the demand matrix covers morning rush hour, form 7 a.m. to 8 a.m. The current Roman composition is assigned: it has been obtained by ANAS databases, and it is made up as follows:

- 25.55% of Low-Emitting cars;
- 33.45% of Medium-Emitting cars;
- 19.94% of High-Emitting cars;
- 20.86% of heavy vehicles;
- 0.2% of motorbikes.

The simulation period has been divided into 9 shorter time intervals, each 900 seconds long. Moreover, the two main trunks of the road have been divided into seven smaller sections, with a total of fourteen segments, which coincide with the road stretches between two consecutive junctions. However, in the results presented in the next paragraph, to provide an overview of the outcomes, values will be averaged over time (over all the time intervals) and over space (over all the road segments), maintaining the only subdivision in ascending and descending direction. In is important to notice that the ECODRIVE Project aims at improving the overall environmental quality, without compromising the level of service of the infrastructure. This paper focuses solely on the project's noise-related environmental impact, while briefly mentioning other policies' effects on the network.

## 4.1 | Results

### *4.1.1 | Traffic Mean Speeds*

Despite of the speed limits imposed on the network; vehicles' speed depends on traffic conditions. In fact, in the two directions, not all the vehicles can reach the desired speed, which is equal to the imposed limit, as they are constrained by the speed of the preceding vehicle.

In Fig. 3, Traffic mean speeds obtained as an output of simulations are reported for the first set of policies (Tab. 2). Similarly, Fig. 4, and Fig. 5 exhibit the values of speed for the second (Tab. 3) and the third (Tab. 4) set of speed policies respectively.

| Mean Speeds [km/h] | | | | | | |
|---|---|---|---|---|---|---|
| ID Policy | Ascending Direction | | | Descending Direction | | |
| | Cars | Heavy Vehicles | Motorbikes | Cars | Heavy Vehicles | Motorbikes |
| P01 | 98.24 | 80.75 | 102.20 | 66.37 | 54.16 | 74.27 |
| P02 | 97.22 | 80.67 | 101.91 | 66.59 | 54.50 | 73.00 |
| P03 | 95.92 | 80.60 | 100.04 | 65.96 | 54.52 | 73.47 |
| P04 | 93.65 | 80.46 | 96.67 | 64.54 | 53.97 | 71.33 |
| P05 | 89.16 | 79.57 | 91.71 | 62.75 | 53.80 | 68.83 |
| P06 | 82.47 | 76.98 | 83.75 | 58.87 | 51.61 | 64.73 |
| P07 | 74.10 | 70.48 | 75.38 | 54.49 | 48.61 | 59.59 |

**Fig. 3 – Traffic mean speeds in ascending and descending direction for the first set of policies**

***Velocità medie di traffico in direzione ascendente e discendente per il primo set di politiche***

| Mean Speeds [km/h] | | | | | | |
|---|---|---|---|---|---|---|
| ID Policy | Ascending Direction | | | Descending Direction | | |
| | Cars | Heavy Vehicles | Motorbikes | Cars | Heavy Vehicles | Motorbikes |
| P08 | 97.69 | 80.51 | 102.49 | 65.90 | 53.92 | 73.92 |
| P09 | 97.89 | 80.68 | 102.68 | 65.75 | 53.76 | 74.28 |
| P10 | 96.86 | 80.60 | 101.16 | 66.09 | 54.34 | 73.91 |
| P11 | 96.61 | 80.63 | 102.12 | 65.82 | 54.09 | 73.48 |
| P12 | 95.14 | 80.59 | 99.91 | 65.47 | 54.45 | 72.76 |
| P13 | 94.43 | 80.55 | 98.93 | 64.96 | 53.95 | 73.13 |
| P14 | 91.99 | 80.30 | 95.98 | 64.26 | 54.36 | 71.66 |
| P15 | 90.53 | 80.20 | 94.84 | 63.70 | 54.49 | 70.75 |
| P16 | 86.67 | 79.57 | 91.09 | 61.17 | 53.10 | 68.19 |
| P17 | 84.43 | 78.90 | 89.22 | 59.85 | 52.63 | 67.93 |
| P18 | 79.37 | 75.53 | 82.84 | 56.99 | 50.81 | 64.11 |
| P19 | 76.67 | 74.32 | 81.61 | 56.08 | 50.65 | 62.84 |

**Fig. 4 – Traffic mean speeds in ascending and descending direction for the second set of policies**

***Velocità medie di traffico in direzione ascendente e discendente per il secondo set di politiche***

| Mean Speeds [km/h] | | | | | | |
|---|---|---|---|---|---|---|
| ID Policy | Ascending Direction | | | Descending Direction | | |
| | Cars | Heavy Vehicles | Motorbikes | Cars | Heavy Vehicles | Motorbikes |
| P20 | 97.13 | 80.68 | 101.74 | 66.19 | 54.43 | 73.49 |
| P21 | 95.59 | 80.62 | 100.22 | 65.83 | 54.54 | 73.35 |
| P22 | 92.51 | 80.01 | 96.19 | 64.16 | 53.80 | 71.61 |
| P23 | 87.46 | 77.99 | 90.51 | 61.94 | 52.65 | 68.89 |
| P24 | 79.97 | 72.89 | 83.10 | 58.88 | 50.85 | 65.43 |

**Fig. 5 – Traffic mean speeds in ascending and descending direction for the third set of policies**

***Velocità medie di traffico in direzione ascendente e discendente per il terzo set di politiche***

In each of the figure above, red cells represent higher speeds, while green cells are associated with lower speeds, that are supposed to generate less emissions.

In all the cases analyzed, there are fewer vehicles travelling in the ascending than the descending direction and, for this reason, this direction is characterized by higher speeds and a greater sensitivity to changing limits. On the contrary, speeds variations in the opposite direction are not so marked since the occurrence of congestion in some segments of the external carriageway. Traffic mean speeds show a decreasing trend for increasingly restrictive speed limits, although less marked in the descending direction. The only anomaly to this trend could be represented by the sixth column of Fig. 4, the one related to heavy vehicles in the descending direction. However, focusing on the numbers within the cells, it is possible to notice that the values are quite similar, and these small fluctuations can be attributable to the stochasticity of the simulation tool.

### *4.1.2 | Noise*

Noise was assessed following the CNOSSOS-EU procedure, as the European Directive mandates. In the following tables, noise values in both the carriageways are reported. As an example, two different representative sections belonging to the two directions of travel were considered. In the results shown below, motorbikes are omitted from the graphs, as



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they constitute a negligible percentage in the vehicle composition and are, therefore, irrelevant for the purposes of the analysis.

In Fig. 6, the ascending direction noise results are reported for the first set of policies.

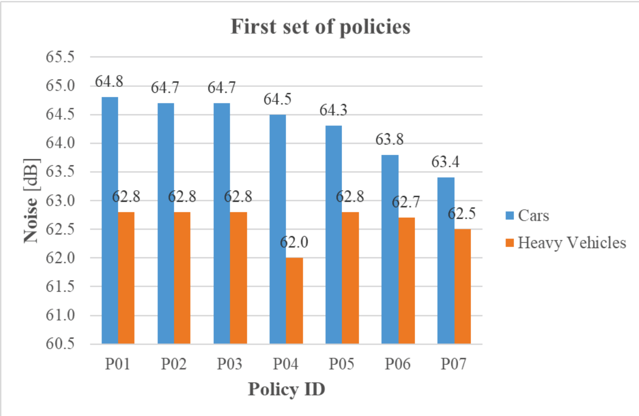


**Fig. 6 – Noise values obtained after the application of the first set of policies, in the ascending direction**

***Valori di rumore ottenuti nell'applicazione del primo set di politiche, in direzione ascendente***

As shown in Fig. 6, with increasingly restrictive speed limits, noise levels show a decreasing trend, especially for cars, which are sub-divided into three different classes and are mainly affected by policies' application. Concerning heavy vehicles, as they are forced to travel with a reduced speed equal to 80 km/h, due to legal limitations, they are affected by the reduction of speed only when it reaches 70 km/h. For this reason, their noise reduction is not so significative.

Similar trends for both cars and heavy vehicles noise emissions are recorded after the application of differentiated speed limits per vehicle class, as reported in Fig. 7, and for differentiation in speeds on a per-lane basis, as Fig. 8 exhibits.

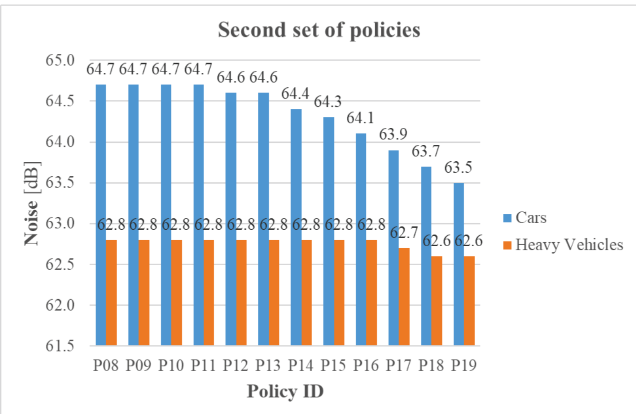


**Fig. 7 – Noise values obtained after the application of the second set of policies, in the ascending direction**

***Valori di rumore ottenuti nell'applicazione del secondo set di politiche, in direzione ascendente***

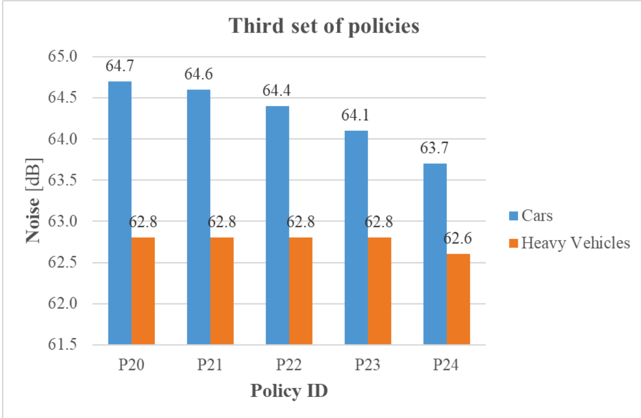


**Fig. 8 – Noise values obtained after the application of the third set of policies, in the ascending direction**

***Valori di rumore ottenuti nell'applicazione del terzo set di politiche, in direzione ascendente***

In the opposite direction, which is the most congested, the quasi-linear trend shown for the internal carriageway is not so marked, as Fig. 9, Fig. 10, and Fig. 11 show.

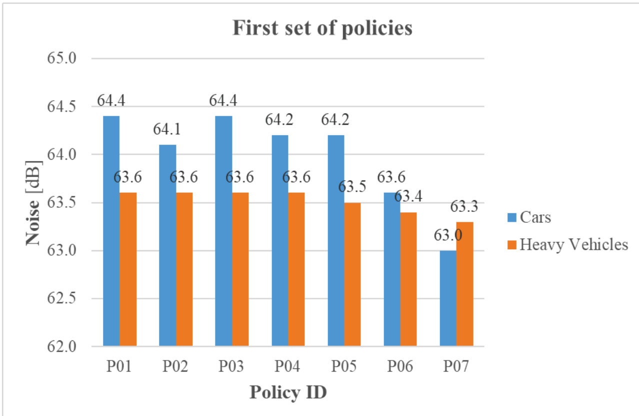


**Fig. 9 – Noise values obtained after the application of the first set of policies, in the descending direction**

***Valori di rumore ottenuti nell'applicazione del primo set di politiche, in direzione discendente***

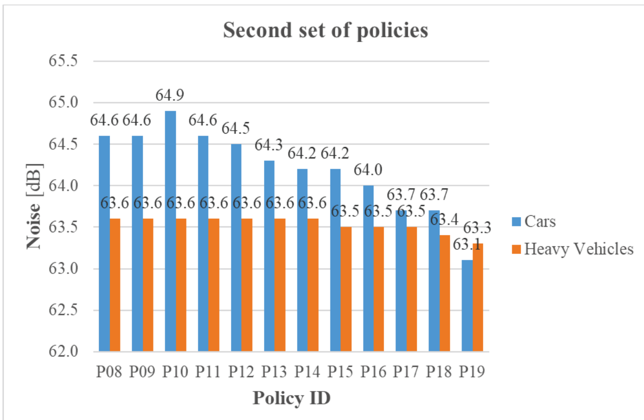


**Fig. 10 – Noise values obtained after the application of the second set of policies, in the descending direction**

***Valori di rumore ottenuti nell'applicazione del primo set di politiche, in direzione discendente***



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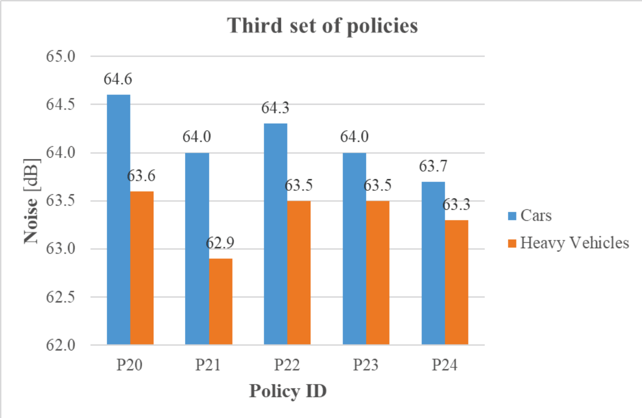


**Fig. 11 – Noise values obtained after the application of the third set of policies, in the descending direction.**
***Valori di rumore ottenuti nell'applicazione del primo set di politiche, in direzione discendente***

This anomalous behaviour can be explained with the higher traffic volumes which pass by the main trunk in this travel direction. Despite of the average speed recorded along the entire direction, at a local level, specific combinations of speed limits can induce a "traffic fluidification", especially in areas close to the congestion, which then reverberate in the adjacent sections. This phenomenon leads to higher speeds and higher traffic volumes. For these reasons, in some cases, such as the ones showed in Fig. 9, Fig. 10, and Fig. 11, noise raises again, after an initial decrease. Such traffic dynamics are beyond the scope of this paper. It is important to note that, regardless of the more or less pronounced speed variations, the noise trend generally decreases even in the descending direction, although the differences from one scenario to the next are not as marked as in the opposite direction. What emerges from a comparison between Fig. 6, Fig. 7, and Fig. 8 and Fig. 9, Fig. 10, and Fig. 11 is that, even though values of mean speeds in the external carriageway are significantly lower than the ones in the opposite direction, the values of noise are lower, but not much different. One explanation for this phenomenon lies in the number of vehicles crossing the two sections: the descending direction, which is more heavily loaded, has significantly more vehicles than the other direction.

To consider these values of reduction acceptable, a comparison with the values in Tab. 1 is necessary. As an example, for each set of policies, the last one was considered and compared with the P01 policy that, for its configuration, coincides with the current combination of speed limits and it can be considered the baseline scenario. The choice of the last policy of each set as an example is since the differences in speed compared to the current state are much more pronounced and the effectiveness of the management policies is more evident. In Tab. 5, a comparison between simulated values of noise and the values reported in Tab. 1 is reported. Since, as mentioned before, heavy vehicles are not affected by direct interventions, the comparison was made on cars, which show the main variations after policies' application. In the last two columns of Tab. 5 the difference between the value of cars noise in the specific scenario and the same value in the current scenario is shown for both simulated values and values reported in Tab. 1, according to the values of speed exhibited in Tab. 1, Fig. 3, Fig. 4, and Fig. 5.

**Tab. 5 – Comparison of noise reductions, with the values of Tab. 1**
***Confronto delle riduzioni di rumore ottenute, con i valori della Tab. 1***

| *Policies compared* | *Direction* | *Simulated Noise reduction [dB]* | *Noise reduction from Tab. 1 [dB]* |
|---|---|---|---|
| P01 → P07 | Ascending | −1.4 | −1.6 |
| | Descending | −1.4 | −0.8 |
| P01 → P19 | Ascending | −1.3 | −1.6 |
| | Descending | −1.3 | −0.8 |
| P01 → P24 | Ascending | −1.1 | −1.3 |
| | Descending | −0.7 | −0.4 |

As reported in Tab. 5, direct and homogeneous interventions on all vehicle classes, generates better environmental benefits in terms of noise. In fact, the first set of policies is the one that best meets the objectives of this paper. Indeed, in the other two sets of policies, only a small number of vehicles are subject to a reduced speed limit, effectively limiting the impact of a speed reduction extended to all vehicles. Surprisingly, the most encouraging results are those related to the descending direction, where noise reduction, although limited compared to the ascending one, results greater than the standard conditions.

### *4.1.3 | Other effects and limitations of the study*

As this paper focuses on the acoustic part of the ECODRIVE project, the effects on the other variables considered in the project will only be mentioned. Since homogeneous intervention in the speed of all classes of vehicles in the fleet circulating on the network seems to be the best solution, and perhaps the most obvious one, it is legitimate to ask why the second and third sets of measures have been implemented. As already mentioned, the ECODRIVE Project is aimed at the reduction of the overall emissions from private road transport, without compromising the level of service of the infrastructure. Limiting speeds reductions to the most pollutant vehicles reduces the number of vehicles that drive at a lower speed than permitted and, therefore, take longer to reach their destination, thus encouraging the use of less polluting vehicles. The main negative consequence of applying the speed limits described in this paper is in terms of travel times. For example, moving from a 130 km/h limit to a 70 km/h limit could increase travel times by more than 30%, making such policies of limited applicability. For this reason, it is necessary to develop an optimisation procedure



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that helps to balance the environmental benefits and the reduction in network service levels. However, it is important to highlight that, for the network in exam, the last important consideration concerns the correction coefficients of CNOSSOS-EU. For the network in exam, a draining asphalt has been considered, which, how is known from literature, reduces road noise by approximately 3 dB. By using standard road pavements, the efficiency of speed-based traffic management and control policies could be increased.

## 5 | Conclusions and future developments

The ECODRIVE project, presented in this paper, aims at reducing the atmospheric pollution and noise emissions generated by private road transport through specific traffic management. The project, which is based on a simulation approach, involves the application of different traffic management and control policies that, by acting on traffic dynamics and on the main flow variables, as well as on all the parameters that influence road transport emissions, make it possible to improve the environmental performance of road transport. This paper focuses mainly on the acoustic part of the project, trying to concentrate the analysis on the effectiveness of these measures in reducing the noise generated by the vehicles. As an example, the results of the speed-based tests are reported. These tests were carried out considering three different sets of measures: in the first set, the speed was progressively reduced by acting on all vehicle classes circulating on the network under study; the second set provided for the differentiation of the speed limit by vehicle class, while, in the last set, the reduction of the limit affected the lanes and not the vehicles. The results, presented separately for the two main trunks of the network, that run in opposite travel directions, highlighted greater effectiveness when speed limits lower than those permitted by law are imposed indifferently on all vehicles on the network. However, in order to also take into account pollutant emissions, the reduction of which is one of the other main objectives of the project, only briefly mentioned, it is necessary to intervene in a differentiated way, according to vehicle classes, in order to promote the circulation of less polluting vehicles and to minimise the increase in travel times that inevitably occurs when users are forced to drive at speeds lower than those allowed by law. The results also show that the effectiveness of the measures in the descending direction, which corresponds to the most heavily trafficked section of the network, is greater than that obtained in the standard conditions shown in Tab. 1, despite the fact that the speed values in the different scenarios slightly differ from one to another. In conclusion, the results presented in support of the objectives of the ECODRIVE project have shown how careful management of road traffic can achieve significant environmental benefits, especially in terms of road traffic noise. However, as already mentioned several times in this paper, in the future developments of the project it is necessary to include other variables, while developing a solution procedure that allows the optimisation of pollutant emissions and traffic noise, trying not to excessively reduce the level of service of the infrastructure.

**Conclusioni e sviluppi futuri**

Il progetto ECODRIVE, che è stato presentato in questo articolo, si pone come obiettivo la riduzione delle emissioni inquinanti in atmosfera e delle emissioni acustiche generate dal trasporto privato su strada tramite un'apposita gestione del traffico. Il progetto, basato su un approccio simulativo, prevede l'applicazione di diverse politiche di gestione e controllo del traffico, che, intervenendo sulle dinamiche del traffico e sulle variabili principali del deflusso, nonché su tutti i parametri che influenzano le emissioni su strada, consentano di migliorare le prestazioni ambientali del traffico stradale. Nel presente articolo, ci si è concentrati principalmente sulla parte acustica del progetto, cercando di concentrare l'analisi sull'efficacia di tali azioni sulla riduzione del rumore generato dai veicoli. A titolo di esempio, sono stati riportati i risultati dei test sulla velocità, condotti considerando tre diversi set di politiche: nel primo set, la velocità è stata progressivamente ridotta agendo su tutte le classi veicolari circolanti sulla rete in esame; il secondo set, invece, ha previsto la differenziazione del limite di velocità per classe veicolare, mentre nell'ultimo set, la riduzione del limite ha interessato le corsie e non i veicoli. I risultati, mostrati separatamente per i due tronchi principali della rete, che corrono in direzioni opposte, hanno evidenziato un'efficacia maggiore qualora limiti di velocità inferiori a quelli permessi per legge siano imposti indifferentemente a tutti i veicoli sulla rete. Tuttavia, per tenere conto anche delle emissioni inquinanti, la cui riduzione rappresenta uno degli atri grandi obiettivi del progetto, che è stato solo brevemente accennato, è necessario intervenire in maniera differenziata sulle classi veicolari al fine di incentivare la circolazione dei veicoli meno inquinanti e di ridurre al minimo gli incrementi dei tempi di viaggio cui, inevitabilmente, si va incontro imponendo agli utenti velocità inferiori a quelle permesse dalla legge. Dai risultati, inoltre, è emerso come l'efficacia delle politiche in direzione discendente, corrispondente alla carreggiata più trafficata della rete, pur presentando valori di velocità che, nei vari scenari, si discostano poco l'uno dall'altro, risulta maggiore rispetto a quella ottenuta nelle condizioni standard riportate nella Tab. 1.

In conclusione, i risultati mostrati a supporto degli obiettivi del progetto ECODRIVE, hanno evidenziato come una gestione oculata del traffico stradale consenta di ottenere notevoli benefici ambientali, soprattutto in termini di rumore dovuto al traffico stradale. Tuttavia, come già menzionato più volte nell'articolo, negli sviluppi futuri del progetto, è necessario includere ulteriori variabili, sviluppando al contempo una procedura risolutiva, che consenta di ottimizzare le emissioni inquinanti e il rumore da traffico, cercando di non peggiorare eccessivamente il livello di servizio dell'infrastruttura.

## 6 | Acknowledgements

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