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Evaluating Mitigation Plans over Traffic Sector to Improve NO_2 Levels in Andalusia (Spain) Using a Regional-Local Scale Photochemical Modelling System

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Abstract

In this contribution, we present an evaluation of different mitigation plans to improve NO_2 levels in Andalusia, a region in the south of Spain. Specifically, we consider four possible mitigation plans: the effects over NO_2 concentration of apply changes in the distribution of Vehicles Park; the effect of realize traffic restrictions (affecting to the density flow of vehicles) over highways and main roads; the effect of replacement of diesel use by natural gas in urban areas; and the effect of applying new velocity limits to access to urban areas. A sophisticated air quality modelling (AQM) system has been used to evaluate these mitigation plans. AQM implemented is composed on WRF meteorological model, an emission model created by the authors and CMAQ photochemical model. AQM analyzes mitigation plans during fifteen episodes of 2011 where NO_2 levels were the highest of the year; so we analyze the effect of mitigation plans in worst conditions. Results provided by the AQM system show that: 1-h maximum daily NO_2 is reduced to 10μg·m^{-3} near circulation roads when traffic restrictions and velocity limits plans are applied (NOx emissions are reduced in 9% - 15%); 1-h maximum daily NO_2 is reduced to 12 μg·m^{-3} affecting all municipalities when changes in the distribution of Vehicles Park are applied (NOx emissions are reduced in 25% - 26%); and the replacement of fuel of urban buses does not affect considerably NO_2 levels.

Keywords

CMAQ, Air Quality Modelling, Environmental Assessment

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1. Introduction

Cities, which concentrate 50% of population in 0.1% of land area, generate the largest amount of gases and aerosols emitted into the atmosphere, influencing weather and climate [1]. In Europe, air emissions have been reduced significantly in recent years [2], although pollutant concentrations remain high, particularly in urban areas. Recently, the World Health Organization [3] has included pollution as one of the cancer-causing agents for the first time. In urban areas and conurbations, the main cause of pollution is road traffic emissions associated with combustion and road dust resuspension processes [4]-[7]. In these areas, nitrogen dioxide (NO_2) is one of the pollutants having higher levels [8] in reference with the air quality standards (European Directive EC/2008/50). In Spain, annual average values of NO_2 are elevated in many urban air quality measurement stations with traffic influence [8]. In this sense, scientific studies have demonstrated that exposure to a NO_2 concentration higher than 150 $\mu g \cdot m^{-3}$ by the population, can increase respiratory problems as inflammation [9], can lead to asthmatic responses in sensitive people to allergens [10] or even cause premature death [11].

In order to improve air quality levels in urban areas, international and national action plans have been developed in the last years [12] [13]. In the same way, numerous regional and local air quality plans have been designed in Spain [14]. Policies to improve air quality have followed different strategies associated: to decrease variables associated with traffic which directly affect the amount of pollutant emissions (velocity or intensity vehicles flow); and to change Vehicles Park distribution introducing new technologies or alternative fuels [15] [16].

Models are a very useful tool for local administrations for planning and managing production, human resources, activities and emergency proceedings; and to introduce improvement plans of air quality in urban areas. During the last years, air quality models have been used in numerous studies providing the difference of pollutants concentration and a quantitative assessment of the effect of policies and mitigation plans [17]-[21].

This work aims to investigate the effect on urban NO_2 concentrations of four possible mitigation plans: the effect of apply changes in the distribution of Vehicles Park; the effect of realize traffic restrictions over highways and main roads; the effect of replacement of diesel use by natural gas in urban buses; and the effect of apply new velocity limits to access to urban areas. We have used WRF-ARW/AEMM/CMAQ modelling system (section 2.2) to evaluate the impact of each scenario by sensitive analysis. To develop this air quality modelling system focused on NO_2 in this study, we have followed the recommendations proposed by [22] on the Guide on modelling Nitrogen Dioxide (NO_2) for air quality assessment and planning to the European Air Quality Directive.

Description of the modelling system used, is presented in Section 2, as well as the area characteristic, data used, episode selection and mitigation plans proposed. A detailed analysis of the results obtained is presented in Section 3, and finally, some conclusions are reported in Section 4.

2. Studied Area and Methodology

In the following sections, we comment a description of the modelling system, the features of the studied area, the period analyzed, action plans considered and its corresponding scenarios.

2.1. Area Characteristic and Episode Selection

The area of study has been Andalusia in the south of Spain (**Figure 1**). Andalusia covers 17.3 percent of the territory of Spain. Andalusia is surrounded by Portugal and the Atlantic Ocean in the east, and by the Mediterranean Sea in the west. Andalusia is one of the main points of entry to Europe for international ships and in the Strait of Gibraltar sail more than 100,000 ships per year. Andalusia provides the main point of connection between Europe and Africa, with a high traffic of vehicles and facilitates the passage of people and goods between both continents.

The population of Andalusia reached in 2012 a population of 8,421,274 (around 18% of Spain). Andalusia is divided into eight provinces: Almeria, Cadiz, Cordova (**Figure 1(b)**), Granada, Huelva, Jaen, Malaga (**Figure 1(c)** and **Figure 1(d)**) and Seville (**Figure 1(a)**), being the city of Seville its capital and the largest urban agglomeration in Andalusia with a population of 1,217,811.

Andalusia has around 1000 km of coast line and presents a varied and complex topography. Main mountain ranges are the Sierra Morena, including Sierra Nevada (Mulhacén Peak, 3481 m.a.s.l), and the Baetic System.

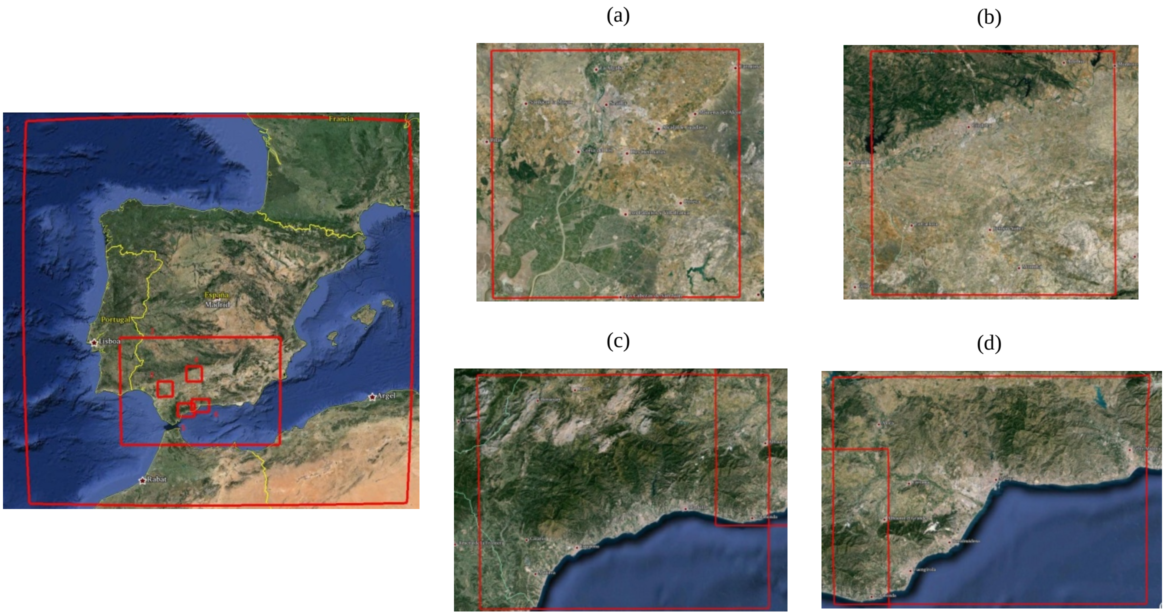


Figure 1. Models domains for simulations (left panel). Zoom domain of Seville (a); Cordova (b); Malaga western (c); Malaga eastern (d). [Images generated using Google Earth].

The Iberian Massif and the Baetic System are separated by a large depression corresponding to the Guadalquivir basin that crosses Andalusia from NE to SW. Different climate and topographic patterns can be associated to each one of these three zones.

Since a climate point of view Andalusia is located in a transition zone from temperate to subtropical climates, presenting a Mediterranean climate ruled by the Azores high. Andalusia's interior is the hottest area of Europe and temperatures rises above 40˚C during summer time. Most precipitation in Andalusia occurs from autumn to spring, associated mainly with Atlantic frontal systems. And in Andalusia is the unique desert area in the Europe (Desierto de Tabernas).

Pollutant air emissions in Andalusia are diverse, considering important natural and anthropogenic contributions. As anthropogenic contributions we can remark traffic emissions from urban areas of Seville and Malaga, industrial emissions from Huelva and Algeciras Bay, and emissions from ships crossing the Strait of Gibraltar. Furthermore, as the authors have analyzed, natural emissions contribute considerably to the air quality levels in the region. In this sense, and depending on the weather conditions, biogenic emissions in Andalusia can contribute up 10% of ozone levels, and sea-salt aerosols and erosion dust can contribute up 10% and 20% respectively.

Regarding the air quality levels, levels of PM_{10} and $PM_{2.5}$ was low during 2011 (without considers Saharan dust) with exceedances of the daily limit value of PM_{10} only in points of Jaen and Granada. NO_2 annual limit value was exceeded in Granada and Seville associated to traffic emissions. O_3 information threshold value was exceeded in three occasions in Seville decreasing considerably regarding the last years. And SO_2 daily limit value only was exceeded in Cadiz associated to the petrochemistry industry in the Algeciras Bay.

In **Figure 1**, we show models domains used for simulations (section 2.2) that represents different areas of Andalusia.

To analyze the effect of mitigation plans we have considered an amount of fifteen meteorological episodes (corresponding five for Seville, five for Cordova and five for Malaga) of 96 hours in 2011. During this year, the NO_2 limit value fixed by the European Directive EC/2008/50 (200 $\mu g \cdot m^{-3}$) was exceeded on 18 times. We have selected meteorological episodes with the highest NO_2 concentration measured, evaluating mitigation scenarios in the worst case since an air quality point of view. For this analysis we have not considered holidays and we have tried to consider all climatic stations.

We have characterized episodes using air quality measurements from the Air Quality Network that belongs to the Environmental and Water Agency of Andalusia. In **Table 1**, we show the date of every episode selected and the maximum 1-h measured in each station.

Table 1. Daily maximum 1-h value measured in the air quality stations in meteorological episodes selected.

Air quality station	NO$_2$ daily maximum 1-h (μg·m^{-3})				
Seville	February, 11st	March, 17th	October, 4th	November, 27th	December, 19th
Alcalá de Guadaira	129	129	116	137	110
Aljarafe	117	97	81	101	113
Bermejales	157	160	146	199	194
Centro	109	124	117	113	127
Dos Hermanas	105	97	76	87	93
Príncipes	145	161	120	163	158
Ranilla	253	211	170	226	210
San Jerónimo	92	92	131	119	153
Santa Clara	110	102	120	136	166
Torneo	181	162	208	146	205
Cordova	April, 7th	June, 19th	September, 6th	October, 5th	October, 13rd
Asomadilla	91	62	103	58	82
Lepanto	110	58	112	126	144
Malaga	February, 22nd	April, 7th	July, 5th	October, 5th	December, 22nd
Campanillas	101	66	108	23	74
Carranque	117	163	135	180	166
El Atabal	93	108	105	119	84
Marbella	82	41	81	61	72

2.2. Modelling Approach

Authors have an extensive experience as modellers [23]-[26] designing and implementing air quality modelling systems and configuring these ones with the optimum parameterizations to reduce the uncertainty of the models [27] [28]. The authors have applied this kind of models as forecast tool as assessment tool of mitigation plans working in collaboration with different regional and local administrations (Environmental and Water Agency of Andalusia Government, Environment and Planning Agency of Madrid Government and Territory and sustainability Agency of Catalan Government).

The air quality modelling system used is composed by a meteorological model, an emission model and a photochemical model. To configure models we have used the recommendations and requirements indicated in the Guideline on modelling Nitrogen Dioxide (NO_2) for air quality assessment and planning relevant to the European Air Quality Directive [22]. We have used these guidelines to choose the kind of models more optimum to evaluate mitigation plans of NO_2 levels.

This coupled air quality modelling system has been applied and tested successfully in urban, industrial and mine areas. Urban areas as Madrid, Barcelona (Spain) or Nice (France); industrial areas as Ponferrada or Tarragona (Spain); and mine areas as Calama (Chile). The air quality modelling system showed has been evaluated using Maximum Relative Directive Error [29] referred in the European Directive EC/2008/50. Results obtained from this evaluation accomplish the model uncertainty limits according to the Directive for the pollutants O_3, NO_2, PM_{10}, SO_2 and CO, having used measurements from more than 120 stations (urban, suburban and rural locations) during a period of three years. In the following lines we present the main features of the models involved in the coupled modelling system.

Weather Research and Forecasting–Advanced Research (WRF-ARW) version 3.3 was used as mesoscale meteorological model [30]. WRF model was configured with six nested domains with 15 (first domain), 3 (second domain) and 0.5 km (inner domains) of horizontal resolution, as we can see in **Figure 1**. First domain, called d01, covers the whole Iberian Peninsula, south of France and north of Africa with 100 × 100 grid cells. Second domain (d02), covers the region of Andalusia with 201 × 136 cells. And the inner domains cover Seville and its metropolitan area (d03 with 115 × 115 cells), Cordova (d04 with 115 × 115 cells) and Malaga-Costa del Sol (d05 with 127 × 103 and d06 with 133 × 97 cells) areas. The vertical resolution includes 32 levels, 22 below 1500 meters, with the first level at approximately 15 meters and the domain top at about 100 hPa. Initial and boundary conditions for domain d01 are updated every six hours using GFS (Global Forecast System) model from the National Oceanic and Atmospheric Administration (NOAA). Planetary boundary layer scheme used in the simulations is Yonsey University [31]. Microphysics scheme corresponds on Lin scheme [32]. GFDL [33] and MM5 [34] scheme are used as long wave and short wave radiation scheme respectively. Noah LSM is the land surface model [35] used, Eta similarity is considered as surface layer scheme [36] and Grell 3D [37] is the cumulus parameterization applied. Two-way nesting is used as relationship between domains.

Emissions are obtained by the Air Emission Model of Meteosim (AEMM) [38]. AEMM is a numerical, deterministic, Eulerian, regional and local-scale model developed by Meteosim S.L. It allows obtaining the intensity of emissions in different areas, either anthropogenic (traffic, industry, residential, etc.) or natural (emissions caused by vegetation or erosion dust) for the area of interest. This model combines two emission calculation methods: top-down and bottom-up. The first is based on the space-time disaggregation of lower-resolution inventories (e.g.: EMEP or EDGAR) in accordance with land use and statistical functions associated with different socio-economical variables. Through the second method the model calculates the cell-to-cell emissions from the relevant domains based on emission factors (EMEP/EEA or EPA) or local emission inventories (e.g.: PRTR or autonomic inventories). AEMM is designed to work with various chemical mechanisms (CB4, CB5, SAPRC, AERO4 and AERO5) and it is adaptable to other chemical mechanisms. AEMM is coupled to the meteorological model WRF and to the CMAQ photochemical model, and may be coupled to other models. AEMM takes into account elevated sources, considering 8 vertical levels for industrial emissions. Monthly, weekly and vertical profiles from the Unified EMEP model are applied to determine the value of an emission for every month and day of the year, and vertical level. To obtain emissions in every domain of simulation, we use the two methods of AEMM. By one hand, we use top-down methodology to calculate emissions for d02 domain using the European annual inventory EMEP/MSC (EMEP Chemical Transport Model www.emep.int), and our disaggregation is based on land used CLC2006 (Corine Land Class 2006) with 250 meters of resolution, coupled with different statistical functions depending on socio-economic variables [39]. On the other hand, we use bottom-up methodology to calculate emissions for d03, d04, d05 and d06 domains. In any cell we consider industrial, residential and institutional, traffic, solvent, ships traffic, airports, waste treatment and natural emissions.

To simulate NO_2 physical and chemical processes into the atmosphere, we use the US Environmental Protection Agency models-3/CMAQ model [40]. CMAQ is an open-source photochemical model which is updated periodically by the research community. In this contribution we use CMAQv4.7.1 (www.cmascenter.org), considering CB-5 chemical mechanism and associated EBI solver [41], and AERO5 aerosol module [42]. Regarding NO_2 atmospheric chemistry, CB-5 considers 155 chemical reactions that involve NOx, non-methanic volatile organic compounds (NMVOCs) or ozone (O_3). CMAQ model uses the same domain configuration as the WRF simulation. Initial and boundary conditions for d02 domain are provided by the results of simulation of d01 domain. And inner domains with very high resolution are initialized using Andalusia domain results. Meteorology-Chemistry Interface Processor (MCIP) version 3.6 is used to prepare WRF output to CMAQ model. And AEMM model prepares emissions as AERO5 and CB-5 modules require.

In **Figure 2**, we show an example of CMAQ output for NO_2 daily maximum 1-h in each domain of high resolution.

Numerical simulations are executed for 96 hours corresponding on every episode selected, taking the first 24 hours as spin-up time to minimize the effects of initial conditions. Air Quality modelling system works operationally in a computing cluster own of Meteosim with 27 nodes and more than 150 cores.

2.3. Mitigation Plans and Scenarios

In this research, four different scenarios over traffic sector have been considered. Every scenario is associated with a mitigation plan. The first one is based on traffic restrictions. Five different areas have been defined, in which a reduction in traffic volume has been imposed. The centre of each city has been defined as Zone 0. In

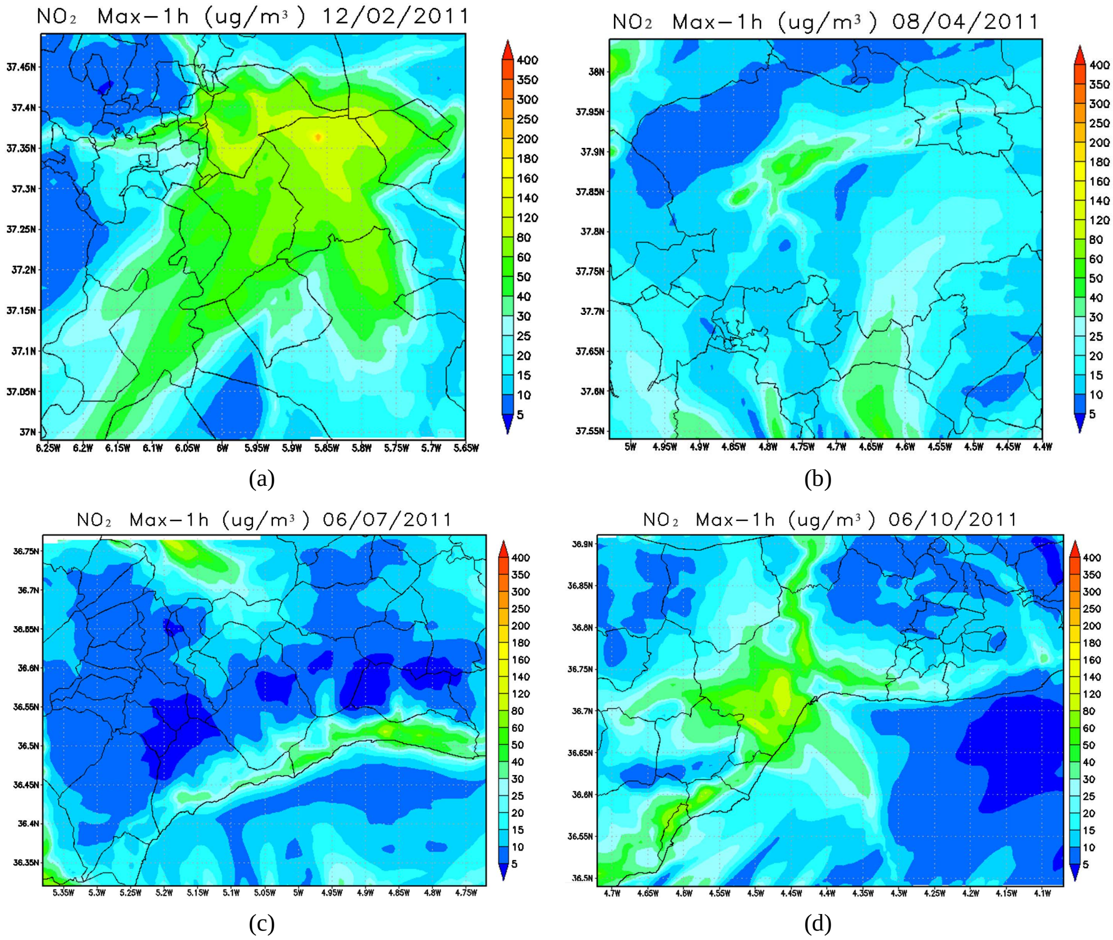


Figure 2. NO_2 daily maximum 1-h obtained from CMAQ in Seville (a, 12/02/2011), Cordova (b, 08/04/2011), Malaga western (c, 06/07/2011) and Malaga eastern (d, 06/10/2011).

this area no traffic has been allowed. Other routes inside the city are defined as Zone 1 and a traffic reduction of 20% has been imposed. Big motorways form the Zone 2, with a reduction of 15%. Regional and national roads make up the Zone 3 with a traffic reduction of 10%. Finally, the rest of routes away of the city are defined as Zone 4 with a traffic reduction of 5%.

The main idea is to impose an effective traffic reduction in the analysed cities. Other forms of public transport have to balance the private traffic reduction, in order to maintain the economical activity in these areas.

In **Figure 3** we can see geographical distribution of traffic restriction designed.

The second scenario imposes a reduction in the velocity. The maximum velocity is decreased between 10 and 20 $km \cdot h^{-1}$, in function of the type of route analysed. The maximum velocity for motorways comes down from 120 $km \cdot h^{-1}$ to 100 $km \cdot h^{-1}$. In regional and national routes, the maximum velocity is reduced from 100 $km \cdot h^{-1}$ to 90 $km \cdot h^{-1}$. Finally, in the rest of routes, maximum velocity decreases from 90 $km \cdot h^{-1}$ to 80 $km \cdot h^{-1}$. Traffic emissions are calculated using AEMM model based on emission factors from EEA/EMEP CORINAIR and these emission factors depends on the velocity of circulation. In **Figure 4**, we can see geographical distribution of velocity limitation designed.

With the third scenario, a renewal of the vehicle fleet is assumed. Each private vehicle with more than 12 years is replaced by a new vehicle with the same cubic capacity and fuel, but according with the new laws about vehicle emissions. Traffic emissions are calculated using AEMM model based on emissions factors from EEA/EMEP CORINAIR. Emission factors relate emissions of a pollutant with a vehicle type depending on the directive to which they belong (age of the vehicles). For this reason, variations in the distribution of the fleet cause different emission values.

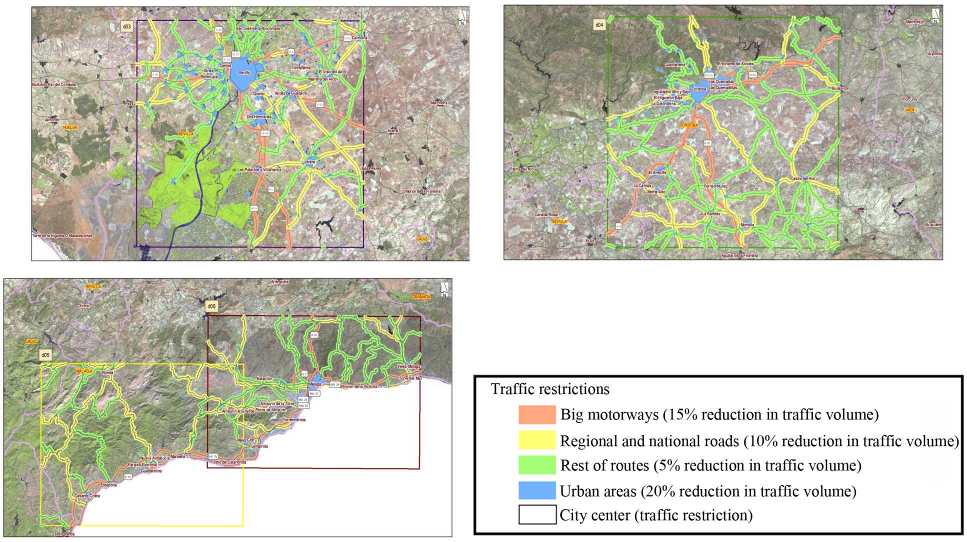


Figure 3. Geographical distribution of traffic restriction plan over Seville, Cordova and Malaga.

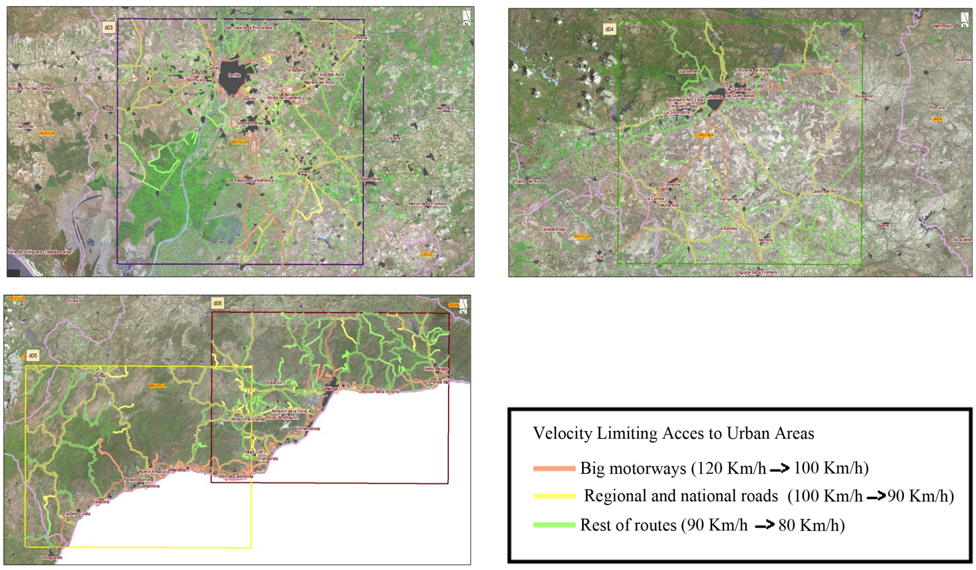


Figure 4. Geographical distribution of velocity limiting access plan over Seville, Cordova and Malaga.

The last scenario supposes a replacement of the current urban public buses by a new fleet of buses powered by natural gas. This replacement affects the emission factors applied for the traffic emission calculation. In **Table 2** we present the emission factor used for urban buses powered by natural gas and by diesel.

3. Results and Discussion

Every defined scenario has been compared with the base case from sensitivity analysis, as [22] [34] recommends. The sensitivity analysis consists in the comparison between the results obtained by the AQM for the real scenario, defined as base scenario, and the results from simulations introducing different emissions, corresponding to the emissions resulting from the implementation of mitigation plans. This approach using air quality models can directly determine the effect of emission reduction measures on pollutant concentrations at any point in space and time.

Base scenario is calculated applying the coupled air quality modelling system developed considering real emissions (industry, traffic, natural, etc.) in the region, whilst every defined scenario is calculated by the same way modifying Vehicles Park Distribution, velocity of circulation or intensity vehicles flow in AEMM.

Table 2. Emission factors used for urban public buses powered by natural gas and by diesel from EEA/EMEP CORINAIR.

Pollutant	Emission ($g \cdot km^{-1}$) Natural Gas	Emission ($g \cdot km^{-1}$) Diesel (50 $km \cdot h^{-1}$)
CO	1.0	1.2
NMVOC	1.0	0.2
NO_x	2.5	6.2
PM_{10}	0.005	0.121
SO_2	0.00	0.15

To analyze the effect of every mitigation plan, we have considered the effect over several statistical values of NO_2 (daily value and daily maximum 1-hour value) and O_3 (daily maximum 1-h and daily maximum 8-h value). We show the results in air quality stations (considering the grid cell that corresponds to every station) and over municipalities. In the last case we analyze two kinds of results: the average value over municipalities that correspond on the average value for all grid cells of modelling domain that cover the municipality; and the maximum reduction obtained in any cell that cover the municipality.

In **Table 3** we present the comparison of the effect over NO_2 daily maximum 1-h and daily value of every mitigation plan designed in each air quality measurement station.

Results show that the mitigation plans designed affects NO_2 levels with different intensity. In any case NO_2 concentration is reduced when mitigation plans are applied. Traffic restriction plan reduce up a 7% NO_2 levels in the air quality stations near the city of Seville and Cordova and up an 11% in the case of Malaga. Velocity limiting plan reduce a 3% NO_2 levels in Seville, 1% in Cordova and up a 10% in the case of Malaga. The effect of rejuvenation of Vehicles Park plan is the most intensive and we can observe reductions up a 12% in Seville, a 9% in Cordova and a 13% in Malaga. And finally, the effect of transport public plan is very low with reductions lower than 0.3%.

In **Table 4** we present the comparison of the effect over NO_2 daily maximum 1-h of every mitigation plan designed in the municipalities that present greater NO_2 levels evaluated by the air quality modelling.

Maximum reduction of NO_2 levels in the domain of Seville obtained applying traffic restriction plan and rejuvenation of Vehicles Park is reproduced in the city of Seville (reducing a 19% and a 26% NO_2 daily maximum 1-h respectively. However, is in Tomares where is reproduced the most important change of NO_2 concentration applying velocity limiting access plan (reducing a 20%).

In the case of Cordova we reproduce the maximum effect of mitigation plans in the city of Cordova and the effect is significantly greater than in the rest of municipalities. Otherwise, in the domain of Malaga-Costa del Sol, Malaga, Fuengirola, Marbella, Torremolinos and Benalmádena show similar results between them.

In the following sections we present individually the effect of mitigation plans defined over NO_2 and O_3 levels in meteorological periods associated with high NO_2 concentration.

3.1. Traffic Restrictions

The application of this plan reduces a 13% traffic nitrogen monoxide emissions in Seville and its metropolitan area; a 14% in Cordoba; and a 15% in Malaga-Costa del Sol.

In **Figure 5** we present the difference between NO_2 daily maximum 1-h between traffic restriction scenario and base scenario averaged for all meteorological periods considered.

As the **Figure 5(a)** shows, the main reduction of NO_2 levels in Seville is obtained in the city centre and in the main routes that connect the centre with the big neighbour towns. This action offers the biggest reduction of the NO_2 levels. In a similar way, the reductions reached in the other analysed areas are bigger in the centre of the cities than in the suburban areas. City centres are the most complicated areas from the point of view of pollutants, because the emission levels are bigger in comparison with other zones. The reduction in these areas is the most important step in order to improve the air quality. This mitigation plan is associated with reductions of NO_2 maximum 1-h greater than 4 $\mu g \cdot m^{-3}$, reducing up 10% NO_2 levels.

Table 3. Effect of mitigation plans over NO_2 values in air quality stations. *These values correspond on average value for all meteorological periods selected. **These values correspond on the difference between the average value of mitigation plan and base scenario.

Air quality station	Scenario									
	Base*		Traffic restriction**		Velocity limiting access**		Rejuvenation of Vehicles Park**		Transport public**	
	NO_2 Max 1 h $\mu g \cdot m^{-3}$	NO_2 Daily $\mu g \cdot m^{-3}$	NO_2 Max 1 h $\mu g \cdot m^{-3}$	NO_2 Daily $\mu g \cdot m^{-3}$	NO_2 Max 1 h $\mu g \cdot m^{-3}$	NO_2 Daily $\mu g \cdot m^{-3}$	NO_2 Max 1 h $\mu g \cdot m^{-3}$	NO_2 Daily $\mu g \cdot m^{-3}$	NO_2 Max 1 h $\mu g \cdot m^{-3}$	NO_2 Daily $\mu g \cdot m^{-3}$
Seville										
Alcalá de Guadaira	24.94	9.20	−0.54	−0.15	−0.41	−0.12	−0.85	−0.24	−0.02	0.00
Aljarafe	41.58	16.60	-2.87	−0.90	−2.15	−0.67	−4.87	−1.54	−0.10	−0.03
Bermejales	85.38	33.78	−3.36	−1.96	−2.33	−1.05	−2.12	−2.32	−0.10	−0.06
Centro	54.87	20.23	−4.49	−1.41	−1.64	−0.54	−5.61	−1.80	−0.12	−0.04
Dos Hermanas	60.71	24.54	−0.47	−0.38	−0.51	−0.34	−0.43	−0.55	−0.02	−0.01
Príncipes	23.57	9.12	−0.57	−0.15	−0.41	−0.12	−0.92	−0.23	−0.02	0.00
Ranilla	59.65	23.21	−4.65	−1.79	−1.89	−0.69	−5.39	−2.17	−0.12	−0.05
San Jerónimo	23.66	9.19	−0.59	−0.15	−0.41	−0.12	−0.93	−0.24	−0.02	0.00
Santa Clara	77.41	30.11	−4.37	−1.91	−3.34	−1.38	−4.77	−2.69	−0.13	−0.06
Torneo	60.09	22.26	−4.92	−1.62	−2.36	−0.68	−6.28	−2.09	−0.13	−0.04
Cordova										
Asomadilla	18.47	6.97	−1.08	−0.39	−0.24	−0.11	−1.29	−0.47	−0.03	−0.01
Lepanto	28.08	11.95	−2.32	−0.92	−0.59	−0.20	−2.57	−0.96	−0.06	−0.02
Malaga										
Campanillas	35.64	12.86	−2.49	−0.70	−1.29	−0.39	−3.73	−1.09	−0.08	−0.02
Carranque	55.00	22.00	−5.97	−2.21	−1.45	−0.59	−5.40	−2.11	−0.12	−0.05
El Atabal	55.00	17.79	−6.22	−1.83	−3.49	−1.06	−6.82	−2.11	−0.14	−0.04
Marbella	23.75	8.88	−2.35	−0.72	−2.35	−0.73	−3.18	−0.96	−0.06	−0.02

3.2. Velocity Limiting Access to Urban Areas

The application of this plan reduces a 9% traffic nitrogen monoxide emissions in Seville and its metropolitan area; a 10% in Cordoba; and a 10% in Malaga-Costa del Sol.

In **Figure 6**, we present the difference between NO_2 daily maximum 1-h between traffic restriction scenario and base scenario averaged for all meteorological periods considered.

Main results are obtained in the access to big cities. This scenario does not suppose big reduction in the city centre but it is possible to reduce an important quantity of pollutants in the entry to the cities, near to 4μgm-3 in this areas. The effect of this measure focuses on the main access roads to Seville (A-4, A-92, AP-4 and A-49), roadways A-4 and A-45 as it passes through Cordoba, and A-7, AP-7 and A-45 near Malaga. It is necessary to remark the results obtained in Malaga western because it is a zone with a high number of motorways, even along the main cities.

3.3. Rejuvenation of Vehicles Park

The application of this plan reduces a 25% traffic nitrogen monoxide emissions in Seville and its metropolitan area; a 26% in Cordoba; and a 25% in Malaga-Costa del Sol.

Table 4. Effect of mitigation plans over NO_2 values in municipalities. *These values correspond on average value for all grid cells that cover the municipality. **These values correspond on the maximum reduction obtained for all grid cells that cover the municipality.

Municipality	Scenario								
	Base	Traffic restriction		Velocity limiting access		Rejuvenation of Vehicles Park		Transport public	
	NO_2 Max 1 h $\mu g \cdot m^{-3}$	Average* $\mu g \cdot m^{-3}$	Maximum reduction** $\mu g \cdot m^{-3}$	Average* $\mu g \cdot m^{-3}$	Maximum reduction** $\mu g \cdot m^{-3}$	Average* $\mu g \cdot m^{-3}$	Maximum reduction** $\mu g \cdot m^{-3}$	Average* $\mu g \cdot m^{-3}$	Maximum reduction** $\mu g \cdot m^{-3}$
Seville									
Camas	64.39	−4.00	−10.11	−3.77	−11.64	−5.27	−13.72	−0.13	−0.27
Seville	64.32	−3.31	−12.09	−2.36	−8.77	−4.02	−16.72	−0.10	−0.30
San Juan de Aznalfarache	62.16	−3.74	−8.54	−3.20	−7.35	−5.68	−14.88	−0.13	−0.28
Tomares	57.46	−4.61	−10.46	−4.48	−11.77	−6.20	−14.28	−0.13	−0.28
Dos Hermanas	53.43	−0.98	−8.99	−0.93	−8.96	−1.08	−12.37	−0.03	−0.24
Cordova									
Guadalcázar	17.48	−0.11	−0.68	−0.09	−0.68	−0.16	−0.93	0.00	−0.02
Pedro Abad	17.14	−0.99	−5.89	−0.94	−6.06	−1.30	−7.65	−0.03	−0.16
Villafranca de Córdoba	16.06	−0.92	−5.07	−0.81	−5.24	−1.21	−6.49	−0.02	−0.13
La Carlota	15.58	−0.38	−4.21	−0.37	−4.30	−0.52	−5.53	−0.01	−0.11
Cordova	15.02	−0.47	−10.18	−0.36	−8.50	−0.63	−12.06	−0.01	−0.25
Malaga									
Fuengirola	34.44	−3.62	−10.38	−3.20	−11.09	−4.51	−12.51	−0.09	−0.26
Marbella	32.85	−3.74	−10.89	−1.30	−10.03	−4.80	−13.94	−0.06	−0.25
Torremolinos	29.86	−2.67	−10.19	−2.20	−9.28	−2.97	−10.73	−0.07	−0.22
Malaga	27.31	−2.02	−11.79	−1.33	−13.07	−2.33	−13.99	−0.05	−0.27
Benalmádena	26.05	−2.52	−10.02	−2.40	−11.20	−3.17	−12.31	−0.07	−0.25

In **Figure 7**, we present the difference between NO_2 daily maximum 1-h between traffic restriction scenario and base scenario averaged for all meteorological periods considered.

The mitigation plan of rejuvenation of Vehicles Park on NO_2 levels causes differences in some municipalities up to 17 $\mu g \cdot m^{-3}$. The effect of this measure has a global impact in every area of application, being its highest intensity in traffic ways where a greater contribution of NO emissions to the atmosphere occurs.

3.4. Replacement of Diesel Use by Natural Gas in Urban Buses

The application of this mitigation plan reduces a 0.4% traffic nitrogen monoxide emission in Seville and its metropolitan area; a 0.4% in Cordoba; and a 0.4% in Malaga-Costa del Sol.

In **Figure 8**, we present the difference between NO_2 daily maximum 1-h between traffic restriction scenario and base scenario averaged for all meteorological periods considered.

The effect individualized of this mitigation plan over NO_2 levels can be considered negligible, causing decreases in NO_2 concentration below 0.3 $\mu g \cdot m^{-3}$ in all cases. This feature is explained because the number of vehicles associated with urban public transport is low compared to the total fleet of vehicles, being this contribution lower than 0.6%.

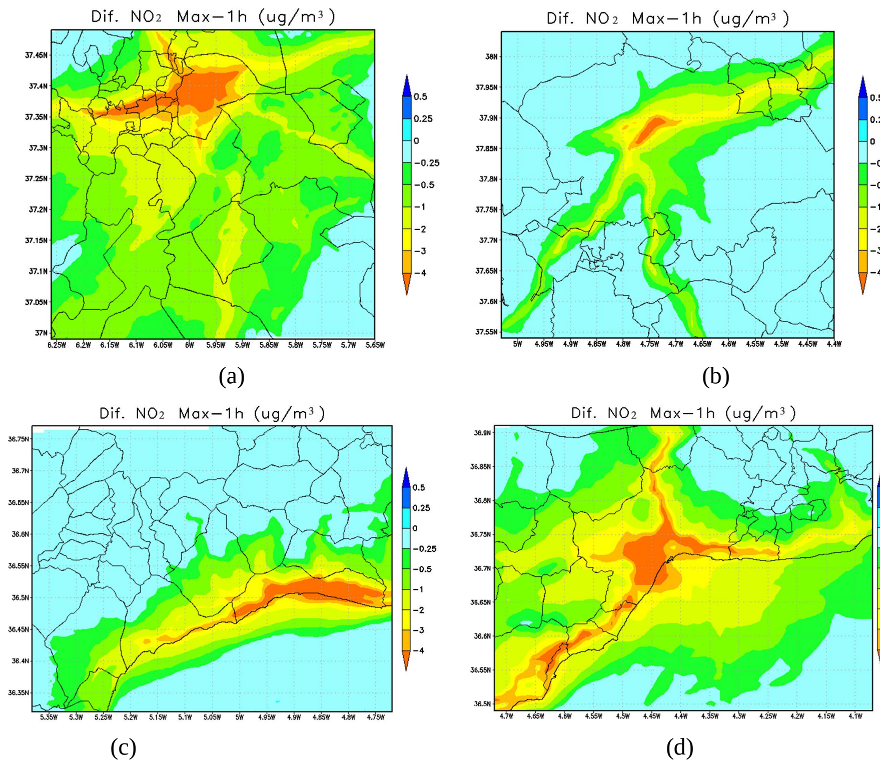


Figure 5. Absolute difference between NO_2 1-h maximum between traffic restriction scenario and base scenario in Seville (a), Cordova (b); Malaga western (c) and Malaga eastern (d).

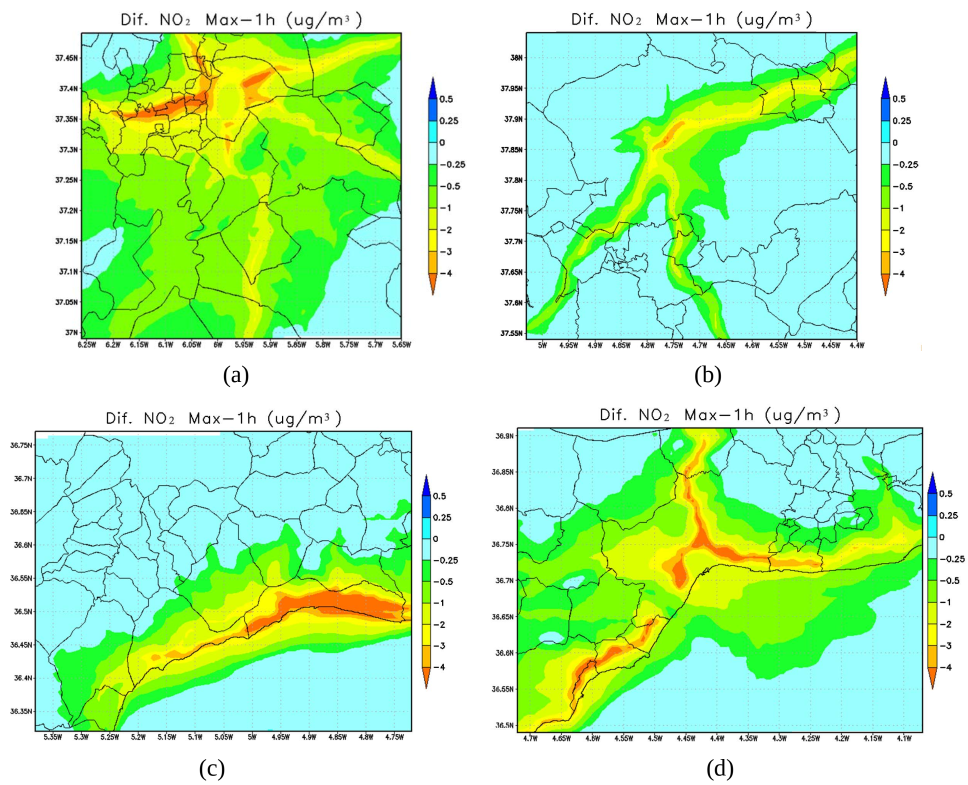


Figure 6. Absolute difference between NO_2 1-h maximum between velocity limiting scenario and base scenario in Seville (a); Cordova (b); Malaga western (c) and Malaga eastern (d).

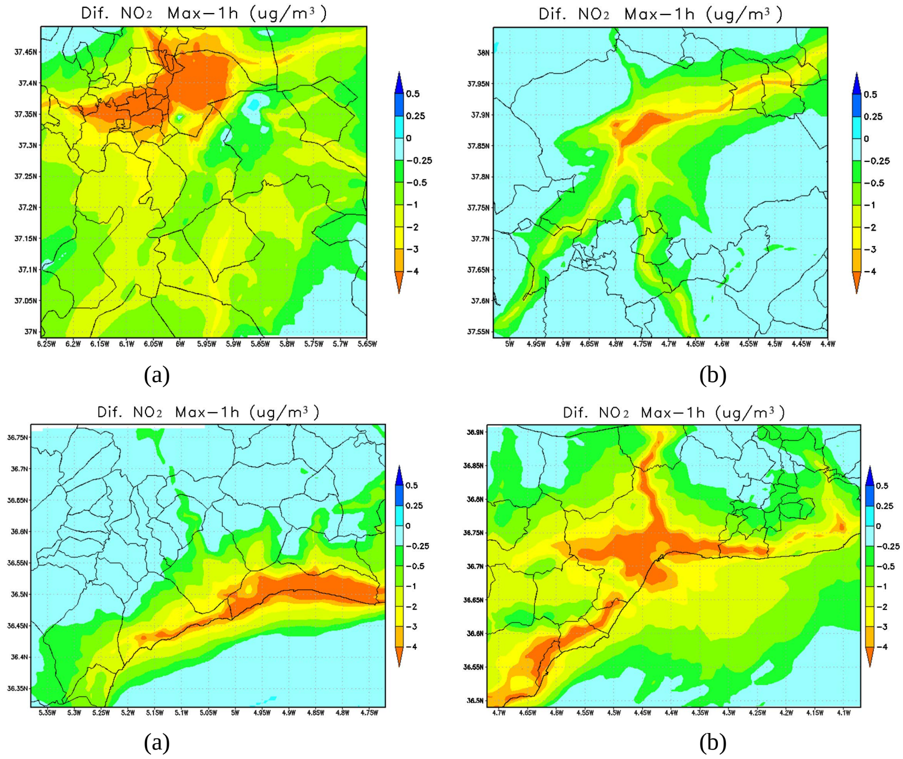


Figure 7. Absolute difference between NO_2 1-h maximum between rejuvenation Vehicles Park scenario and base scenario in Seville (a); Cordova (b); Malaga western (c) and Malaga eastern (d).

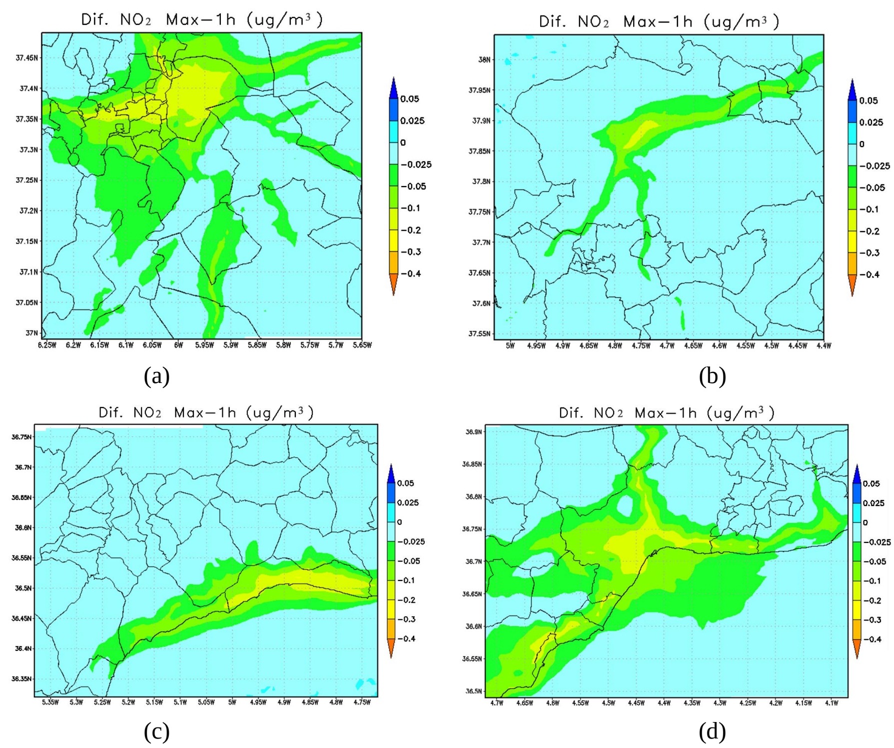


Figure 8. Absolute difference between NO_2 1-h maximum between rejuvenation Vehicles Park scenario and base scenario in Seville (a); Cordova (b); Malaga western (c) and Malaga eastern (d). Note: colour scale is a factor 10 lower than the rest of figures of each scenario.

3.5. Effect of Action Plans over Ozone Levels

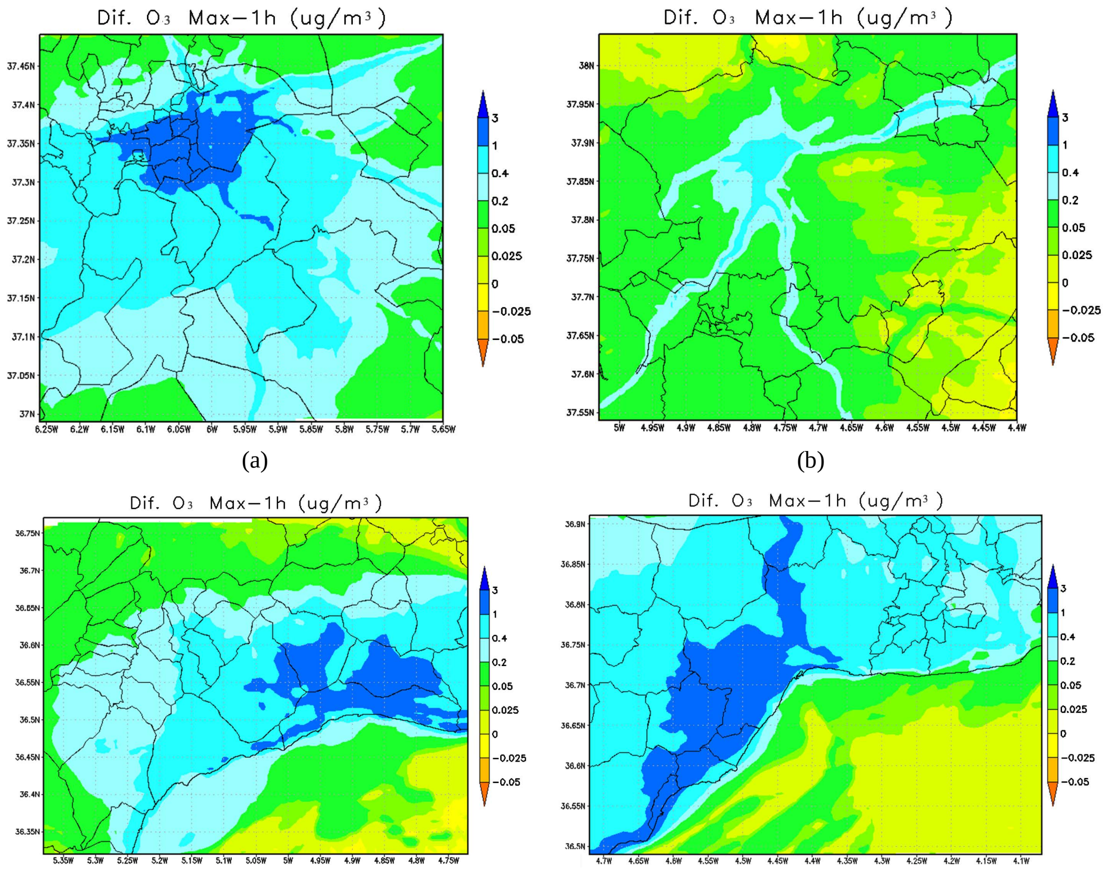
As shown in the above results, a significant reduction in the volume of vehicles or in its form of action directly results in a reduction of the levels of primary pollutants, such as NO_2.

But the same does not occur with a secondary pollutant, such as ozone. The effect of mitigation plans over ozone depends on the kind of area (urban, suburban or rural), on the effect over volatile organic compounds (VOCs) emissions of every measure, and on the weekend effect. This phenomenon refers to the weekly behaviour shown by surface ozone concentrations in urban atmospheres, in which a reduction of the levels of its precursors (nitrogen oxides and volatile organic compounds) during the weekend carries an increase of ozone concentrations [43]-[45].

However, depending on the weather scenarios and levels of reducing emissions of precursors, the so-called weekend effect in ozone can or not be produced. There may be a reduction of NOx and VOCs, but this reduction may not be sufficient to reduce ozone or other factors could involve the elimination of the potential ozone depletion. In this sense, the influence of the actions that lead to the reduction of pollutants should be considered in a potential increase in tropospheric ozone concentrations in the study area. **Table 5** and **Figure 9** shows the variation of ozone levels between scenario base and the other scenarios analyzed.

Table 5. Effect of mitigation plans over O_3 values in air quality stations. *These values correspond on average value for all meteorological periods selected. **These values correspond on the difference between the average value of mitigation plan and base scenario.

Air quality station	Scenario									
	Base*		Traffic restriction**		Velocity limiting access**		Rejuvenation of Vehicles Park**		Transport public**	
	O_3 Max 8 h $\mu g \cdot m^{-3}$	O_3 Max 1 h $\mu g \cdot m^{-3}$	O_3 Max 8 h $\mu g \cdot m^{-3}$	O_3 Max 1 h $\mu g \cdot m^{-3}$	O_3 Max 8 h $\mu g \cdot m^{-3}$	O_3 Max 1 h $\mu g \cdot m^{-3}$	O_3 Max 8 h $\mu g \cdot m^{-3}$	O_3 Max 1 h $\mu g \cdot m^{-3}$	O_3 Max 8 h $\mu g \cdot m^{-3}$	O_3 Max 1 h $\mu g \cdot m^{-3}$
Seville										
Alcalá de Guadaira	74.43	80.86	0.02	0.01	−0.05	−0.06	0.20	0.19	0.00	0.00
Aljarafe	66.89	76.60	0.51	0.23	0.10	−0.13	1.70	1.17	0.02	0.01
Bermejales	59.59	72.59	0.90	0.57	0.17	−0.03	2.21	1.73	0.03	0.02
Centro	57.85	77.63	0.75	0.37	0.04	−0.04	1.58	0.87	0.02	0.01
Dos Hermanas	57.88	76.21	0.21	0.10	−0.01	−0.10	0.87	0.62	0.01	0.01
Príncipes	74.36	80.52	0.02	0.02	−0.05	−0.06	0.21	0.20	0.00	0.00
Ranilla	65.76	76.28	0.96	0.49	0.11	−0.03	1.85	1.05	0.03	0.02
San Jerónimo	74.06	80.48	0.03	0.02	−0.06	−0.06	0.22	0.20	0.00	0.00
Santa Clara	62.16	75.07	0.73	0.39	0.28	0.09	2.01	1.26	0.03	0.02
Torneo	66.23	76.64	0.87	0.46	0.09	−0.03	1.76	1.03	0.02	0.01
Cordova										
Asomadilla	91.31	96.88	0.15	−0.05	−0.19	−0.28	0.60	0.40	0.01	0.00
Lepanto	90.52	97.06	0.38	0.09	−0.22	−0.32	0.92	0.57	0.01	0.01
Malaga										
Campanillas	78.86	84.28	0.42	0.26	−0.08	−0.23	1.37	1.18	0.02	0.01
Carranque	74.56	80.76	1.07	0.74	0.08	−0.03	1.53	1.11	0.02	0.02
El Atabal	77.39	83.33	0.96	0.83	0.26	0.13	1.77	1.69	0.03	0.02
Marbella	83.99	89.77	0.25	0.12	−0.09	−0.20	1.10	−0.87	0.01	0.01



(a) (b)

(c) (d)

Figure 9. Absolute difference between O3 1-h maximum between rejuvenation Vehicles Park scenario and base scenario in Seville (a); Cordova (b); Malaga western (c) and Malaga eastern (d).

It is possible to find an increase of ozone concentration around the city centre because of the reduction of primary pollutants. This fact is especially relevant in Seville (**Figure 9(a)**) and Malaga (**Figure 9(c)** and **Figure 9(d)**). In Seville, the higher increase of ozone concentration is observed in the west of the city centre, in an area called Aljarafe. This area usually shows the highest values of ozone in Seville, and probably in Andalusia. The expected increase is between 1 $\mu g \cdot m^{-3}$ and 3 $\mu g \cdot m^{-3}$. The legal value for comparison is the threshold value for the information of the public (one-hour ozone concentration 180 $\mu g \cdot m^{-3}$). Then, the actions to reduce the primary pollutants lead an increment of about 1.5% of the legal value whereas the reduction for primary pollutants means a reduction of 2% over the legal value (reduction of 4 $\mu g \cdot m^{-3}$ over the 1-hour limit value 200 $\mu g \cdot m^{-3}$).

4. Conclusions

A numerical experiment has been developed to evaluate different mitigation plans over traffic sector to improve NO_2 levels in Andalusia. We have considered four mitigation plans: traffic restrictions, velocity limiting access to urban areas, rejuvenation of Vehicles Park, and replacement of diesel use by natural gas in urban buses. We are evaluated the mitigation plans in worst conditions, where NO_2 levels were the highest of the year, and the results are representative of the effect of these plans during environmental episodes of this pollutant.

Every scenario designed reduces into a 14% NO emissions, 10%, 25%, and 0.4% respectively, in the urban areas of Seville, Cordova and Malaga.

We have observed that mitigation plans defined as restriction of traffic and velocity limitations have a local impact and its effect is observed directly near the roads where the measures are applied. In both cases the maximum reductions of daily NO_2 maximum value is around 10 $\mu g \cdot m^{-3}$. The plan defined as rejuvenation of the fleet has an overall impact and we can note the effect over every municipality that covers model domains. Reductions up 17 μg·m^{-3} have been obtained. The measure designed over transport public has not significant effects on NO_2 levels due to the low number of vehicles that affects the plan.

Mitigation plans has the effect with opposite sign and provide an increase (1.5%) of ozone concentration in areas where typically ozone levels are high. Nevertheless, the analysis is representative of high NO_2 conditions and in the future the authors extend the study to high O_3 conditions to obtain a better evaluation of the effect of mitigation plans over this atmospheric pollutant.

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