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Thessaloniki City Report

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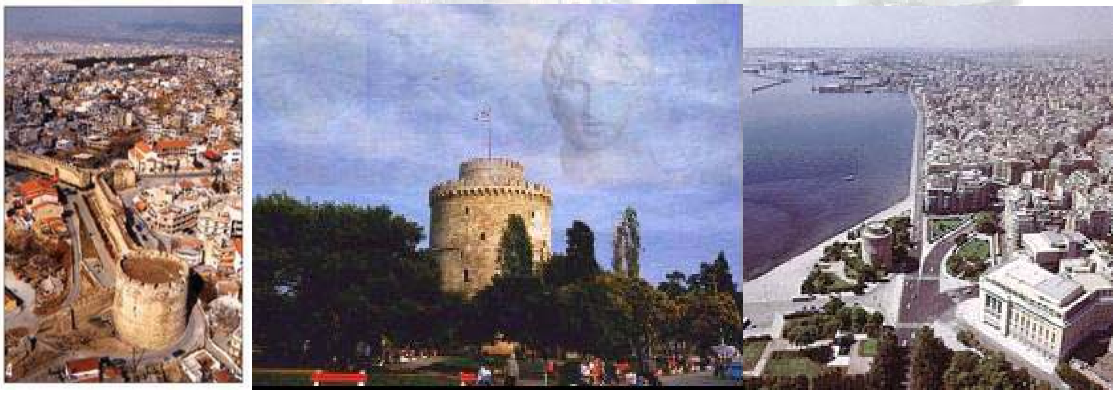
Executive Summary

The Thessaloniki City Report aims to give a comprehensive overview of the work performed in applying the SUTRA model cascade for the Thessaloniki case study. Results for the baseline and scenario analysis are presented for each of the models applied. The results are presented in terms of the indicators for sustainable urban transportation, as defined in work package WP08 and required by WP13 for the scenario analysis.

Keywords: air quality modelling, traffic modelling, energy modelling,



1. Introduction

The objectives of this deliverable are:

- To present the simulations and analysis of the set of scenarios defined in WP10 for the city of Thessaloniki.
- The evaluation of the scenarios in terms of the indicators of sustainable urban transportation defined in work package WP08.

2. City-case description

Thessaloniki is the second largest city in Greece, the capital of the Macedonia region and a growing metropolitan area with much influence in the area surrounding it. Due to its important geographical location, Thessaloniki has always played a major role in the Balkan Peninsula. In the past there has been much trade between Thessaloniki and Bulgaria, Romania as well as Yugoslavia, however the war in Yugoslavia diminished the trading relations with the former Yugoslavian Republics. As the standard of living in Bulgaria and Romania is expected to rise, also in view of the expansion of the EU to include these countries, this is also going to influence the local industrial production in Thessaloniki as well as the exports to these countries. Experts predict that in the next 10 years, the overall industrial production in Greece will rise by ~10% whereas exports will rise by ~30% due to the opening of the Balkan market. Overall, future plans for Thessaloniki aim to improve the current infrastructure (buildings, roads) in order to attract foreign investments especially with regard to the tertiary sector.

The population of the Wider Urban Area of Thessaloniki (WUAT) in 2001 (given by the latest census) was 894435. However this is not the actual number of people that the city hosts on a daily basis, as there are many commuters from an even greater area working in the city and also a large number of higher education students studying in one of the three higher education institutes, 2 universities (located in the city centre) and a technical institute located at 17 km from the city centre, close to the industrial area. The actual number of people that “live” in the city and for which services and infrastructure must be provided for is estimated to be around 1000000. The population of the region Thessaloniki is 1048151 (NSSG, 2001).

The city’s location is at geographic latitude: 40° 39΄N, longitude: 23° 07΄E and altitude: 2 m. The eastern part of the city is on the Thermaikos Bay, whereas towards the north western are hills and a mountain not exceeding 1000m altitude. These constraints are the reason for the city’s longitudinal shape, with main traffic flows moving from east to west and vice versa and consequently the main road axis are also oriented from east to west (west to east).

The main road axis is Egnatia St. which accommodates around 110,000 vehicles per day. Other main road axes are Tsimiski St., Vas. Olgas St., Nikis St., with daily traffic ranging from 60,000 to 80,000 vehicles.

2.1 Atmospheric pollution problems and meteorological conditions

Transport demand

The main source of air pollution in the WUAT, at least for most pollutants, is the transport sector.

- The mean occupancy rate for passenger cars is **1,52** for the year 2000, and rises to **1,56** if taxis are also considered.
- The percentage of public transport use fell from **36,4%** in **1990** to **27,5%** in **2000.**
- New technologies (FCV, EV, etc.) have not yet penetrated the market neither in the private not in the public transport sector, moreover the only means of public transport in the city are diesel buses.
- The law requires that each year all private vehicles obtain an “exhaust card” verifying that the exhausts produced are within acceptable limits. However, it is estimated that up to 40% of the vehicles does not have such a card, hence pollute more than actually estimated.
- In the decade 1989-1999 the number of vehicles in Thessaloniki increase by 75,6% from 283.000 to 497.000, which indicates the definite preference for private transport. However this must be considered in conjunction with the lack of a variety of public transport means.

Apart from the increasing emissions, meteorology also plays a significant role in the city’s air quality. The meteorological conditions and the morphology of the surrounding area favour the persistence of air pollutants in the WUAT for a long period.

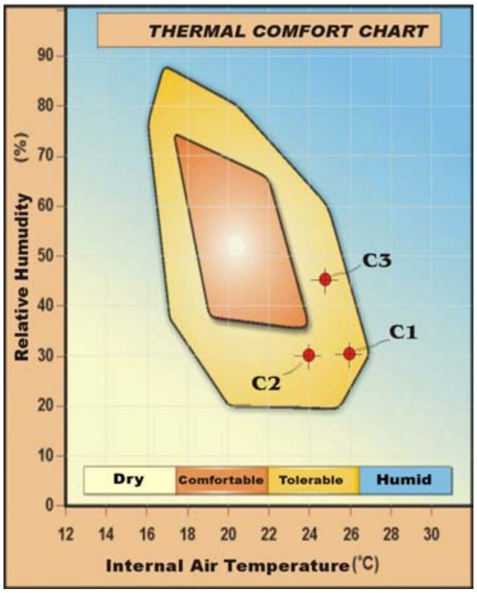


Figure 1. Thermal comfort valuation chart.

Basic characteristics of the area are:

- For almost half of the year (around 45%), the days are characterised by stagnant conditions.
- The Gulf of Thermaikos a closed bay, without major currents allowing for water circulation with the Agean sea.
- The city is densely built, characterised by narrow street canyons.
- Increased levels of humidity are observed, which together with the high temperatures lower the comfort index (see Fanger’s comfort relations figure 1).
- Increased insolation, mainly during the summer months from May to August, favouring the production of ozone

Air pollution is an important problem in the WUAT. In particular PM_{10} are a growing problem in the city centre and close to the industrial area, whereas O_3 is more of a problem in the suburbs of the city. SO_2 levels have significantly decreased in the last years and exceedances with respect to the EU limit values are not observed, however NO_x is still considered a problem.

As concerns PM_{10}, in figure 2 the results of statistical analysis using AIRBASE data shows that exceedances of limit values for daily average and yearly average are observed in all stations.

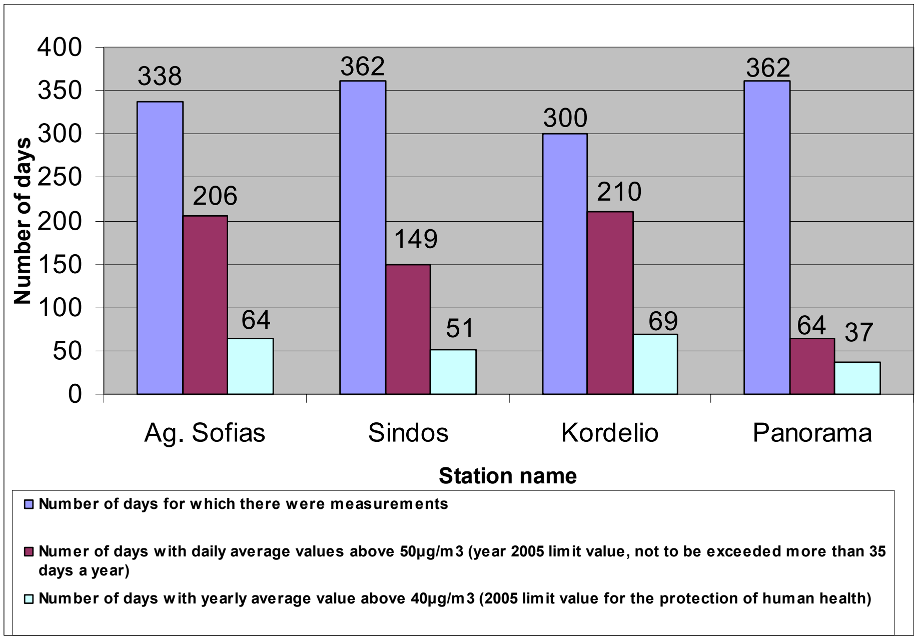


Figure 2. Statistical analysis of PM_{10} measurements using year 2001 data.

In table 1 the average yearly values for each of the stations in the WUAT are shown.

Table 1. Yearly average values for different types of stations in Thessaloniki

Name of station	average yearly value	Type of station
Ag. Sofia	64	Traffic
Sindos	51	industrial
Kordelio	69	"
Panorama	37	background

In stations located in the city centre, but also in stations located more towards the western part of the city and thus closer to the industrial area, it has been found that the traffic related PM_{10} concentrations (dust induced by car circulation, use of diesel fuel, etc.) were very high, between 60-65% in city centre stations (like Ag. Sofia) and around 45% in stations like Kordelio which are closer to the industrial area.

The study of ozone shows that the problem is located far from the city centre, closer to the suburbs. Figure 3 shows that O_3 exceedances of the 120μg/m^3 limit value (not more than 25 days per calendar year) are observed for the stations Sindos, Kordelio, University and most of all for Neohorouda and Panorama stations located in the city's suburbs. As concerns the 180μg/m^3 limit value, this is exceeded in Kordelio, but especially in Panorama and Neohorouda stations which also show a large exceedance of the 120μg/m^3 limit value. It should be noted that exceedances are also observed in Kalamaria station, although this station does not show so many exceedances for the 120μg/m^3 limit value, but that may in fact be due to the small number of measurements available.

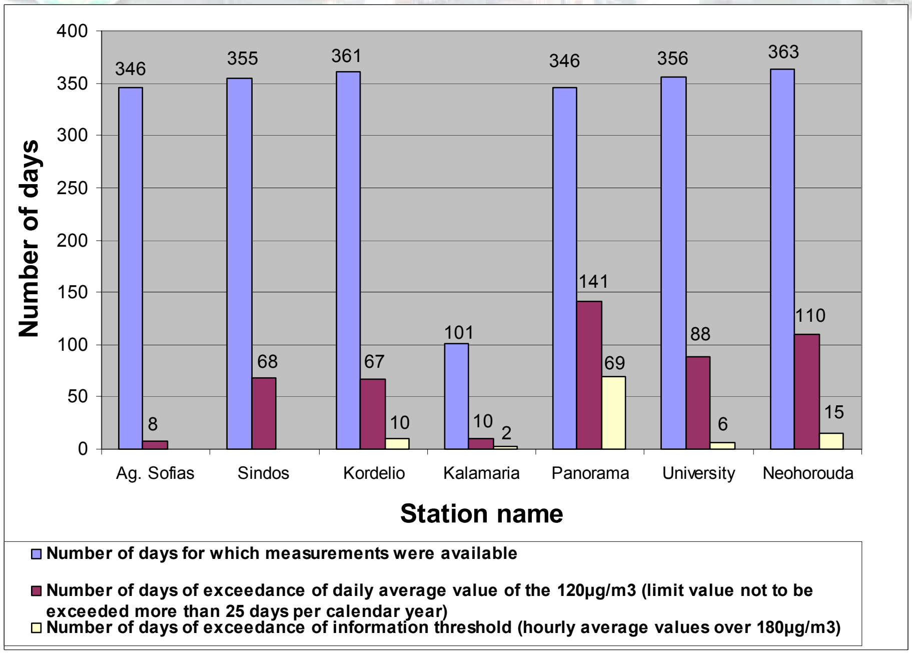


Figure 3. Statistical analysis of O_3 measurements using year 2001 data.

The analysis for NO_x hourly and yearly average values can bee seen in figures 4 and 5. Exceedances of hourly values are observed in all stations except Kordelio station and the same is observed for the yearly average values.

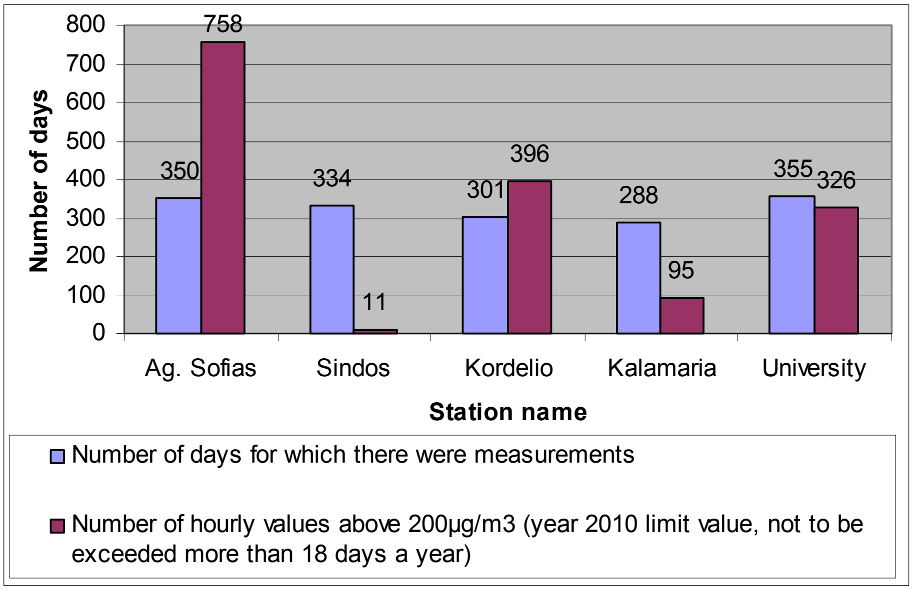


Figure 4. Statistical analysis of hourly NO_x values using year 2001 data.

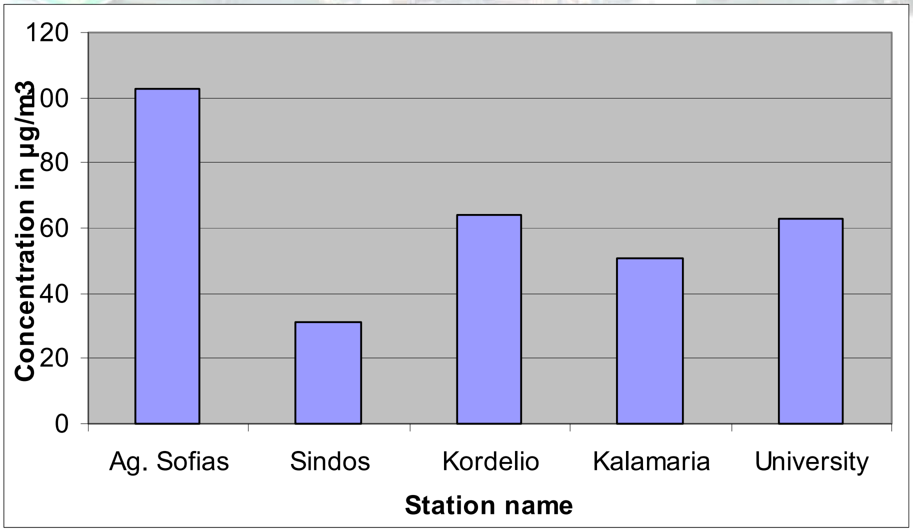


Figure 5. Statistical analysis of yearly average values of NO_x, using year 2001 data.

Summarising:

- The historical and commercial part of the city (city centre) is the principal recipient of the aforementioned pressures.
- High levels of air pollution are also observed in the western part of the city, due to traffic congestion but also due to its neighboring with the industrial area located in Sindos and Kalohori.
- The Eastern part of town has less a problem, but high levels of ozone values are observed (Kalamaria station).
- Maximum concentrations are observed at traffic peak hours, when there is an increase in the anthropogenic activities.
- The situation is better during night hours and during the weekends.

2.2 Demographic, economic, technological and land-use indicators

The following information is related to demographic, economic, technological and land use indicators elaborated in the context of the S.U.TRA. project.
Values (related to year 2000) are reported with reference to the VISUM domain (corresponding to the WUAT), the Region of Thessaloniki and the national level.

- *Demography* is represented by:
  - population size;
  - ageing structure.

Domain	n° Inhabitants	young (0-18)	working age (18-64)	pensioners (64+)
WUAT	894435	203037	593010	98388
Region of Thessaloniki	1057825			
Greece	10964080			

- *Economic data:*

There has been a large increase of almost 250% in the GDP per capita since 1990 more than the average National GDP/capita increase (Figure 6).

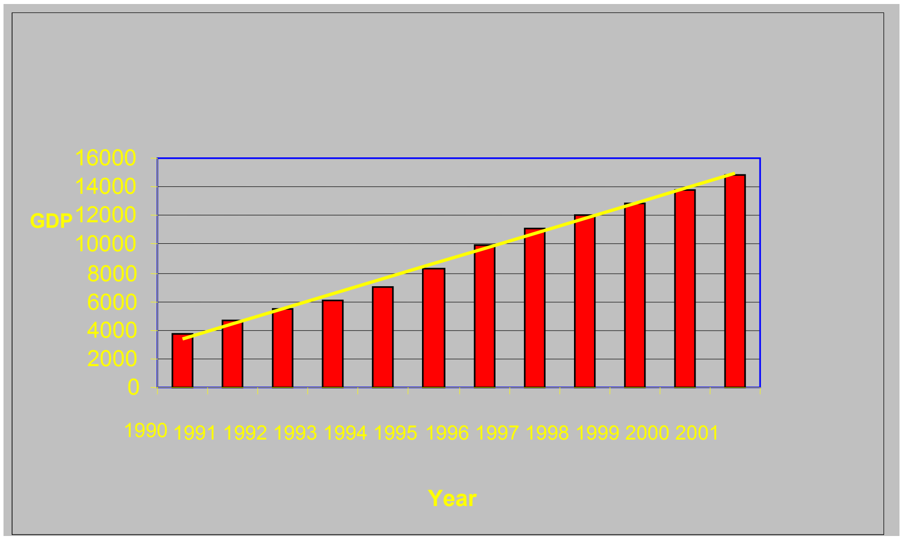


Figure 6. Increase in the GDP per capita (€) for Thessaloniki in the last 10 years.

The economy of the area is mainly based on employment in the tertiary sector (services) and the % of the population employed in this sector is higher than the average National percentage:

Domain	% employment in service
VISUM	72.73
OFIS	72.73
National	70

The % of employment in teleworking in the WUAT is close to 0.

3. Reference/Baseline situation: definition and model cascade application

3.1 VISUM

3.1.1. Domain Definition

The VISUM domain for Thessaloniki includes the following Municipalities and communes:

Area 1 and 2: Thessaloniki Municipality
Area 3: Kalamaria Municipality
Area 4: Municipalities of Panorama, Pylaia and Triandria
Area 5: Municipalities of Ag. Pavlou, Neapolis, Sikies, Polihni and Communes of Pefka and Efkarpia
Area 6: Municipalities of Stavroupolis, Eleftherio, Ampelokipon, Menemenis, Evosmou
Area 7: Municipalities of Ehedorou, Oreokastro, Thermaikos, Hortiatis and parts of Kalithea

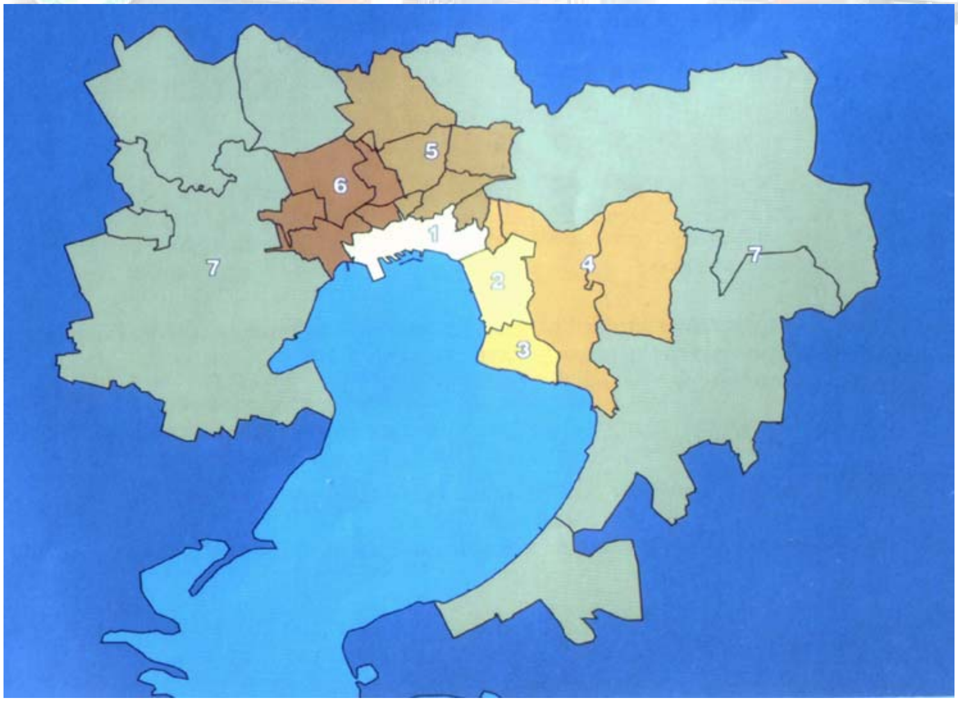


Figure 7. The VISUM domain for the Thessaloniki City Case.

The VISUM domain covers an area of 1100 square kilometres and includes the wider urban area of Thessaloniki (Figure 7).

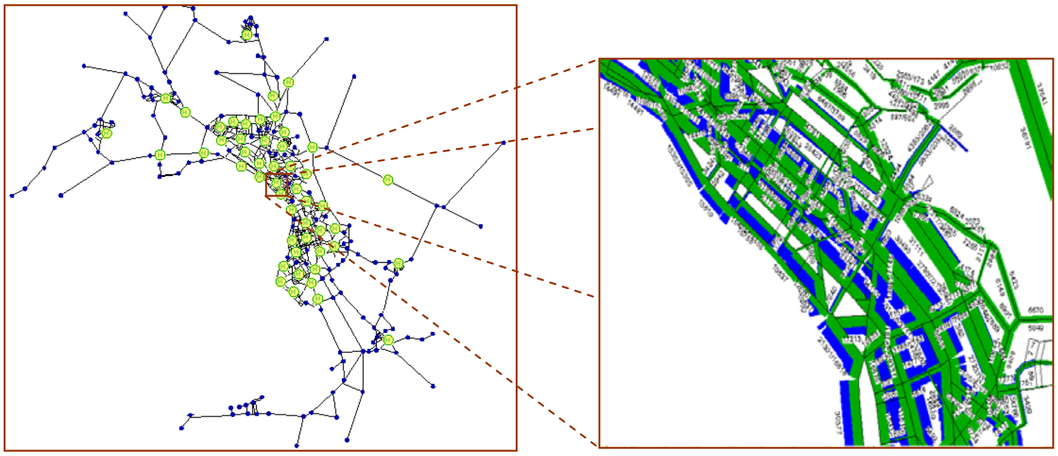


Figure 8. a) Road network of Thessaloniki considered by the transport model VISUM, b) sample of graphical representation of the volume of private and public transport per road link

One of the main sources of data regarding the trips generation for the WUAT was the “General transportation study for the wider urban area of Thessaloniki”, where an analytical survey of transport demand conducted in 1998 revealed that there are almost 1600000 trips generated every day, with all means of transport, 40.6% of these trips used private transport (car) and 27.5% of these used public transport (buses).

3.1.2 Input Data Description

The VISUM model requires information about the public and private transport. The baseline and scenario simulation can be distinguished in various phases, the network definition (Figure 8), the definition of Origin-Destination (OD) matrices for both public and private demand, and finally the trips assignments.

The network

The WUAT network consists of 1381 private transport nodes out of which 469 are also stops, 2034 links (road segments) and the area is split into 316 origin-destination zones which represent the travel demand.

- <u>Private transport</u>

There are 22 types of roads (links) in the VISUM network, each one has a unique set of private transport capacity and maximum allowed velocity values:

TYPE	Cap-PrT	v0-PrT
21	30000	50
22	30000	60
23	30000	70
24	40000	90
31	8000	60
32	12000	60
33	15000	60
34	15500	60
35	20400	60
36	30000	60
37	12000	60
38	15500	60
41	4500	50
42	8500	50
43	12000	50
44	13000	50
45	30000	50
51	4500	30
52	6000	30
53	8500	30
54	9500	30

- <u>Public transport</u>

Public transport networks, timetables and stops

Public transport in the baseline Thessaloniki network consist only of buses (and taxis but they have been considered in the Private Transport OD matrix).

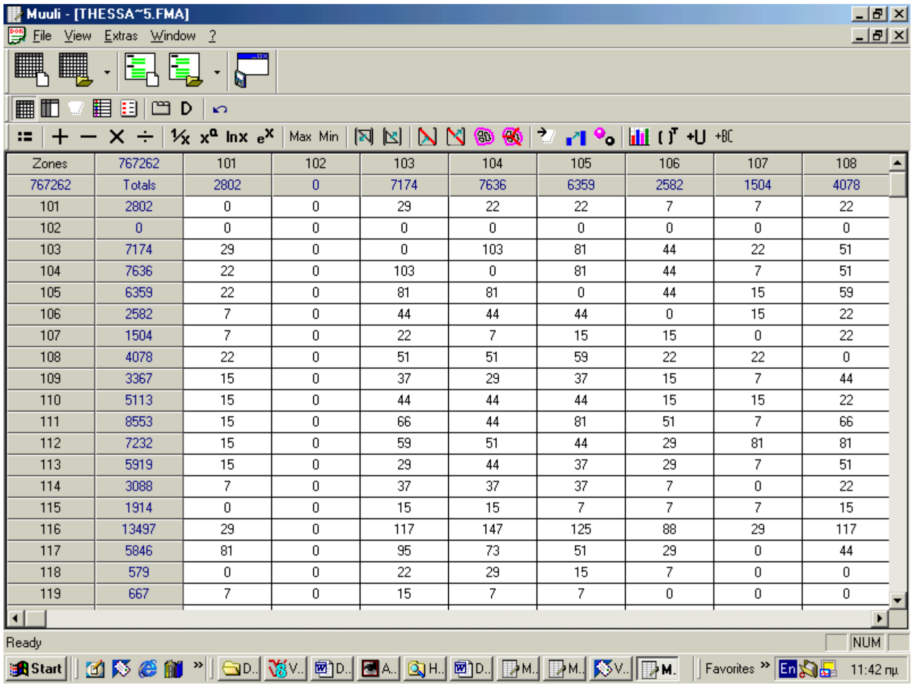
The bus lines entered in the VISUM network are 35 out of a total of 55 bus lines that exist in the WUAT and, as all the main bus lines were considered, these 35 lines accommodate 91% of passengers travelled and hence contribute to 91% of the trips performed (using public transport) in 2001.

The total number of buses that operate in the 35 lines considered are 371 in 2000.

The timetables, stops, statistical data concerning the passengers travelled were obtained from the bus company (OASTH) and entered in VISUM.

OD Matrices

- Public transport



Zones	767262	101	102	103	104	105	106	107	108
767262	Totals	2802	0	7174	7636	6359	2582	1504	4078
101	2802	0	0	29	22	22	7	7	22
102	0	0	0	0	0	0	0	0	0
103	7174	29	0	0	103	81	44	22	51
104	7636	22	0	103	0	81	44	7	51
105	6359	22	0	81	81	0	44	15	59
106	2582	7	0	44	44	44	0	15	22
107	1504	7	0	22	7	15	15	0	22
108	4078	22	0	51	51	59	22	22	0
109	3367	15	0	37	29	37	15	7	44
110	5113	15	0	44	44	44	15	15	22
111	8553	15	0	66	44	81	51	7	66
112	7232	15	0	59	51	44	29	81	81
113	5919	15	0	29	44	37	29	7	51
114	3088	7	0	37	37	37	7	0	22
115	1914	0	0	15	15	7	7	7	15
116	13497	29	0	117	147	125	88	29	117
117	5846	81	0	95	73	51	29	0	44
118	579	0	0	22	29	15	7	0	0
119	667	7	0	15	7	7	0	0	0

Figure 9. Public Transport OD Matrix for the Wider Urban Area of Thessaloniki.

The daily OD Matrices were calculated starting from peak hour OD matrices which resulted from the "General transportation study for the wider urban area of Thessaloniki", a detailed study conducted in 1998, which included measured data and (among other) finally yielding the peak OD matrices used in SUTRA. The public transport peak hour OD matrix was multiplied by an appropriate factor considering the statistical information concerning the average number of public transport (bus) passengers per day travelling in Thessaloniki, finally resulting in a total of 313663 trips considered. The Public Transport OD matrix represents all the trips performed (number of passengers moved) from on zone to another in one day. In Figure 9 appears the public transport OD matrix used for the baseline scenario, as it is viewed through the MULI tool, an additional to the VISUM tool provided by the PTV company.

- Private transport

The daily private transport OD matrix resulted again from the peak hour OD matrix available from the "General transportation study for the wider urban area of Thessaloniki" (see details in Public Transport section above), which included cars and taxis. The "General transportation study for the wider urban area of Thessaloniki" revealed that 8% of the trips in Thessaloniki are conducted during peak hour, therefore this resulted in the factor by which the OD matrix was multiplied in order to obtain the daily OD matrix needed for the calculation of indicators. As the VISUM model provides the transport volumes for each link as input to the TREM model for calculating emissions, the rest of the private transport (light duty vehicles, heavy duty vehicles, motorcycles) had also to be taken into account. Thus the Private Transport OD matrix sum was increased in order to include these private transport means. The heavy duty vehicles considered are only the ones travelling in the city (ie rubbish collecting vehicles, school buses, tourist buses) as these are the only ones that can (with acceptable error) be assumed to follow the given Private Transport OD matrix, since they are actually allowed to travel anywhere in the city. However, the heavy duty vehicles operating at construction sites around the city centre are not allowed to enter the city centre, hence were not included.

This resulted in an OD matrix sum of 777246 vehicles or 767262 passenger car units.

3.1.3 Results analysis

The model runs showed increased traffic load in several streets in the centre of the city, as expected. Streets like Egnatia, Tsimiski, Alexander the Great Avenue and the ring road have the largest transport volume, and therefore tend to suffer from congestion.

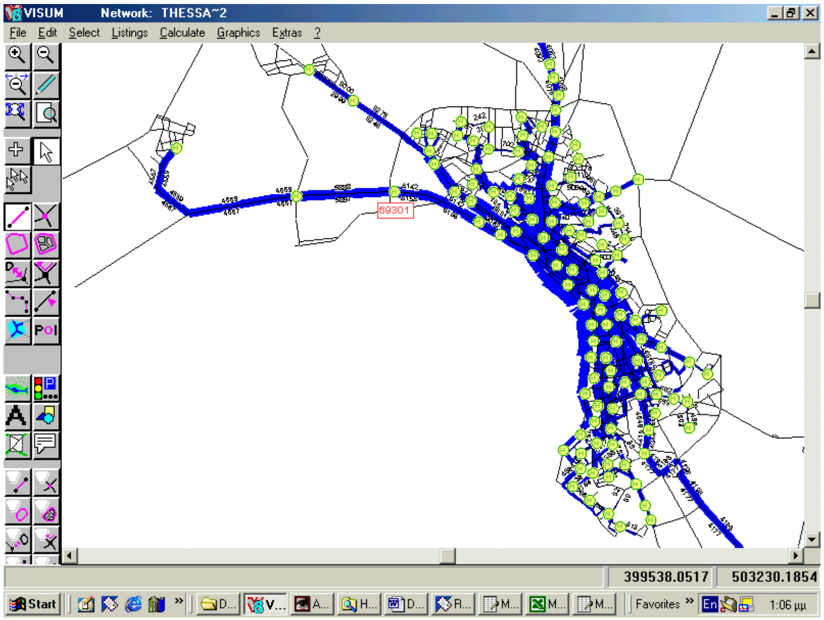


Figure 10. Results for the private transport: Number of vehicles/link per day

The indicators obtained after running PComTest are:

Baseline		
Indicators	By Mode	
	PrT	**PuT (Bus)**
Vehicle-km	5249940	
Vehicle-hr	282148	
Additional vehicle-hr due to congestion	200400	
Vehicle-hr in jam	121117	
Passenger-km		1637348
Passenger-hr		112577
Passenger-hr in overcrowded vehicles		17148

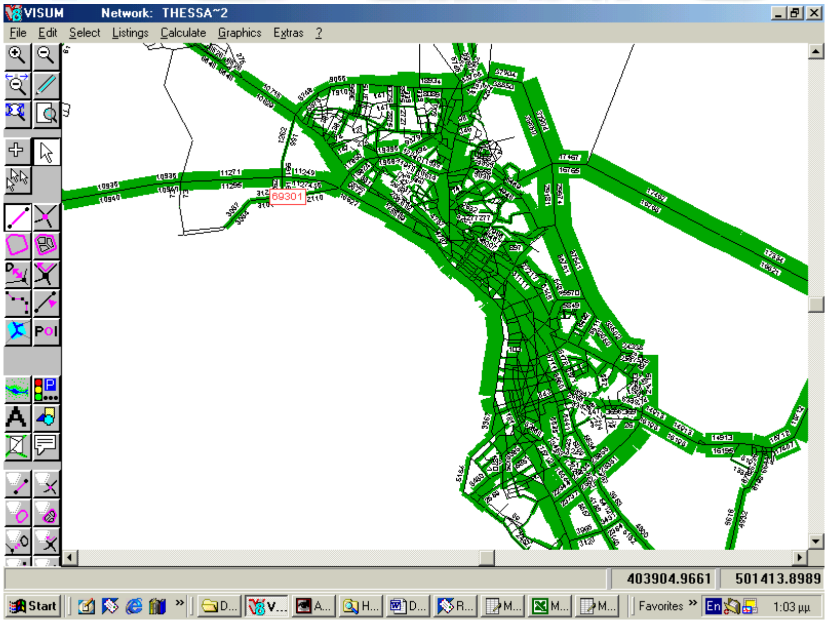


Figure 11. Results for the public transports: Number of passengers/link per day.

Passenger transport demand (pkm per year):

VISUM domain	**2000**
Private transport (car)	2989315836
Public transport	597632020

3.2 TREM

3.2.1. Domain Definition

Transport Emission Model for Line Sources (TREM) was applied to the Wider Urban Area of Thessaloniki (WUAT) in order to estimate amount of pollutants emitted to the atmosphere by road traffic. The traffic volume data provided by VISUM model were used in order to calculate the emissions from road transport. A definition of the study area is based on availability of traffic volume data required for emission estimation, and for this reason the TREM application area coincides with the domain selected for VISUM transportation model.

3.2.2. Input Data Description

The main inputs required by TREM are:

- traffic volumes for all the links (road segments) in the city (provided by VISUM);
- vehicle speed (provided by VISUM);
- distribution of vehicles by categories (passenger cars, LDV, HDV, etc.);
- distribution of vehicles by classes (based on age and technology).

This data are mainly related to traffic characteristics and driven conditions, but some additional parameters such as air temperature and fuel properties are also required.

In order to prepare the inputs to the emission model, statistical data on the vehicle split of Thessaloniki obtained from a study conducted in 1998 (see above-"General transportation study for the wider urban area of Thessaloniki) were used for the reference year, whereas the vehicle fleet composition was provided by the TRENDS model predictions for Greece as no city specific data was available for the year 2000. Comparisons were performed between national and city specific data as regards the fleet composition, for the years for which these data were available and thus the distribution of vehicles per vehicle class for Thessaloniki for the year 2000 was estimated. Due to detailed information absence, the same distribution of vehicles by categories was considered for all roads.

Data for the reference year 2000 was used whenever possible. If such data was not available, data for the year most close to the reference year was used.

Vehicle categories

The vehicle split for the Wider Urban Area of Thessaloniki that was used for the runs (Figure 12) is characterised by an important contribution of passenger cars (84.12%) without reflecting the national trend which rounds about 54%. The role of motorcycles in Thessaloniki is also very considerable (9.47%). As a general trend, LDV and HDV reveal to have not very important part in WUAT fleet (5.92% and 0.24%) compared with national values (16% and 4%).

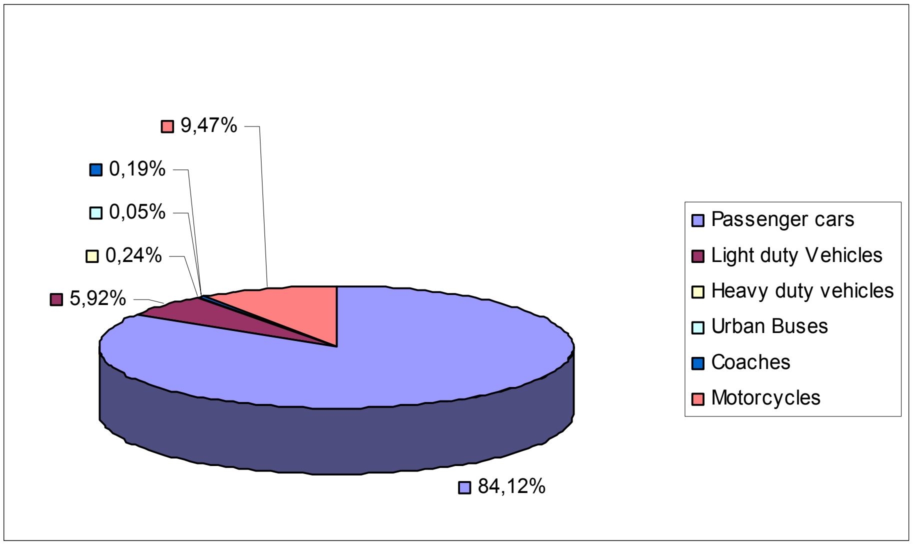


Figure 12. Vehicle split of the Wider Urban Area of Thessaloniki for the year 2000

Vehicle classes:

Vehicle classes (vehicle technologies) reflect the vehicles age which is one of the important characteristics for emission estimation. The data on the vehicle fleet composition provided by the TRENDS model predictions for Greece summarise the age distribution of vehicles in circulation in Thessaloniki (Table 2).

Table 2. Age distribution of vehicles in circulation in Thessaloniki for the year 2000

Age (years)	**Passenger Cars**	**LDV**	**HDV**	**Busses-Coaches**	**Motorcycles**
>20	130483	36790	1621	1554	49700
15-20	85008				
9-15	125112				
5-9	169527				
1-5	149341	9248	252	371	17187

The TREM model is directly connected to the transportation model VISUM to obtain the traffic volume data for each road segment. The outputs from the VISUM model were adapted in order to obtain the input data necessary for the emission model, according to the required resolution and in the specified format.

3.2.3. Results analysis

The TREM model was applied to the VISUM domain of the WUAT, for a typical day. Therefore, the network description was provided directly from the VISUM outputs (.ver file) whereas information on the cold distance (distance covered under cold vehicle engine) was derived through the running of PcomTest (a software application created by PTV especially for this purpose).

The derived emissions –hot, cold and total- for the road network cover the following pollutants: CO, CO_2, NO_x, PM, SO_2 and VOC. Fuel consumption is also part of the model results. The form of the model outputs is presented in table 3. Results of the model calculations are presented in table 4.

Table 3. Sample of the TREM results

Link_nr	Type	VolVeh	Vo	Length	Gradient	CO(gr)	CO_2(gr)	NOx(gr)	PM(gr)	SO_2(gr)	VOC(gr)	Fuel(gr)
1	1	3264	30	578	0	24780	416600	1902	71	39	4185	281800
1	1	2832	30	578	0	21300	329100	1642	61	34	4446	180100
2	1	8452	50	109	0	7163	136500	988	27	15	1603	72810
2	1	0	0	109	0	0	0	0	0	0	0	0
3	1	0	0	104	0	0	0	0	0	0	0	0
3	1	5210	30	104	0	7410	121200	547	20	11	1386	90830
4	1	2406	30	274	0	9185	148800	666	25	14	1949	106800
4	1	0	0	274	0	0	0	0	0	0	0	0
5	1	2812	30	284	0	12050	182800	802	30	17	3342	130700
5	1	0	30	284	0	0	0	0	0	0	0	0
6	1	3179	30	337	0	16180	240200	1085	40	22	4761	164100
6	1	277	30	337	0	1513	21570	97	4	2	439	15120

Table 4. Total emissions per pollutant calculated by TREM for the baseline scenario for Thessaloniki

	CO	**CO_2**	**NOx**	**PM**	**SO2**	**VOC**	**Fuel cons**
gr/day	38427175	777740238	6615918	143462	79890	8536852	397756838
tons/year	14026	283875	2415	52	32	3116	145181

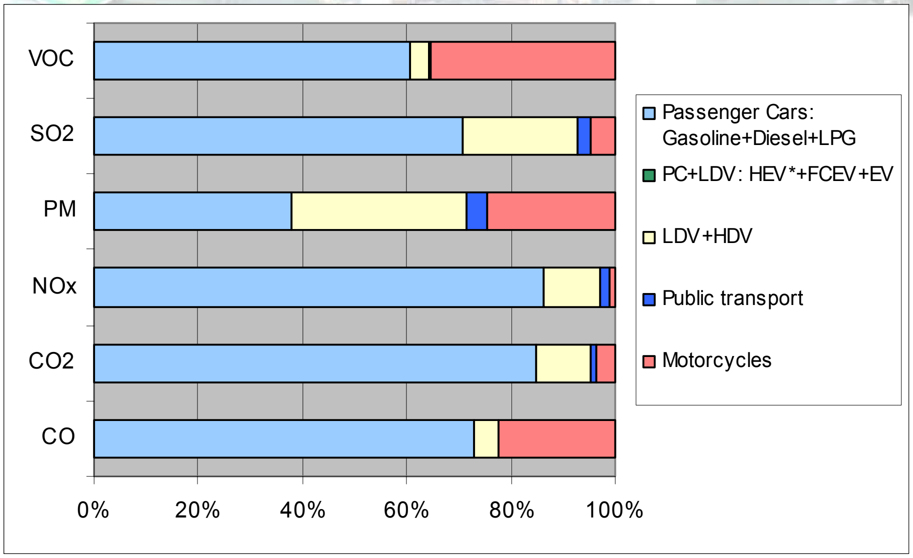


Figure 13. % contribution of vehicle categories emissions to the total emissions for the baseline scenario

From the comparison of the contribution of each vehicle category to the total emission per pollutant (Figure 13) it can be concluded that the major contributor to the total emissions in almost all pollutants is the passenger cars fleet (above 60%) except from the PM emissions where emissions from diesel-engined cars and motorcycles prevail.

The TREM model results were compared to other emission inventories available for the Region of Thessaloniki for 1995, which were created using the COPERT methodology and were found to be underestimated. This could be due to the fact that there is an underestimation of the HD vehicles considered to circulate in the city (see section 3.1.2, OD-matrices-private transport), but also due to the vehicle speed considered by the VISUM model.

3.3 VADIS

3.3.1. Domain Definition

The street canyon model VADIS was applied to a specific hot spot area in the centre of Thessaloniki, where high air pollutants levels are expected to occur because of heavy traffic emissions. The dimension of the domain is 300x300 m^2 (Figure 14). It is a highly commercial area located in the centre of the city. The City Hall is situated within the domain whereas in its vicinity there is a terminal bus station and zones of historic importance, like Aristotelous Street and Square.

The VADIS domain co-ordinates are:

x	y
410221.7568	498739.2226
410465.0758	49856.0043
410641.2941	498806.3233
410397.9751	498982.5416

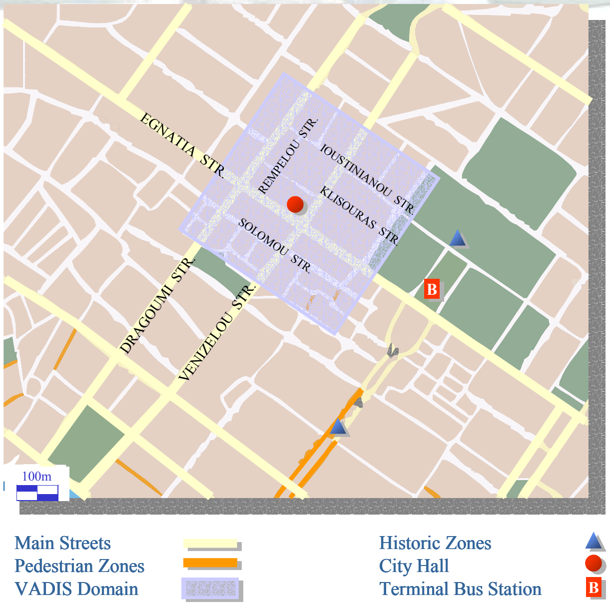


Figure 14. The VADIS domain

3.2.2. Input Data Description

The input data required by the model were collected and included:

- data concerning the number, position and dimension of the “obstacles” (buildings) that block the circulation of air and “trap” the air pollutants from the lines sources in the street canyons
- the location of the emissions
- the description of the emission sources, namely the number, type (point, line and/or volume sources) and emission rates as these were computed by the TREM model
- the description of meteorology, namely the wind velocity and direction at the lateral boundaries of the domain at a specified reference height and air temperature

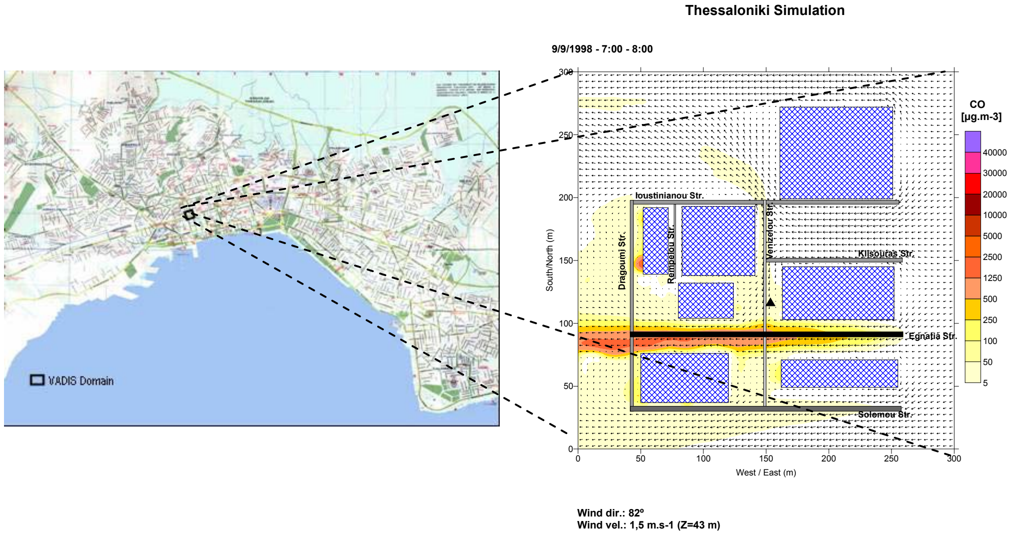


Figure 15. a) Location of VADIS domain in Thessaloniki, b) CO dispersion simulation for Thessaloniki for 7:00-8:00 a.m. of 9 September 1998

The VADIS domain studied contained only line source emissions (streets) and hence the input data for the simulation consisted of seven line sources and seven buildings. Low wind speed characterized the meteorological conditions of the day considered (9/9/1998).

3.3.3. Results analysis

In the scope of this work, the CO concentration field for a traffic rush hour with specific dispersion conditions were calculated. The results showed good aggreement when compared with the concentration values from the air quality station located in the simulation domain, which measured a CO concentration value of 2900 μg/m^3 at 7 a.m. Figure 15 shows the wind and concentration fields obtained with the VADIS model.

Bellow one can find the state indicators, ie peak concentration values (μg.m^{-3}) computed for each of the pollutants CO, NO$_x$ and PM$_{10}$ for the baseline scenario:

State indicators – Peak concentrations:

	Baseline
CO (μg.m^{-3})	5130
NOx (μg.m^{-3})	545
PM10 (μg.m^{-3})	15,89

3.4 OFIS

3.4.1. Domain Definition

An area of 150×150 km^2 with the considered city in the centre and rural area all around is the typical domain of OFIS. In the case of Thessaloniki this extended area includes a large part of the Central Macedonia Region, as can be seen in the following figure.

Figure 16. a) Map of Greece with the location of the OFIS domain b) Number of days with maximum 8hour running average ozone concentration exceeding 120μg/m^3 (IND120)

3.4.2. Input Data Description

Input data required by the OFIS model include information about the geography of the city, its population figure, hourly total emissions for a typical day, average diurnal data about the atmospheric trace gases and meteorology for every day of the simulation period. The emissions data prepared for the model were prepared using the CORINAIR 1995 emissions that are available for the NUTS3 level, ie the region of Thessaloniki. EMEP data were used to construct the boundary conditions and meteorological file. More details can be found in the deliverable D5.1 of the SUTRA project.

3.4.3. Results analysis

City runs revealed that during the 6-month period studied, ozone concentrations exceeded the threshold of 120 μg/m^3: 4 days in the city centre, 10 days in the suburban area and 31 days in the rest of the domain, ie away from the city centre, but in an area influenced by it (Figure 16). Although the prevailing wind direction is northeastern, exceedances are also observed in the northwestern part of the domain and that is due to the sea breeze effect which is observed in the area and which results in an inversion of the wind direction for the sea breeze days.

The indicators that derived from the model runs are included in table 5.

Table 5. OFIS indicators- definitions

	AOT(max),	AOT(ave),	AOT(sub),	AOT(town)
AOT60	3.21	1.95	0.62	0.29
	E120(domain)	E120(sub)	E120(town)	
DAYS	31	10	4	

AOT60	AOT(max), Maximum **ppb x hours** index within the computational domain	AOT(ave), Average **ppb x hours** index within the computational domain	AOT(sub), Average **ppb x hours** index within the suburban area	AOT(town) Average **ppb x hours** index within the town area
DAYS	E120(domain) Number of days with exceedance s of the 120 μg/m^3 value in the whole domain	E120(sub) Number of days with exceedance of the 120 μg/m^3 value in the suburban area	E120(town) Number of days with exceedance of the 120 μg/m^3 value in the town area	

3.5 MARKAL

3.5.1 Domain Definition

The domain chosen for the application of the MARKAL-Lite model includes besides the Municipality of Thessaloniki, 18 municipalities and 2 communes around the city (Figure 18). It corresponds to the VISUM/TREM domain, it covers an area of 1100 km^2 and the population in 2000 was 894435.

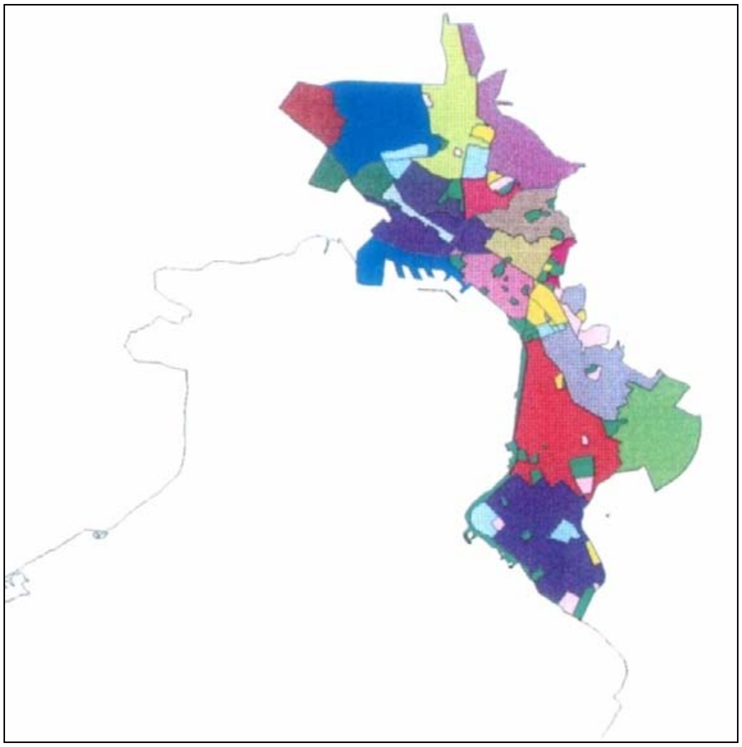


Figure 18. The MARKAL domain for the Thessaloniki City Case.

3.5.2 Input Data Description

The model input requirements include the following:

- Imported energy prices for:

  Biogaz, Coal, Light fuel oil, Diesel fuel for transport, Ethanol EURO-125, Geothermal, Gasoline unleaded, Gasoline with lead, Hydrogen, Hydraulic, Latent heat, Natural Gaz for Cars, Methanol, Municipal solid waste, Natural gas for households, Natural gas for FCC, Natural gas for industry, Dummy input, Solar energy, Solar energy (heat), Latent heat for heat pump, Wood residential.

- Demand data for 1990-2000 with forecasts until 2030 for the sectors:
  - Transportation
    - Public transport: buses, Tramway
    - Private Transport: cars, motorcycles, taxis
    - Commercial transportation: Trucks and delivery vehicles
  - Heating
    - Residential heating demand
    - Commercial heating demand

        - Industrial heating demand
        - Public Heating demand
    - Warm water
        - Residential warm water demand
        - Commercial warm water demand
        - Industrial warm water demand
        - Public warm water demand
    - Electrical appliances and light
        - Electrical appliances and light / Residential Sector
        - Electrical appliances and light / Commercial Sector
        - Electrical appliances and light / Industrial Sector
        - Electrical appliances and light / Public Sector
        - Electrical appliances and light / Agricultural Sector
- Residual capacities, techno-economic data, input/output coefficients, availability and lifetime of all technologies which used in order to satisfy all the demands.
- Pollutants emissions associated with technologies.

3.5.3 Results analysis

Fuel consumption

Fossil fuel consumption over the given time periods for:

COA	coal
DSL	light fuel oil
DST	Diesel fuel for transport
GSW	gasoline with lead
HYD	hydraulic
MET	methanol
MSW	municipal solid waste
NGA	natural gas for households
WOR	wood residential

is presented in the following graph (Figure 19).

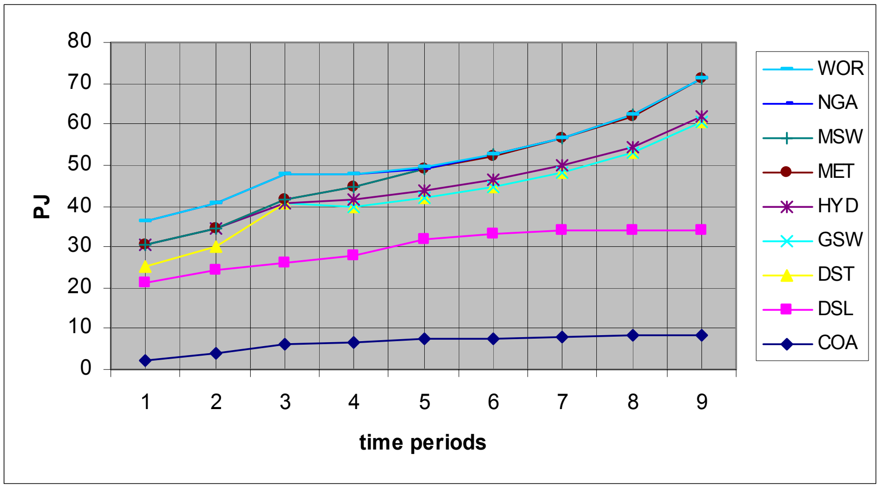


Figure 19. Consumption of fossil fuels

Transportation

The total emissions for NO_2, SO_2, CO and VOC in tn/year as modelled for transportation are presented in figure 20.

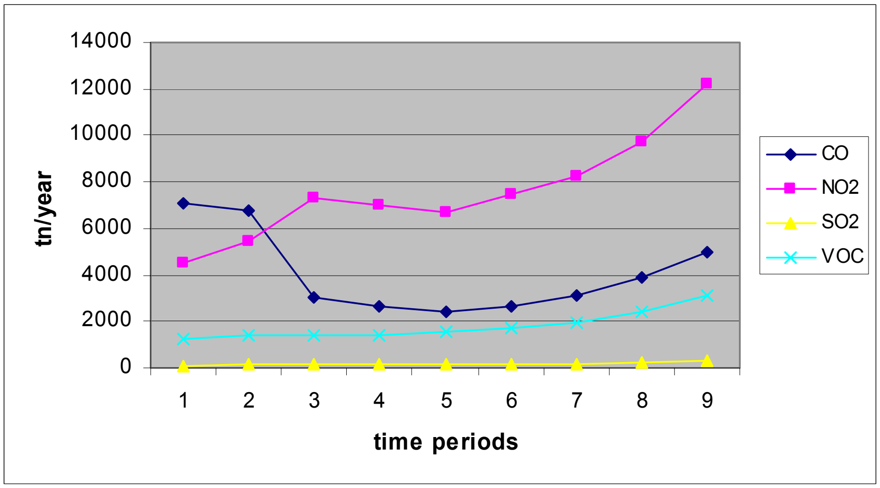


Figure 20. Total emissions from transport sector

The emissions CO, NO_2, SO_2 and VOC in tn/year for each of the modes are shown in the diagrams below (Figures 21-24).

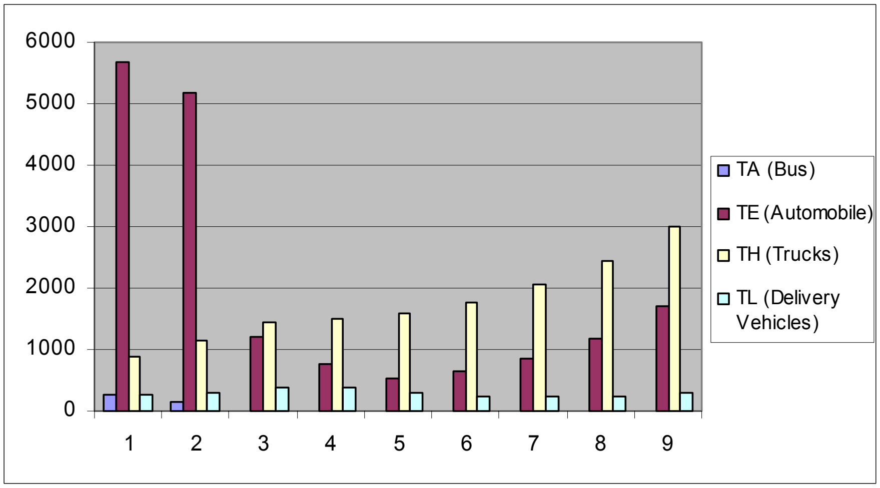


Figure 21. CO emissions for each vehicle category in tons/year

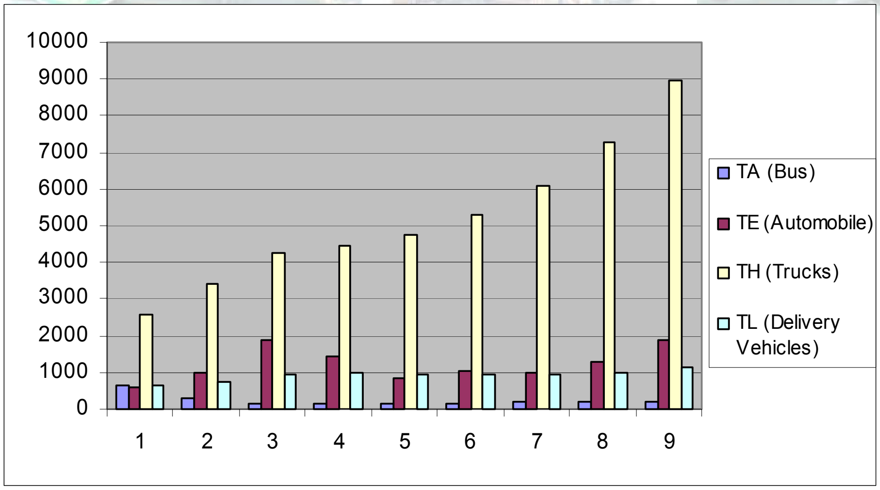


Figure 22. NO_2 emissions for each vehicle category in tons/year

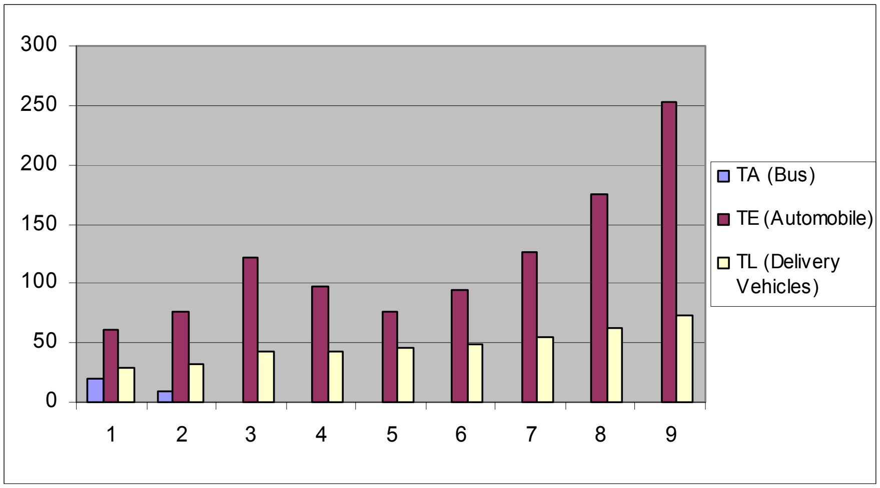


Figure 23. SO_2 emissions for each vehicle category in tons/year

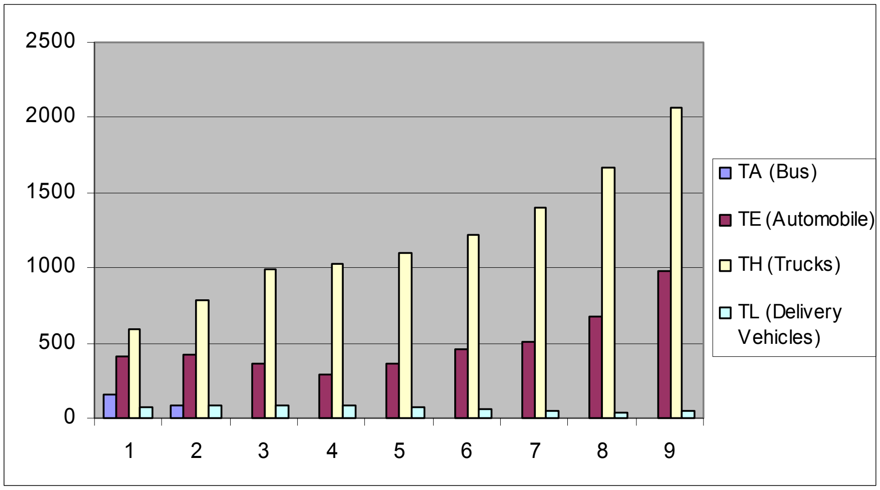


Figure 24. VOC emissions for each vehicle category in tons/year

Heating

For the heating sector the NO_2 emissions results are presented in figure 25:

(S,N=Summer, Night, S,D=Summer Day, I,N= Intermediate Night, I,D= Intermediate day, W,N= Winter Night, W,D= Winter Day)

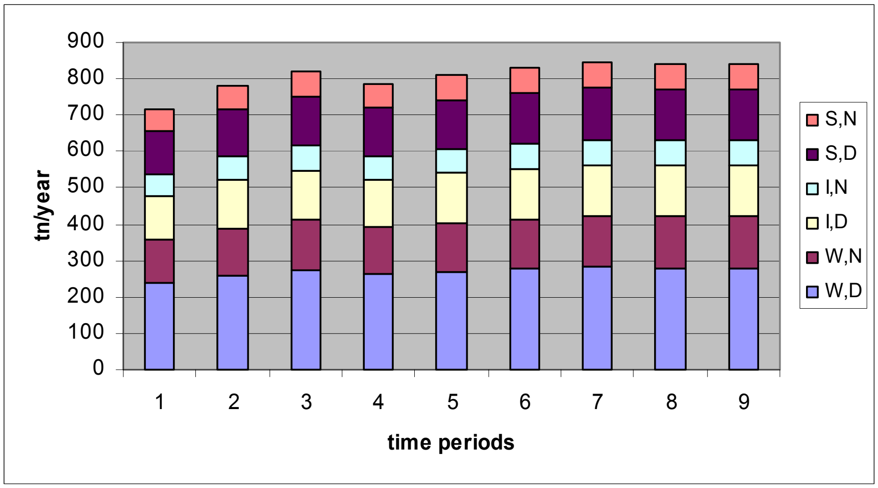


Figure 25. NO_2 emissions from the heating sector

4. Common scenarios

General description

All models were run for a baseline situation (2000) and results have been described in the above sections. However as the aim of the SUTRA project was to investigate and plan a “City of Tomorrow” each city ran every model under conditions highlighted in a set of “common scenarios”. Four scenarios were chosen which depicted four variation of change in four parameters: demography, economy, land-use and technology, for the year 2030. Each city ran exactly the same scenario so that comparisons could be made between cities experiencing identical changes by 2030.

Description of the four common scenarios:

•Dynamic, rich and virtuous city
a young and growing city moving fast to high-tech services jobs, which cares about the environment and adopts clean technologies and careful planning

•Dynamic, rich and vicious city
a young and growing city moving fast to high-tech services jobs, which, however, saves on clean technologies and grow chaotically into the countryside around

•Virtuous pensioners’ city
a city becoming a city of pensioners, it does not grow, does not change its economic structures, yet, it cares about the environment and adopts clean technologies and careful planning

•Vicious pensioners’ city
a city becoming a city of pensioners, it does not grow, does not change its economic structures. It does not adopt clean technologies or careful planning

Table 6. Changes of parameters for each scenario.

	Dynamic, rich and virtuous	Dynamic, rich and vicious	Virtuous Pensioners City	Vicious Pensioners City
Demographic	Increasing	Increasing	Decreasing	Decreasing
Economic Structural	Increasing	Increasing	Decreasing	Decreasing
Technological	Increasing	Decreasing	Increasing	Decreasing
Land Use	Increasing	Decreasing	Increasing	Decreasing

For the Thessaloniki case and for the Common scenarios CS1 and CS2 which assume that the city is getting younger, an increase in population by 53% compared to the year 2000 population is considered, whereas for scenarios CS3 and CS4 where it is assumed that the city is getting older, a decrease in the population by 26% is considered.

For the virtuous scenarios (CS1 and CS3), which hope for an eco-sensitive population making use of car pooling, the occupancy rate is considered to increase significantly, reaching a value of 1.64.

In the vicious scenarios (CS2 and CS4) it is expected that the private car use will continue to increase and hence the occupancy rate will fall, hence an occupancy rate of 1.54 is considered for the WUAT.

In the optimistic growth scenario (CS1) we assume that the population will make more use of public transport and hence an increase of 112% to the current number of passengers travelled is assumed, reaching a total of 663508 passengers travelled per day. In the young but vicious scenario an increase in the number of passengers is again assumed, since there is an increase of 53% in the population, but smaller than the previous scenario (38%). The old but virtuous scenario considering a city of eco-sensitive pensioners assumes an increase is public transport use of the order of 2%, a very low percentage since the elderly have less transport needs, and finally the old but vicious scenario assumes a decrease in public transport use by 34%.

4.1 VISUM

4.1.1 Input data description

Indicators from PTV macro

The summary table produced by the PTV macro providing the input data used for each of the common scenarios can be found bellow:

		Young and Virtuous	Young and Vicious	Old and Virtuous	Old and Vicious
Indicator	**Analysis**	**CS1**	**CS2**	**CS3**	**CS4**
Population	894435	1398074	1398074	661614	661614
Average Trip Rate	1.89	1.67	1.67	1.69	1.69
PuT Share	0.28	0.43	0.28	0.43	0.28
PrT Share	0.53	0.38	0.53	0.38	0.53
Car Occupancy Rate	1.560	1.638	1.544	1.638	1.544
PuT Matrix Sum	313663	663508	432052	318975	207705
PrT Matrix Sum	767261	721663	1067532	346933	513206
Average Distance PuT	6.00	4.85	7.17	4.85	7.17
Average Distance PrT	7.60	5.87	9.21	5.87	9.21
Distance Change PuT		-19.2%	19.5%	-19.2%	19.5%
Distance Change PrT		-22.7%	21.2%	-22.7%	21.2%

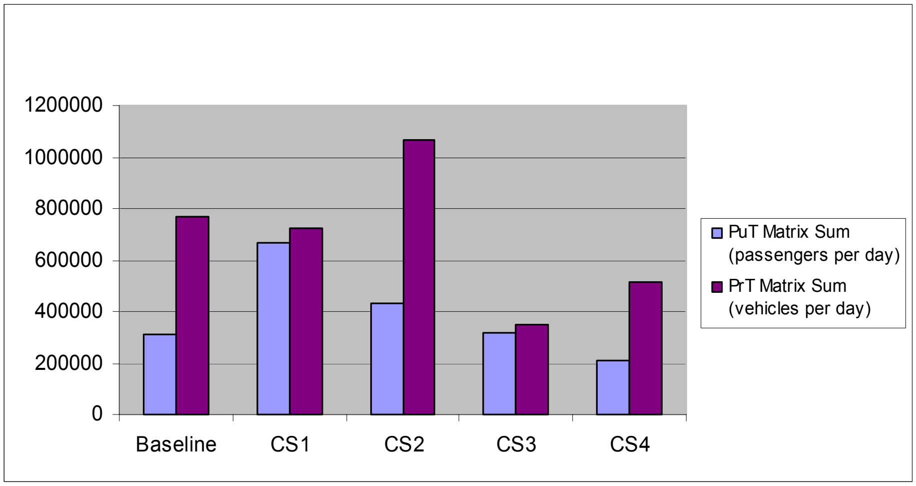


Figure 26. Comparison of PuT and PrT Matrix Sums used for the Baseline and the Common Scenarios

The figure 26 above presents the general attitude of the citizens of Thessaloniki towards public and private means of transportation for each common scenarios compared to the baseline scenario.

4.1.2 Analysis of scenarios results

Common scenario 1

Transport indicators results

CS1		
Indicators	By Mode	
	PrT	**PuT (Bus)**
Vehicle-km	3.730.869	
Vehicle-hr	117.794	
Additional vehicle-hr due to congestion	59.415	
Vehicle-hr in jam	13.629	
Passenger-km		2.884.273
Passenger-hr		198.460
Passenger-hr in overcrowded vehicles		4.713

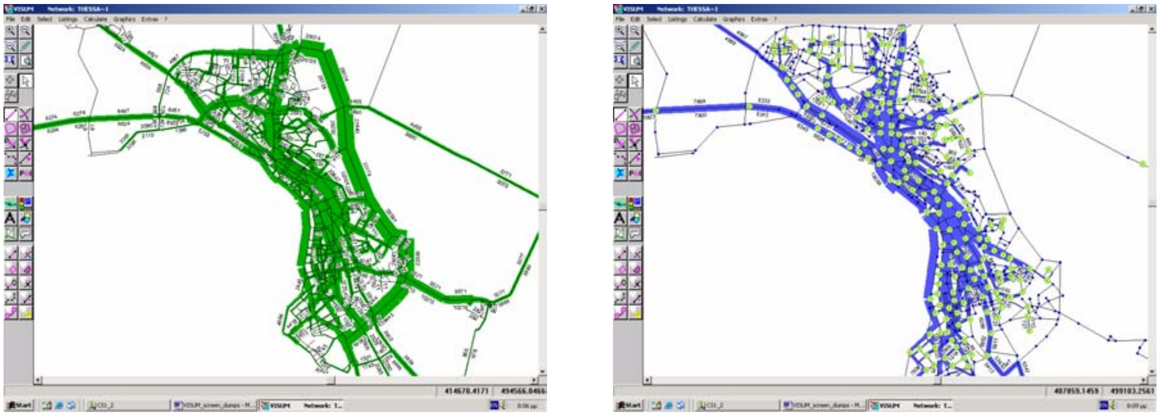


Figure 27. On the left are the results for the private transport systems and on the right are the results for the public transport assignment (number of passengers/link per day)

Analysis:

Private Transport

A decrease of 29% with respect to the baseline is observed as concerns the total veh-km performed by private transport, in line with the young and virtuous scenario which predicts an increase public transport use by 112%. Moreover the total veh-hrs spent using private transport fall by 58%. The additional veh-hrs due to congestion also fall significantly (70% decrease) since there is less private transport use, and the same goes for the vehicle-hr is traffic jams, which falls significantly reaching 11% (!) of its initial value.

Public Transport

The increase in public transport use results in an increase in the pass-km with public transport by 76% with respect to the baseline and consequently there is an increase in the total pass-hrs spent using public transport. Furthermore an important decrease in the total pass-hrs spent in crowded vehicles is observed with respect to the baseline (-73%), since there overall capacity of the public transport system as a whole has increased to account for the 56% increase in population.

Common scenario 2

Transport indicators results

CS2		

Indicators	By Mode	
	PrT	**PuT (Bus)**
Vehicle-km	8.830.531	
Vehicle-hr	1.861.537	
Additional vehicle-hr due to congestion	1.721.957	
Vehicle-hr in jam	1.679.033	
Passenger-km		2.630.366
Passenger-hr		180.749
Passenger-hr in overcrowded vehicles		14.169

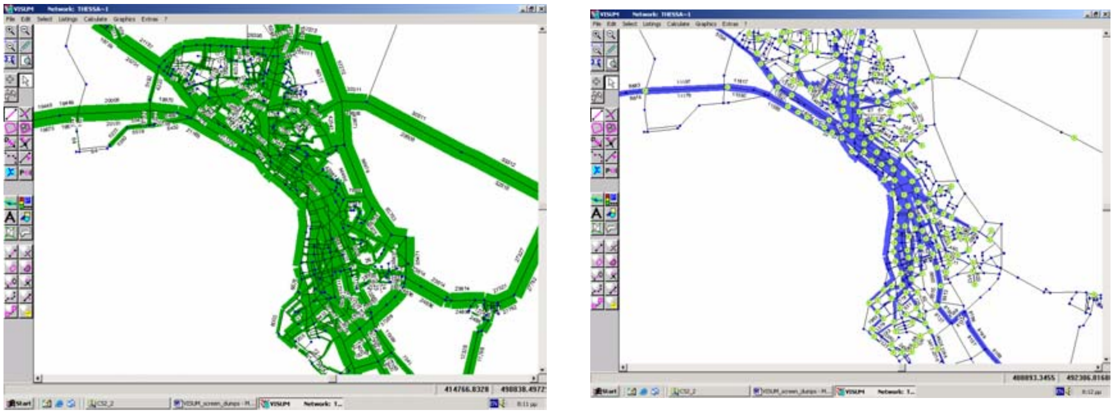


Figure 28. On the left are the results for the private transport systems and on the right are the results for the public transport assignment (number of passengers/link per day)

Analysis:

Private Transport

An increase of 68% with respect to the baseline is observed as concerns the total veh-km performed by private transport, in line with the young but vicious scenario which predicts an increase in the population, but also an increase in private transport use by 39%. With respect to the young but virtuous scenario the increase in veh-km is 37%. Consequently there is a very large increase in the total veh-hrs spent using private transport. The additional veh-hrs due to congestion also increase to reach the tremendous amount of 1721957, since there is such a large increase in the private transport use and there is also a large increase in the vehicle hours spent in traffic jams, since the network is so overloaded with private transport.

Public Transport

An increase in the pass-kms is observed with respect the baseline, (61%), due to the increase in population. However, with respect to the young and virtuous scenario there is a decrease in the total pass-kms performed using public transport, by 9%. Consequently, as concerns the pass-hrs, there is again a decrease in the total pass-hrs spent using public transport with respect to the CS1. The total pass-hrs in overcrowded vehicles also increases with respect to the young and virtuous scenario, since it is considered that the overall public transport capacity would decrease in the vicious scenario, however they decrease with respect to the baseline scenario, as new means of transport will be provided, a necessity in line with the increase in population.

Common scenario 3

Transport indicators results

CS3		

Indicators	By Mode	
	PrT	**PuT (Bus)**
Vehicle-km	1.598.080	
Vehicle-hr	30.213	
Additional vehicle-hr due to congestion	4.800	
Vehicle-hr in jam	125	
Passenger-km		1.387.672
Passenger-hr		95.479
Passenger-hr in overcrowded vehicles		252

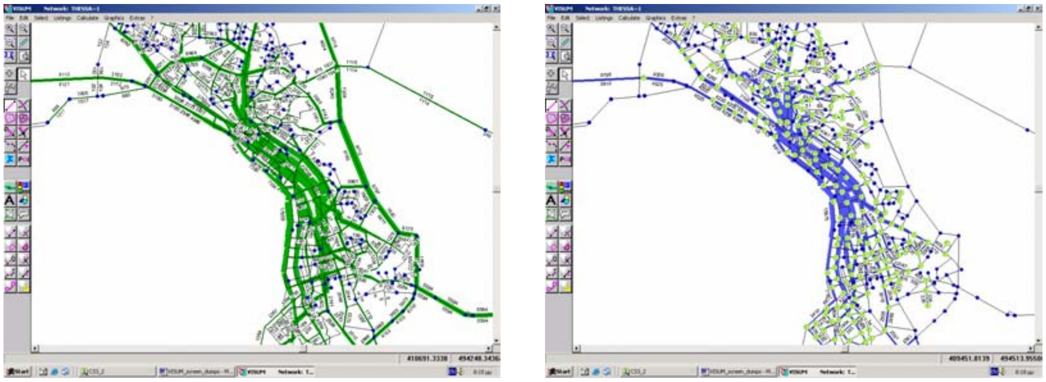


Figure 29. On the left are the results for the private transport systems and on the right are the results for the public transport assignment (number of passengers/link per day)

Analysis:

Private Transport

A decrease of 70% with respect to the baseline is observed as concerns the total veh-km performed by private transport, in line with the old but and virtuous scenario which predicts a decrease in population by 26%, but an increased use of public transport by 2%, which although small is large compared to the decrease of population. Moreover, the total veh-hrs spent using private transport fall by 89% with respect to the baseline scenario and the additional veh-hrs due to congestion also fall significantly, since there is less private transport use and an important decrease of the population altogether. Consequently the vehicle-hrs in traffic jams is also very low.

Public Transport

The decrease in population with respect to the baseline scenario results in a decrease of 15% in pass-kms, which is small compared to the decrease in population (-26%), since there is general increase in public transport use. Moreover, a decrease of 15% with respect to the baseline situation is observed as concerns the total pass-hrs spent using public transport. The old and virtuous scenario pass-hrs spent in overcrowded vehicles decreases significantly with respect to the baseline, as there is a decrease in the population but an improvement in the public transport means provided and thus an increase in the capacity of the public transport system as a whole.

Common scenario 4

Transport indicators results

CS4		

Indicators	By Mode	
	PrT	**PuT**
Vehicle-km	3.912.214	
Vehicle-hr	106.768	
Additional vehicle-hr due to congestion	48.087	
Vehicle-hr in jam	7.453	
Passenger-km		1.263.579
Passenger-hr		86.821
Passenger-hr in overcrowded vehicles		6.340

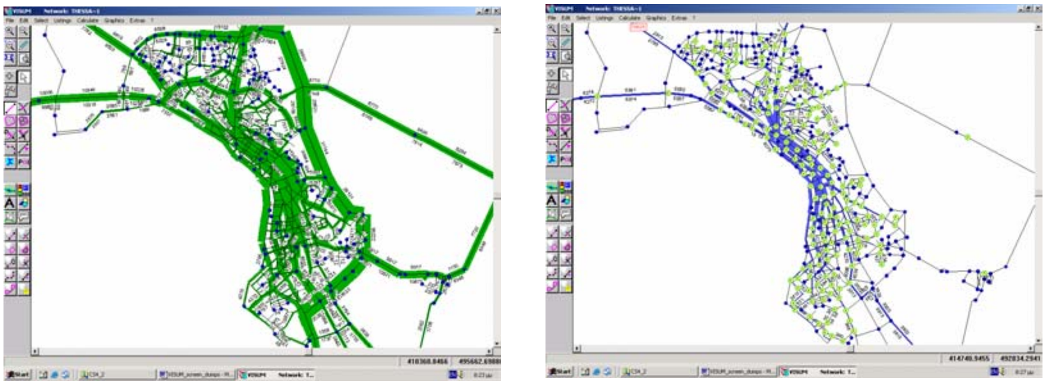


Figure 30. On the left are the results for the private transport systems and on the right are the results for the public transport assignment (number of passengers/link per day

Analysis:

Private Transport

A decrease of 25% with respect to the baseline is observed as concerns the total veh-km performed by private transport, in line with the old but vicious scenario which predicts a decrease in population by 26%, but an increased in the use of private transport by 45% is observed when compared to the old but virtuous scenario which considers the same population decrease as the vicious scenario. As a consequence, the total vehicle-hrs spent using private transport increases significantly with respect to the old but virtuous scenario and hence a significant increase in both the additional vehicle-hrs due to congestion and the vehicle-hr in traffic jams is also observed.

Public Transport

In the old and vicious scenario, there is a 23% decrease in the pass-km travelled with respect to the baseline, in line with the population decrease, but also a decrease of 9% is observed with respect to the old and virtuous scenario, since there is a decrease in public transport use. The same trends are observed in the pass-hrs spent using public transport, a 23% decrease is observed with respect to the baseline, and an 9% decrease with respect to the CS3. Concerning the pass-hrs spent in public transport, an increase with respect to the young and virtuous scenario is observed, since there is no significant increase in the capacity of the public transport system as a whole, however there is a decrease with respect to the baseline scenario (63%), due to the decrease in the population.

The above transport indicators have been used for the calculation of pressure and state indicators for each scenario. Each of these indicators is presented graphically in figures 31 to 33 to give a graphical representation in order to best view the change for each indicator, depending on the scenario.

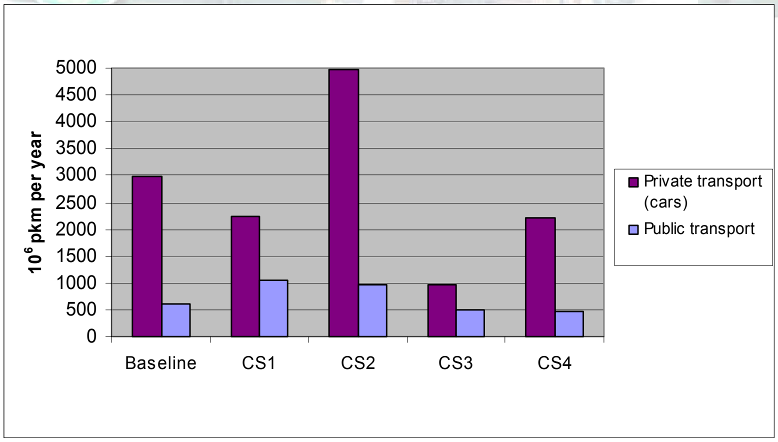


Figure 31. Passenger transport demand

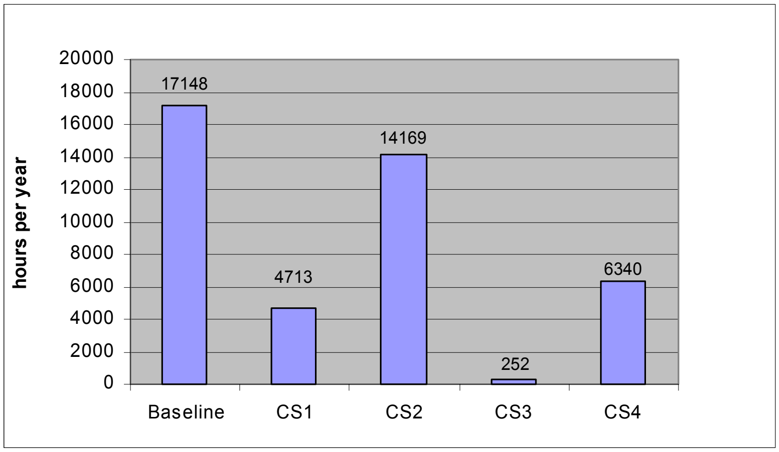


Figure 32. Crowding hours in an overcrowded public transport means.

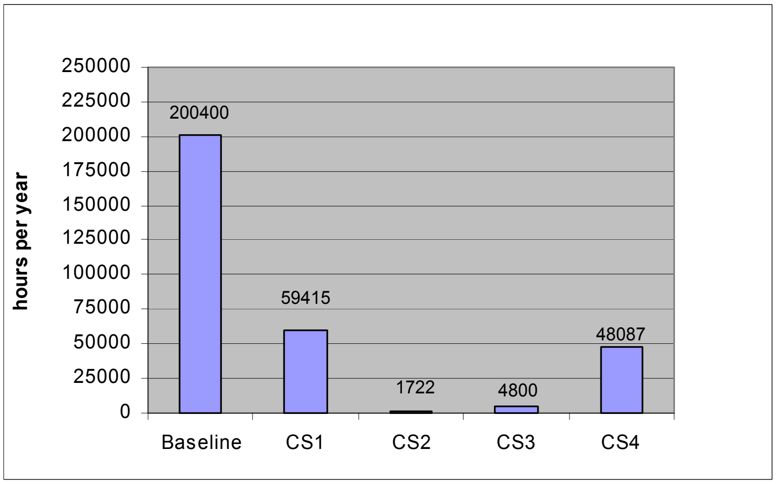


Figure 33. Hours spent in traffic jams (by using private transport)

4.2 TREM

4.2.1 Input data description

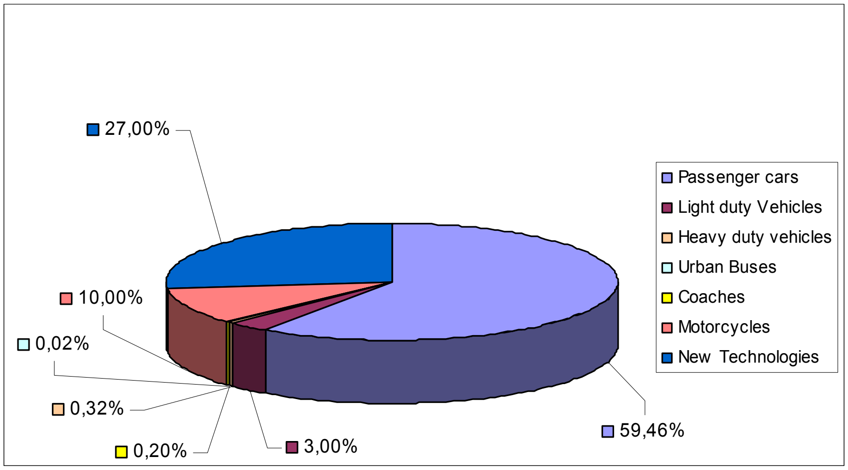


Figure 34. Modal split for the young and virtuous scenarios.

In CS1 new technologies are considered to penetrate the vehicle fleet, 25% of these new technology vehicles are considered to enter the passenger cars category and 2% enter the LDV category, giving a total penetration of 27%. The same modal split is considered in CS3, but the total number of vehicles is different.

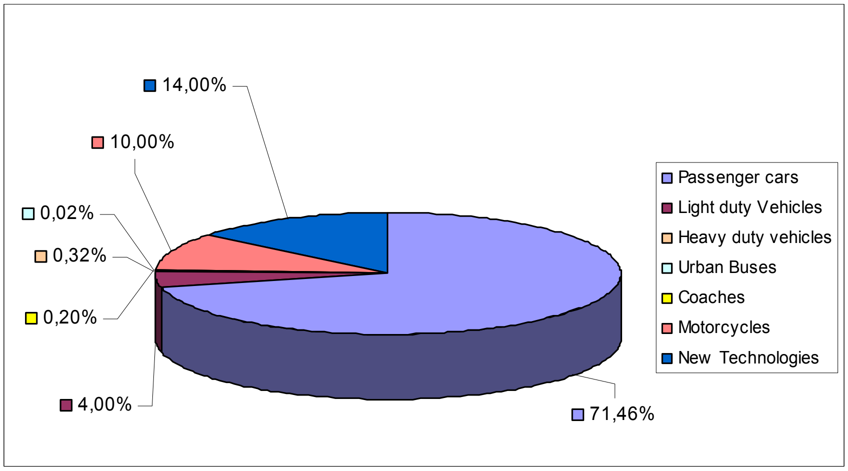


Figure 35. Modal split for the young and vicious scenarios.

In CS2, new technologies are considered to penetrate the vehicle fleet, 13% of these new technology vehicles are considered to enter the passenger cars category and 1% enter the LDV category, giving a total penetration of 14%. The same modal split is considered in CS4, but the total number of vehicles is different.

As concerns the vehicle class split (Figure 36), the information was provided by the MEET /COST predictions for 2020. This information was provided for the national level so the methodology followed for the baseline was also applied in order to get the classification for the WUAT.

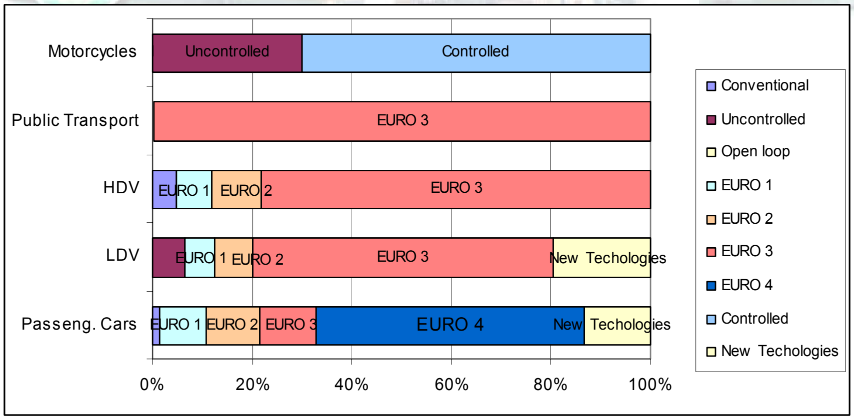


Figure 36. Vehicle fleet classification

4.2.2 Analysis of scenarios results

As for the baseline scenario, the derived emissions calculated for the common scenarios –hot, cold and total- for the road network covered the following pollutants: CO, CO_2, NO_x, PM, SO_2 and VOC. Fuel consumption was also part of the model results.

As it was expected, emissions from transport are closely related to the number of the vehicle park and the penetration of new technologies for each scenario (Figures 37 to 42). Penetration of new technologies refers, from the one hand, to the replacement of non catalytic cars with catalytic, replacement of open loop and part of EURO 1 and EURO 2 technologies with EURO 3 and EURO 4, and on the other hand, to the penetration of totally new technologies (hybrid electric vehicles, fuel cell electric vehicles and electric vehicles) into the Passenger cars and LDV fleet.

For a better view of the absolute reduction of emission which will occur due to penetration of new technologies and replacement of old technologies, one could compare CS1 with baseline scenario as the total vehicle fleet for these two scenarios is more or less the same. Thus, concerning CO_2 emissions a 33% reduction is achieved through CS1. Of course, by following the CS2 with lower penetration of new technologies and an increase of trips in the area under investigation an increase of 55% will inevitably occur (Figure 37).

NOx emissions (Figure 38) will be dramatically reduced for all four scenarios (varying from 24% to 4%) by the almost total replacement of non catalytic by catalytic cars (as the vehicle class distribution for all four scenarios remains the same).

A total reduction of VOC, CO, VOC and PM_{10} will also occur for each of the common scenarios (Figures 39 to 42). More detailed information about the **%** emission reductions per pollutant for each common scenario compared to the baseline scenario is presented in table 7

Fuel consumption follows more or less the number of the vehicles circulating in the city according to each common scenario (Table 8)

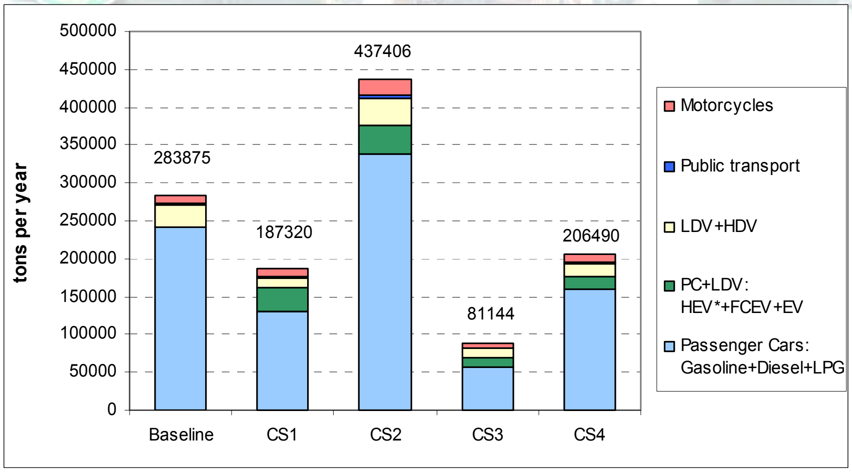


Figure 37. CO_2 emissions from Transport

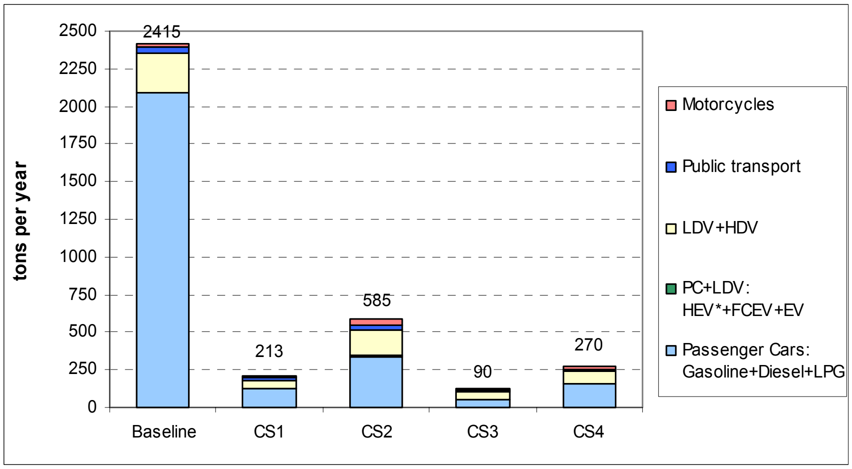


Figure 38. NO_x emissions from Transport

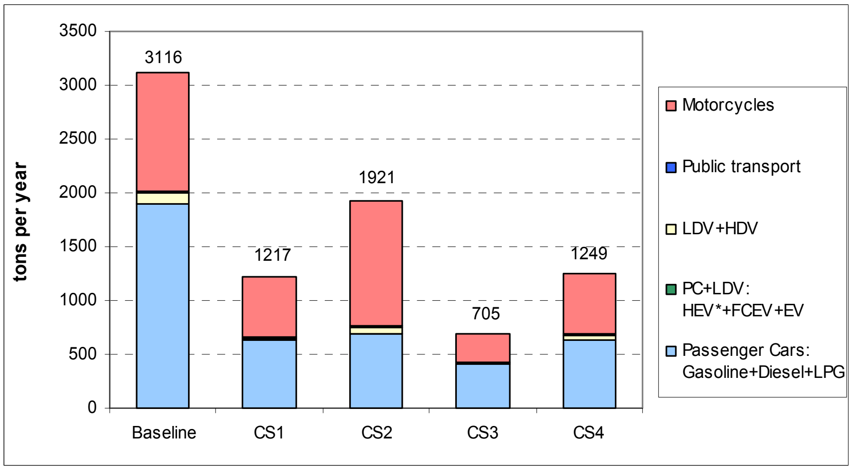


Figure 39. VOC emissions from Transport

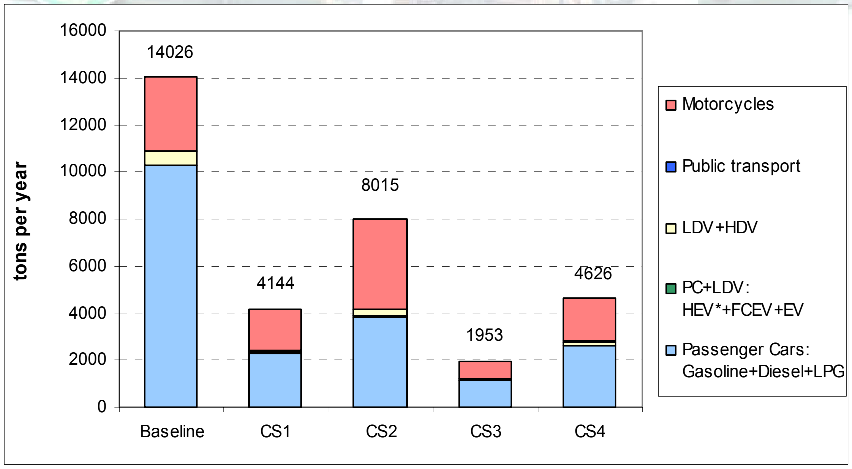


Figure 40. CO emissions from Transport

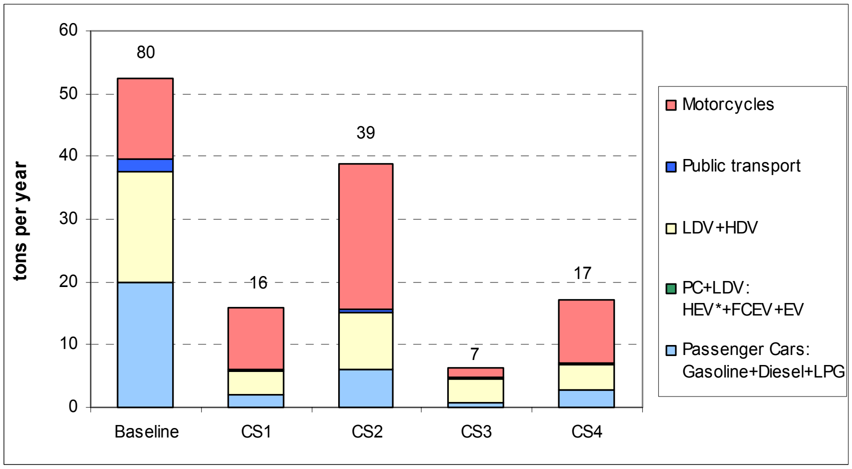


Figure 41. PM_{10} emissions from Transport

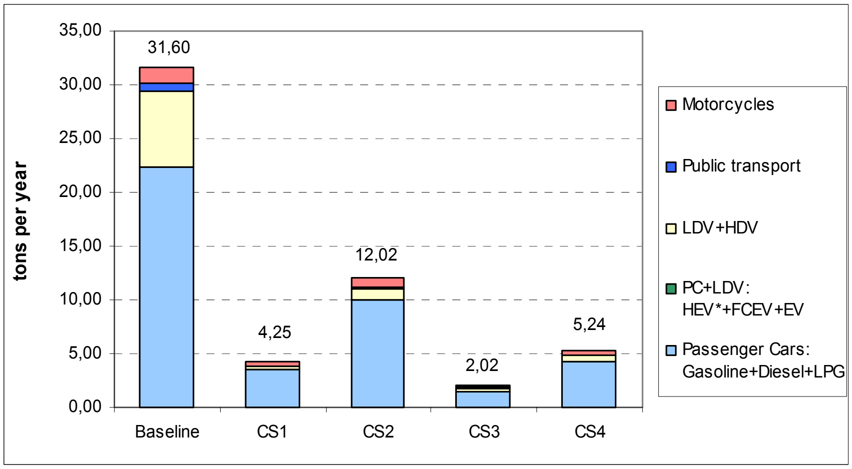


Figure 42. SO_2 emissions from Transport

Table 7. % emission reductions per pollutant for each common scenario compared to the baseline scenario

	CS1	CS2	CS3	CS4
CO2	34%	-54%	71%	27%
Nox	91%	76%	96%	89%
VOC	61%	38%	77%	60%
CO	70%	43%	86%	67%
PM	69%	25%	87%	67%
SO2	87%	62%	94%	83%

Table 8. Fuel consumption for the common scenarios

	Baseline	**CS1**	**CS2**	**CS3**	**CS4**
fuel consumption (tons/year)	145181	82536	169569	39733	97232

4.3 VADIS

4.3.1 Input data description

The emissions needed for the application of the VADIS model, were provided by the emissions model TREM (see details in the above section). The remaining input data (meteorological and location of obstacles and sources) were the same as those described in the baseline scenario.

4.3.2 Analysis of scenario results

In the scope of this work, the CO concentration field for a traffic rush hour with specific dispersion conditions were calculated, it order to compare them to the baseline model application. The wind and concentration fields obtained with the VADIS model can be see in figures 26-29.

COMMON SCENARIO 1

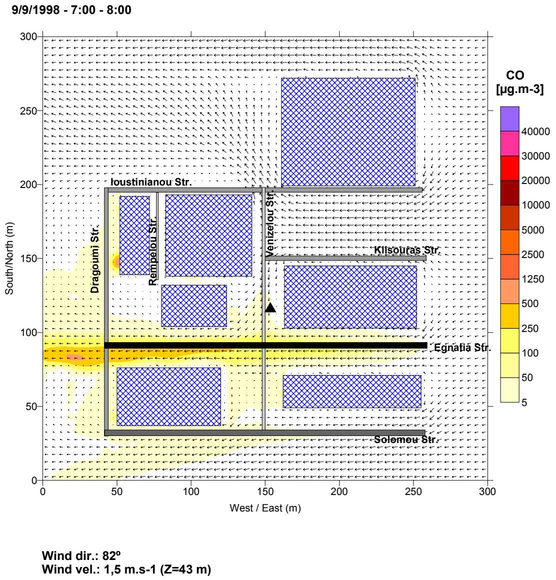
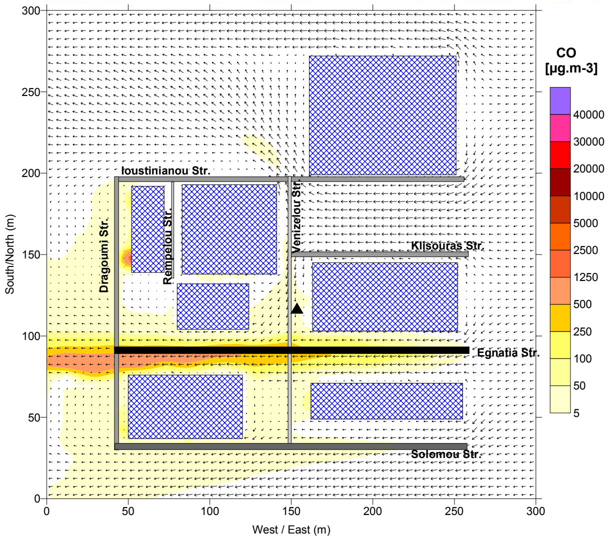


Figure 43. CO concentration fields for common scenario 1.

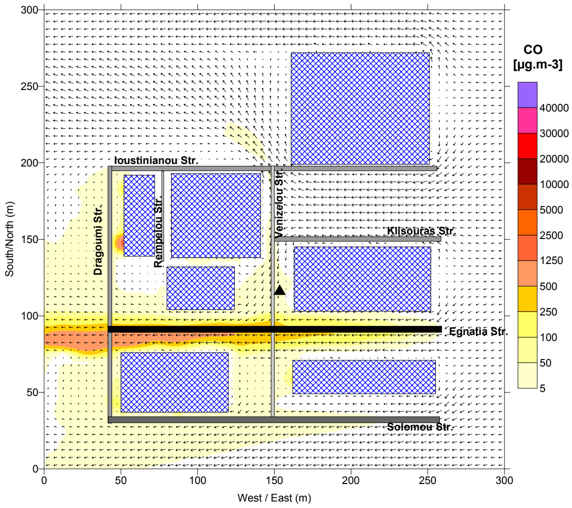
<u>Common scenario 2</u>



Wind dir.: 82º
Wind vel.: 1,5 m.s-1 (Z=43 m)

Figure 44. CO concentration fields for common scenario 2.

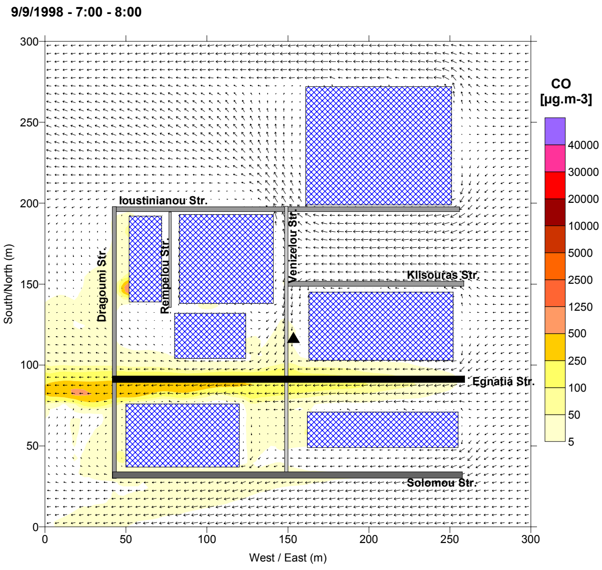
Common scenario 3



Wind dir.: 82º
Wind vel.: 1,5 m.s-1 (Z=43 m)

Figure 45. CO concentration fields for common scenario 3.

Common scenario 4



Wind dir.: 82º
Wind vel.: 1,5 m.s-1 (Z=43 m)

Figure 46. CO concentration fields for common scenario 4.

Bellow one can find the sate indicators, ie peak concentration values (μg.m^{-3}) computed for each of the pollutants CO, NO$_x$ and PM$_{10}$ for each of the common scenarios (Table 9):

Table 9. State indicators – Peak concentrations

	CS1	CS2	CS3	CS4
CO (μg.m^{-3})	1461	2574,1	2846,4	1439,4
NOx (μg.m^{-3})	52,4	137,7	99,6	50,2
PM10 (μg.m^{-3})	4,8	10,3	7,9	4,1

In all common scenarios the peak concentrations for the pollutants studied appear lower than in the baseline. This is expected, since the new technology vehicles that enter the vehicle fleet are expected to improved air quality in hotspot urban areas.

4.4 OFIS

4.4.1 Input data description

Emissions of air pollutants for OFIS

Trail of thoughts - methodology

It was decided to investigate the changes in annual emissions per pollutant and per sector, as this kind of information would be used as an input to the OFIS model. Firstly there was a ranking of the source activities (snaps) that contribute most to each pollutant emitted. For this purpose two information sources where used: An inventory of air pollutant emissions for the Region of Thessaloniki for the year 1995, and an estimation from CORINAIR Annual National Data for Greece and the Region of Thessaloniki (NUTS3) for the years 94 and 2000. For the trends expected to be observed in the road transport sector, the "General transportation study for the wider urban area of Thessaloniki" and the TREM outputs for the Common Scenarios were also used as references. At a second stage, the specific regulations and shifts between technologies and fuels that are going to be applied in the future were considered. Then the specific characteristics that characterise each particular scenario where taken into consideration.

General trends expected to be met after 30 years (in 2030):

1. Energy industries
    - Low sulpfur in diesel (1%) used for industrial activities (Council Directive 32/99). The starting date for the application of this directive is 01/01/2003. This obligation will lead to a reduction in SO_2 emissions.
2. Domestic and commercial combustion
    - Penetration of Natural Gas estimated at a rate of 50-60% will lead to a reduction in SO_2 emissions. However, for the scenarios which anticipate an increase in population it is estimated that an increase of 10% in CO emissions due to increased heating needs will occur.
3. Industrial combustion
    - A switch from high sulphur liquid fuels to natural gas and low sulfur fuels is expected to lead to a 25-30% reduction of NO_x emissions depending on the scenario (young and virtuous scenario will show a greater increase) and also a 90% reduction of SO_2 emissions is estimated.
4. Industrial processes
    - In the emissions from industrial processes, no variation with respect to the baseline level was considered.
5. Extraction and distribution of fossil fuels
    - Activities in the area of Thessaloliki are very limited and hence no significant variation in the emissions from such activities is expected.
6. Solvent use
    - A 10% reduction of NMVOC emissions is expected due to the implementation of the Solvents Directive. No other pollutants are affected from this activity.
7. Road transport
    - Improvements in engine technologies (affecting VOC), almost total replacement of cars with catalytic converters (affecting NO_x), zero sulphur fuels which extend the life of catalytic converters (affecting VOC, CO, NO_x, PM) and reduction in the use of urban buses (affecting SO_2) will all lead to reductions fluctuating according to the general trends which each scenario represents (population increase/decrease, private/public transport use, etc.).
8. Other Mobile Sources and Machinery
    - Emissions resulting from this anthropogenic activity are expected to show a 5% increase, whenever combined with an increase in population.
9. Waste treatment
    - No important change in the emission of pollutants related the processes considered in this activity were expected to occur even after 30 years which in combination with the increase in population would lead to emission reductions, hence emissions from this sector were considered to remain the same.
10. Agriculture
    - This sector does not play an important role in the emissions around the Thessaloniki area, hence emissions were considered to be the same as in the baseline.
11. Nature
    - No change is expected after 30 years.

Table 10. % change in emissions since reference year 2000

Common Scenario 1 **% Change in emissions compared to the Baseline**

SNAP category	NOx	CO	SO2	NMVOC
1:PUBLIC POWER, COGENERATION AND DISTRICT HEATING PLANTS	0%	0%	-15%	0%
2:COMMERCIAL, INSTITUTIONAL AND RESIDENTIAL COMBUSTION PLANTS	0%	30%	-50%	0%
3:INDUSTRIAL COMBUSTION	-30%	0%	-90%	0%
4:PRODUCTION PROCESSES	0%	0%	0%	0%
5:EXTRACTION AND DISTRIBUTION OF FOSSIL FUELS	-	-	-	0%
6:SOLVENT USE	-	-	-	-10%
7:ROAD TRANSPORT	-81%	-60%	-77%	-51%
8:OTHER MOBILE SOURCES AND MACHINERY	5%	5%	0%	0%
9:WASTE TREATMENT AND DISPOSAL	0%	0%	0%	0%
10:AGRICULTURE	0%	0%	0%	0%
11:NATURE	-	-	-	0%

Common Scenario 2

SNAP category	NOx	CO	SO2	NMVOC
1:PUBLIC POWER, COGENERATION AND DISTRICT HEATING PLANTS	0%	0%	-10%	0%
2:COMMERCIAL, INSTITUTIONAL AND RESIDENTIAL COMBUSTION PLANTS	0%	30%	-30%	0%
3:INDUSTRIAL COMBUSTION	-25%	0%	-90%	0%
4:PRODUCTION PROCESSES	0%	0%	0%	0%
5:EXTRACTION AND DISTRIBUTION OF FOSSIL FUELS	-	-	-	0%
6:SOLVENT USE	-	-	-	-10%
7:ROAD TRANSPORT	-66%	-33%	-52%	-28%
8:OTHER MOBILE SOURCES AND MACHINERY	5%	5%	0%	0%
9:WASTE TREATMENT AND DISPOSAL	0%	0%	0%	0%
10:AGRICULTURE	0%	0%	0%	0%
11:NATURE	-	-	-	0%

Common Scenario 3

SNAP category	NOx	CO	SO2	NMVOC
1:PUBLIC POWER, COGENERATION AND DISTRICT HEATING PLANTS	0%	0%	-15%	0%
2:COMMERCIAL, INSTITUTIONAL AND RESIDENTIAL COMBUSTION PLANTS	0%	-25%	-70%	0%
3:INDUSTRIAL COMBUSTION	-25%	0%	-90%	0%
4:PRODUCTION PROCESSES	0%	0%	0%	0%
5:EXTRACTION AND DISTRIBUTION OF FOSSIL FUELS	-	-	-	0%
6:SOLVENT USE	-	-	-	-10%
7:ROAD TRANSPORT	-86%	-76%	-84%	-67%
8:OTHER MOBILE SOURCES AND MACHINERY	0%	0%	0%	0%
9:WASTE TREATMENT AND DISPOSAL	0%	0%	0%	0%
10:AGRICULTURE	0%	0%	0%	0%
11:NATURE	-	-	-	0%

Common Scenario 4

SNAP category	NOx	CO	SO2	NMVOC
1:PUBLIC POWER, COGENERATION AND DISTRICT HEATING PLANTS	0%	0%	-10%	0%
2:COMMERCIAL, INSTITUTIONAL AND RESIDENTIAL COMBUSTION PLANTS	0%	-25%	-50%	0%
3:INDUSTRIAL COMBUSTION	-25%	0%	-90%	0%

4:PRODUCTION PROCESSES	0%	0%	0%	0%
5:EXTRACTION AND DISTRIBUTION OF FOSSIL FUELS	-	-	-	0%
6:SOLVENT USE	-	-	-	-10%
7:ROAD TRANSPORT	-79%	-57%	-73%	-50%
8:OTHER MOBILE SOURCES AND MACHINERY	0%	0%	0%	0%
9:WASTE TREATMENT AND DISPOSAL	0%	0%	0%	0%
10:AGRICULTURE	0%	0%	0%	0%
11:NATURE	-	-	-	0%

4.4.2 Analysis of scenario results

COMMON SCENARIO 1

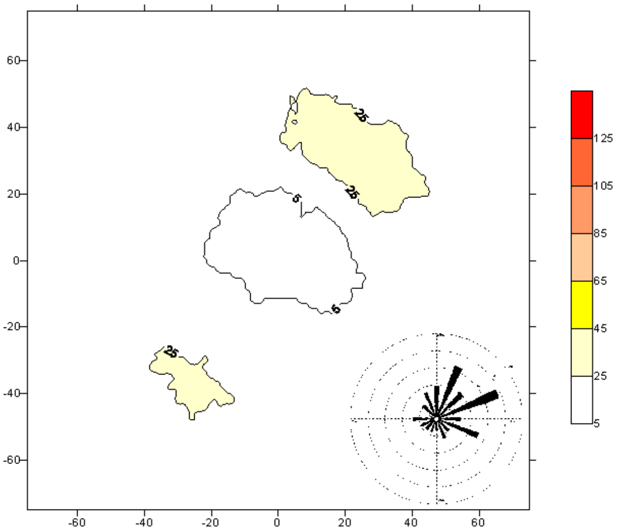


FIGURE 47. ***NUMBER OF DAYS WITH MAXIMUM 8HOUR RUNNING AVERAGE OZONE CONCENTRATION EXCEEDING 120MG/M^3 (IND120), CALCULATED BY THE OFIS MODEL, FOR A 150X150KM^2 AREA SURROUNDING THESSALONIKI, AND WIND ROSE OF PREVAILING WIND DURING THE SUMMER SEMESTER OF 1995 (COMMON SCENARIO 1).***

As was expected to occur, the exceedances compared to the baseline scenario have dropped considerably, in line with the reduction of emissions considered to occur in the young and virtuous scenario. Although population increases, the new EU directives imposing stricter emission ceilings, the eco-friendly behaviour of the citizens and the increased use of natural gas (see description of input data section) play an important role in improvement of the city’s air quality in the future.

COMMON SCENARIO 2

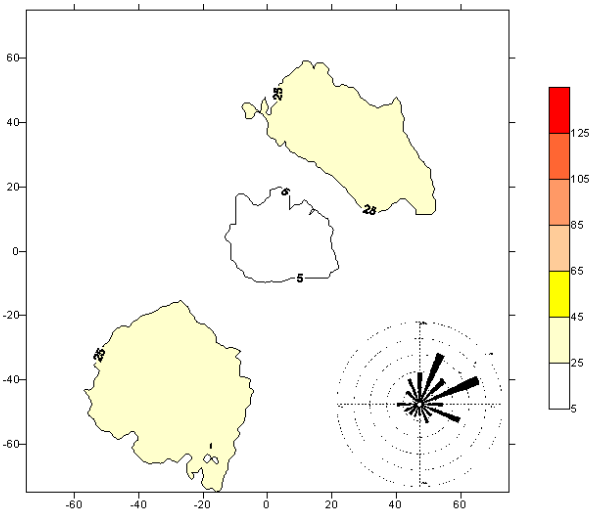


Figure 48. Number of days with maximum 8hour running average ozone concentration exceeding 120μg/m^3 (IND120), calculated by the OFIS model, for a 150x150km^2 area surrounding Thessaloniki, and wind rose of prevailing wind during the summer semester of 1995 (common scenario 2).

In the young and vicious scenario, the exceedances with respect to the young and virtuous scenario appear increased, in line with the smaller emission reductions expected to occur in the future, as less penetration of new technologies is considered, increased emissions from transport and less compliance with EU directives are expected. However the emissions are still reduced with respect to the baseline scenario, since up to a certain point EU directives are still expected to be followed and also shift from diesel to natural gas is expected to occur irrespective of the virtuous or vicious scenario, as is it less costly.

COMMON SCENARIO 3

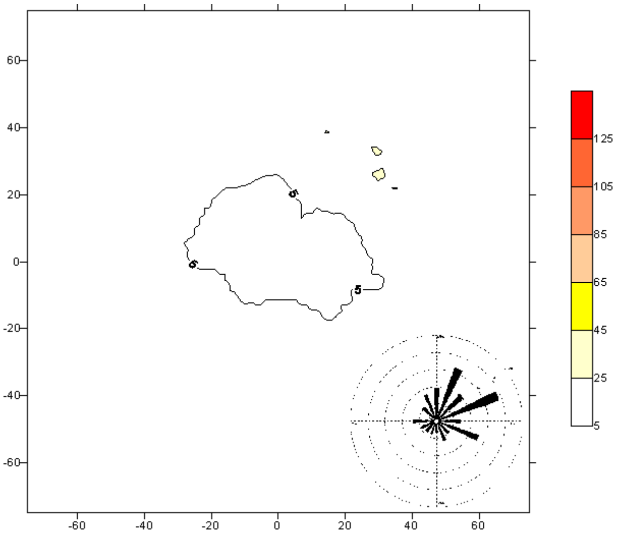


Figure 49. Number of days with maximum 8hour running average ozone concentration exceeding 120μg/m^3 (IND120), calculated by the OFIS model, for a 150x150km^2 area surrounding Thessaloniki, and wind rose of prevailing wind during the summer semester of 1995 (common scenario 3).

IN THE OLD AND VIRTUOUS SCENARIO, THE EXCEDANCES DROP COMPARED TO THE BASELINE SCENARIO, BUT ALSO COMPARED TO THE YOUNG AND VIRUOUS SCENARIO, SINCE THERE IS A DECREASE IN POPULATION, BUT ALSO DUE TO THE STRICTER EMISSION CEILINGS AND OTHER EU DIRECTIVES WHICH ARE EXPECTED TO BE FOLLOWED IN THE FUTURE

COMMON SCENARIO 4

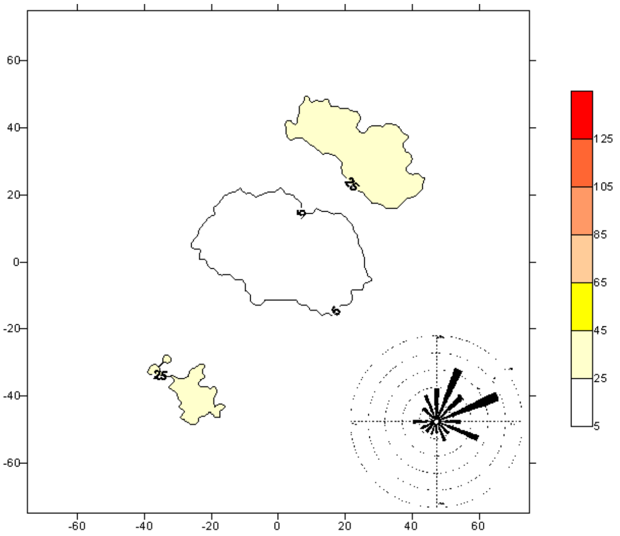


Figure 50. Number of days with maximum 8hour running average ozone concentration exceeding 120μg/m^3 (IND120), calculated by the OFIS model, for a 150x150km^2 area surrounding Thessaloniki, and wind rose of prevailing wind during the summer semester of 1995 (common scenario 4).

In the old and vicious scenario, the exceedances with respect to the old and virtuous scenario appear increased, in line with the smaller emission reductions expected to occur in the future, as less penetration of new technologies is considered, increased emissions from transport and less compliance with EU directives are expected.

4.5 MARKAL

4.5.1 Input data description

For the four common scenarios the input data that remain the same as in baseline scenario are:

- Imported energy prices,
- Residual capacities, techno-economic data, input/output coefficients, availability and lifetime of all technologies which used in order to satisfy all the demands,
- Pollutants emissions associated with technologies and

- Demand data for 1990-2000.

The Demand data for the rest periods have calculated based on the common scenarios CS1 and CS2 (increase in population by 53%), and scenarios CS3 and CS4 (decrease in population by 26%).

	2000	CS1	CS2	CS3	CS4
Population	894435	1398074	1398074	661614	661614

Specifically for Heating, Warm water and Electrical appliances and light the demand data have been calculated according with increase or decrease of population from the year 2000 until 2030.

As regards the transportation input data, the vehicle-kms provided by PComTest for each of the common scenarios for the year 2030, were used to estimate the % change in each scenario (with respect to the baseline), which was then applied to the MARKAL baseline data in order to calculate the total vehicle-kms and thus vehicle-kms for each category (automobile, trucks, buses, LDV, motorcycles) for each of the common scenarios. The in-between periods were calculated using the excel forecast function.

4.5.2 Analysis of scenarios results

Fuel consumption

The fossil fuel consumption for all the four scenarios over the given time periods are presented in figure 51:

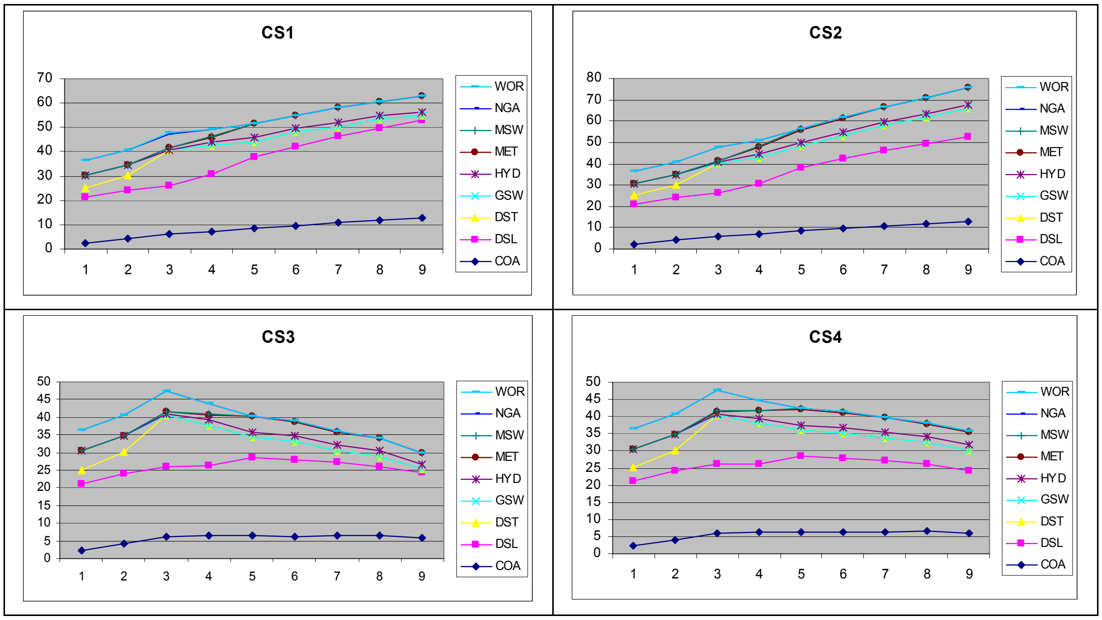


Figure 51. Consumption of fossil fuels for the four common scenarios

Comparing the results between baseline and four scenarios especially for DST (Diesel fuel for transport) a decrease was noted for all the four common scenarios with respect to the baseline (93%, 51%, 96% and 77% respectively).

Transportation

Total emissions for NO_2, SO_2, CO and VOC as modelled for transportation (TA = Bus, TE = Automobile, TH = Trucks, TL = Delivery vehicles) for all four common scenarios are presented graphically in figure 52.

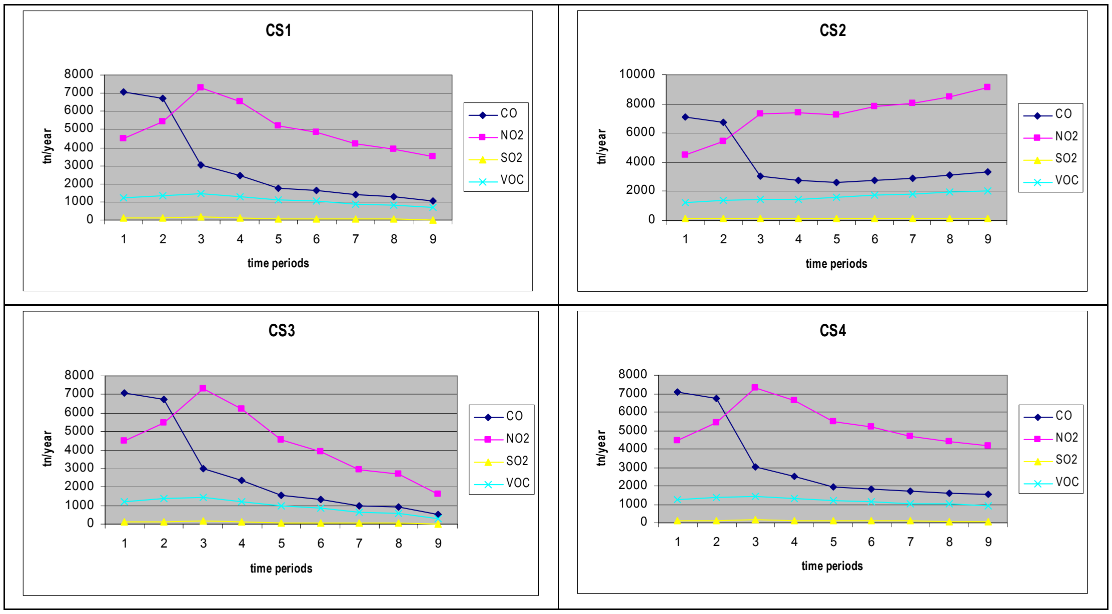


Figure 52. Total emissions from transport for each common scenario

In figure 53 a comparison per scenario for each of the air pollutant emissions can be found. The same tendency of emissions increase/decrease can be seen and the Common Scenario 3 is the one which has the highest percentage of decrease in comparison to the baseline scenario for all the emissions (84% for CO, 78% for NO_2, 91% SO_2 and 78% for VOC).

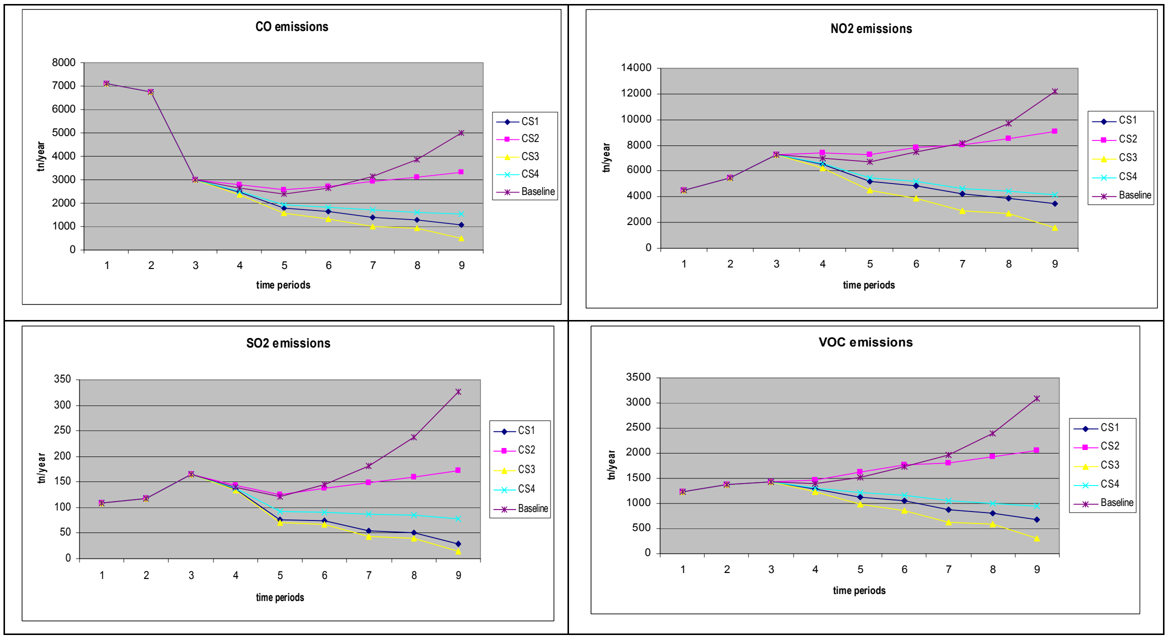


Figure 53. Comparison per scenario for each of the air pollutant emissions from transport

Heating

Concerning the NO_2 emissions from heating, the results obtained after the application of the MARKAL model can be seen in the figure below (Figure 54). Common scenarios 3 and 4 are those which give the lowest NO_2 emissions, in comparison to the baseline scenario, which is expected since both scenarios consider a decrease in the population.

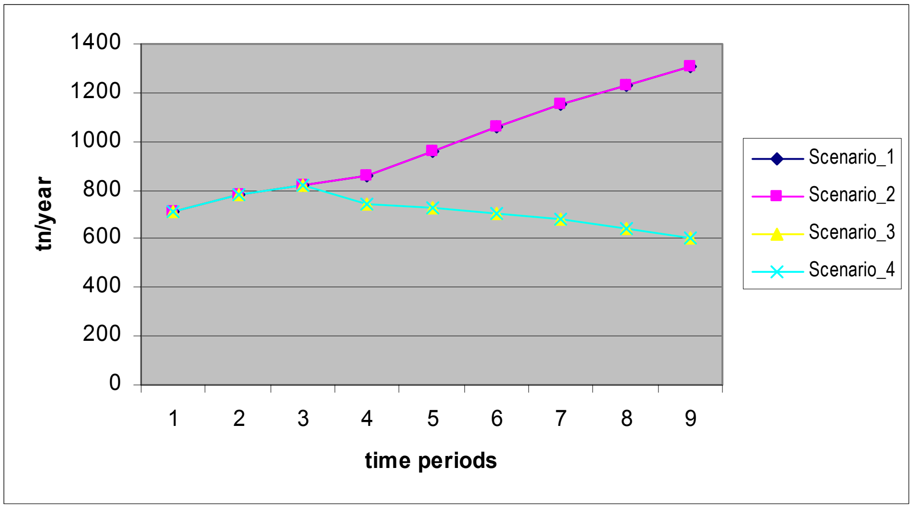


Figure 54. NO_2 emissions from heating sector

5. City specific scenarios

General description

The city specific scenarios for Thessaloniki are a vision of the city for the years after 2015. These considered a series of important infrastructure works for which extended studies have already been conducted and data was available. The main objectives of these works are twofold, (a) to provide higher quality public transport, facilitating access to the city centre and (b) facilitation of the flow of existing private transport, as the network that currently exists is clearly not sufficient.

The following works were considered:

1. Basic subway line in the centre of the city (METRO)
2. Underwater vehicle tunnel
3. TRAM
4. Upgrading of the main highway (External Regional Ring Road)
6. Parking spaces
7. Network of bus lines-lanes

5.1 Input data description

The *demographic changes* considered likely to occur in the next 20 years are an increase in the population by 25% (in line with the General Transportation study for the WUAT), increasing from 894435 in 2000 to 1125000 in the year 2020. The General Transportation study for the WUAT predicts an increase in car ownership of 37% for the years after 2015, but also an increase of 40% in the trips performed in the urban area.

Two types of scenarios were considered, an optimistic and a pessimistic scenario. The optimistic hopes for an increase of public transport use, especially since new means of transport will be available. The pessimistic considers the case that there is an increase in private transport use, even though the new means of public transport are available.

City specific 1 – optimistic scenario

The optimistic scenario considers that there is a small increase in the use of private transport linked to the increase in population. However, it considers an increase of 30% for public transport use.

The occupancy rate was also considered to increase from 1.56 to 1.638, like in the optimistic growth scenarios (CS1,3). A slight decrease in the Heavy Duty Vehicles (HDV) was considered, in order to consider the decrease in the number of buses operating due to the availability of the new transportation means.

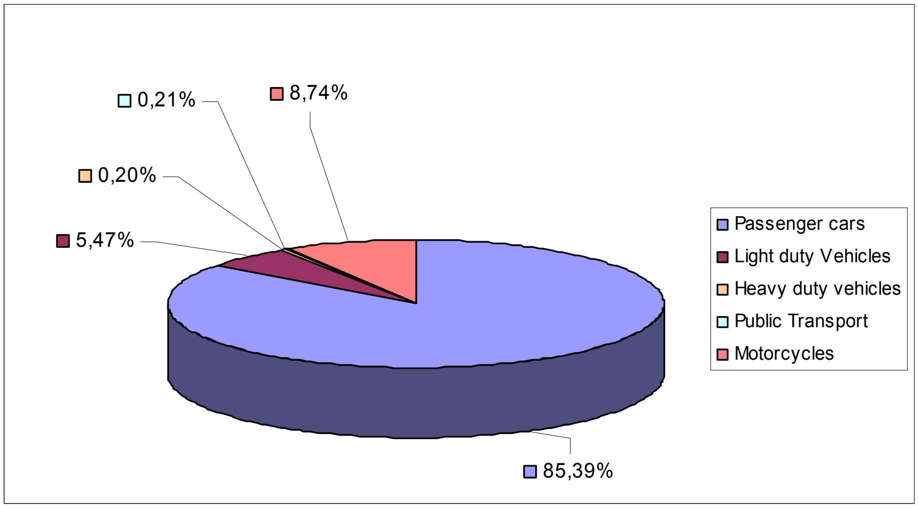


Figure 55. Modal split for the optimistic-city specific 1 scenario

In the city specific scenario 1, new technologies were not considered to penetrate the vehicle fleet. As concerns the vehicle class split, the information was provided by the MEET /COST predictions for 2020. This information was provided for the national level so the methodology followed for the baseline was also applied in order to get the classification for the WUAT.

City specific 2 – pessimistic scenario

The pessimistic scenario considers a small increase of 10% in the use of public transport, linked to the increase in population and a much larger increase of 30% for private transport use, since although the new means of public transport are available, the behaviour of the urban population does not change and private transport is still the most popular means for travel. This increase of 30% in private transport use was all considered to occur in the passenger cars category.

In addition to the above, the occupancy rate was considered to decrease from 1.56 to 1.544, like in the pessimistic common scenarios (CS2,4). No decrease in the Heavy Duty Vehicles (HDV) was considered.

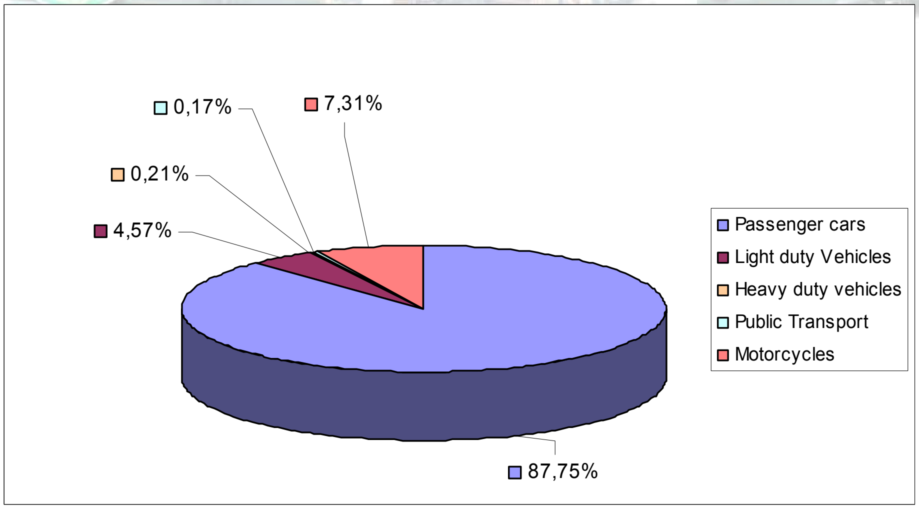


Figure 56. Modal split for the pessimistic-city specific 2 scenario.

In the city specific scenario 2, new technologies were not considered to penetrate the vehicle fleet. As concerns the vehicle class split, the information was provided by the MEET /COST predictions for 2020. This information was provided for the national level so the methodology followed for the baseline was also applied in order to get the classification for the WUAT.

5.2 Analysis of scenarios results

5.2.1 VISUM results

City specific 1 optimistic

Transport indicators results

Indicators	**By Mode**		**By Transport System**			
			Car	**Bus**	**Tram**	**Subway (METRO)**
	PrT	**PuT**	PrT	PuT	PuT	PuT
Vehicle-km	5306887		5306887			
Vehicle-hr	206815		206815			
Additional vehicle-hr due to congestion	127349		127349			
Vehicle-hr in jam	40062		40062			
Passenger-km		2122312		1141485	658290	322537
Passenger-hr		100503		81211	12963	6329
Passenger-hr in overcrowded vehicles		6983		6620	363	0

Private Transport indicators

A small increase in the use of cars (10%) is considered, resulting in a small increase in the total vehicle km by private transport (1%). Vehicle hours by private transport mode decrease by 27% with respect to the baseline, since there are new infrastructure works (roads) enabling the better circulation of private transport. The additional vehicle hours due to congestion decrease with respect to the baseline by 26%, since the new infrastructure works ensure faster circulation of private transport. The vehicle hours in traffic jams, decrease significantly (-67%) due to the new infrastructure works that decongest the network.

Public Transport indicators

The increase in public transport use results in an increase in the pass-km with public transport by 30%. The total pass-hrs spent using public transport decrease slightly with respect to the baseline (-11%), since although there is an increase in public transport use, hence an increase in total pass-hrs, the new public transport means enable faster transport, finally resulting in an overall decrease in total pass-hrs. An important decrease in the total pass-hrs spent in crowded vehicles is observed with respect to the baseline (59%), since the new means of public transport increase the capacity of the public transport system as a whole.

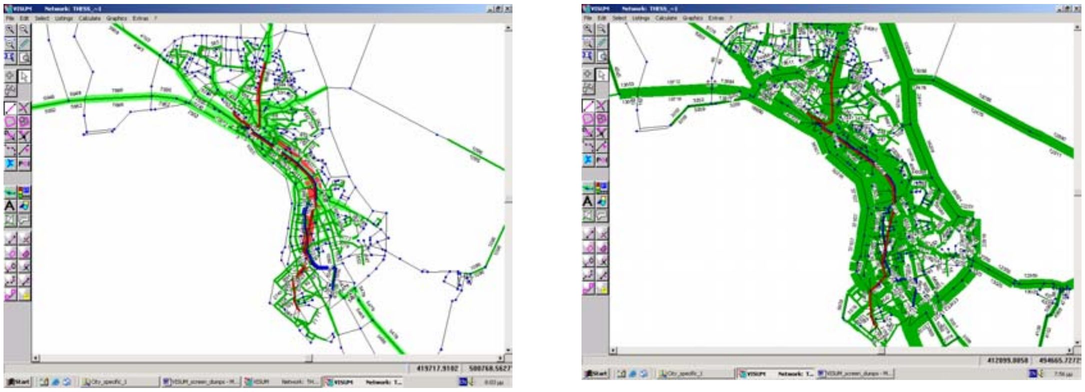


Figure 57. On the left are the results for the city specific optimistic scenario public transport systems, with red the metro, with blue is the tram and with green in the bus (number of passengers/link per day) and on the right are the results for the private transport (number of vehicles/link per day).

City specific 2 pessimistic

Indicators	**By Mode**		**By Transport System**			
			Car	**Bus**	**Tram**	**Subway (METRO)**
	PrT	**PuT**	PrT	PuT	PuT	PuT
Vehicle-km	6484986		6484986			
Vehicle-hr	393304		393304			
Additional vehicle-hr due to congestion	295004		295004			
Vehicle-hr in jam	193225		193225			
Passenger-km		1794942		966012	556552	272377
Passenger-hr		105049		88744	10960	5345
Passenger-hr in overcrowded vehicles		6029		5825	204	0

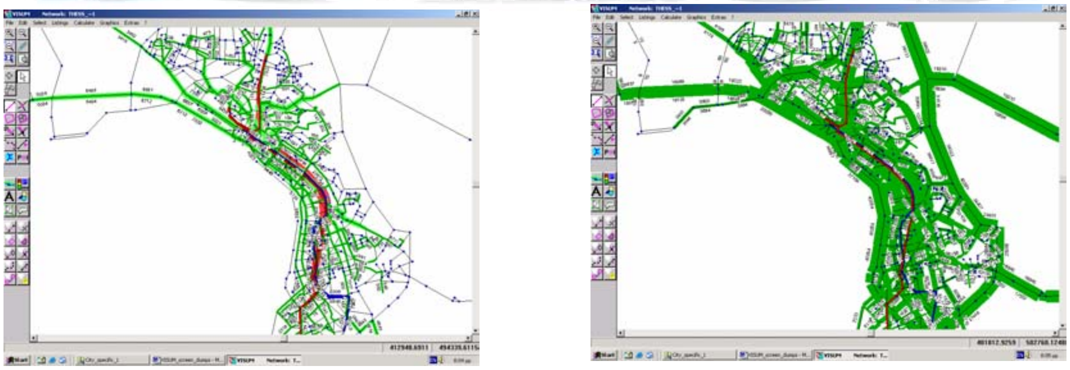


Figure 58. On the left are the results for the city specific pessimistic public transport systems, with red the metro, with blue is the tram and with green in the bus (number of passengers/link per day) and on the right are the results for the private transport (number of vehicles/link per day).

Private Transport indicators

Private transport use increases by 30%, so the total vehicle-km that the private transport performs also increase. The total vehicle-km increase both with respect to the baseline (24%, but also with respect to the optimistic city scenario (22%), since more private transport is used. An increase in the total vehicle hours performed using private transport is observed, due to the increased use of private transport. This is observed both with respect to the baseline (39% increase) and the optimistic scenario (90% increase), where there is less use of private transport. An enormous increase in the additional vehicle hours due to congestion is observed, both with respect to the baseline (47%), but especially compared to the city optimistic scenario (132%!). This is obviously due to the increased use (by 30%) of private transport. The vehicle-hrs in traffic jams increase, both with respect to the baseline (60% increase) and with respect to the optimistic city scenario, where a significant decrease with respect to the baseline was already observed. The 30% increase in private transport use seems to be very pronounced in terms of vehicle-hr in traffic jams.

Public Transport indicators

A small increase in the pass-km of public transport is observed with respect to the baseline, in line with the small overall increase of public transport use. As a consequence, a decrease in the pass-hrs spent in public transport is also observed with respect to the baseline (7%), since there are new means of public transport which move faster, however there is an increase of the pass-hrs spent in public transport by 5% with respect to the optimistic city scenario, since due to the increase in private transport, public transport means such as buses move slower.

There is a significant decrease (65%) in the hrs spent in overcrowded vehicles with respect to the baseline, but there is also a small decrease (14%) with respect to the optimistic scenario, since the public transport infrastructure works are the same, but there are fewer passengers using it.

5.2.2 TREM results

As it was expected, the emissions calculated for the optimistic scenario for the WUAT appear to be reduced for all emissions (NO_x, VOC, CO, SO_2 and PM) except from CO_2 emissions where- alike with common scenario 2 with an increase in vehicle fleet- an increase of 6% for city specific 1 and 27% for city specific 2 appears (Figures 54 to 59) Reductions in emissions regarding city specific 1 scenario appear to be greater than those of city specific 2 scenario, that is, for city specific 1 scenario there are reductions of 53% in CO, 82% in NOx, 55% in PM, 73% in SO_2 and 47% whereas, for city specific 2 scenario there are reductions of 50% in CO, 79% in NOx, 52% in PM, 67% in SO_2 and 45% in PM.

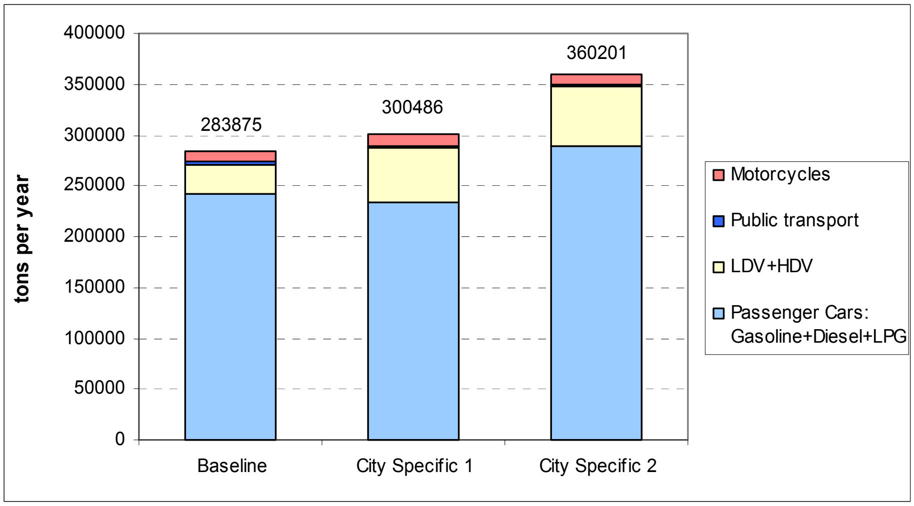


Figure 59. CO_2 emissions from Transport for city specific scenarios optimistic (1) and pessimistic (2)

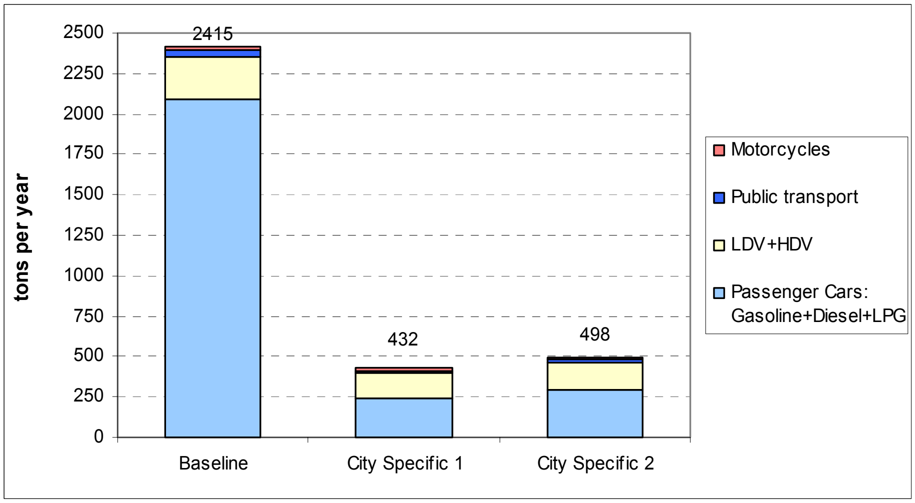


Figure 60. NO_x emissions from Transport for city specific scenarios optimistic (1) and pessimistic (2)

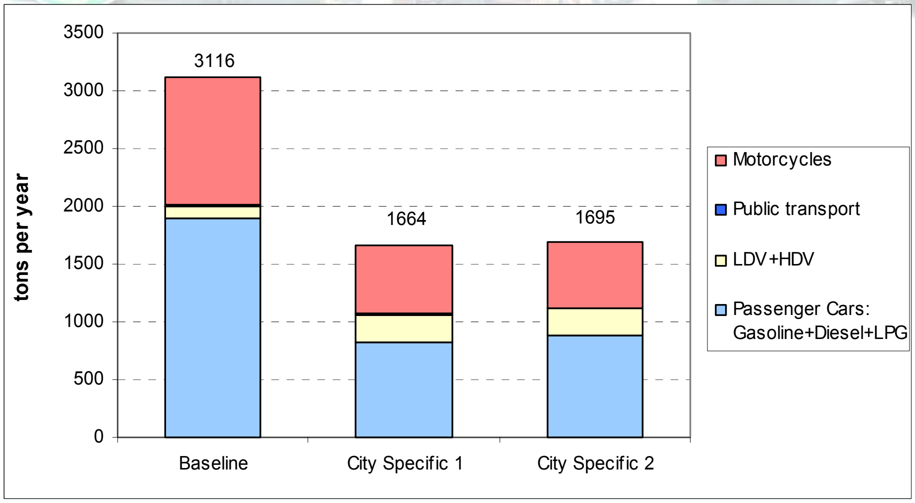


Figure 61. VOC emissions from Transport for city specific scenarios optimistic (1) and pessimistic (2)

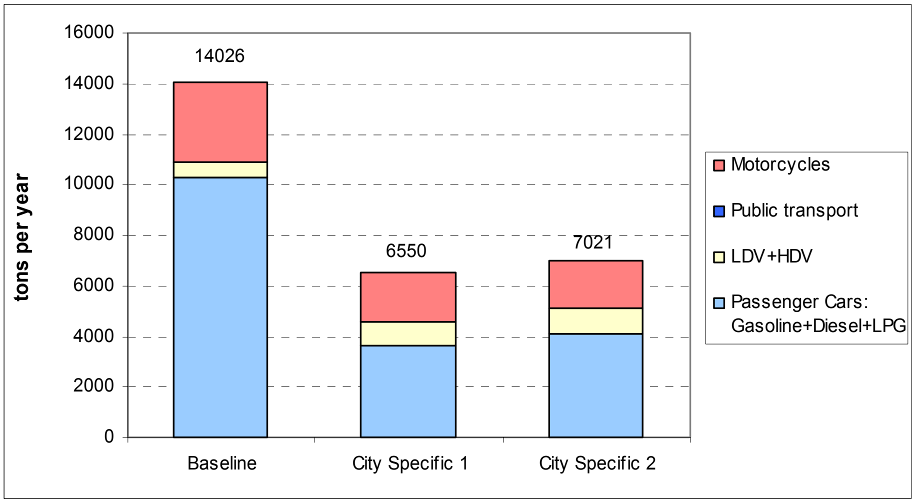


Figure 62. CO emissions from Transport for city specific scenarios optimistic (1) and pessimistic (2)

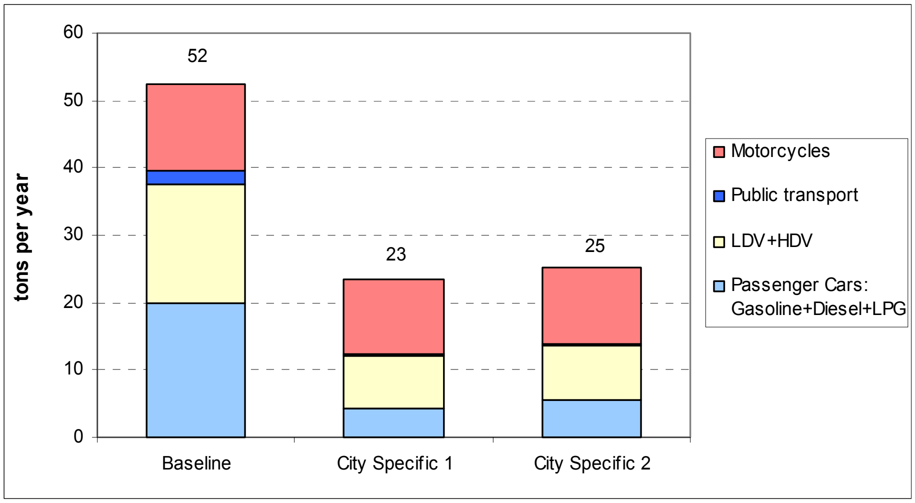


Figure 63. PM_{10} emissions from Transport for city specific scenarios optimistic (1) and pessimistic (2)

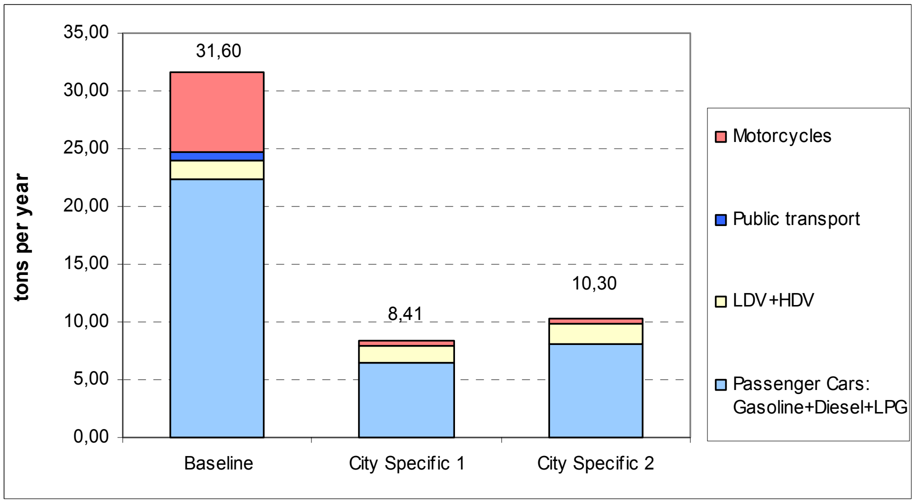


Figure 64. SO_2 emissions from Transport for city specific scenarios optimistic (1) and pessimistic (2)

5.2.3 OFIS results

For the city specific 1 optimistic scenario, the emission reductions expected to occur in the year 2020 are considered to be the same as common scenario 1, since there is an increase in population and an optimistic/eco-friendly attitude, hence the results are the same as those for the young and virtuous city (see table 10 and figure 47).

For the city specific 2 pessimistic scenario, emission reductions are again expected to occur since new technologies will penetrate the market and the application of various EU directives playing a significant role in the reduction of air pollution is expected to be mandatory (see section 4.1.1). Hence the emission reductions that are considered are the same as those for the common scenario 2 and the concentrations/exceedances results are the same (see table 10 and figure 48).