TAIEX Workshop on Air Pollution Control National Programs

The implications of Air Pollution Control Programmes – example and experience of Greece (methods and results)

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Air Pollution

1. Identify the problem

- Pollutants
- Exceedances
- Geographical distribution
- Sources (quantitative detailed analysis, if necessary)

2. Make the problem politically visible

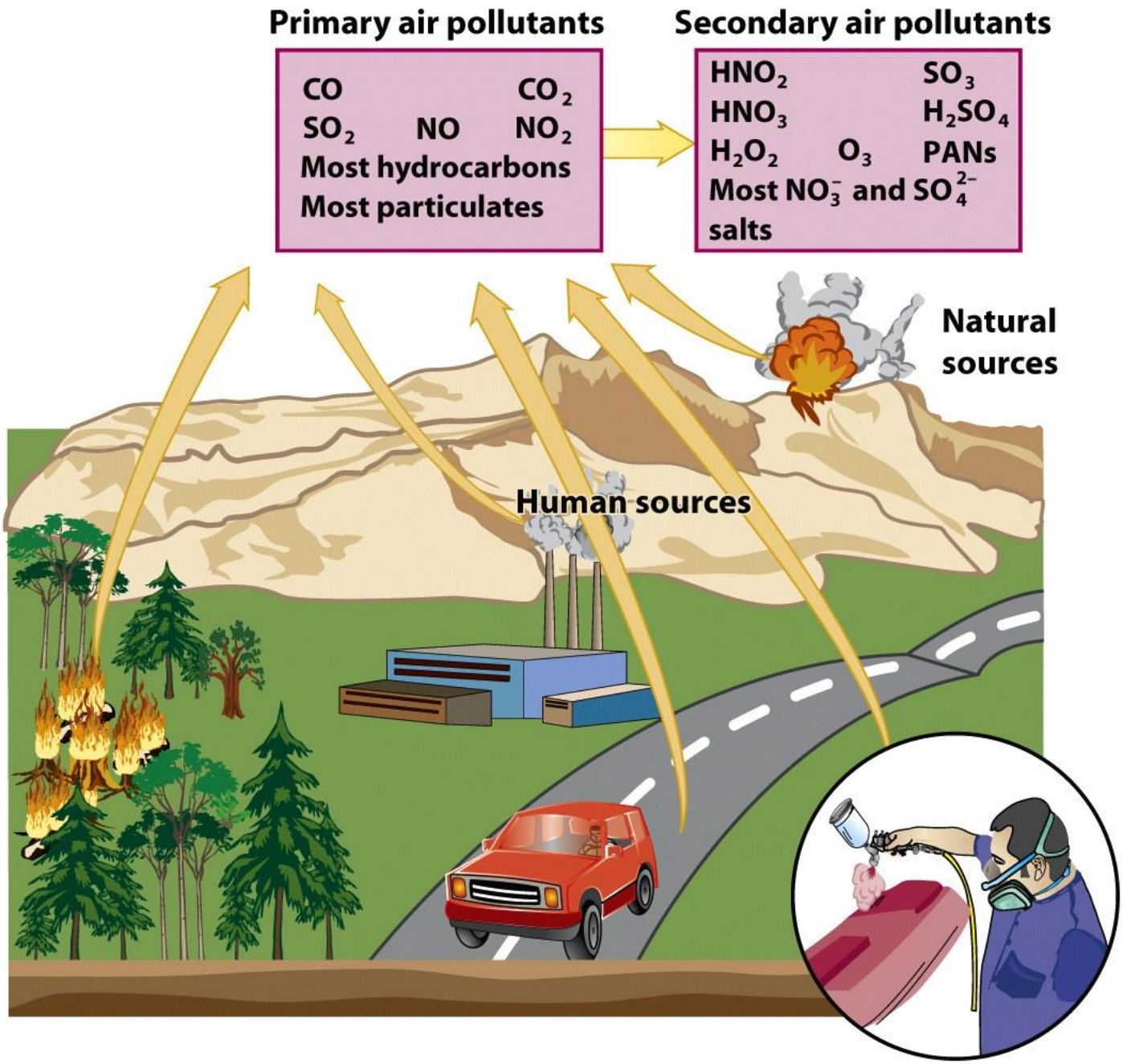
- Academia
- Press
- Citizens
- Political authorities

3. Take measures

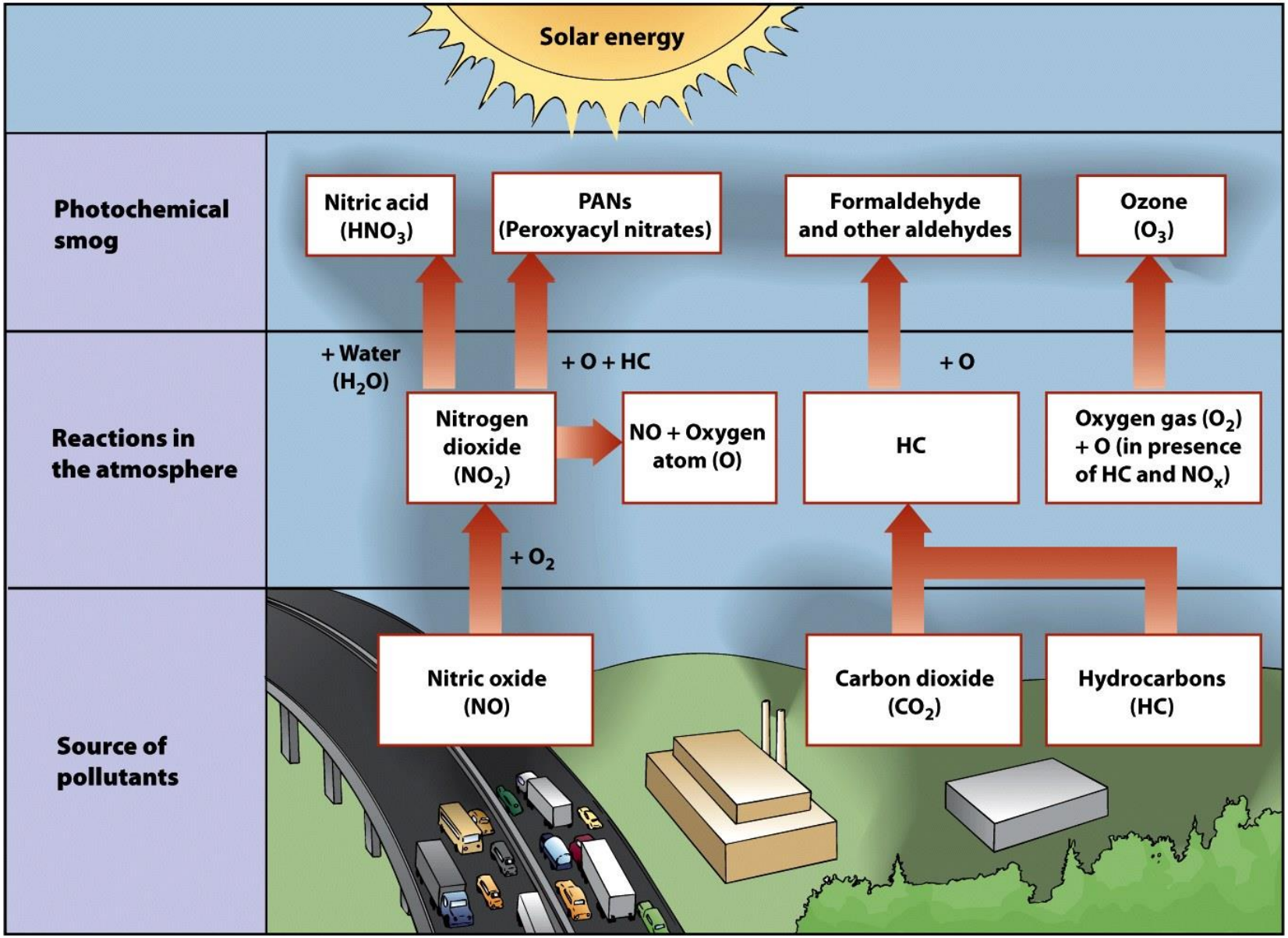
- Interministerial cooperation
- Enforcement

4. Monitor their effectiveness

- Systematic accurate monitoring + modelling


Primary air pollutants
CO
CO_2
SO_2
NO
NO_2
Most hydrocarbons
Most particulates
Secondary air pollutants
HNO_2
SO_3
HNO_3
H_2SO_4
H_2O_2
O_3
PANs
Most NO_3^- and SO_4^{2-} salts
Natural sources
Human sources

Creation of photochemical smog



Legal framework

<u>Air quality standards</u>

Directive 2008/50:

- **Limit Values for CO, NOx, SO_2, PM10, PM2,5, Benzene, Pb**
- **Provision for subtracting of natural sources**
- **Reference methods and certification of data, sampling points**

Directive 2004/107: Target Values for arsenic, cadmium, mercury, nickel and polycyclic aromatic hydrocarbons

<u>Total emissions</u>: NEC Directive 2016/2284/EU - Emission reductions compared to 2005 for SO_2, NO_x, NMVOC, NH_3 & $PM_{2,5}$

Main sources of urban air pollution

Road transport - Central heating - Industry

Other factors that can play a role:

- Urbanization
- Transfer of dust from afar
- Lack of plant cover of nearby mountains
- Aging of the car fleet
- Increase of cars (in GR, from 1,7 million cars in 1990 we reached 4,7 million cars in 2007)
- Increase of fuel consumption (e.g. because of larger vehicles)
- Climatic conditions
- Topography

Legal framework for measures

Road transport

- Euro standards:
  - Regulation 715/2007 on EURO 5 & 6 – ELVs for PCs and LDVs for CO, NMHC, NOx & PM and
  - Regulation 595/2009 on EURO VI for HDV
- Real driving emissions Regulation 2017/1151 (Amended by 2017/1154) with adjustments factors (1,5 by Jan. 2020)
- Regulation 2016/1628 – ELVs for non road vehicles
- Regulations 443/2009 and 510/2011 for CO_2 emissions from cars and vans
- ILUC Directive 2015/652 for 2nd generation biofuels: 10% biofuel, 6% reduction in GHG intensity of EU transport fuels by 2020 compared to 2010
- Directive 2014/94 on the deployment of alternative fuels infrastructure

Legal framework for measures

Industrial emissions

- Industrial Emissions Directive 2010/75
- Large Combustion Plant BREF (Decision 2017/1442/EE)
- Directive 2015/2193 on Medium Combustion Plants (1 to 50 MW) that sets ELVs for NOx, SO_2 and Dust. For existing installations, if > 5 MW → from 1/1/2025, if ≤ 5 MW from1/1/2030. About 500 MCPs
- Directives 94/63 and 2009/126 (stage II petrol vapour recovery) for gas stations

- Draft Regulation on electricity market: Capacity mechanism - requirements regarding CO_2 < 550 gr CO_2/kWh of energy or < 700 kg CO_2 on average per year per installed kW

Legal framework for measures

Climate Change Mitigation

GHG: CO_2, CH_4, NO_2, HFCs, PFC και SF_6

A. Period till 2020

- 20% reduction of GHG vs 1990
  - ❖ ETS: 21% reduction vs 2005
  - ❖ Non ETS: 10% reduction vs 2005 (4% reduction for GR)
- 20% energy consumption from RES
- 20% increase of energy efficiency

B. Period till 2030

- 40% reduction of GHG vs 1990
  - ❖ ETS: 43% reduction vs 2005
  - ❖ Non ETS: 30% reduction vs 2005 (16% reduction for GR)
- 32% energy consumption from RES
- 27% increase of energy efficiency

Legal framework for measures

<u>Fuel quality</u>

- Fuel Quality Directive 2009/30 on biofuels
- Directive 2003/17 – sets max S content in petrol and diesel (reduction to 50mg/kg), max content for benzene and Pb in petrol and Polycyclic Aromatic Hydrocarbons in diesel.
- Directive 2016/802 – set max S content in certain liquid fuels (0,5% in the marine fuel by 2020).
- Paints Directive 2004/42 max content for VOCs in organic solvents

The case of Athens

- Topography: surrounded by mountains
- Climate: High temperature, many days of sunshine favor temperature inversions, the accumulation of pollutants and the formation of secondary pollutants.

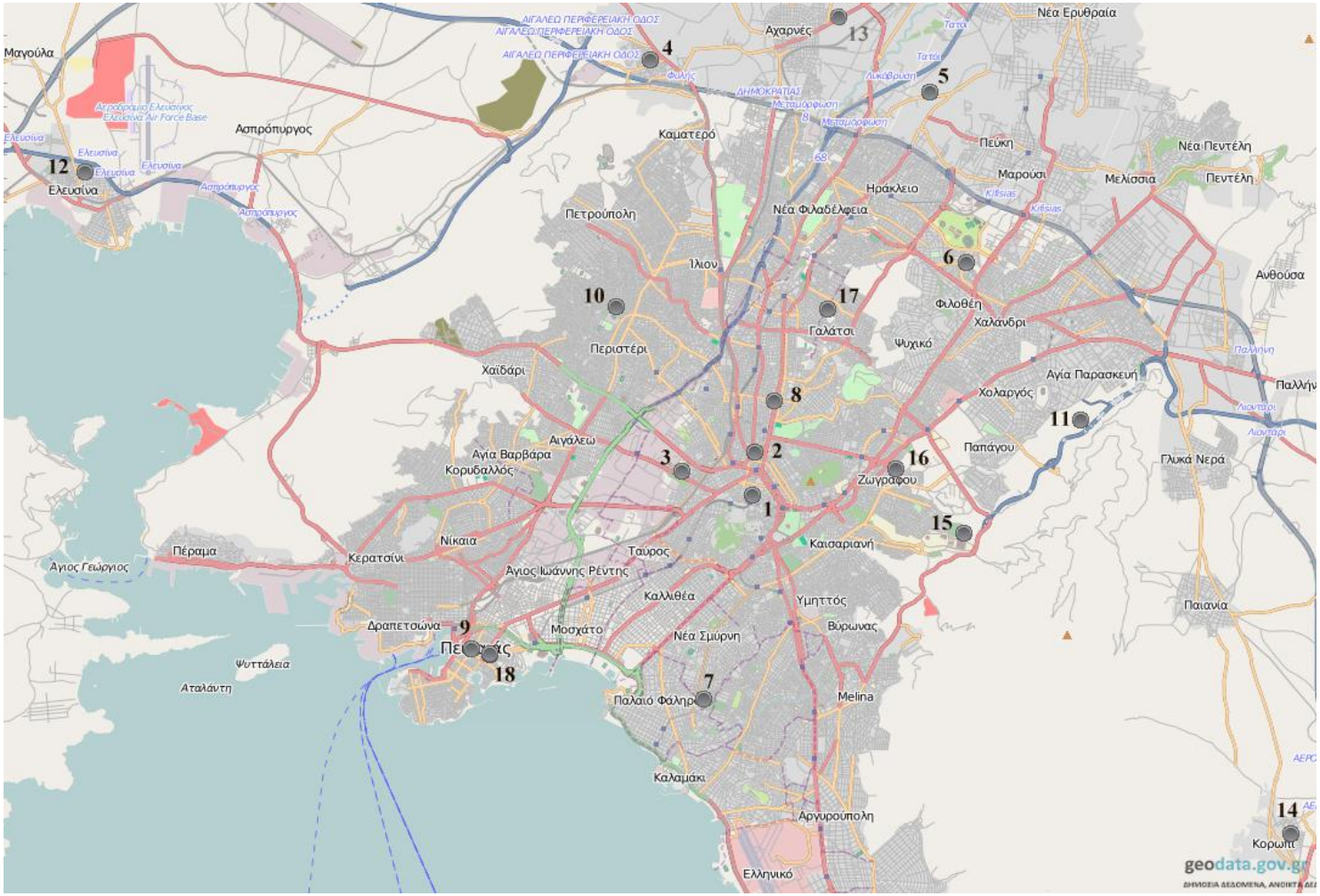
Sea breeze from south west favors the transfer of pollution to the periphery of the Attica basin whereas north winds are strong and short and result in the dispersion of the pollutants.

70s and 80s: Smog but also SO_2 causing the ancient marbles of Acropolis turning to gypsum

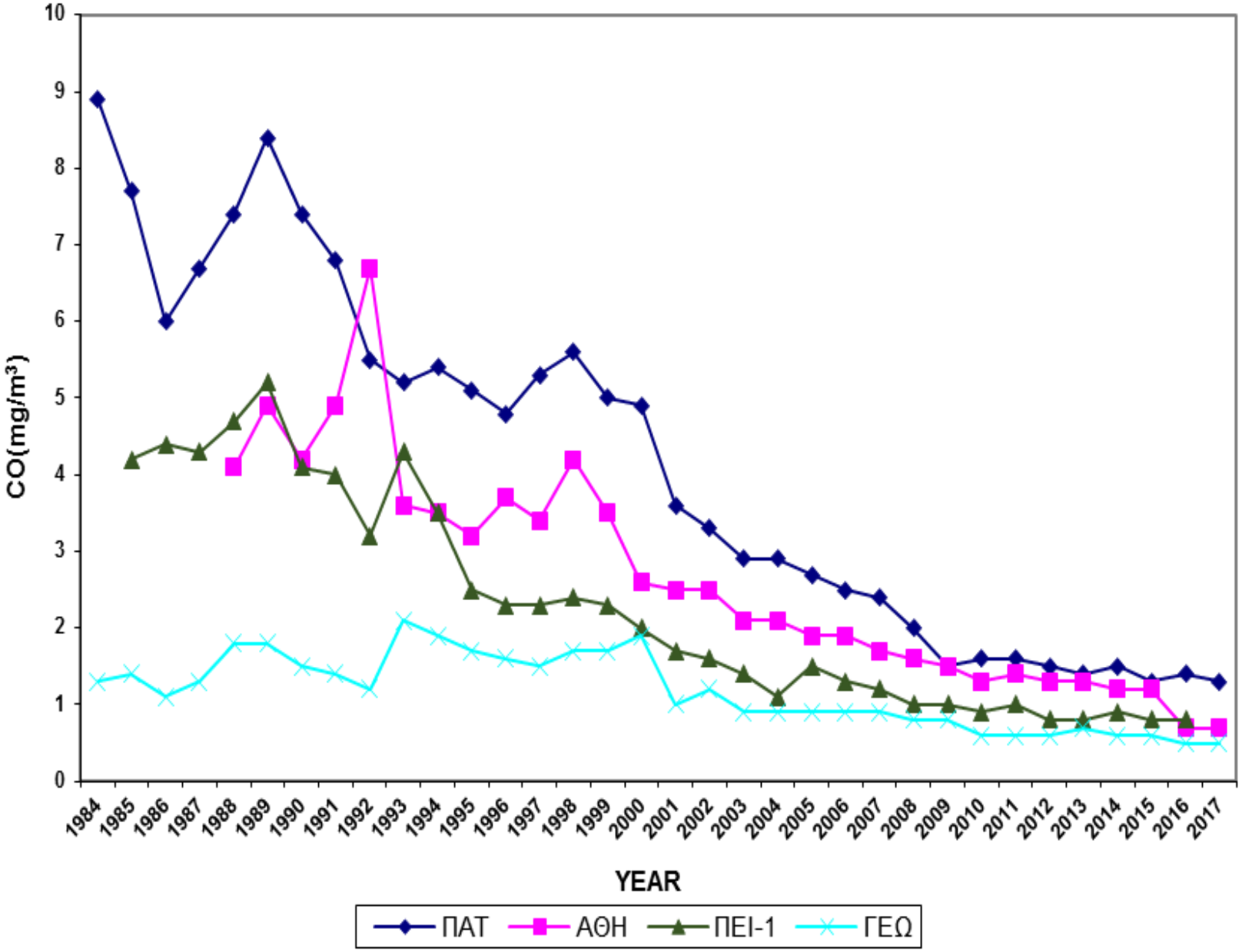
Smog in Athens

National Air Quality Monitoring Network

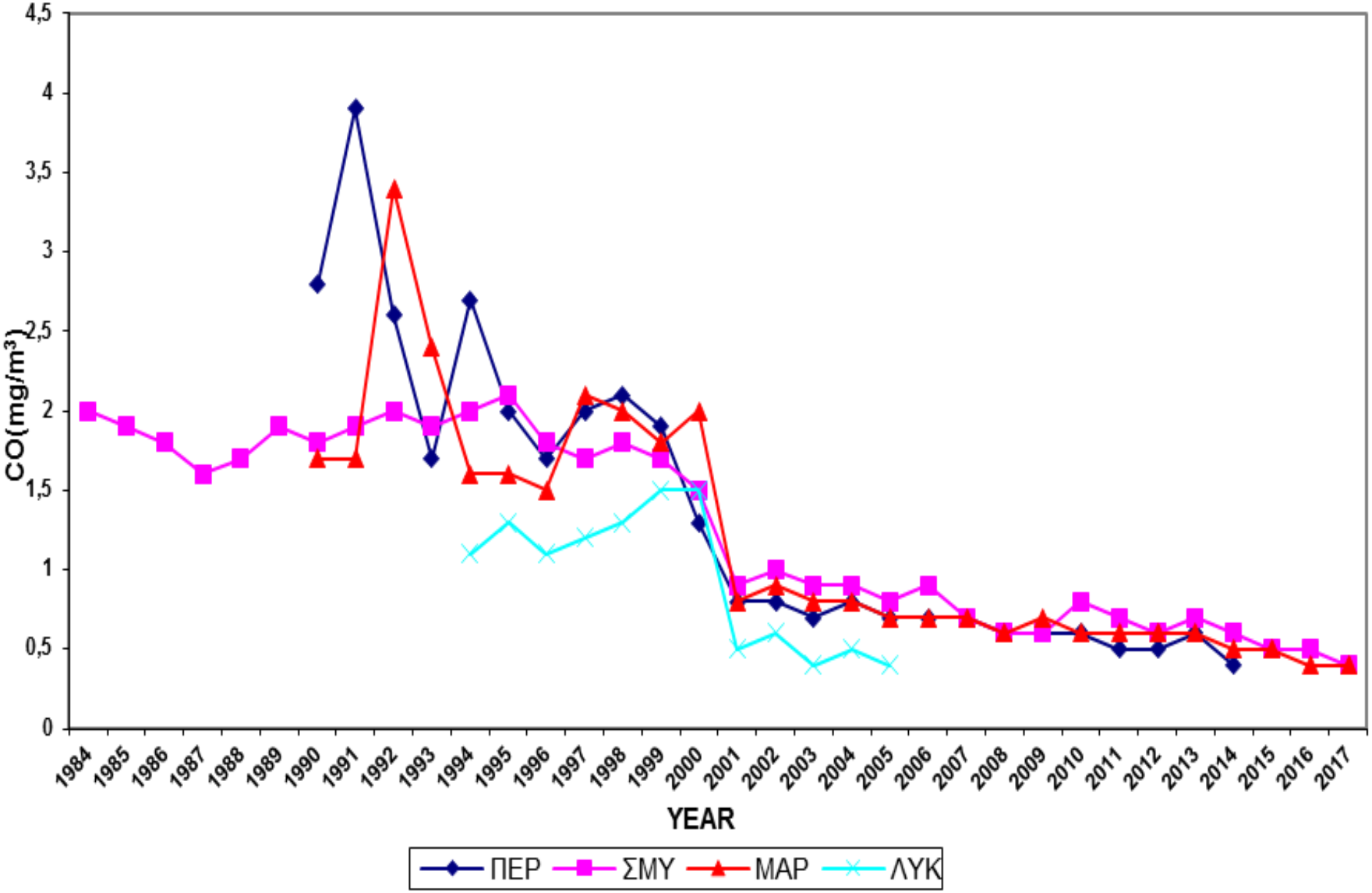
30 automatic stations (14 in Athens), monitoring air pollution on a 24-h basis. Systematic monitoring since 1984. Calibration and certification of data in the certified lab of the ministry



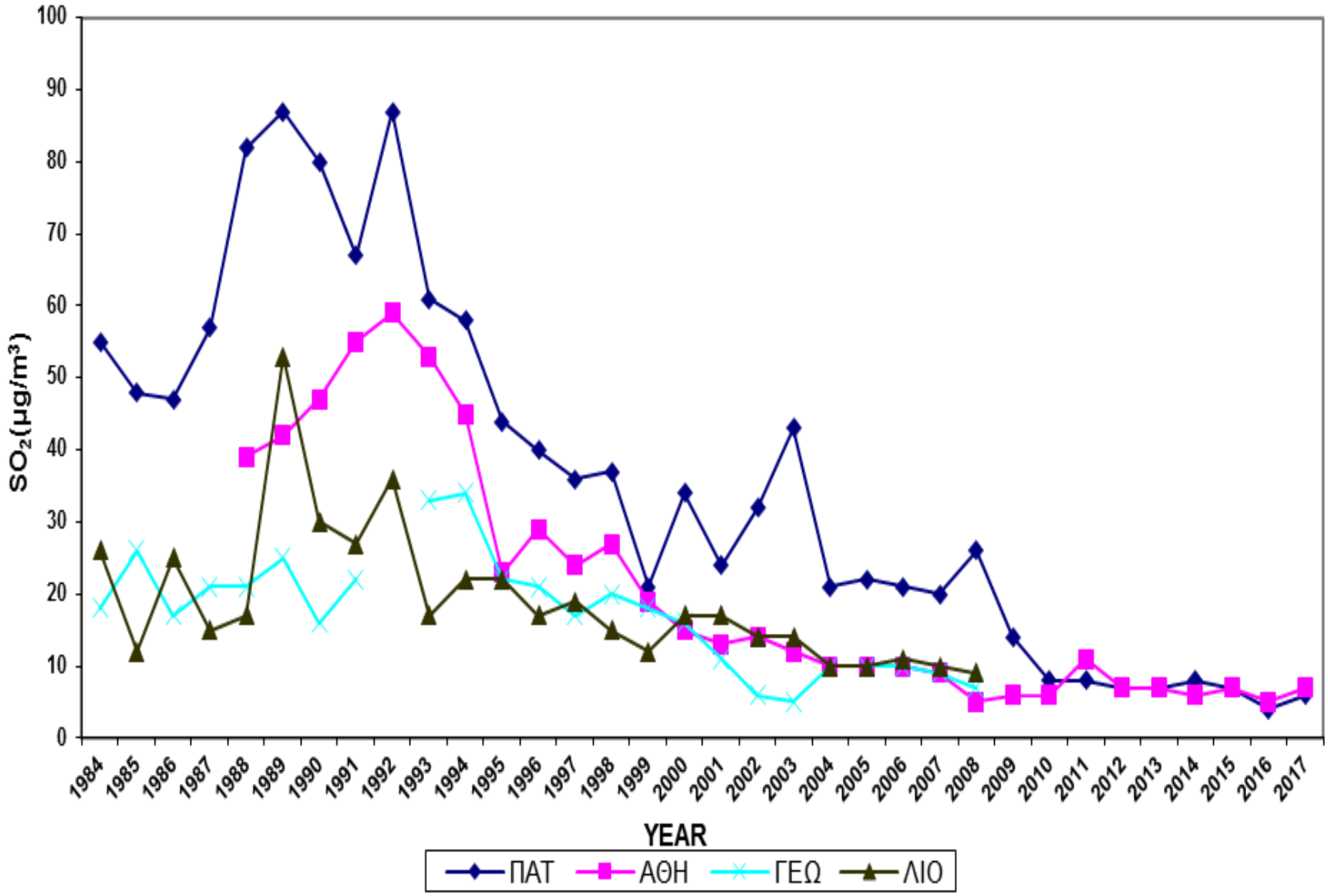
Temporal variation of mean annual CO values in mg/m³



Temporal variation of mean annual CO values in mg/m³



Temporal variation of mean annual SO_2 values in μg/m³



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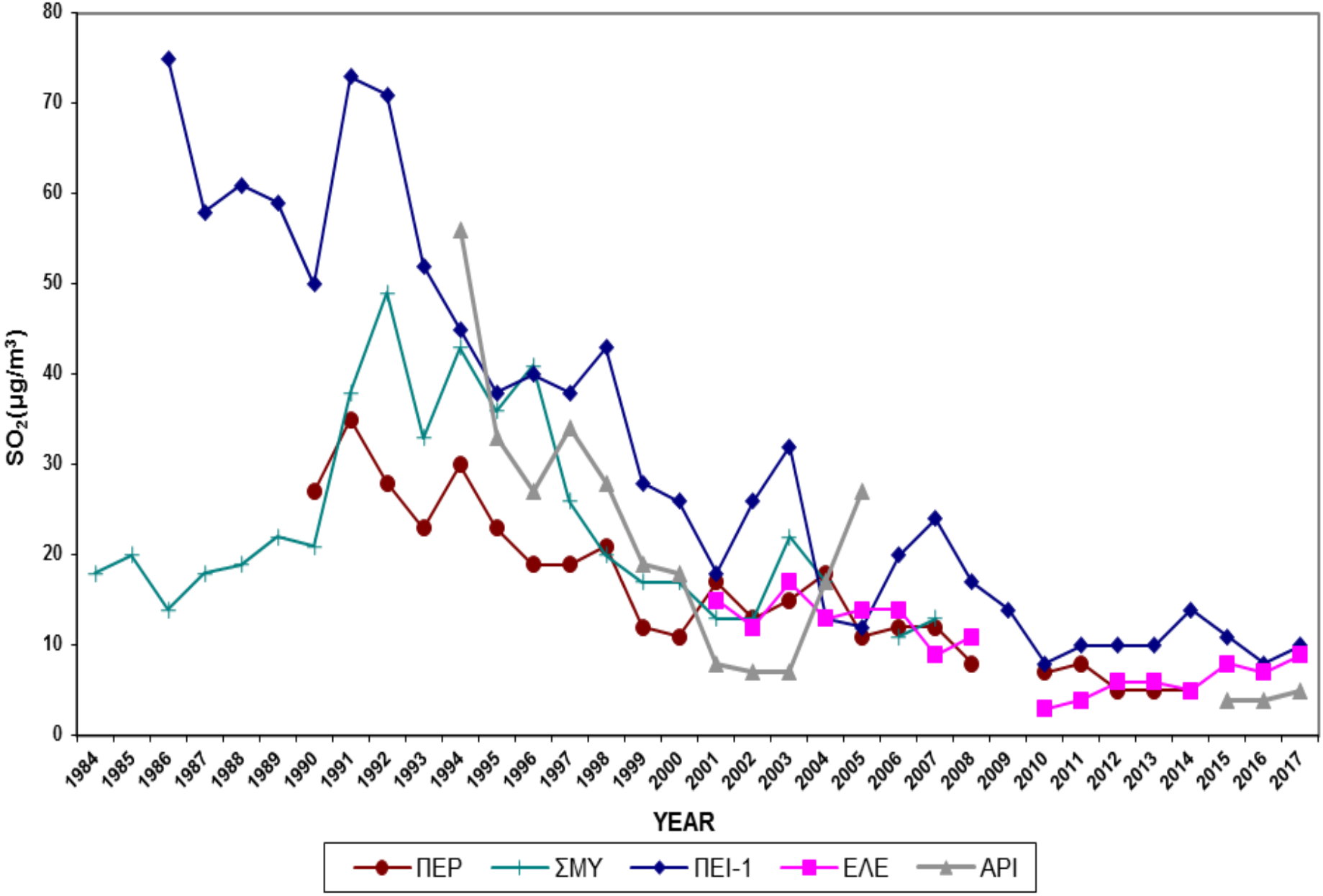
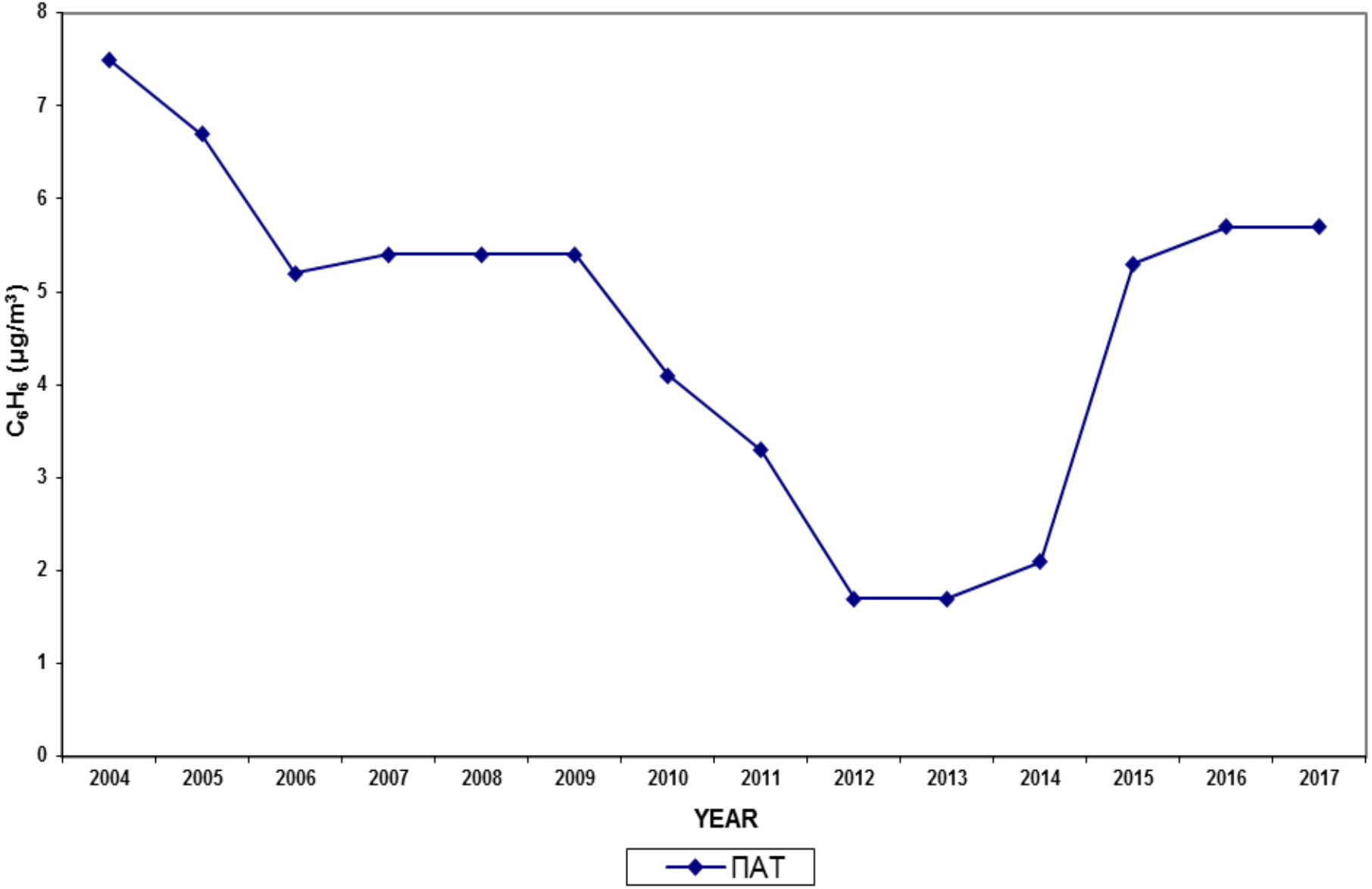
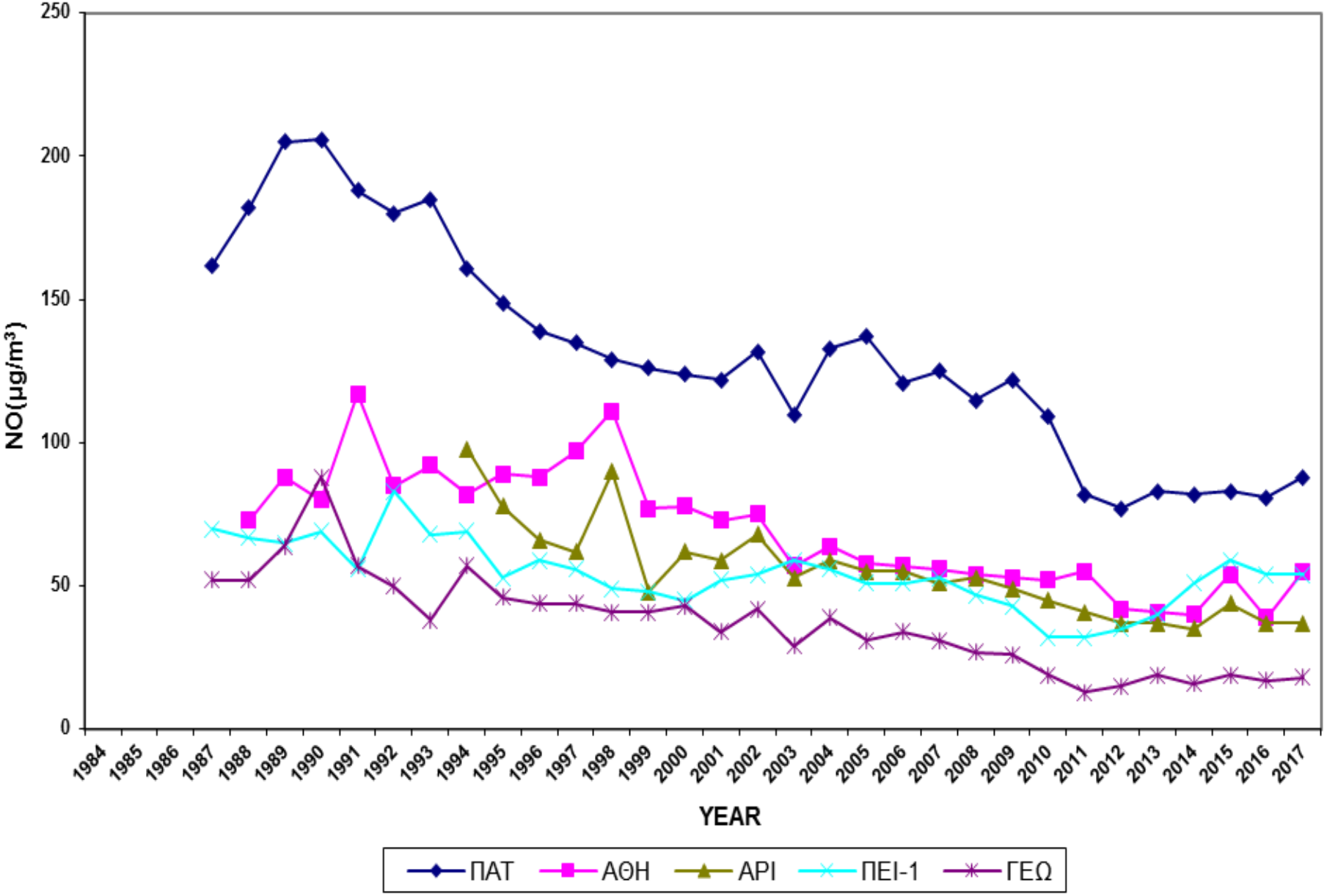


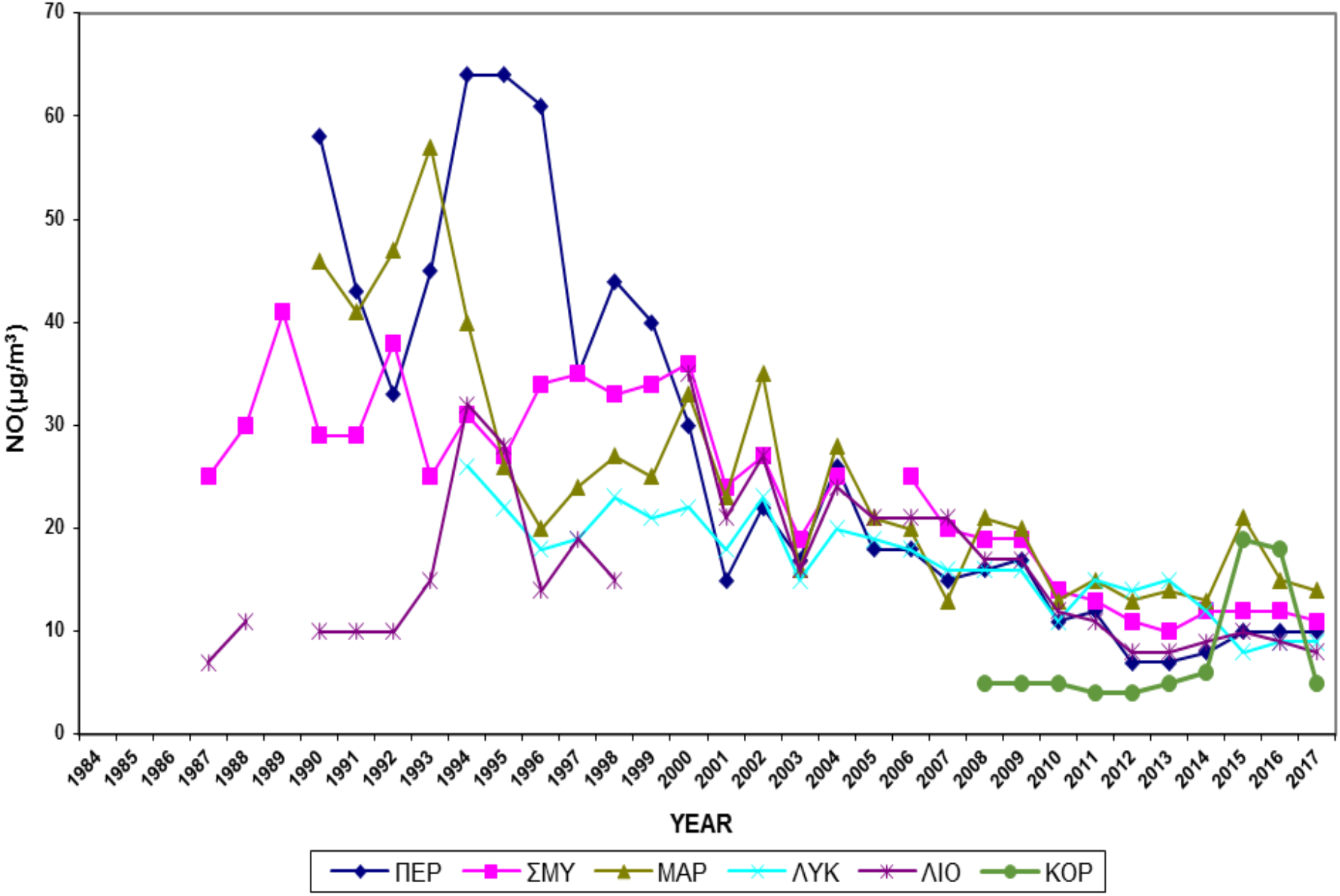
Temporal variation of mean annual C_6H_6 values in μg/m³



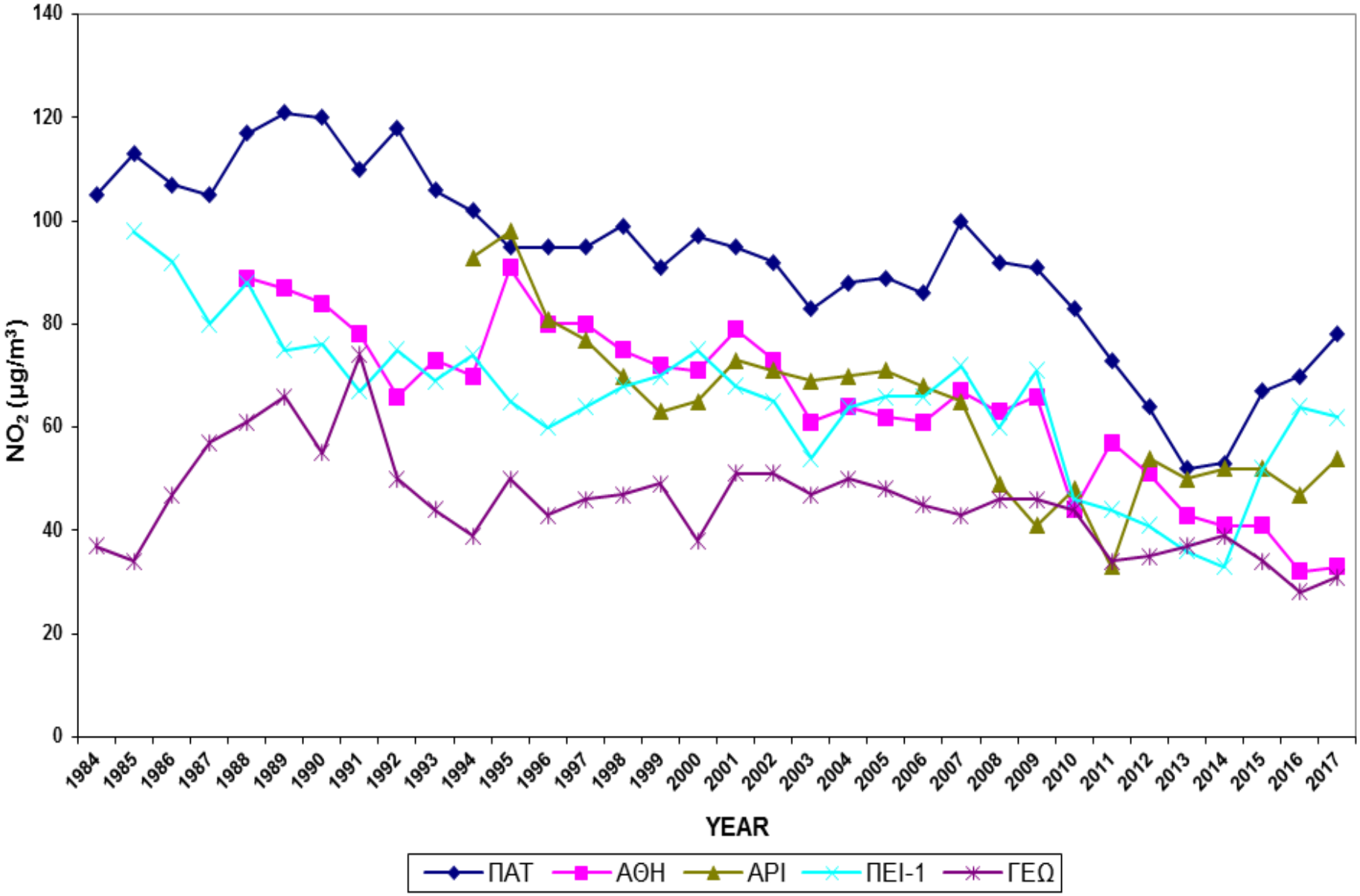
Temporal variation of mean annual NO values in μg/m³



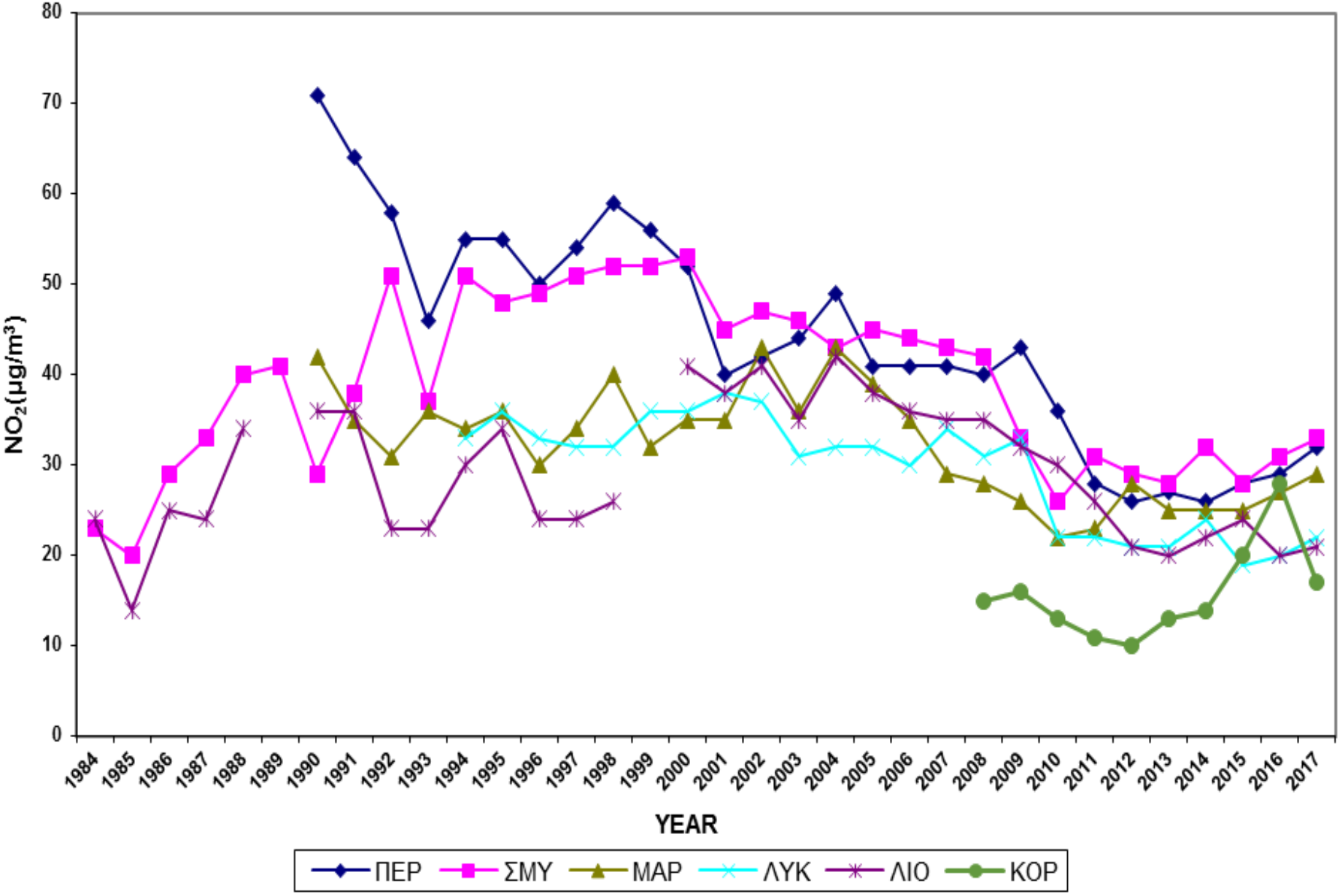
Temporal variation of mean annual NO values in μg/m³



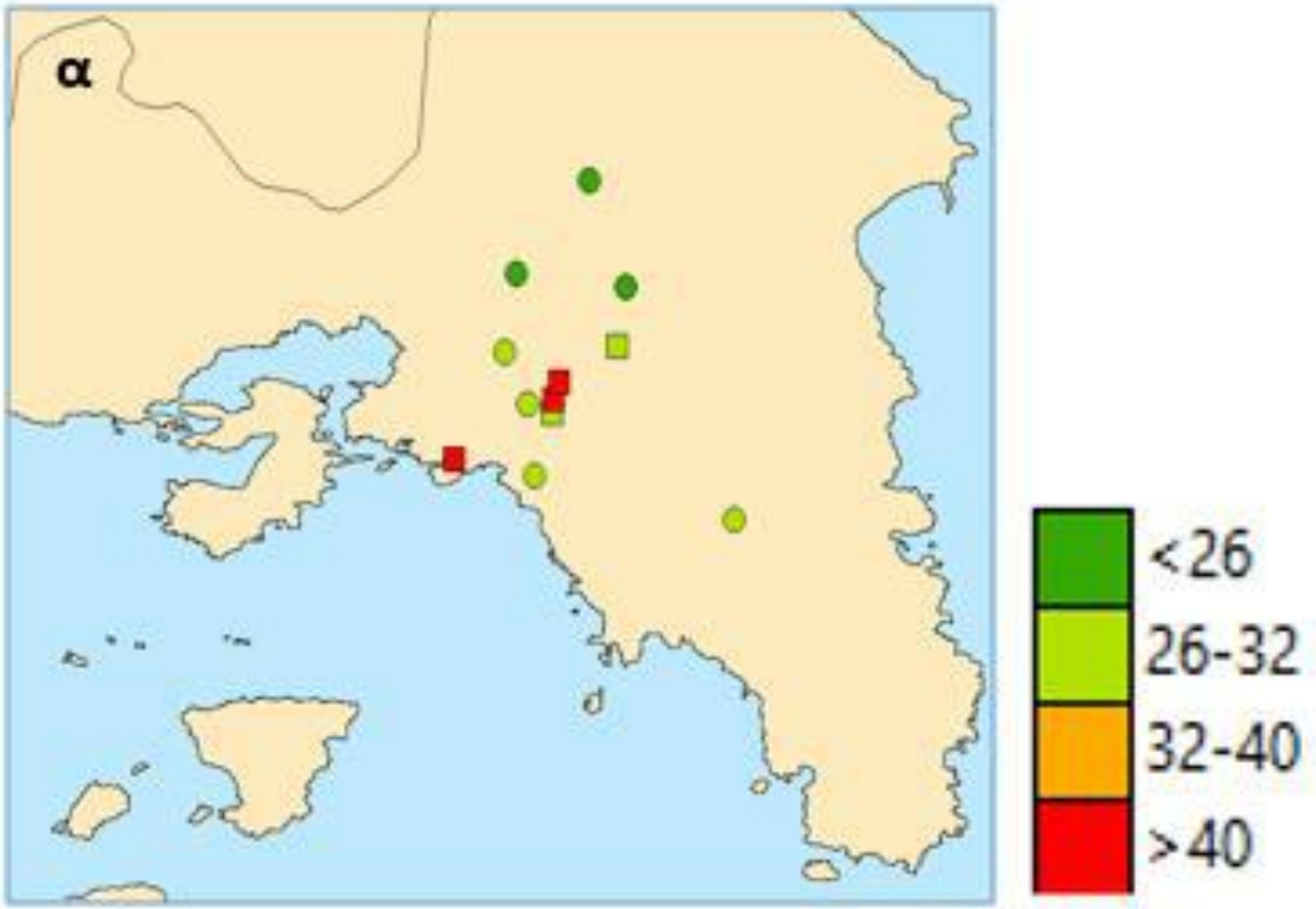
Temporal variation of mean annual NO_2 values in μg/m³



Temporal variation of mean annual NO_2 values in μg/m³

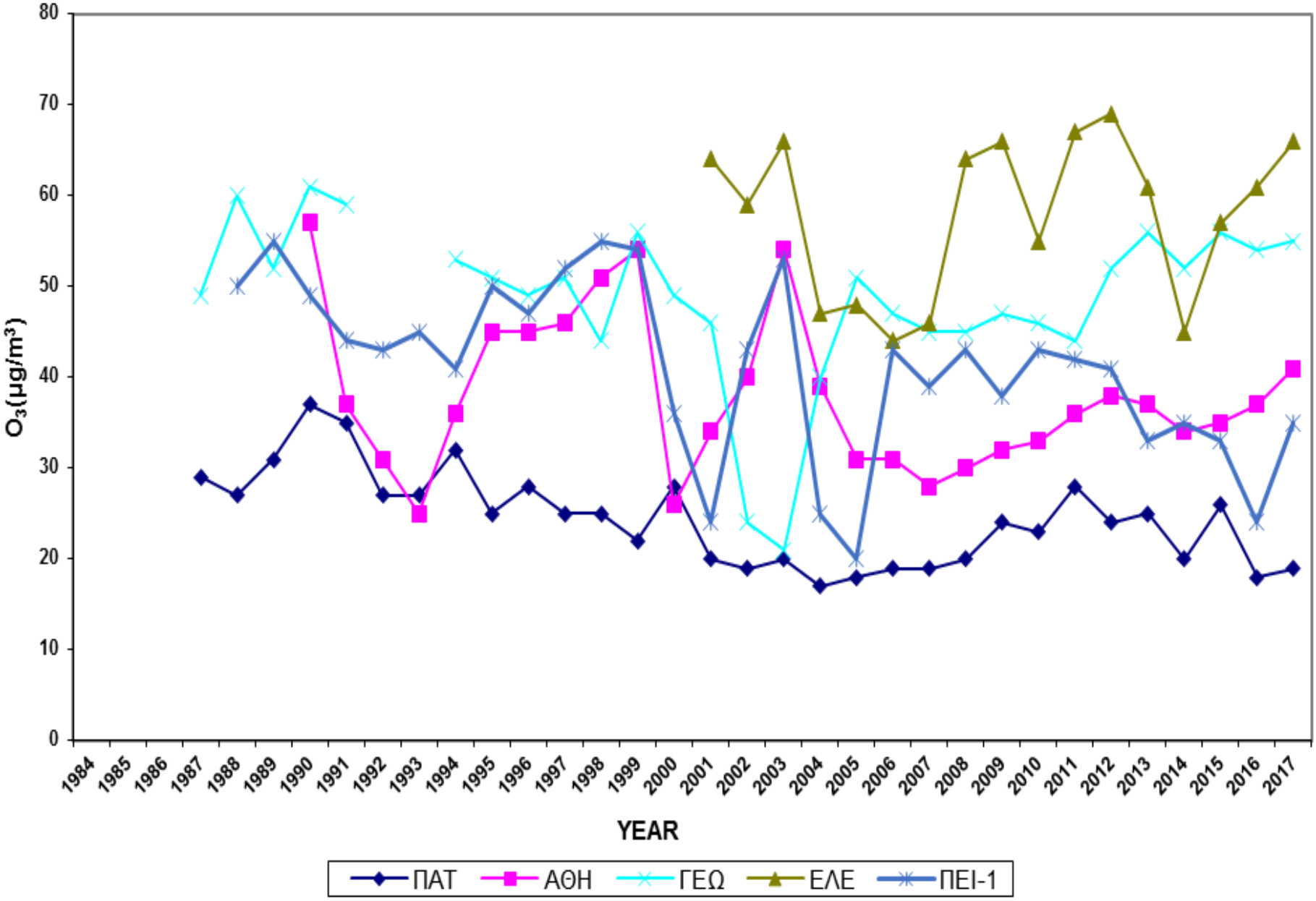


Geographical distribution of mean annual NO_2 values in μg/m^3

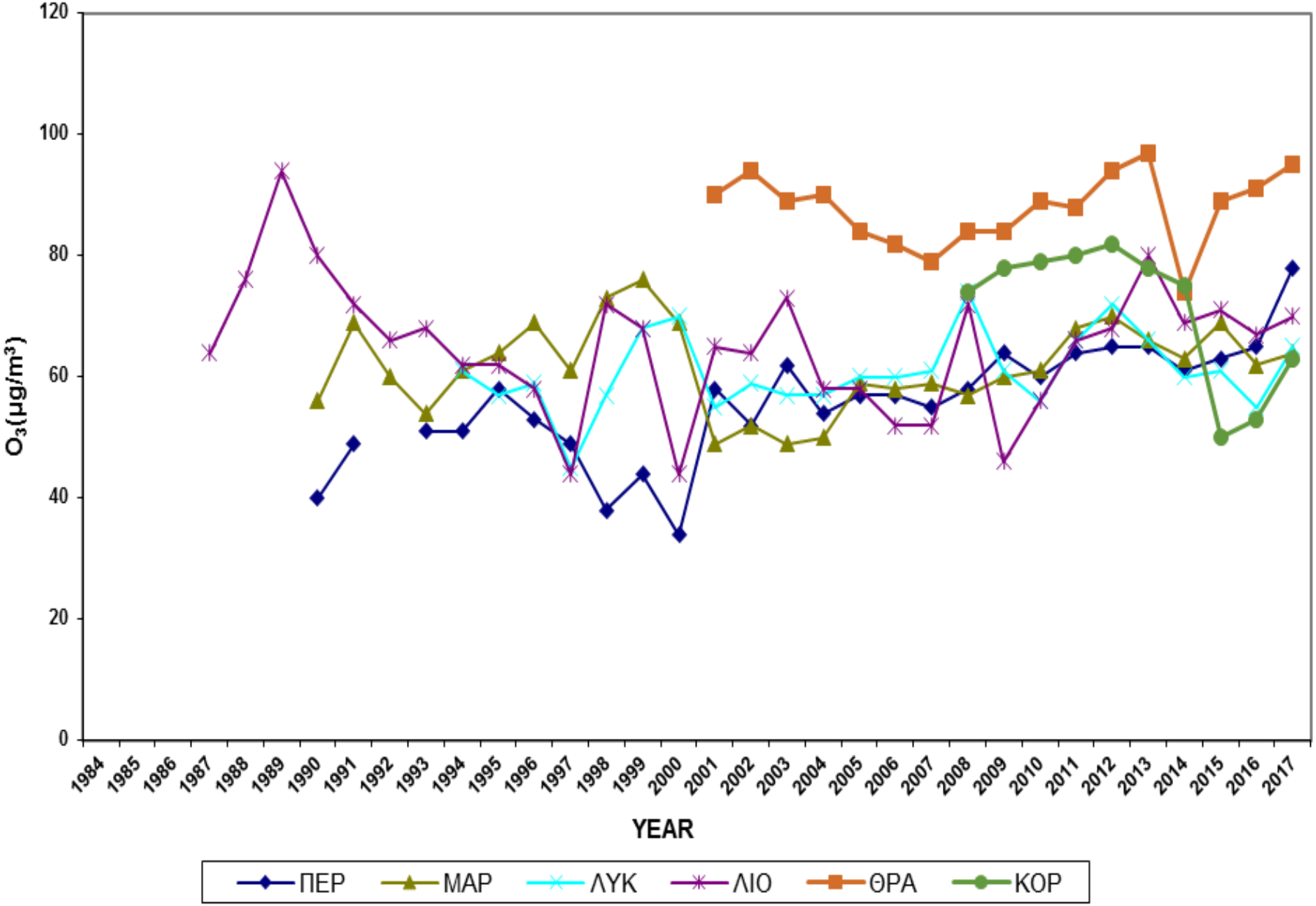


circle: background station, square: road stations, rhombus: industrial station

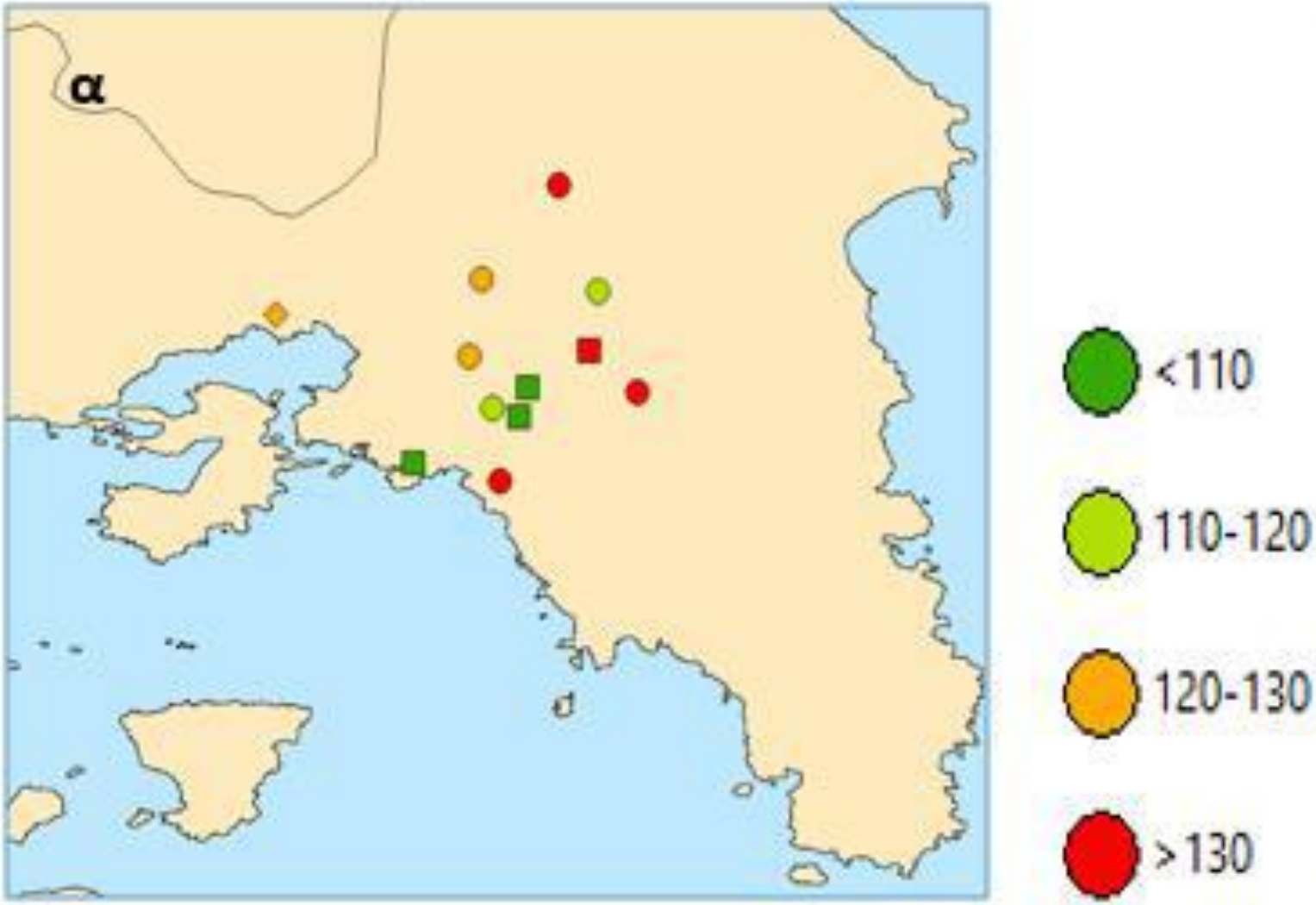
Temporal variation of mean annual O_3 values in μg/m³



Temporal variation of mean annual O_3 values in μg/m³

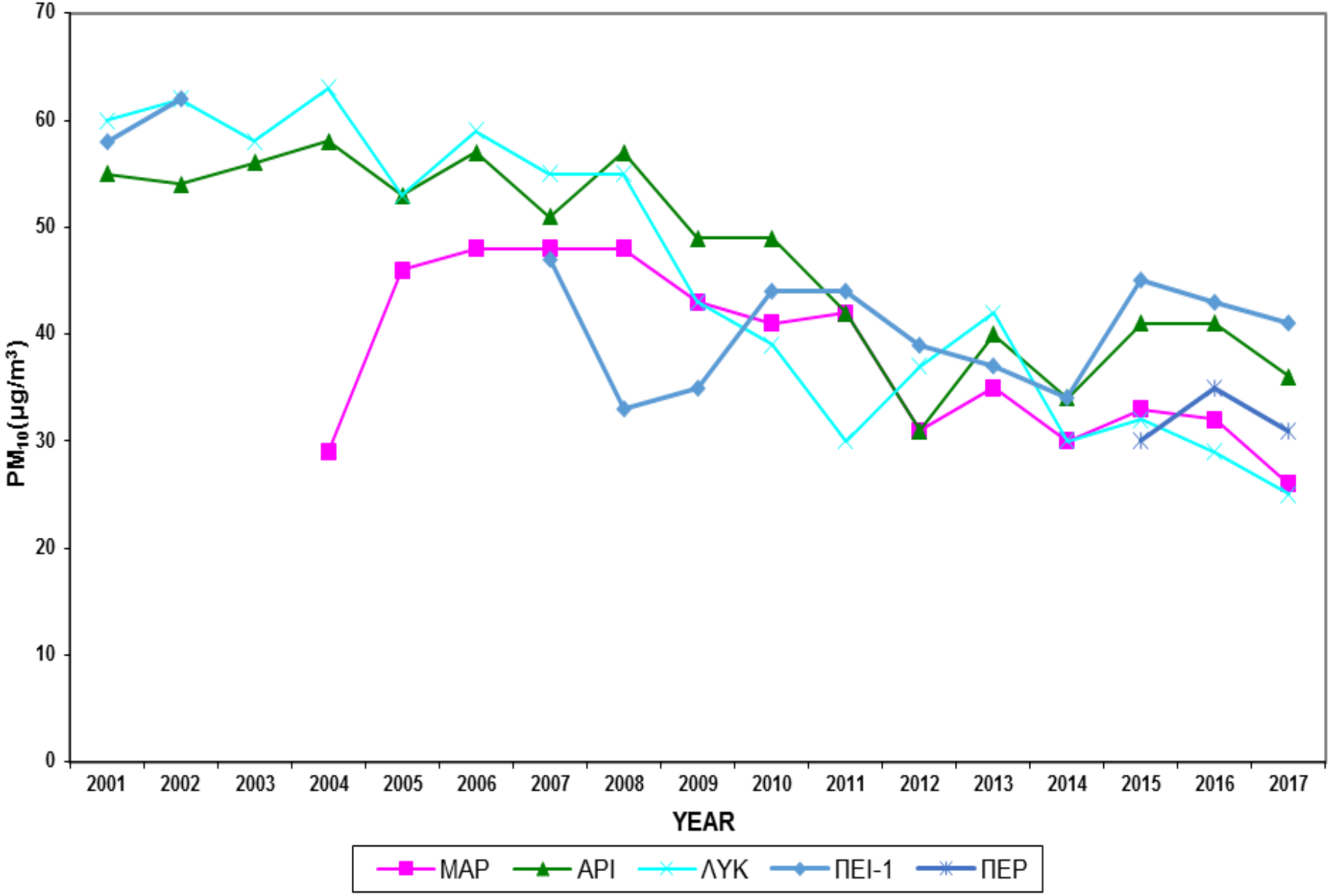


Geographical distribution of the 26th exceedance of the LV of max daily 8-hour O_3 values in µg/m³

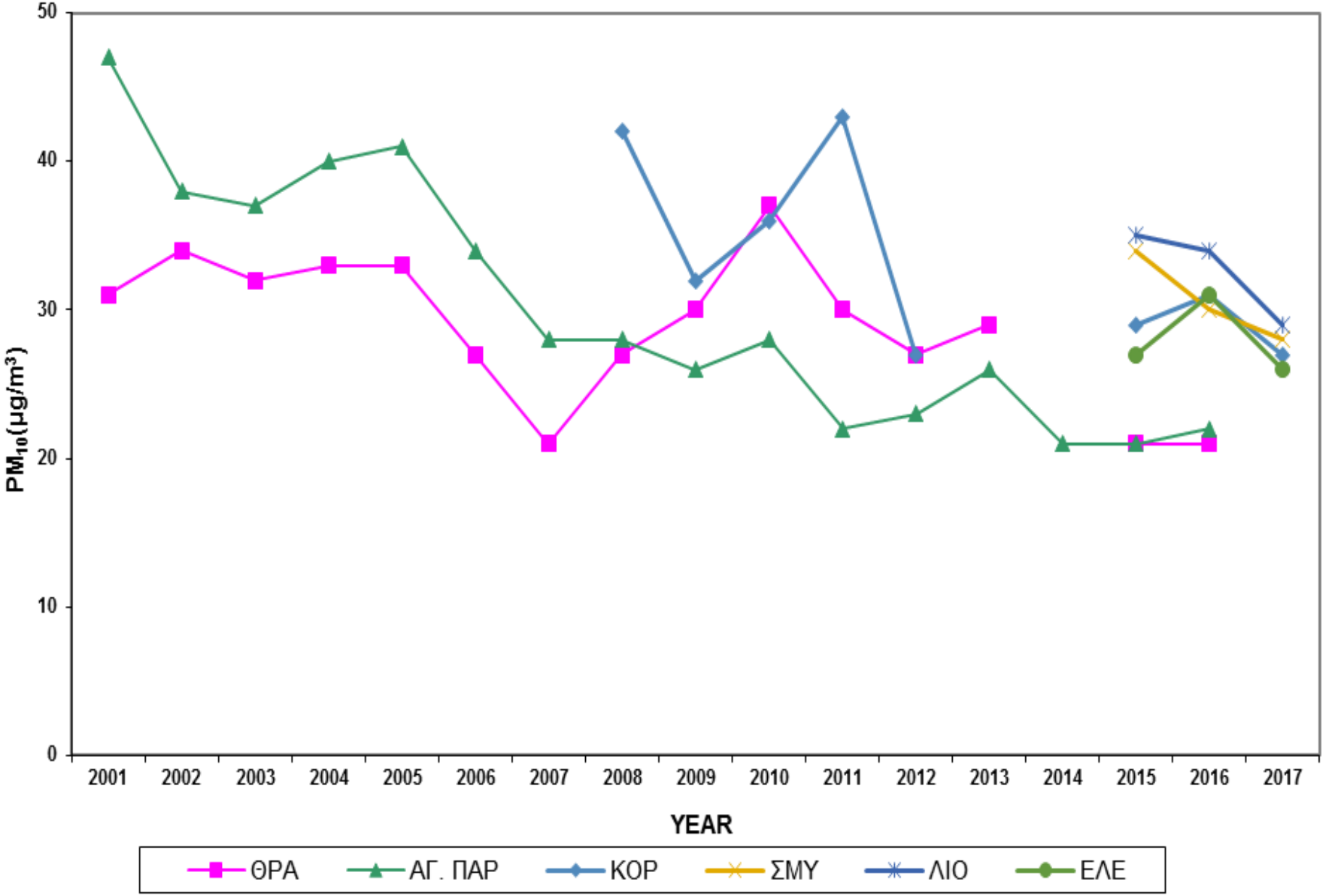


circle: background station, square: road stations, rhombus: industrial station

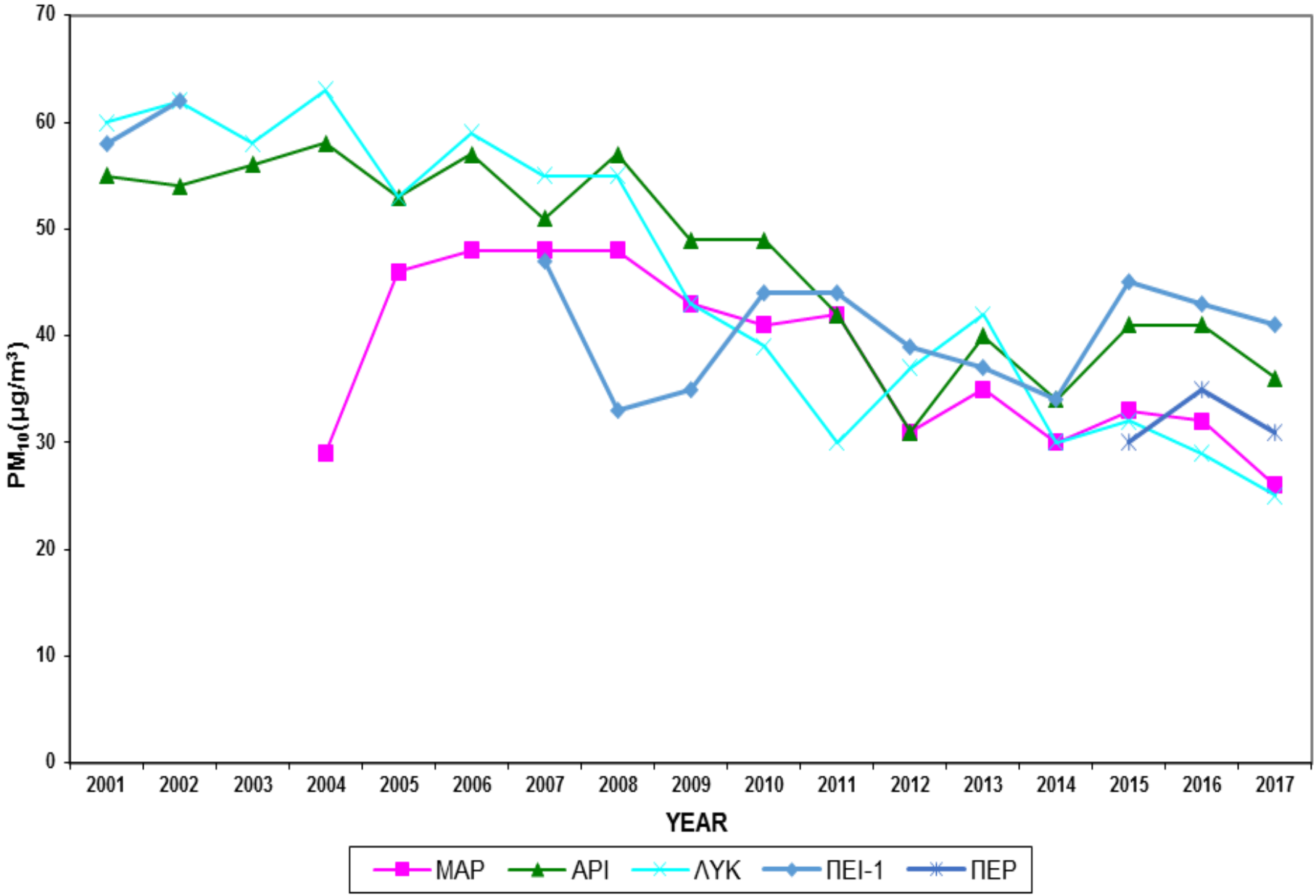
Temporal variation of mean annual PM_{10} values in μg/m³



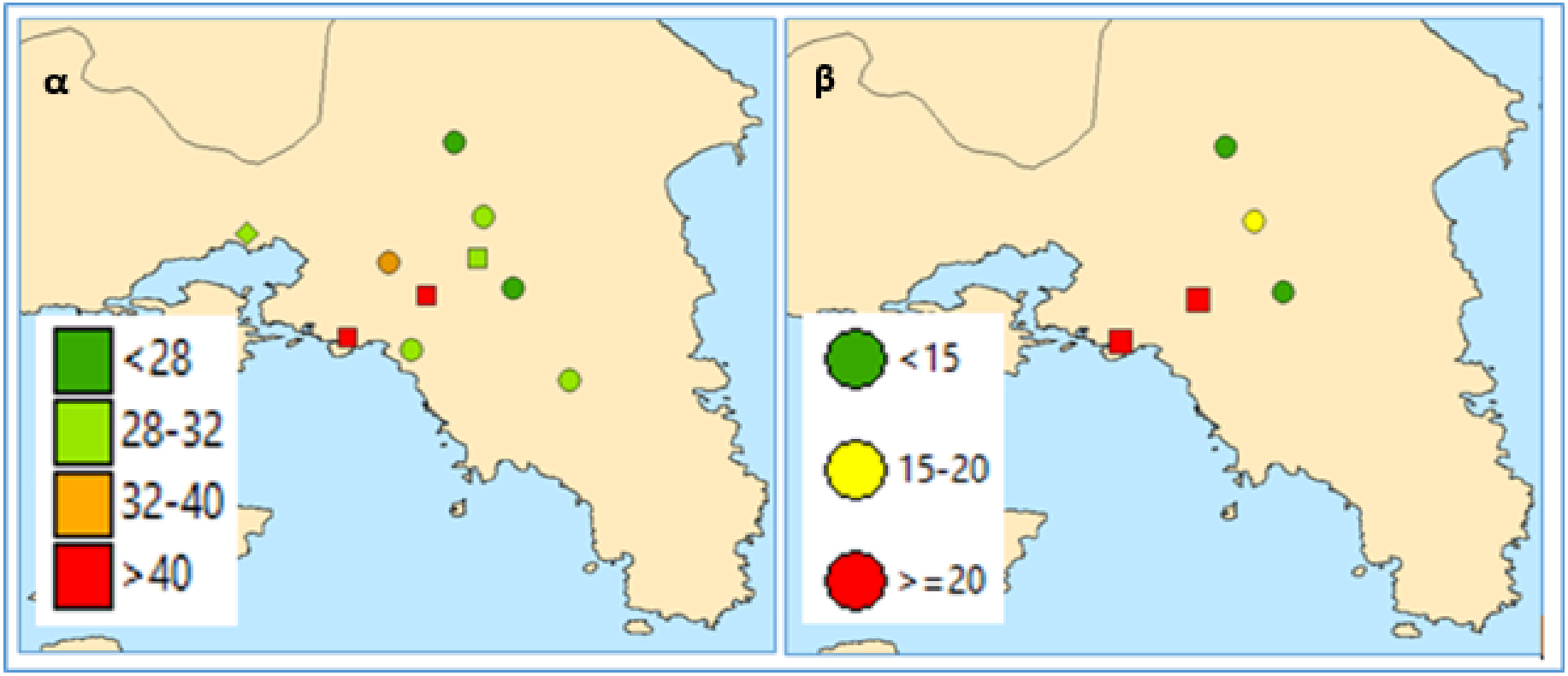
Temporal variation of mean annual PM_{10} values in μg/m³



Temporal variation of mean annual $PM_{2,5}$ values in μg/m³



Geographical distribution of mean annual PM_{10} (α) and $PM_{2,5}$ (β) values in μg/m³



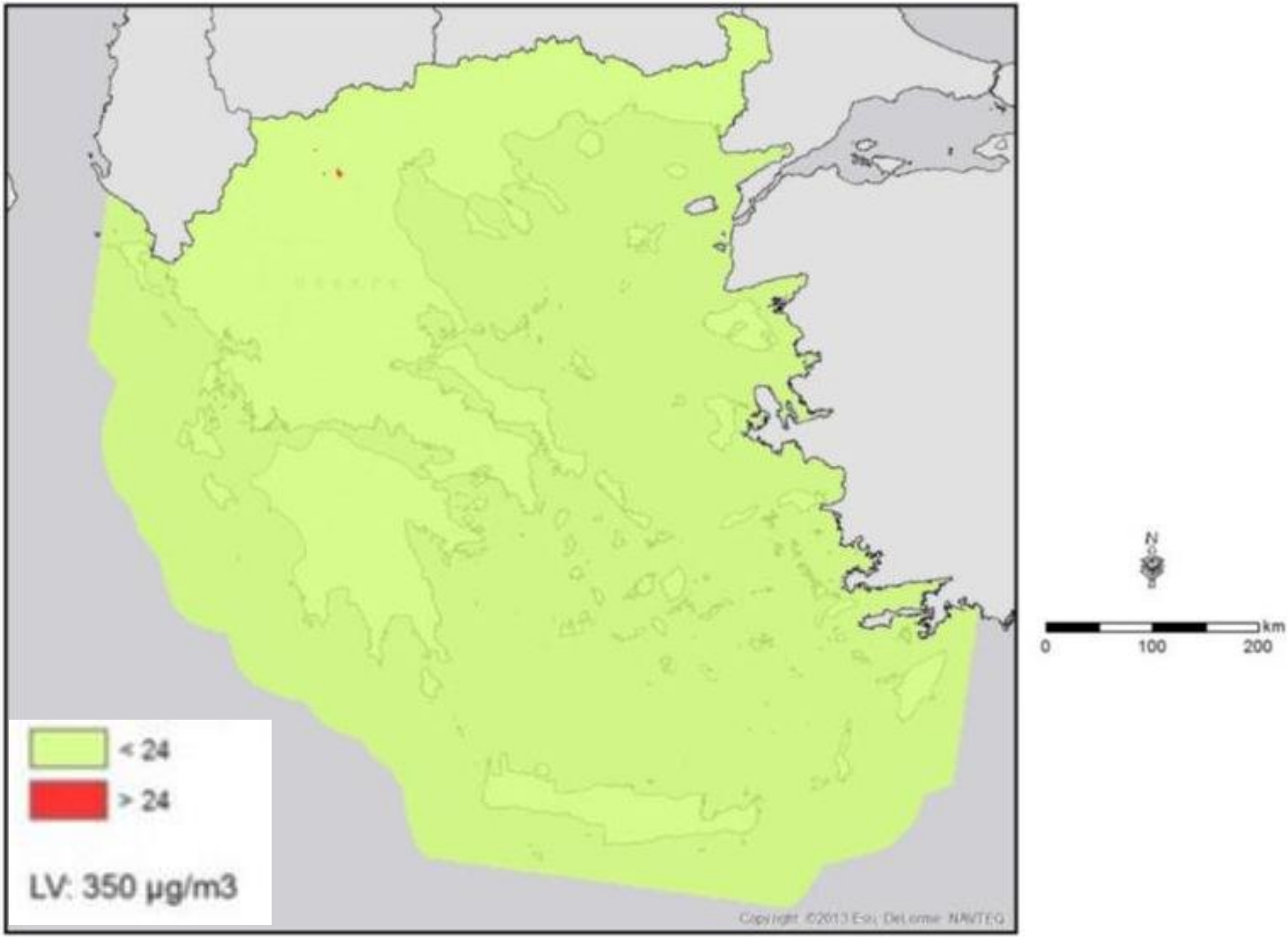
circle: background station, square: road stations, rhombus: industrial station).

Air quality trends

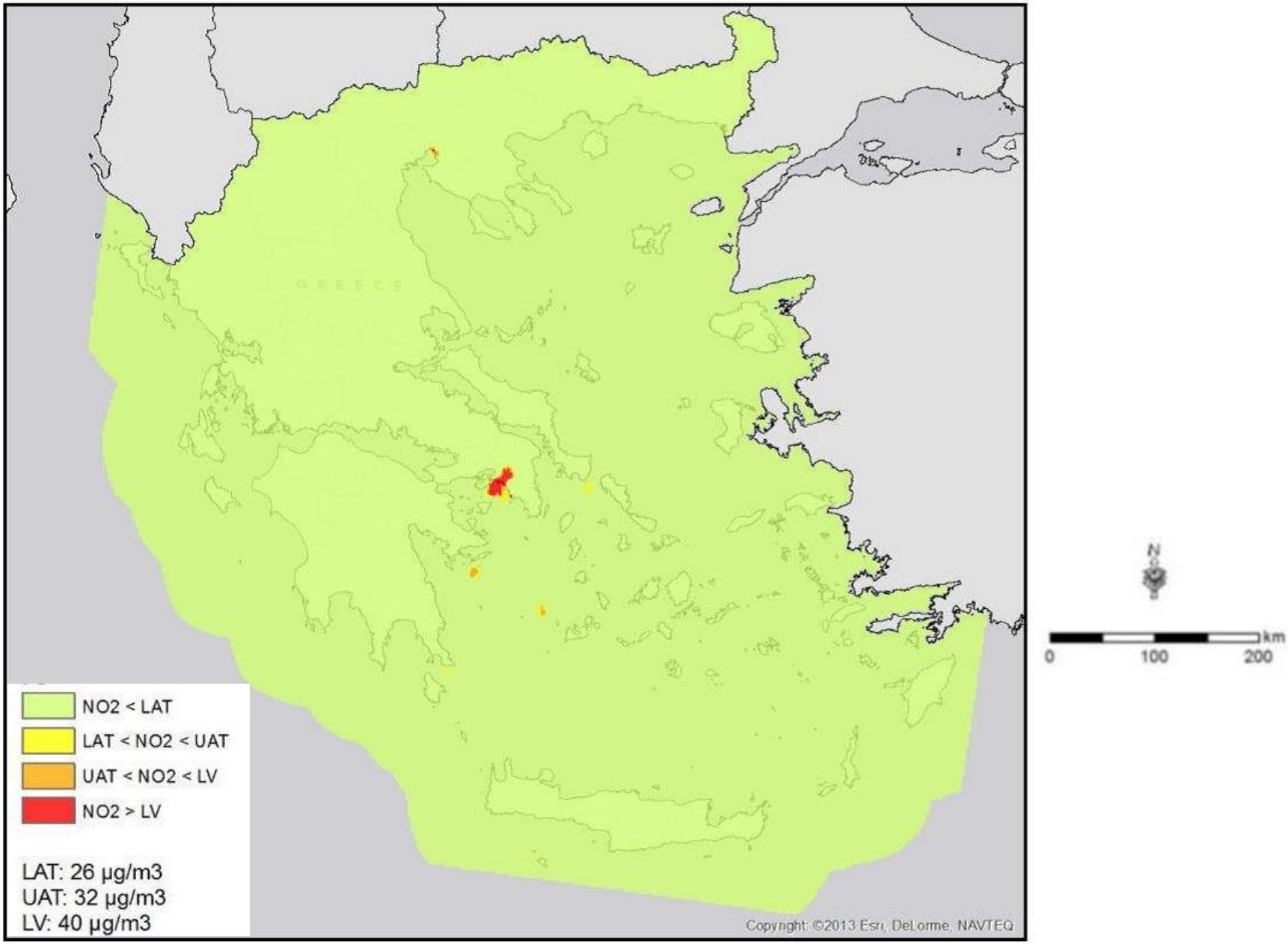
- General decrease of concentrations of the primary air pollutants, such as CO, NO and SO_2.
- O_3 remains almost stable (high solar radiation and sunshine duration favour its photochemical production). Exceedance of LV is frequent during the warm period of the year in Athens.
- PM_{10} violate LV for some monitoring stations. Saharan dust events are frequent throughout the year while high values of PM_{10} are also present under favourable meteorological conditions some winter days due to biomass burning for heating.
- Benzene exceeds the LV in the Athens city center.
- Concentration values of SO_2, NO_2, and CO are higher at the downtown monitoring sites, while for O_3, typically higher values are observed at the suburban sites. Topography combined with southwestern sea breeze in Athens often result in O_3 accumulation in the northern and north-eastern suburbs, especially during the summertime afternoon hours.
- NO_2 exceedances of the annual LV are observed mainly at the periphery of in Athens.
- SO_2 and CO concentrations during the winter period are higher than those during summer period. Max CO values coincide with traffic peaks. These pollutants never exceed LV.
- Heavy metals like As, Cd. Ni, Pb are below LAT.

Assessment of atmospheric pollution of the country using numerical models

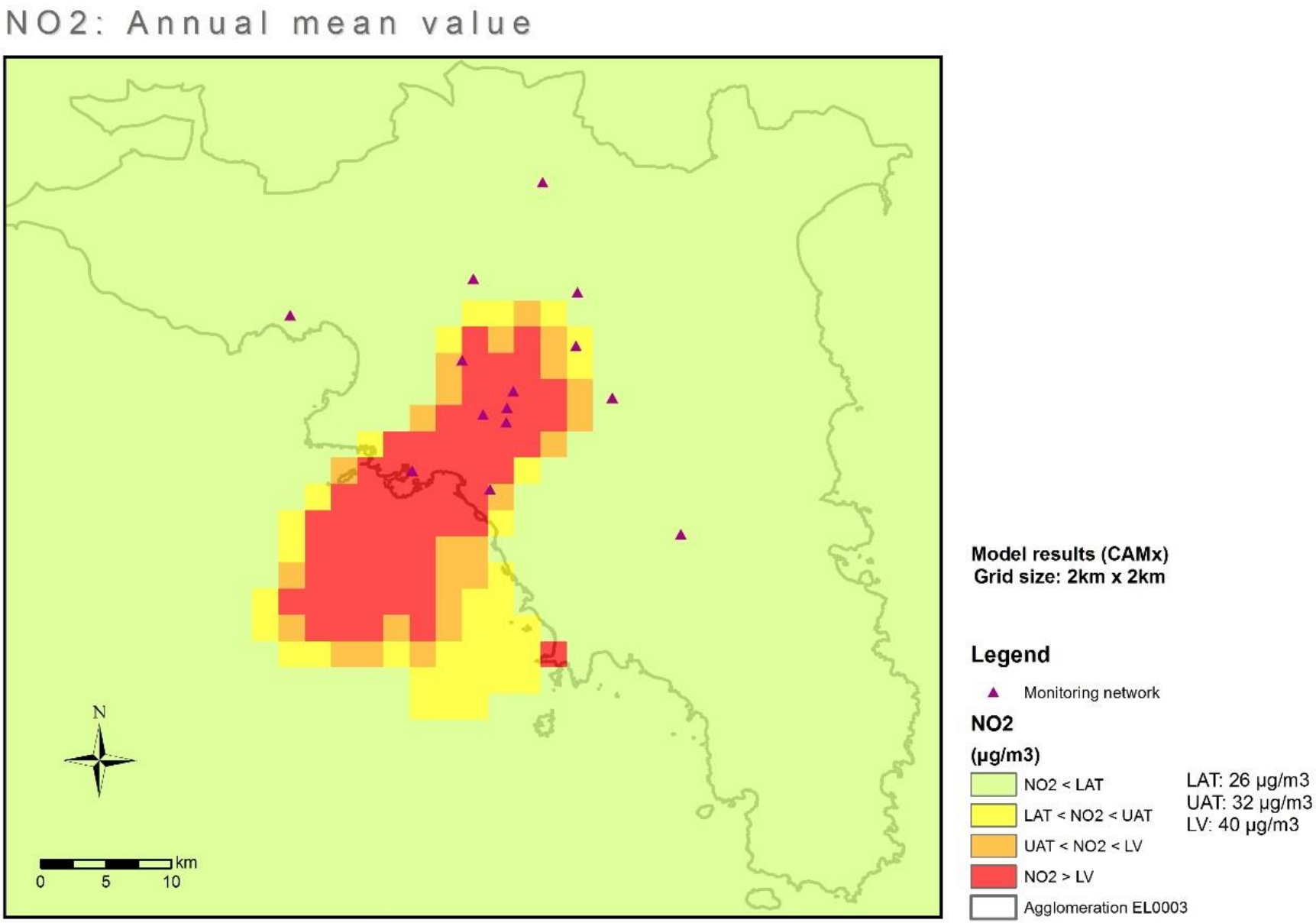
SO_2: Exceedances of hourly limit values (350 µg/m^3)



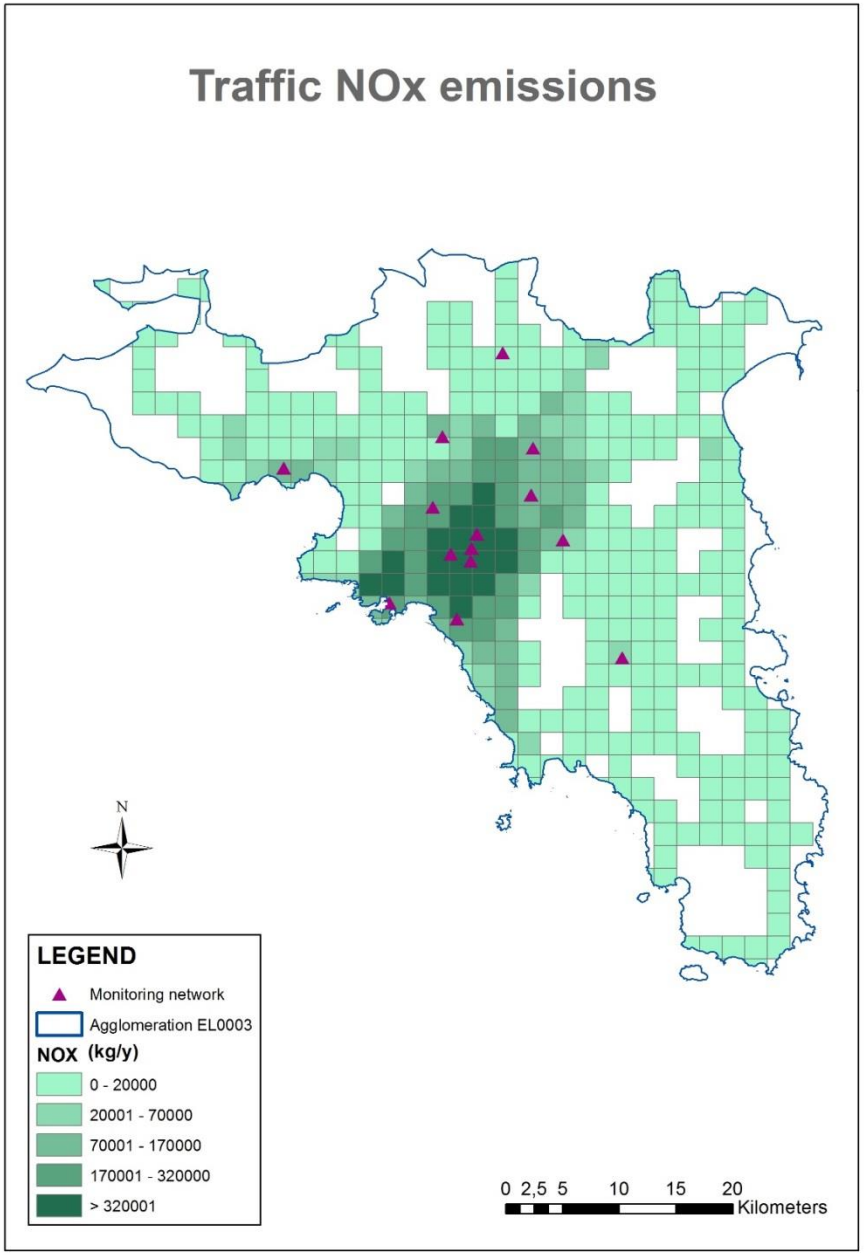
NO_2: Mean annual value (40 µg/m^3)



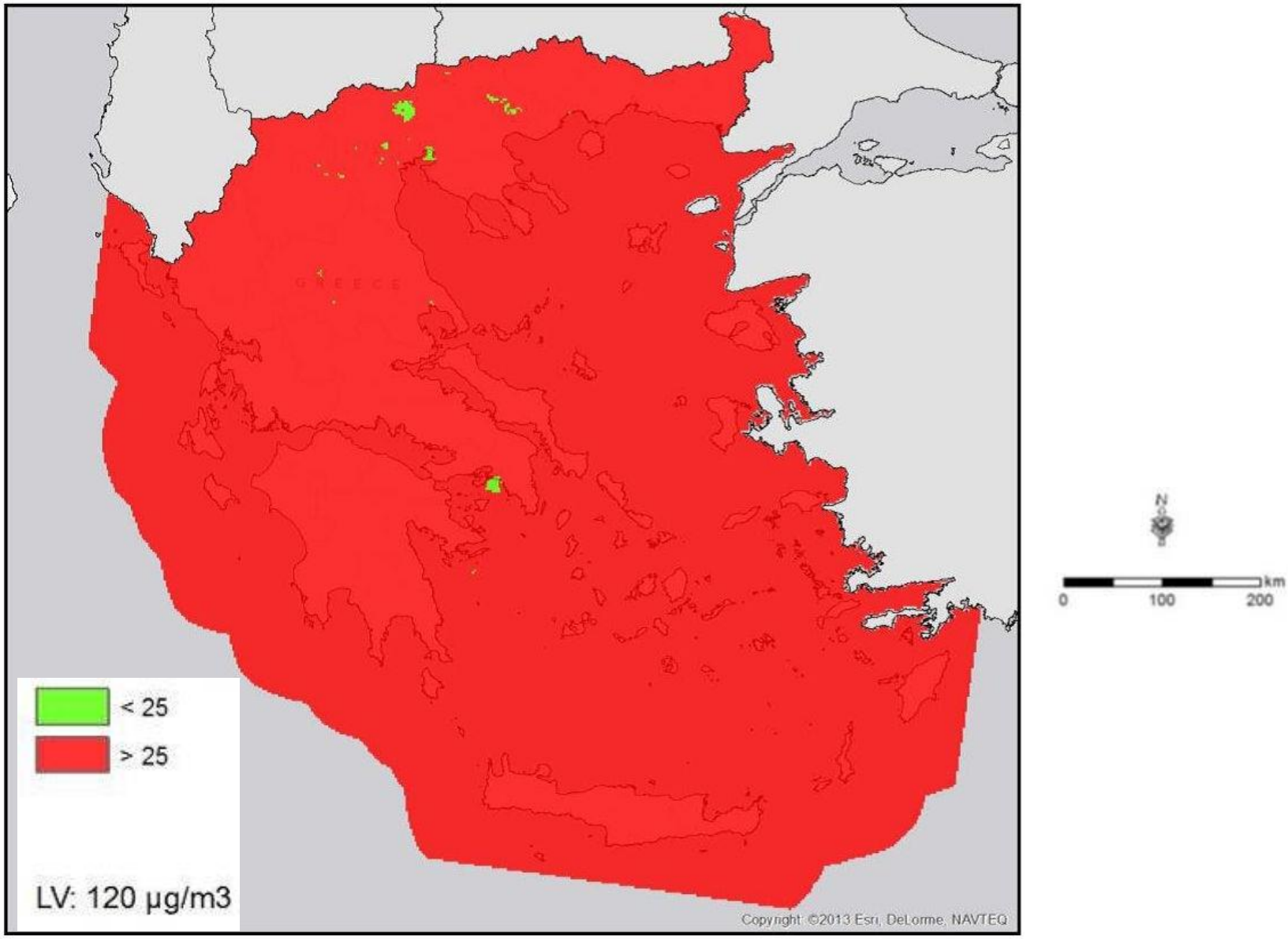
NOx: Mean annual value in Athens from all sources



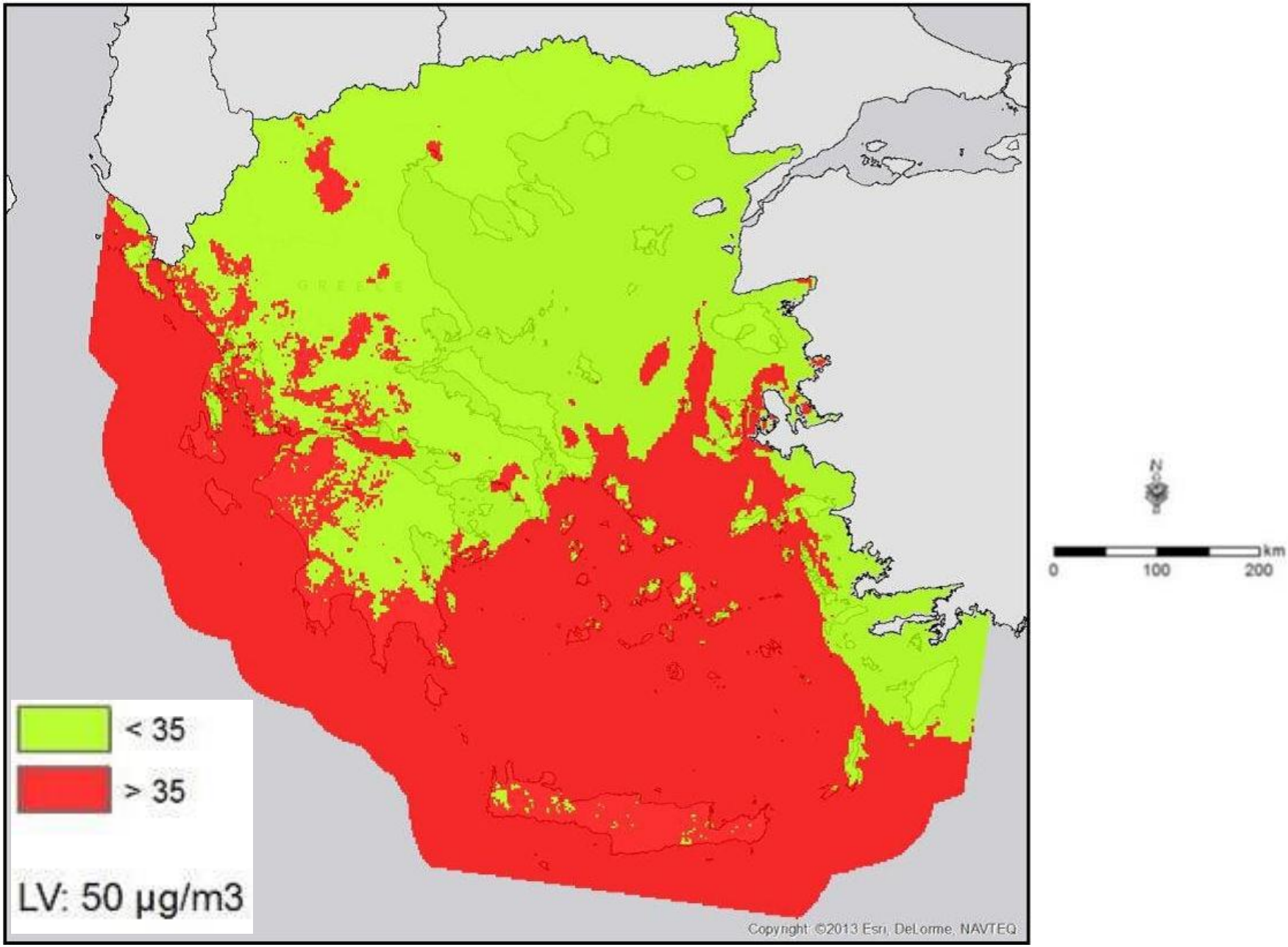
NOx: Mean annual value in Athens from road sources



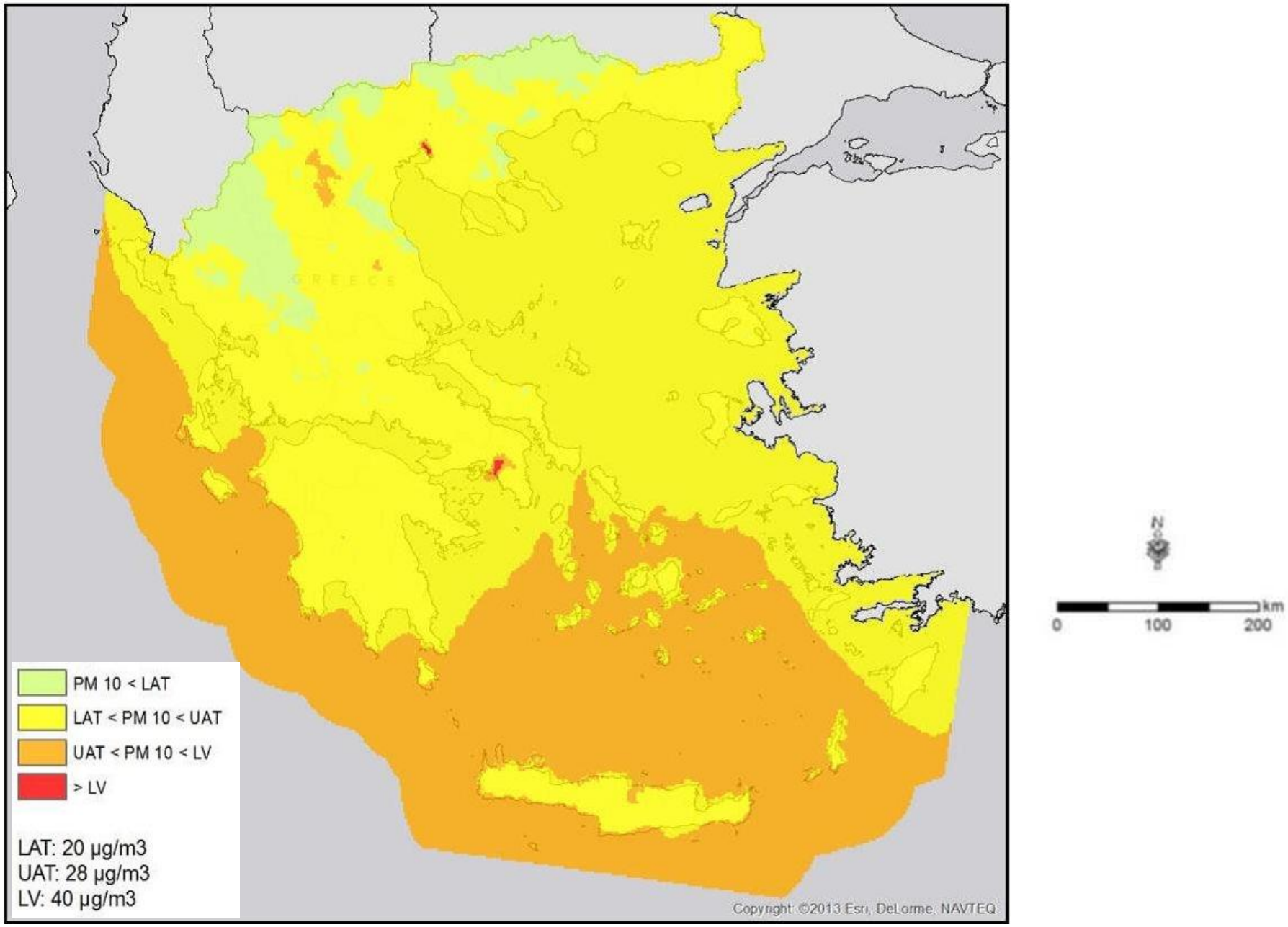
O_3: Exceedances of max daily 8-hour mean (from hourly running 8 hours)(LV: 120 µg/m^3) - 3 years average



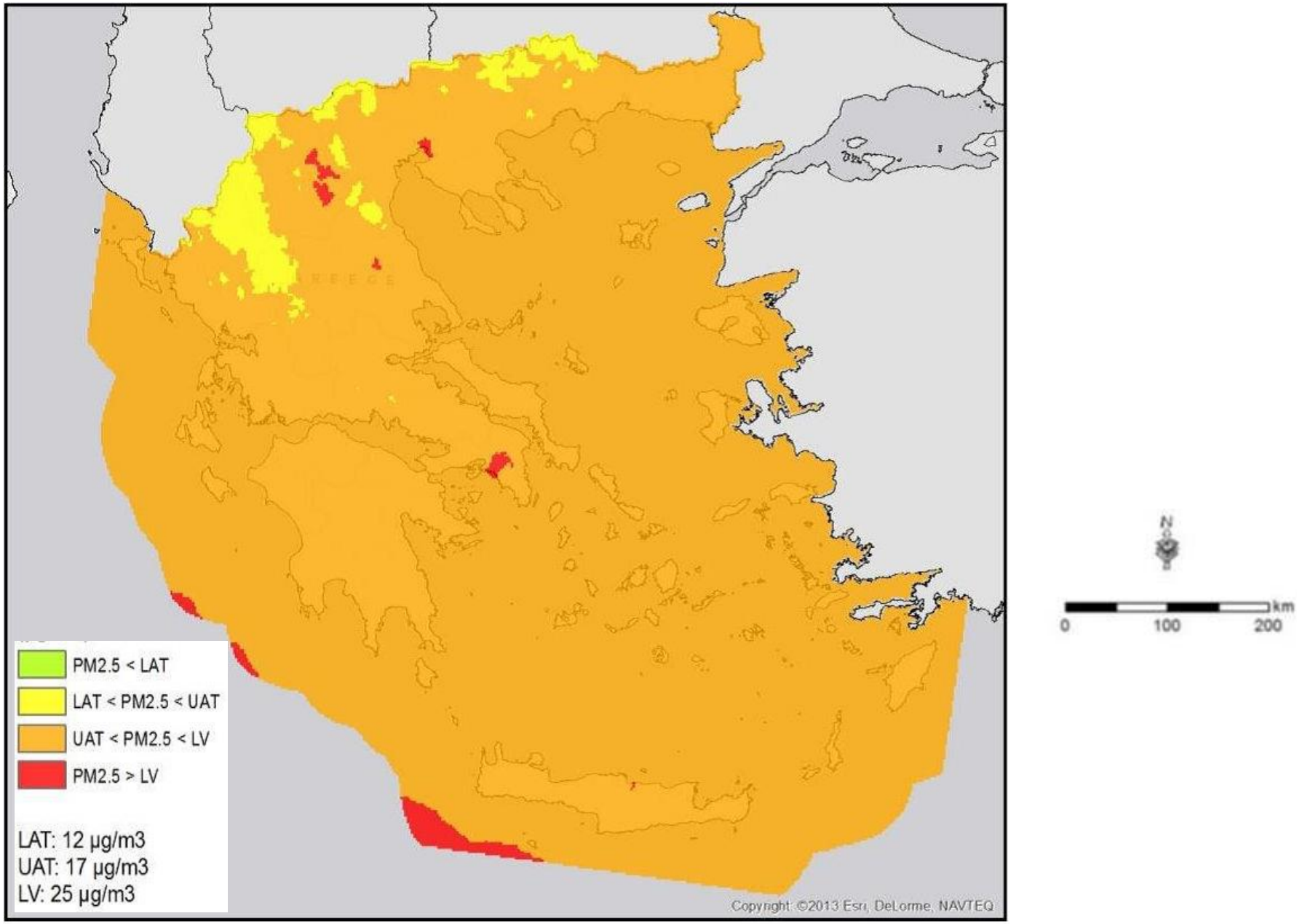
PM_{10}: Daily values - exceedances of limit value (50 µg/m³)



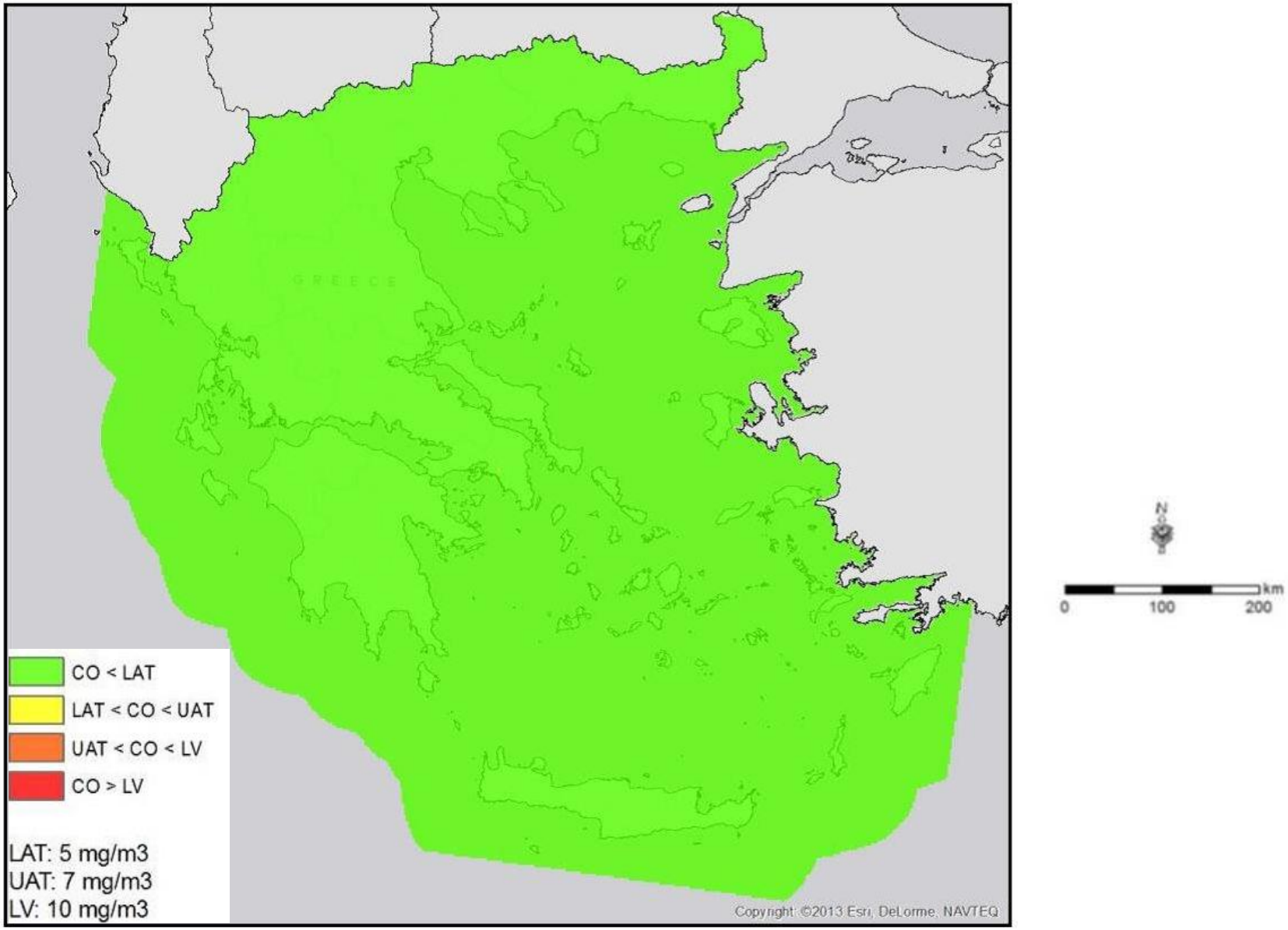
PM_{10}: Mean annual value (40 µg/m³)



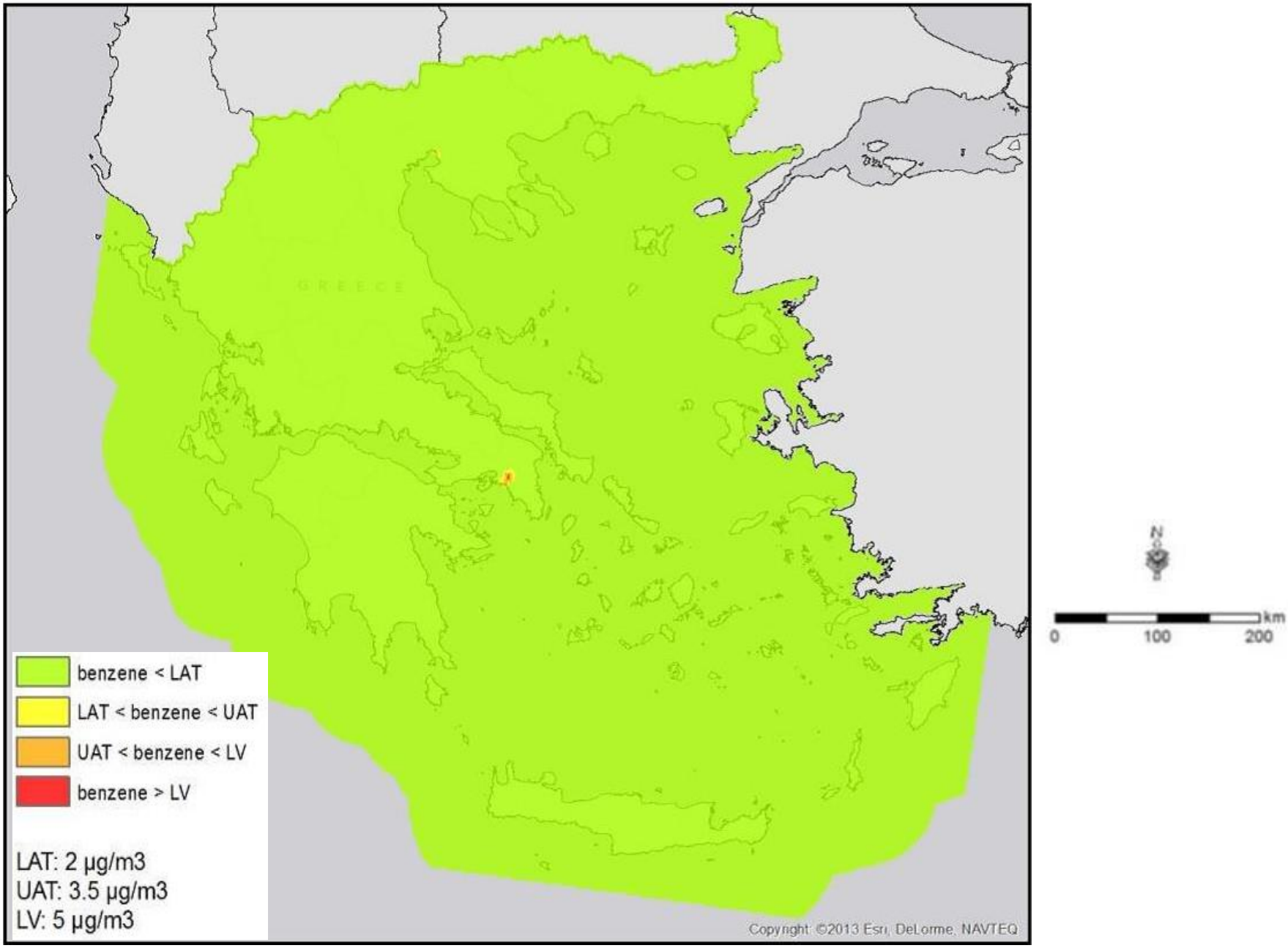
$PM_{2,5}$: Mean annual value (25 mg/m^3)



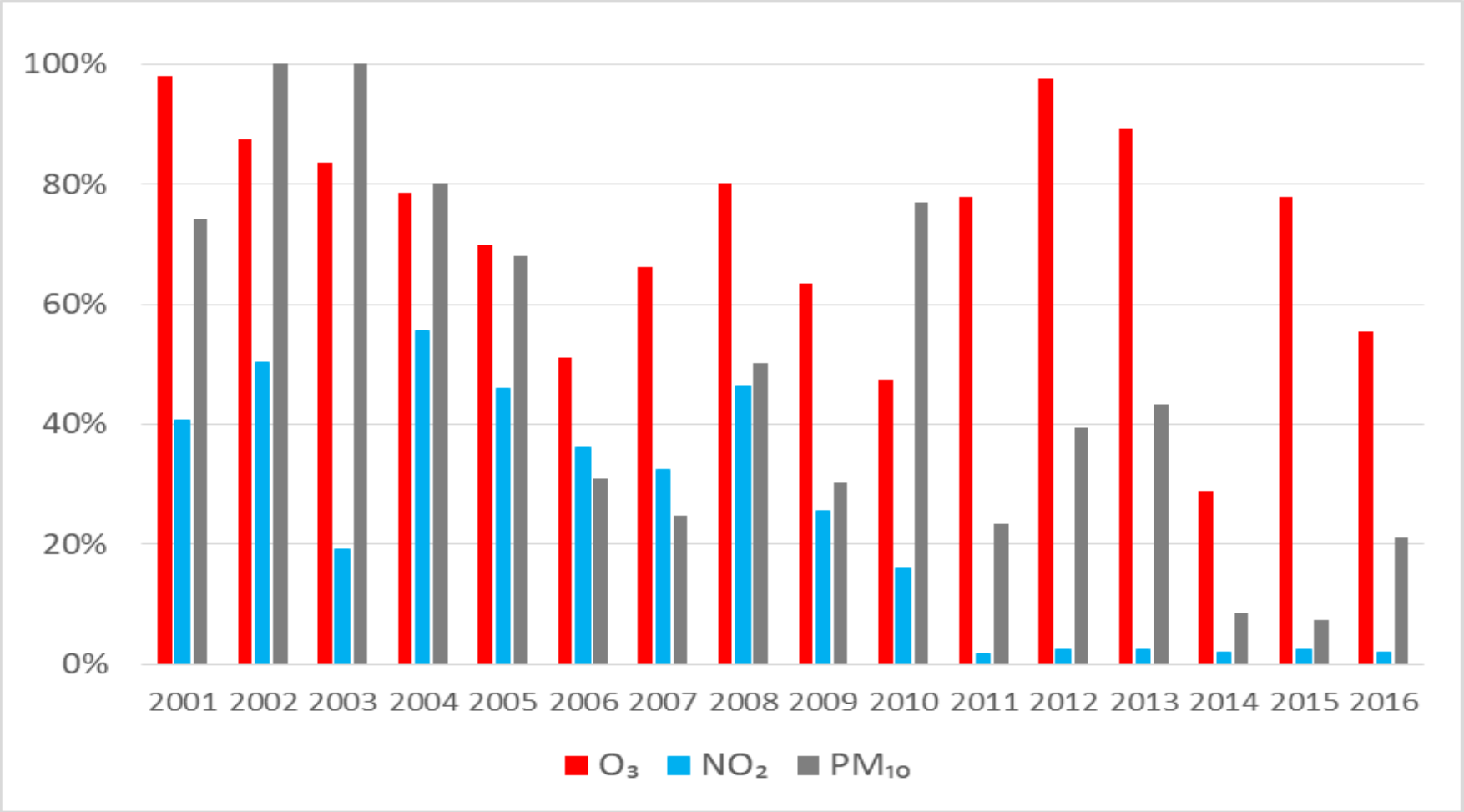
CO: **Exceedances of max daily 8-hour mean LV (from hourly running 8 hours)(LV: 10 mg/m^3) - 3 years average**



Benzene: Mean annual average (5 µg/m³)



Population exposure to air pollution above LVs (2016)



O_3: 55%
NO_2: 2% (annual LV)
PM_{10}: 21% (daily LV)

Benzene: 2% (annual LV)
No exposure to $PM_{2.5}$ (annual LV) and SO_2 (daily LV)

Main sources of Athens air pollution

Road transport

- CO: 90% caused by road transport
- NO_2: 80% caused by road transport
- O_3: 80% caused by road transport
- Benzene: 90% caused by road transport
- PM: 40-80%, depending on the area

Other PM sources: central heating, road dust and industry

SO_2: Industry and central heating

Initial measures for SO_2 and smog

First measures taken at late 70s and early 80s - aim at reducing SO_2 and traffic (reducing air emissions as a collateral benefit):

- Ban heavy fuel oil in central heating in 1977
- Close down of a heavy fuel oil power plant located in Piraeus and of another one at cape Sounio, 45 km from Athens
- Improving traffic conditions through synchronization of traffic lights, construction of bridges, inner ring during the week days (odd-even systems - 1979) etc.
- Planting trees at the curbside! (wherever there is an open space)
- Prohibition in circulation of diesel PCs since the 1980s in Athens and Thessaloniki.
- Measures to force the relocation of all industries out of the city – they become the enemy (social-political aspect)
- Closure of some other factories for economic reasons

Ongoing measures in the last decades

1. Heating:

- Allowing only 0,1% S content in diesel - mandatory use of natural gas downtown where available –
- Economic incentives to promote natural gas
- Economic incentives to use of electricity instead of biomass during high pollution days
- Money allowance for purchase of heating oil according to the personal income
- Standards for solid biomass fuels

1. Industry:

- Still measures to discourage the installation or the expansion of factories in Athens mainly through land use restrictions!!!
- Promotion of natural gas
- Improved environmental inspections

Ongoing measures in the last decades

3. Road transport:

- Economic incentives to withdraw the old conventional PCs and to replace them with catalytic-converter cars in the early 1990s. Also valid in 2010-2014 to renew the fleet.
- Green Ring in Athens
- Circulation fees are based on the emissions in CO_2
- Construction of extended road network bypassing the city centers and increasing the mean speed.
- Improvement of the technical inspection system for cars
- Improvement of fuel quality controls
- Construction of metro (2000, 2 new lines about 50 km, 1,4 million people daily), tram (3 lines – 2004, 25,9 km) and suburban railway and continuous expansion.
- Improvement of the level of service of public bus transportation – bus lanes
- Renewal of public buses (60% diesel, 25% natural gas, 15% trolleys)

4. Warning system: Inform and advise the population if pollution is above a certain threshold and take extraordinary measures if above highest threshold

The measure of car withdrawal

Critical factors/parameters to fine tune the right measures and measure its effectiveness: type of vehicles, age of fleet, maintenance, km/vehicle

Expected reductions (%) in emissions in 2011 compared to 2010, 75.000 cars

YEAR	PM	NOx	NMVOC	CO
2011	0	-2	-4	-4

Problem: all imported

Air emissions from road transport in Athens

Parameters:

- Type of vehicle (PCs, taxis, LDVs, trucks and buses, motorcycles)
- Age distribution
- Number of km per type of vehicle
- Speed profile
- Ambien temperature

COPERT IV

t/y	CO	NMVOCs	NOX	PM	CO2 (kt/y)
PCs	75639	11347	8665	Private 36 Taxis 59	4706
LDVs	15571	1926	2212	57	518
HDVs	3990	1775	13517	613	1176
Buses	939	277	4065	123	417
2-Wheel Vehicles	31425	3520	864	48	313
TOTAL	**127563**	**18845**	**29322**	**936**	**7131**

Annual air emissions per vehicle type in Athens

Green ring in Athens (proposal by Chemical Engineering School of NTUA)

- Banning passenger cars > 22 years from the inner ring
- PCs with registration number ending in an odd number (1,3, …) are only allowed in the inner ring (downtown) on odd dates while those cars with registration number ending in an even number (0, 2, …) are allowed on even dates (from 07:00 to 20:00 every week day or 15:00 on Friday).
- The following vehicles are allowed in the inner ring independently of their license plate:
  - Electrical PC
  - Euro 4 hybrid PCs that emit < 140g CO_2/km
  - Euro 5 and 6 PCs that emit < 140g CO_2/km
- Heavy vehicles (trucks and buses) > 22 (15) years are not allowed in the outer ring – exemptions in 3 main highways
- Green badge on the car
- No restrictions in the weekends

Green ring in Athens Emission estimates

NTUA proposal of banning PC > 22 year

Estimated emission reductions in the Athens Greater Area in a typical day from road transport

CO	NMVOC	NO_X	N_2O	CH_4	CO_2
-54%	-45%	-13%	-10%	-28%	-10%

Allowing EURO 5 & 6 diesel PC in Athens

Emission reductions in 2015 vs 2010 (including car withdrawal)

	PM	NO_x	NMVOC	CO	CO_2
No diesel	-2%	-10%	-31%	-29%	3%
With diesel	1%	-7%	-32%	-32%	-5%

Green ring in Athens – Emission estimates

Banning buses and trucks > 15 years in the outer ring

Estimated emission reductions in Greater Athens Area from road transport in a typical day

Age of HDV in the outer ring	PM_{10}	NMVOC	NO_X	N_2O	CH_4
< 15 year	-66%	-71%	-44%	-7%	-52%
< 22 year	-40%	-13%	-20%		-6%

NEC Directive

Emission reductions compared to 2005 for SO_2, NO_x, NMVOC, NH_3 & $PM_{2,5}$

	2016 (existing situation)	2020-2029	➢ 2030
Reduction SO_2	86,98%	74%	88%
Reduction NO_x	44,74%	31%	55%
Reduction NMVOC	33,38%	54%	62%
Reduction NH_3	12,62%	7%	10%
Reduction $A\Sigma_{2,5}$	45,62%	35%	50%

- National program of measures – interministerial committee
- National Committee for Energy and Climate

NEC Directive – Existing measures

EU Climate –Energy package for 2020 and 2030

- ETS & non ETS (Effort Sharing Decision)
- ILUC Directive
- Renewables
- Energy Efficiency
- Ecodesign provisions on solid fuel combustion
- etc…

EU transport legislation

- Regulations CO2 emissions from cars and vans
- Euro standards
- Fuel Quality Directive &Marine Fuel Directive
- Non road mobile machinery Regulation
- Alternative fuel infrastructure Directive

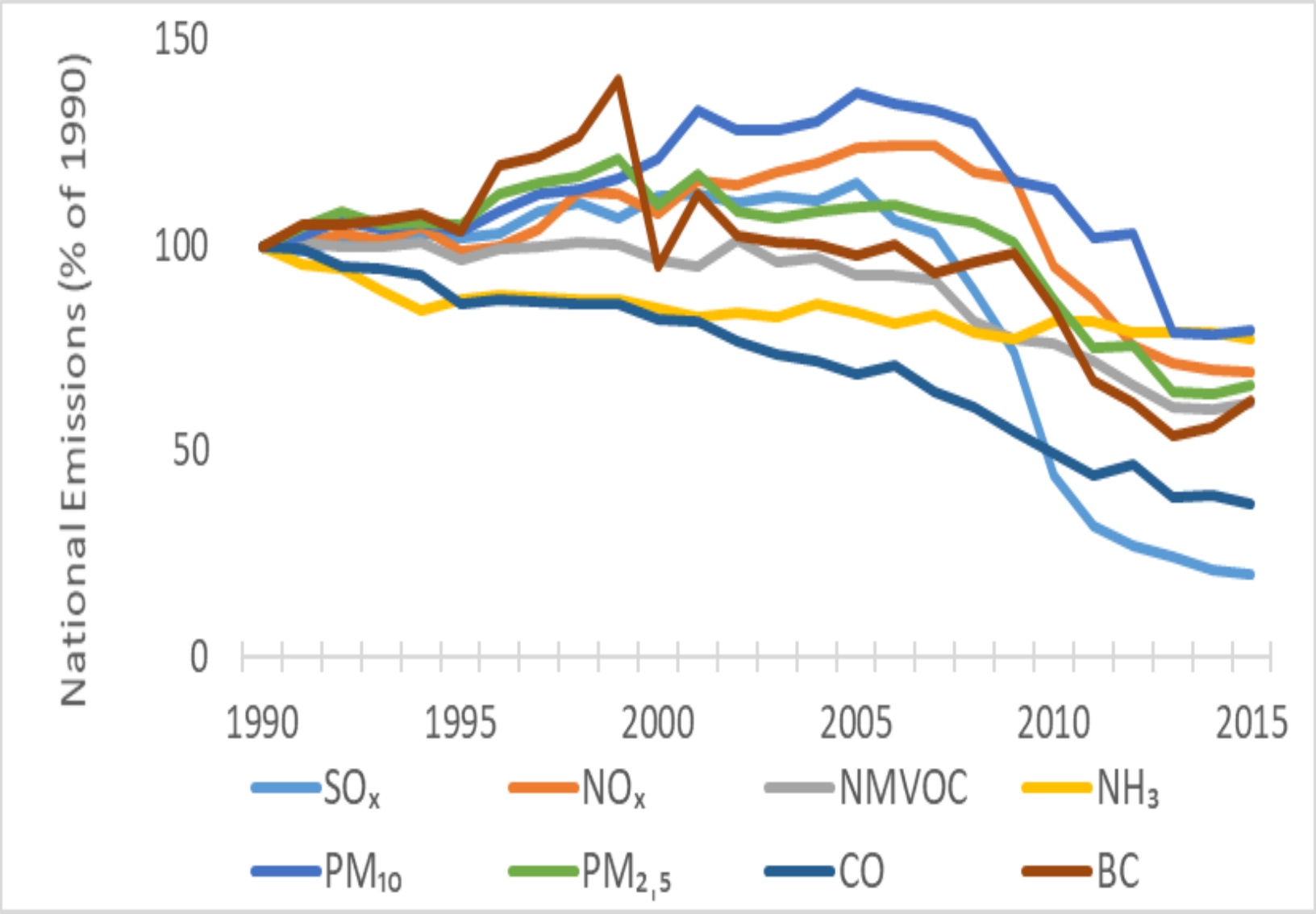
Industry

- IED & MCP Directives

Other

- Nitrates Directive,
- CAP
- etc.

NEC Directive – Overall picture



NOx

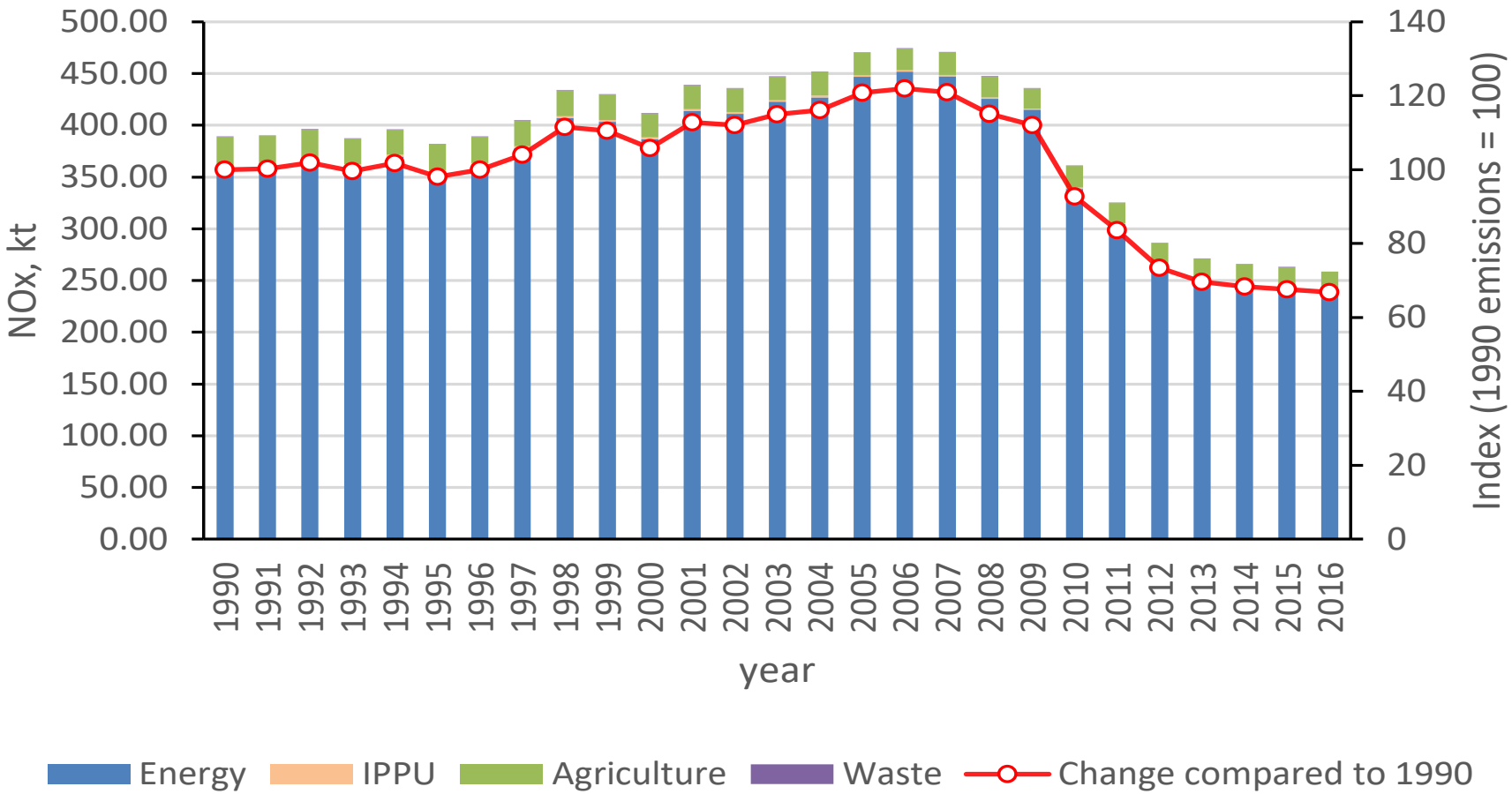
Sources

- Power plants - 30%
- HDV road transport – 18%
- Rest road transport – 8%
- Shipping – 17%
- Industry – 7%

Policy measures:

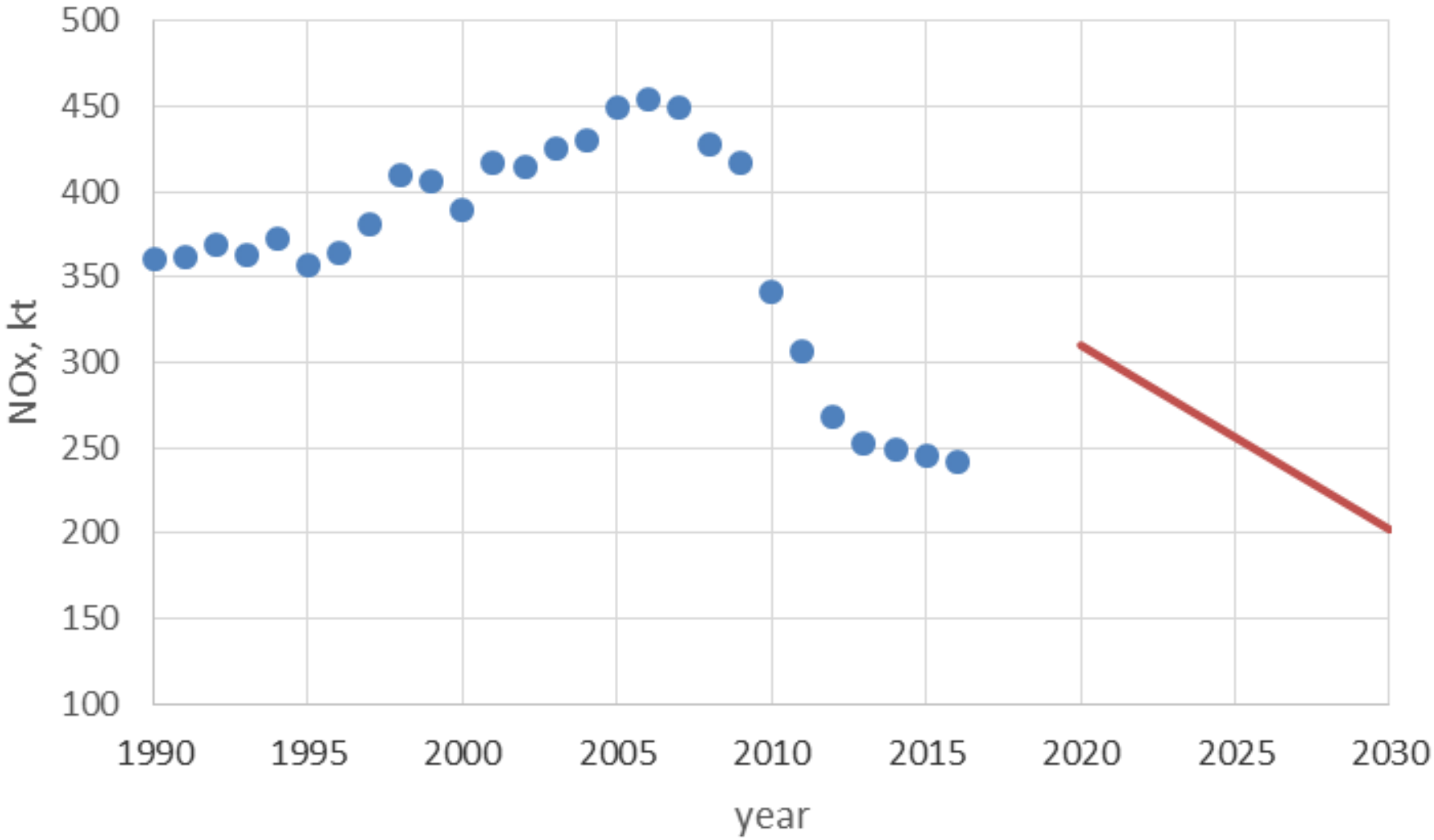
- RES
- Promotion of natural gas
- Interconnection of the islands
- Withdrawal of old power plants
- Renewal of HDW fleet
- Directives 2015/2193/EU (MCP), 2010/75/EU (LCP ELV), 2017/1442/EU (LCP BAT)

NOx



Emissions 2016: -33.21% compared to1990
-44,74% compared to 2005

NOx



Only emissions sectors that are accounted for the NEC Directive are included

SO_2

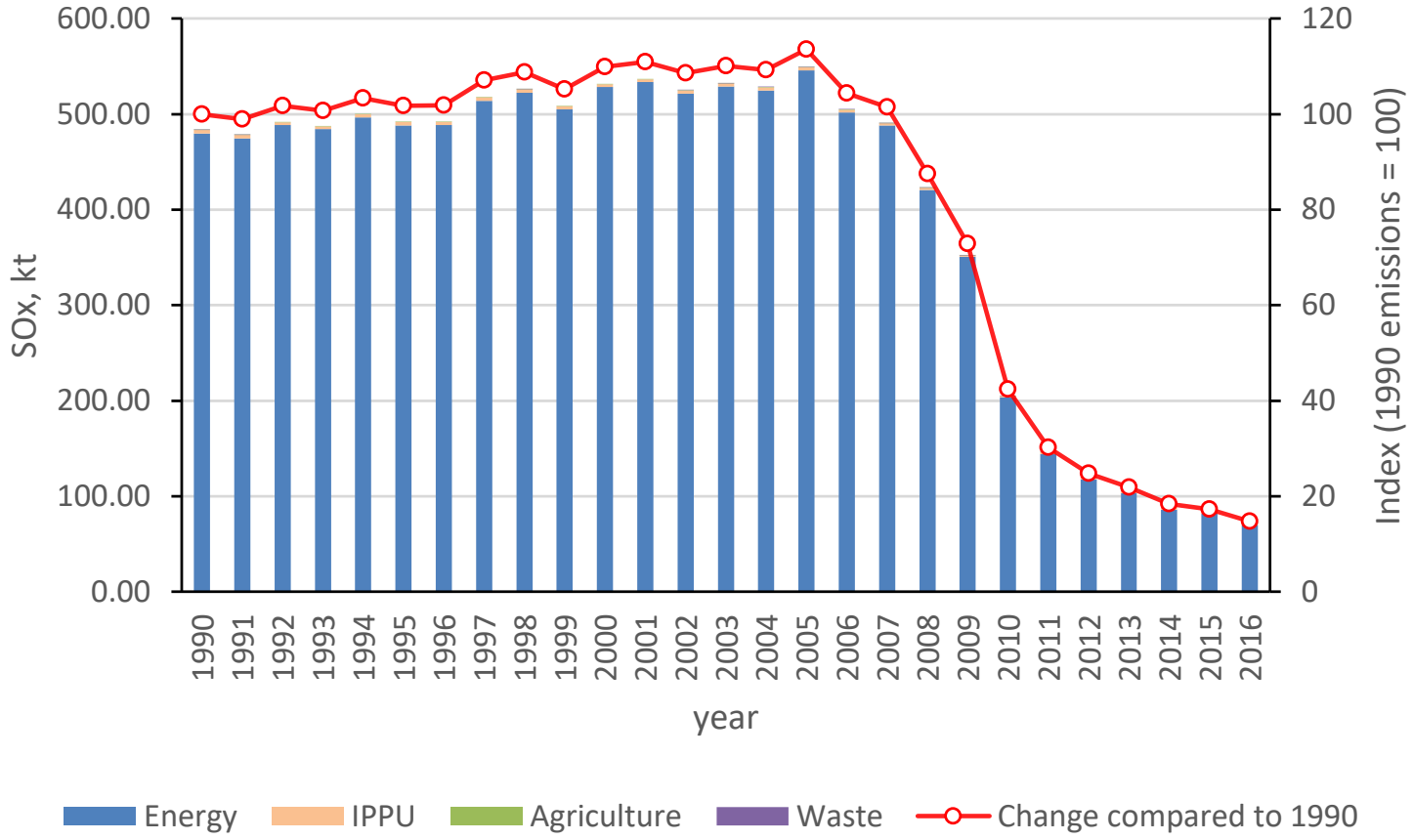
Sources

- Power plants - 69%
- Petroleum refinery– 14%

Policy measures:

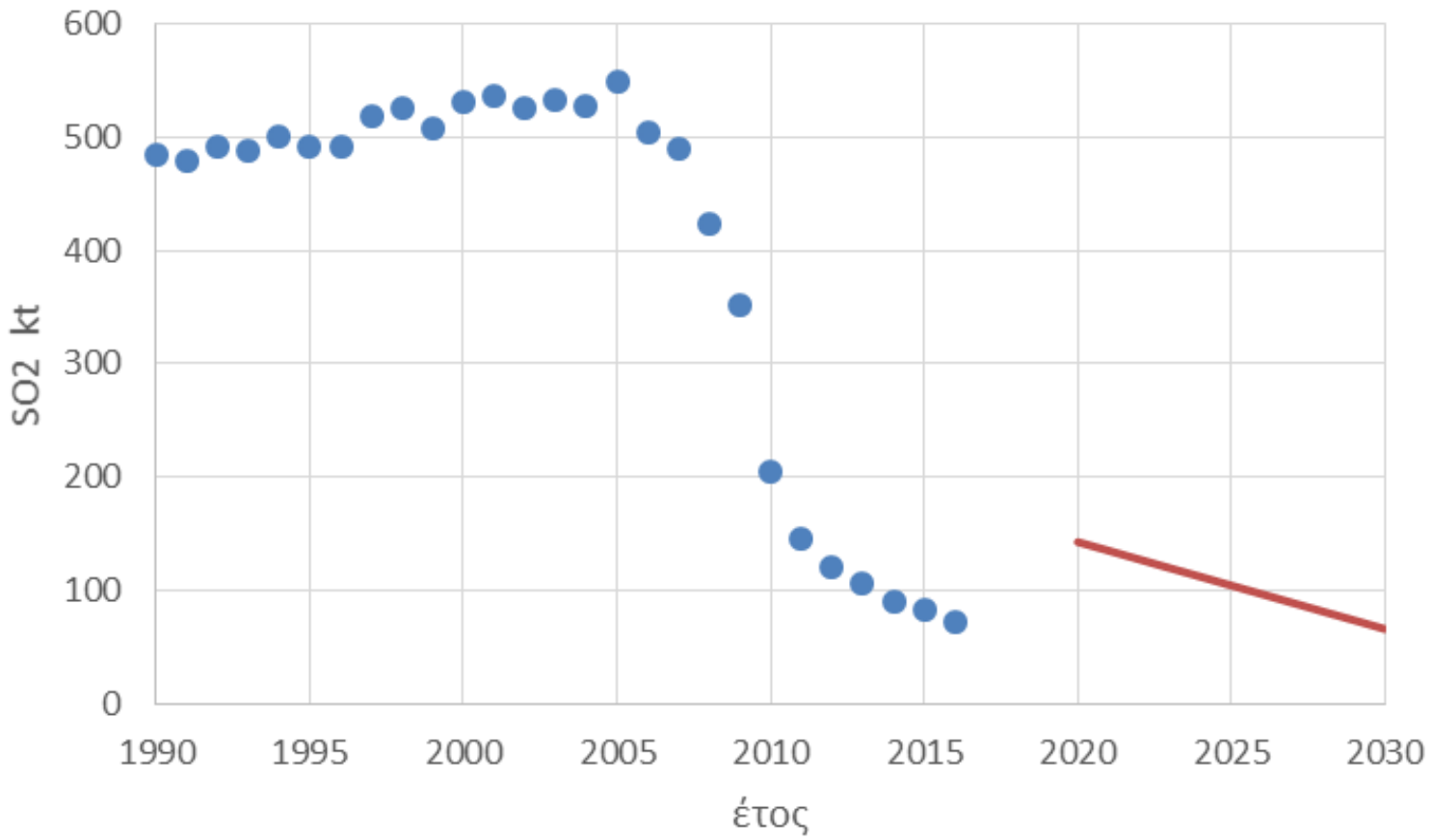
- Reduction of fuel S content
- Desulphulization in power plants
- RES
- Promotion of natural gas
- Interconnection of the islands
- Withdrawal of old power plants

SO2



Emissions 2016: -85.21% compared to1990
-86,98% compared to 2005

SO2


600
500
400
300
200
100
0
SO2 kt
1990
1995
2000
2005
2010
2015
2020
2025
2030
έτος

NH_3

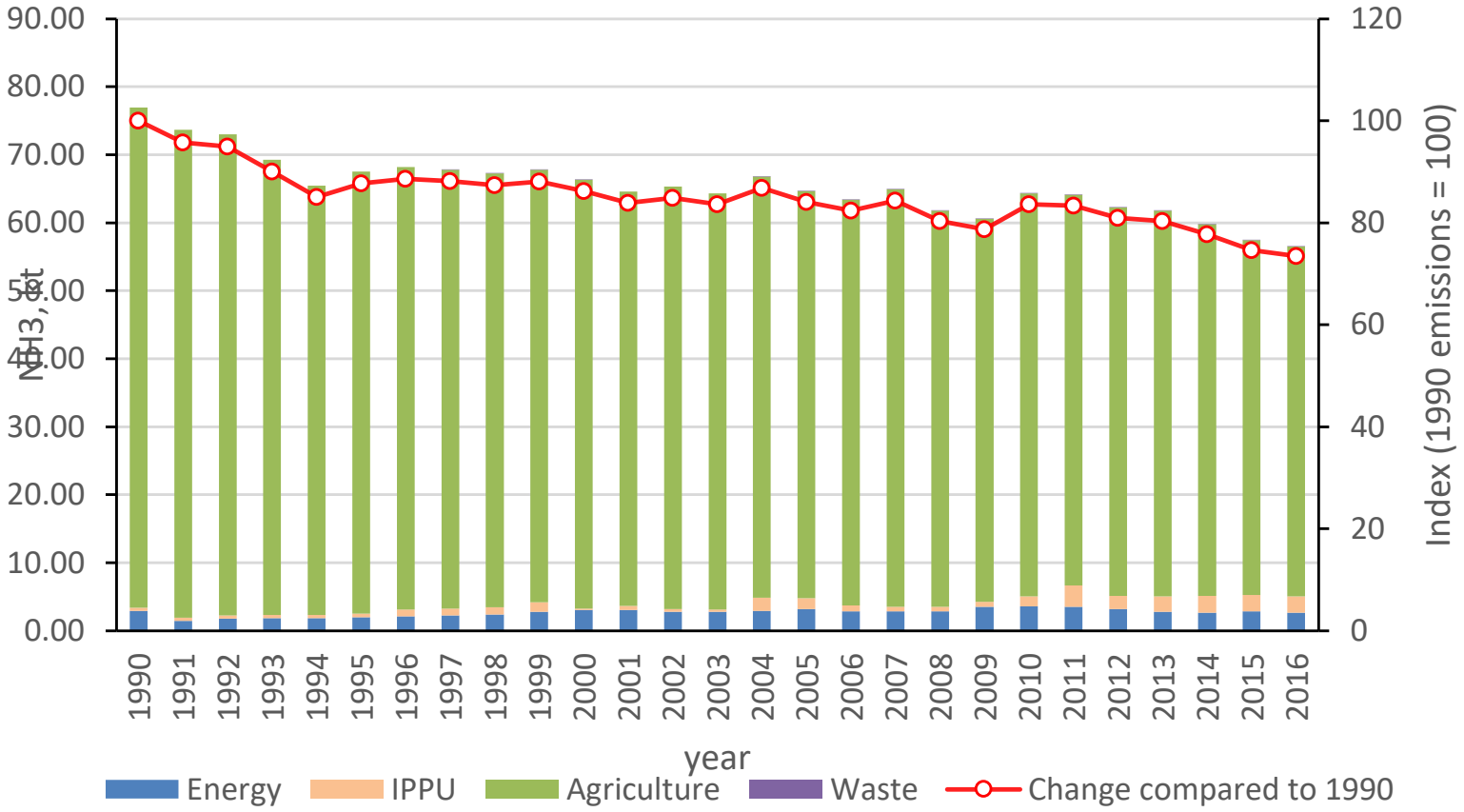
Sources

- Manure - 66%
- Fertilizers – 16%

Policy measures:

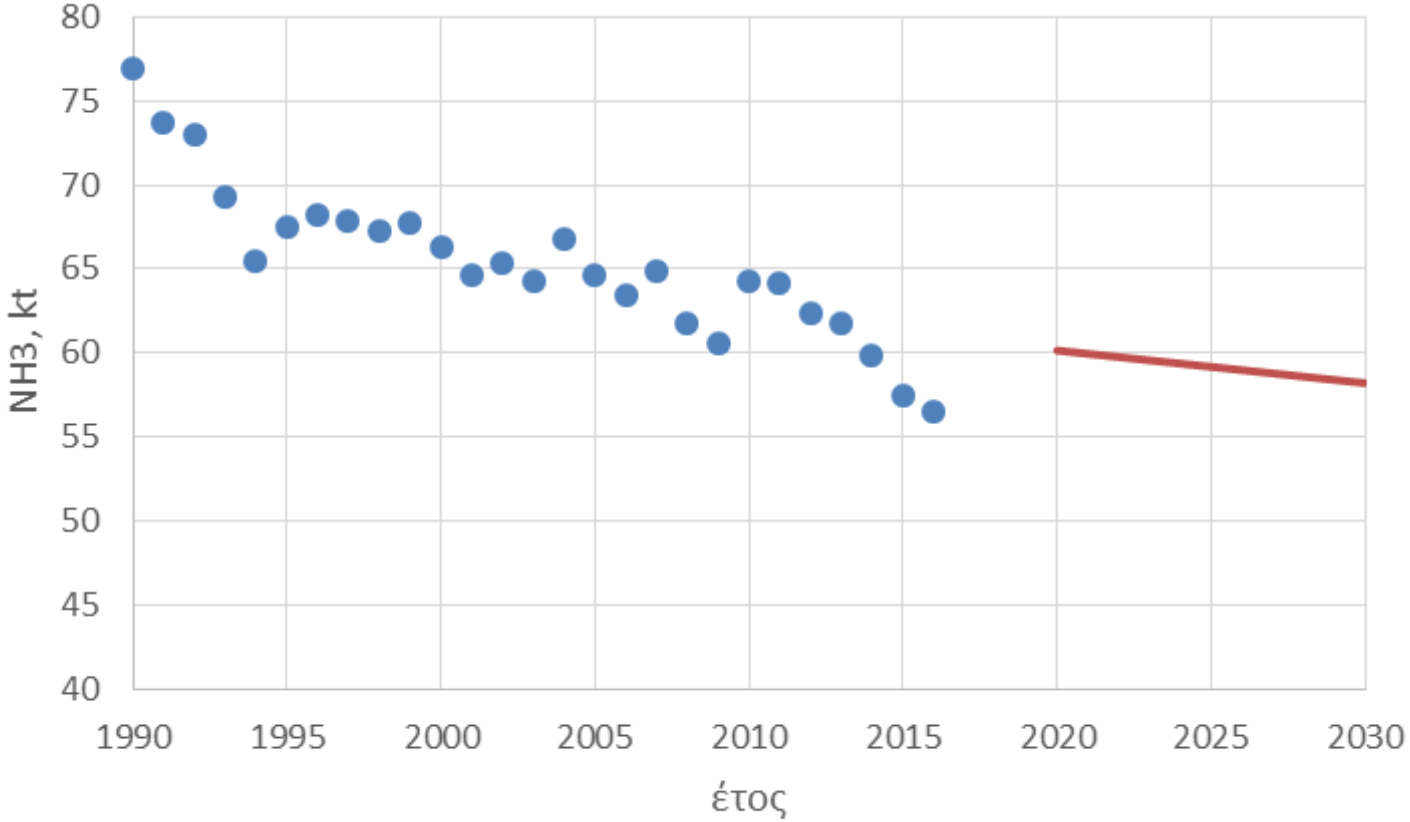
- Reduction of use of fertilizers
- Organic farming
- Manure management
- CAP – green payments
- Code of Good Agricultural Practice for the reduction of nitrate pollution of groundwaters

NH_3



Emissions 2016: - 26.55% compared to1990
-12.62% compared to 2005

NH_3


80
75
70
65
60
55
50
45
40
NH3, kt
1990
1995
2000
2005
2010
2015
2020
2025
2030
έτος

$PM_{2,5}$

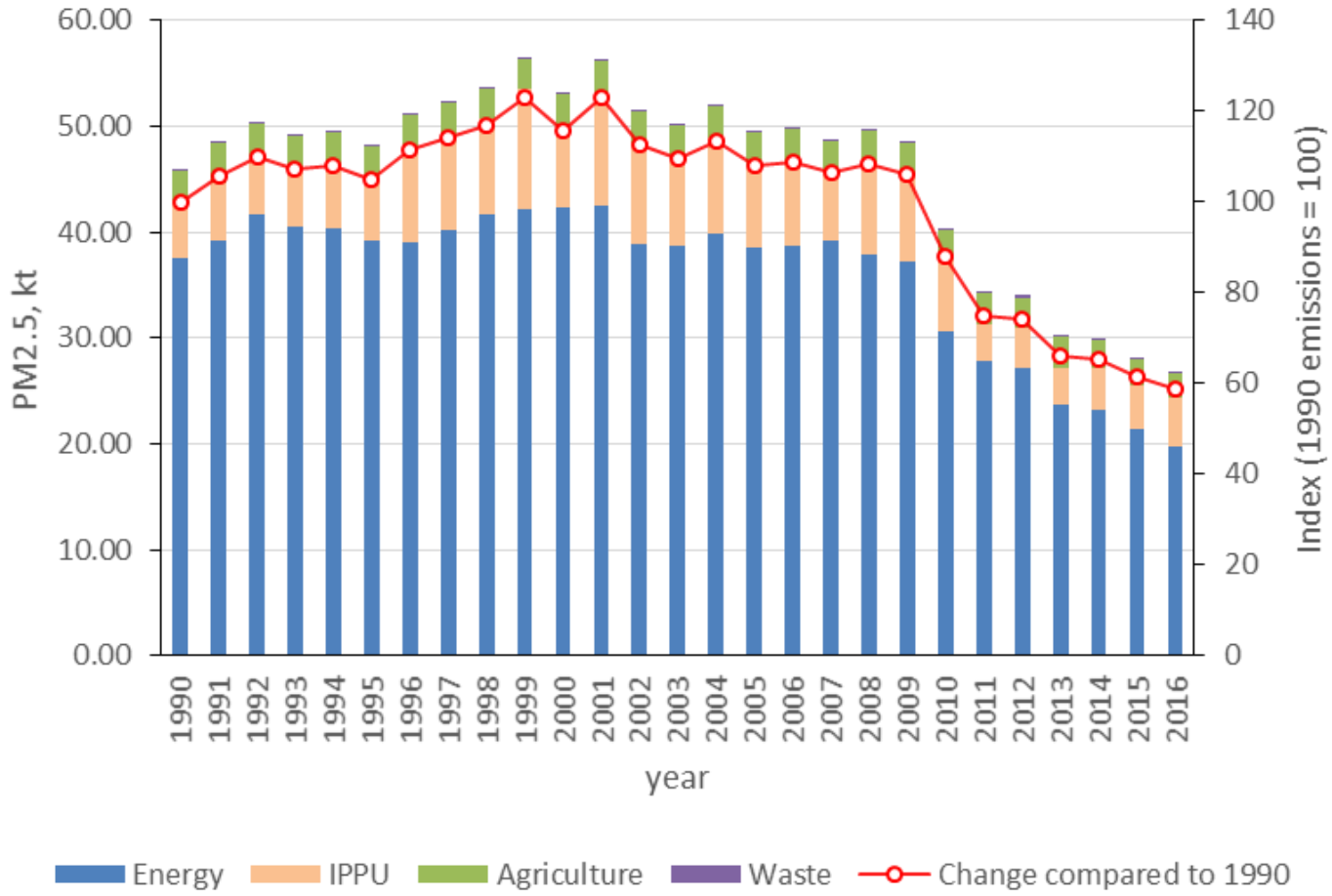
Sources

- Households (central heating) – 35%
- Industry – 10%
- Shipping – 8%
- Power plants - 7%
- HDV road transport – 6%

Policy measures:

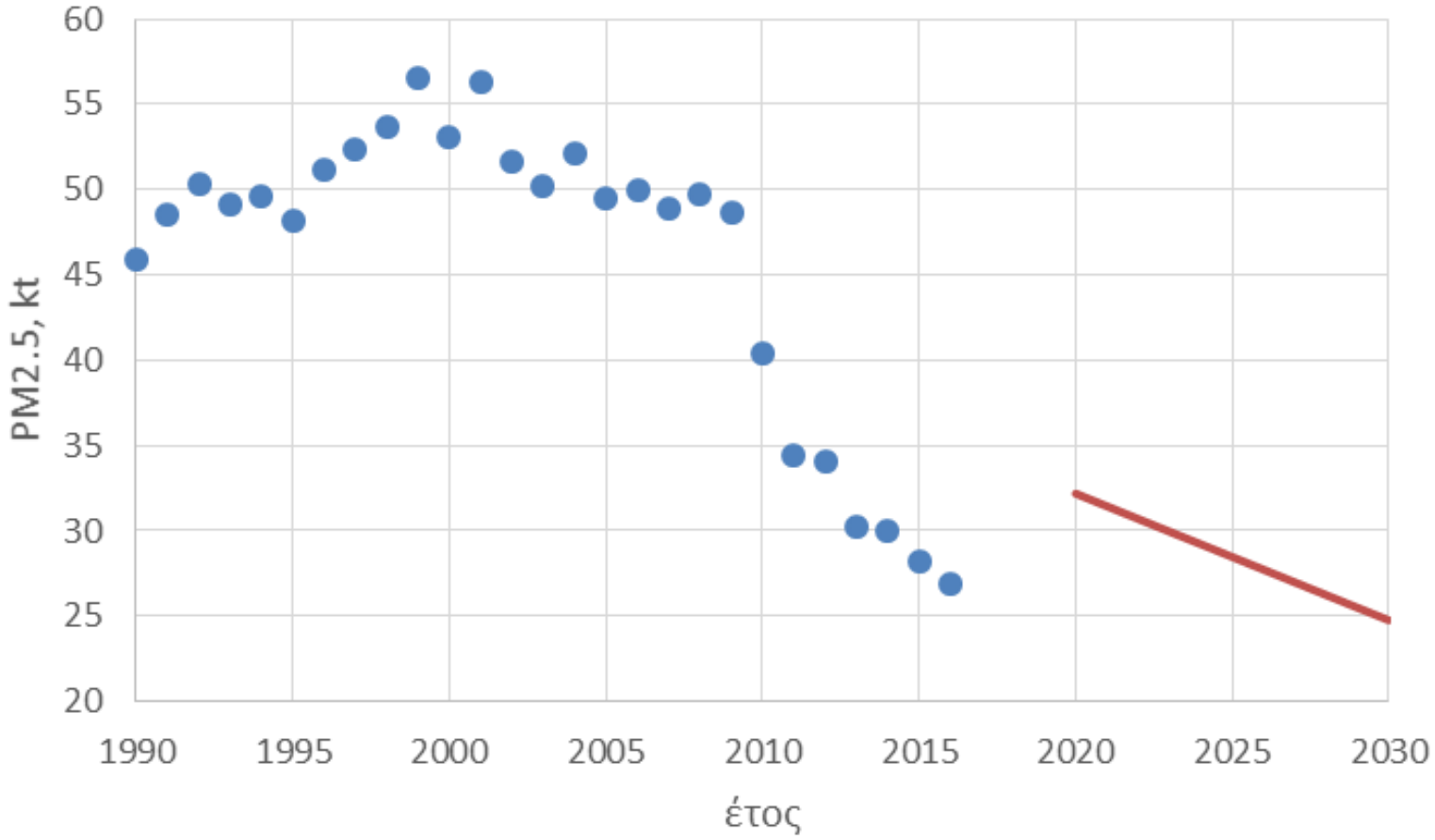
- RES
- Promotion of natural gas
- Interconnection of the islands
- Withdrawal of old power plants
- Renewal of HDW fleet
- Directives 2015/2193/EU (MCP), 2010/75/EU (LCP ELV), 2017/1442/EU (LCP BAT)

$PM_{2,5}$



Emissions 2016: - 41,28% compared to1990
- 45,62% compared to 2005

$PM_{2,5}$


60
55
50
45
40
35
30
25
20
PM2.5, kt
1990
1995
2000
2005
2010
2015
2020
2025
2030
έτος

NMVOC

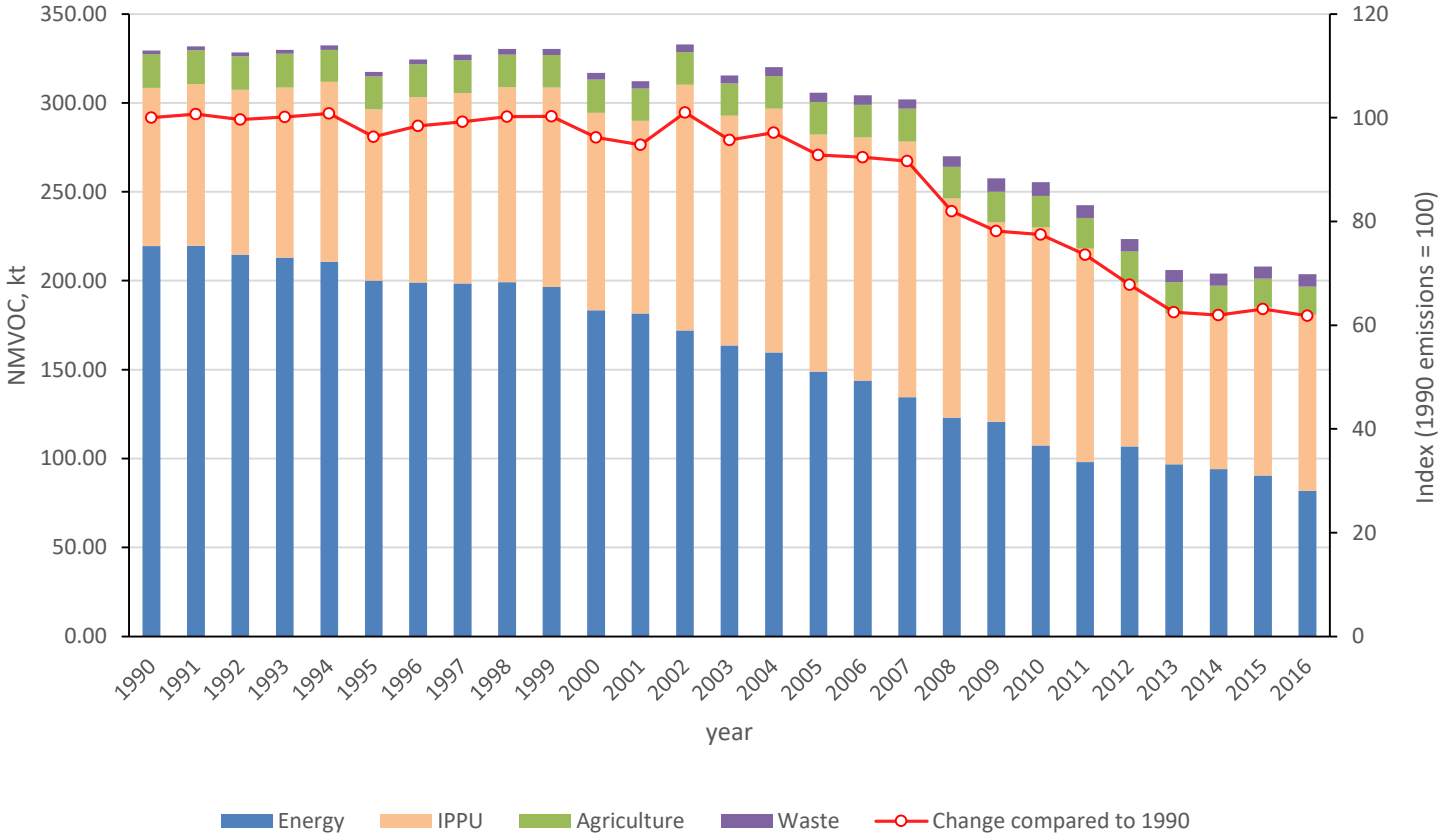
Sources

- Use of organic solvents - pigments – 45%
- Road transport – 24%

Policy measures:

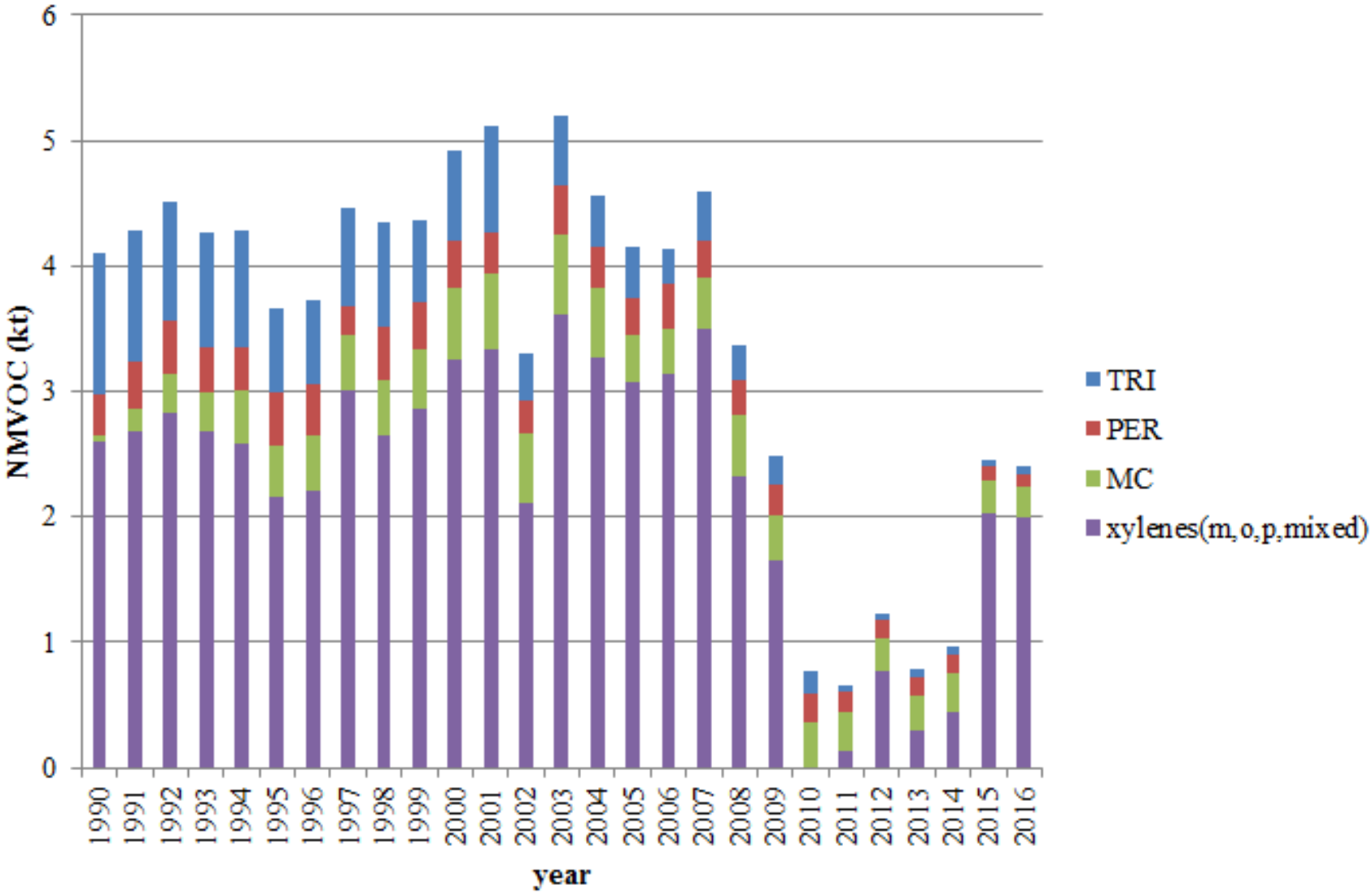
- Implementation of Directive 1999/13 (reduction of VOC emissions resulting from the use of organic solvents)
- Implementation of Directive 2004/42 (max concentration of VOC in pigments)
- Renewal of vehicle fleet

Non Methane Volatile Organic Compounds (NMVOC)

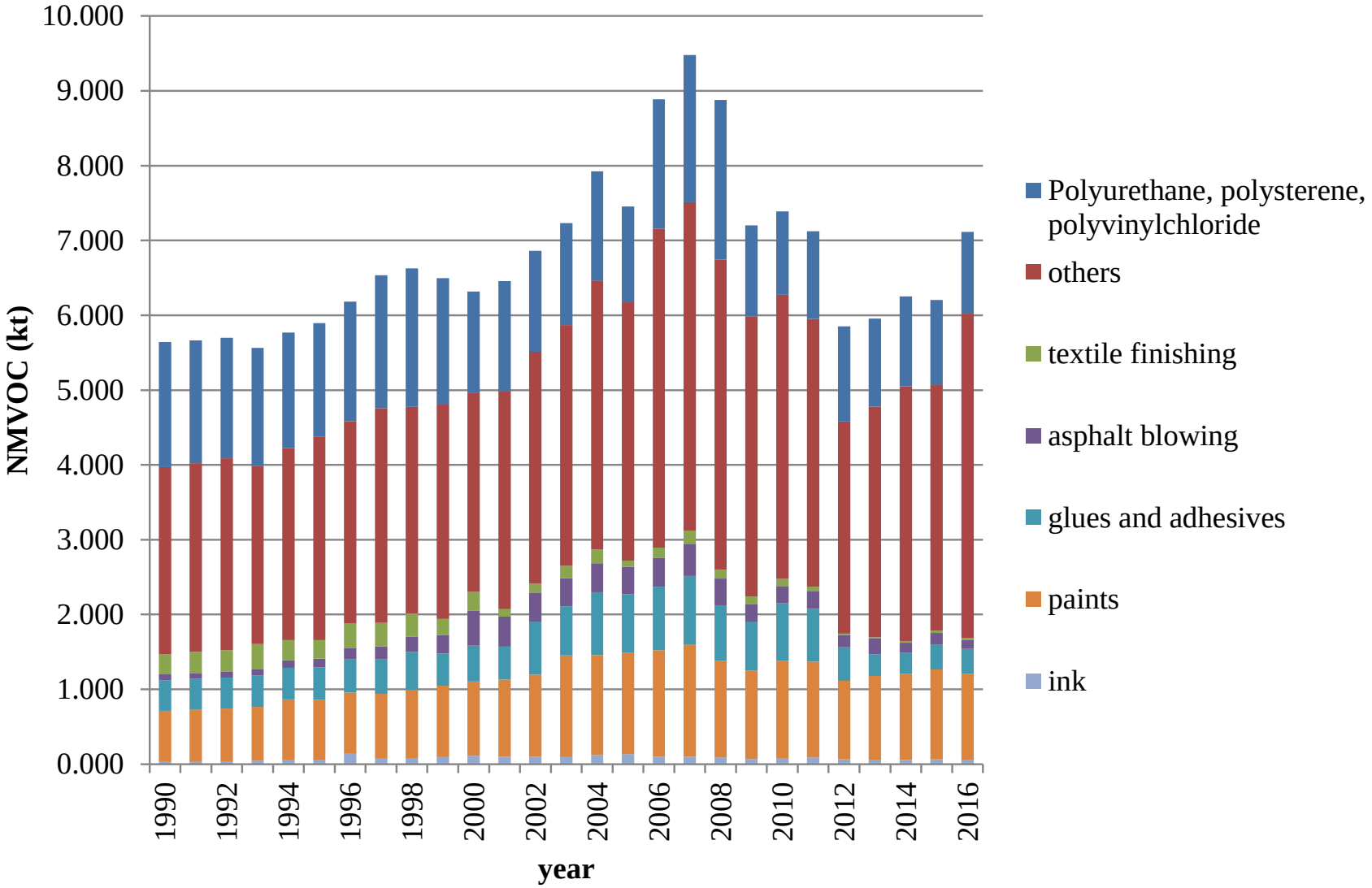


Emissions 2016: - 38,18% compared to1990
- 33,38% compared to 2005

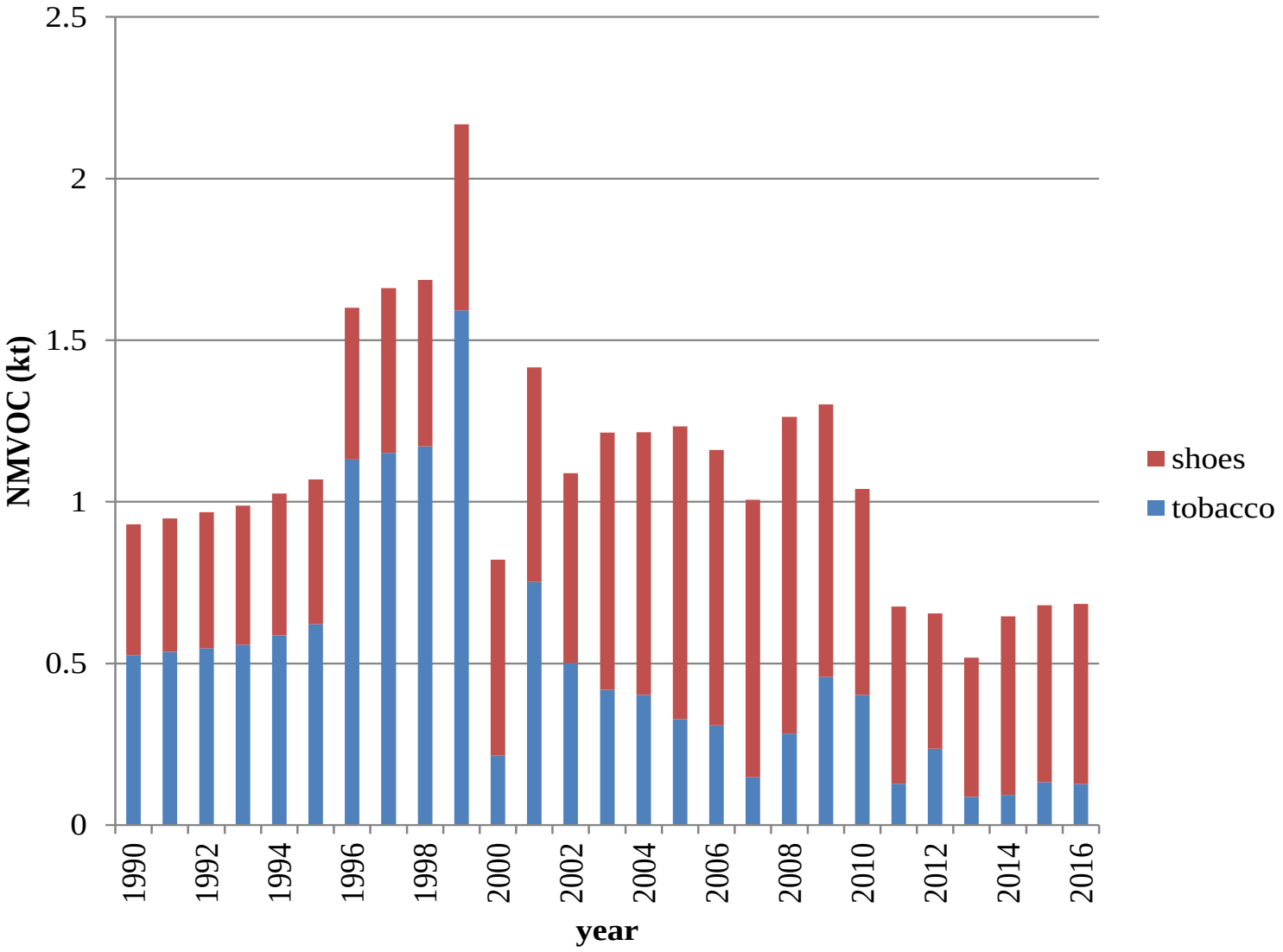
Contribution of each organic solvents on NMVOC emissions



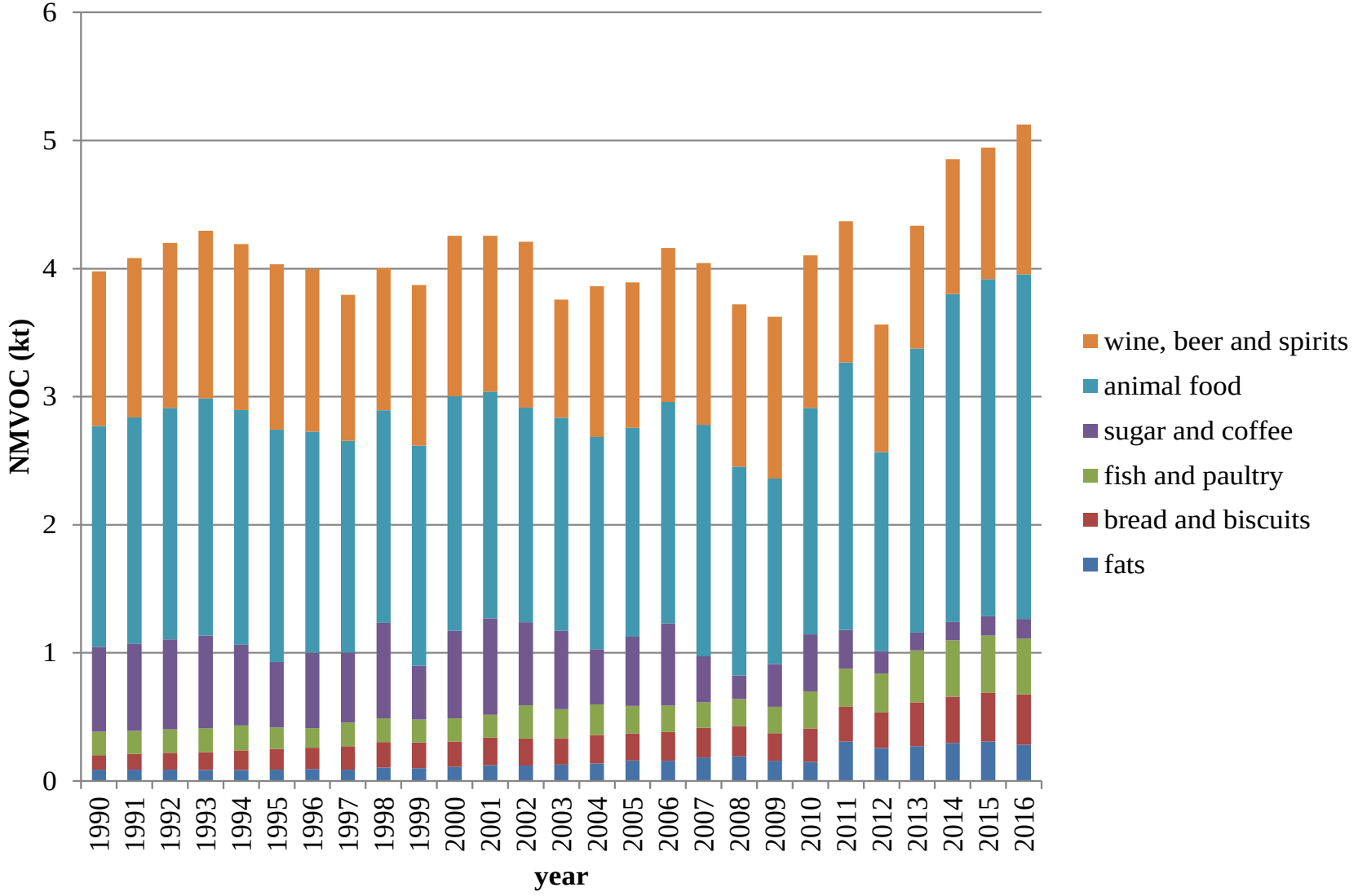
Contribution of product groups and processes on NMVOC emissions due to the use of chemical products



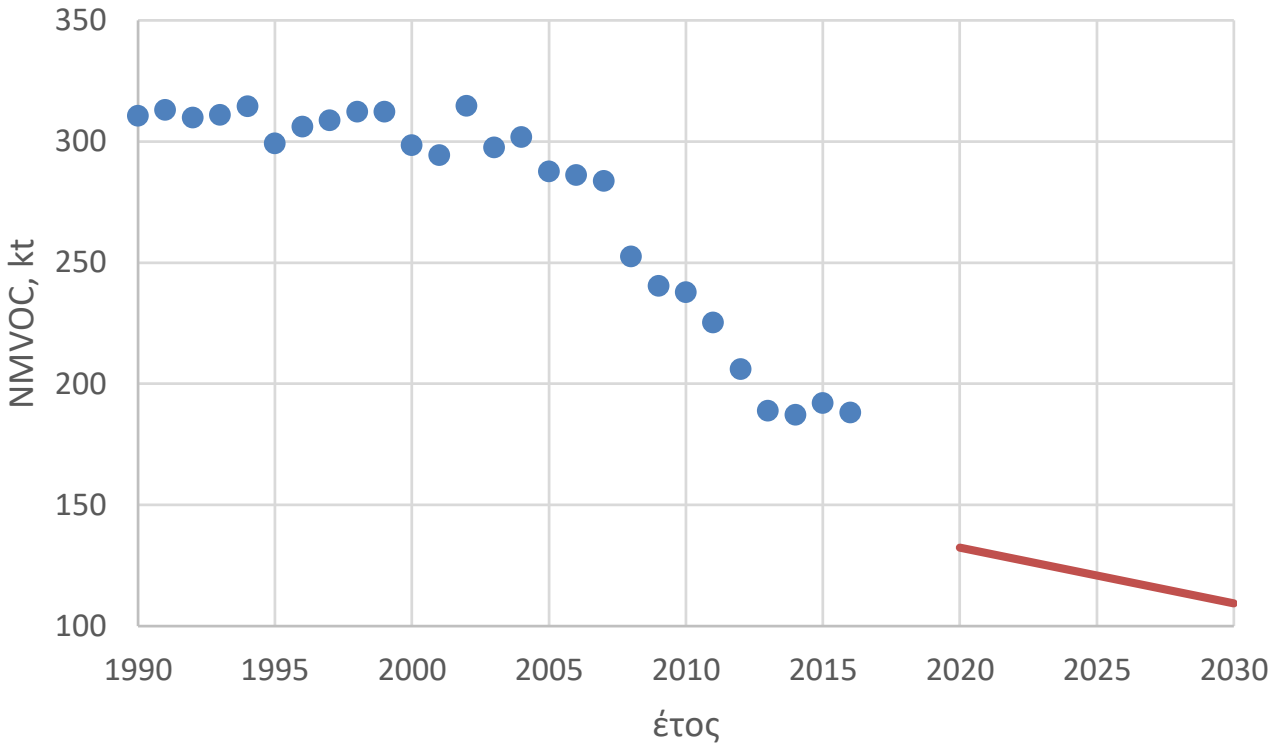
Contribution of other activities with solvent use on NMVOC emissions



Contribution of food and beverage on NMVOC emissions

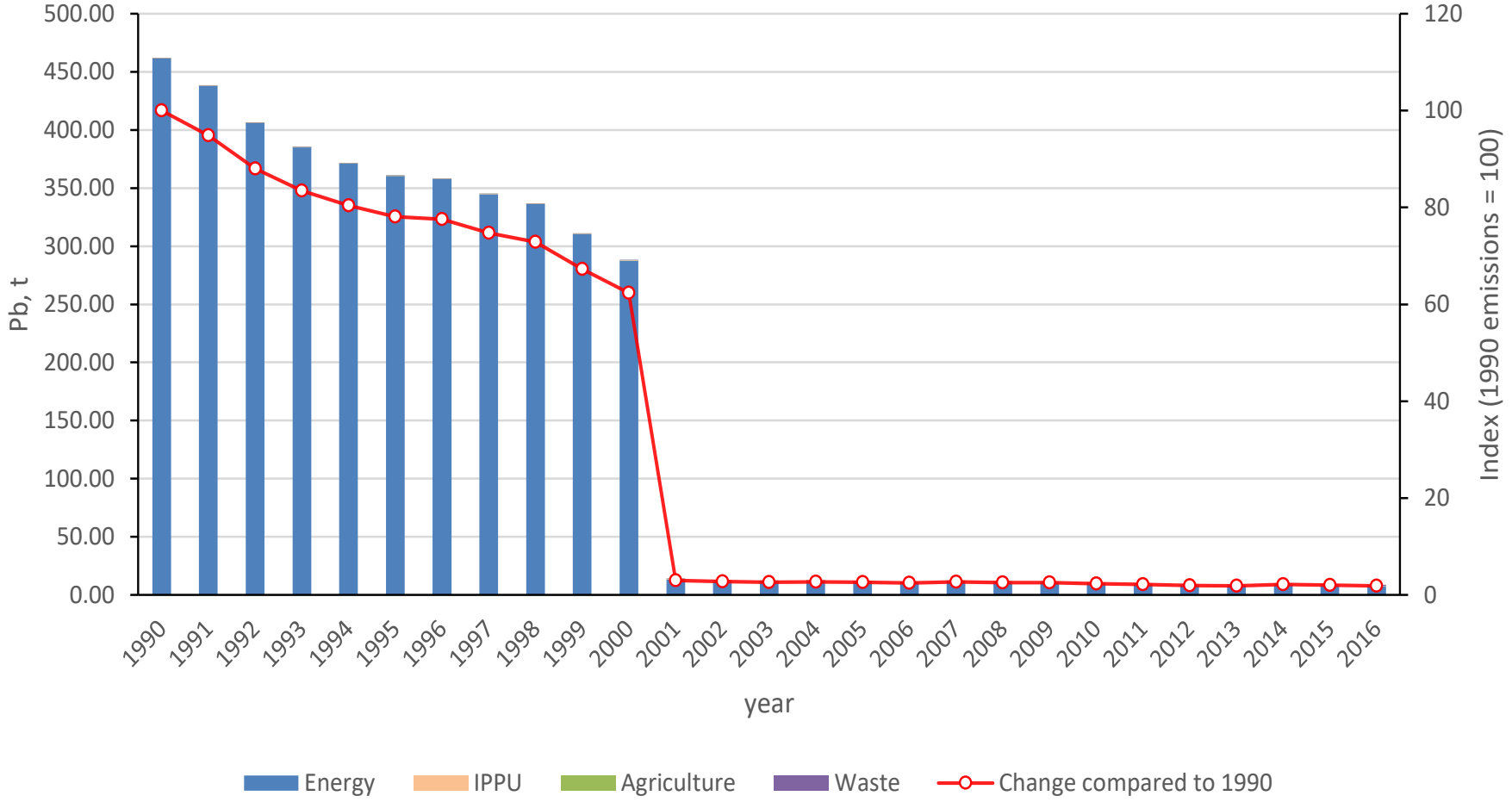


Non Methane Volatile Organic Compounds (NMVOC)



Only emissions from sectors that are included in the NEC Directive

Pb



Pb emissions by sector (in kt) for the years 1990 – 2016

Projections

Air emissions till 2040 (all sources included)

Pollutant	2017 Emission Inventory			Projections WM scenario			
(kt)	2005	2010	2015	2020	2025	2030	2040
NOx	440.29	342.95	252.97	250.03	234.16	226.48	203.42
NMVOC	305.93	252.36	205.54	187.81	186.94	181.62	172.36
SOx	570.44	219.13	99.15	89.16	90.00	81.93	75.68
NH_3	65.09	63.59	60.33	60.27	61.42	62.70	65.22
PM2.5	57.58	45.69	34.68	35.90	36.86	36.76	36.13
BC	8.40	7.28	5.36	6.48	6.38	6.38	6.00

Air emissions till 2040 (all sources included)

Pollutant	2017 Emission Inventory			Projections WM scenario			
(kt)	2005	2014	2015	2020	2025	2030	2040
NOx	419.16	236.44	234.23	230.89	214.68	206.66	182.88
NMVOC	295.74	191.57	176.70	175.27	174.13	168.55	158.74
SOx	570.44	103.49	99.15	89.16	90.00	81.93	75.68
NH_3	65.09	61.39	60.33	60.27	61.42	62.70	65.22
PM2.5	57.58	33.70	34.67	35.90	36.86	36.76	36.13
BC	8.40	4.78	5.34	6.48	6.38	6.38	6.00