FAIRMODE Technical Meeting
Working Group 2 - Emissions
27-29 June 2016
Zagreb, Croatia

Comparing the new open Flexible Emission Inventory for Greece and the Greater Athens Area (FEI-GREGAA) with the TD emission inventory TNO_MACC-III

Kyriaki-Maria Fameli and Vasiliki D. Assimakopoulos

Institute for Environmental Research and Sustainable Development, National Observatory of Athens, Greece

Introduction

✓The Greater Athens Area has significantly changed in recent years due to large scale infrastructure works.

✓Photochemical and particulate pollution episodes continue to appear.

✓Limited numerical studies of pollutant dispersion above the GAA due to the lack of detailed and updated emissions data.

✓Development of an updated emission inventory, with open structure (FEI-GREGAA) for the years 2006-2012.

✓Use as input data to the photochemical CAMx model for Greece and the GAA.

Introduction

Earlier efforts to develop such databases for Greece and the GAA

✓resulted from temporal and spatial annual low resolution data (50x50km^2) from (EMEP) *(Aleksandropoulou et al. 2004, 2011)* – reference year 2007,

✓the reference year was old (2003) without updated traffic volume data *(Markakis et al. 2010),*

✓only consisted of annual emissions not spatially and temporally allocated *(Progiou and Ziomas 2011, 2012),*

Introduction

Objective	• Quantitative and qualitative conclusions concerning the type of sources that contribute to the air quality of the GAA • Applications with photochemical models
Pollutants	• CO, NOx, PM, SO_2, NH_3, NMVOC
Spatial scale	• 6x6 km^2(Greece) and 2x2 km^2 (Athens)
Data sources	• Official data provided by national authorities (e.g, DoT, DoE, ...)
Period	• 2006-2012
Methodology	• EMEP/EEA Emission Inventory Guidebook 2013 • Development of a methodology for the spatial mapping of emissions • Development of temporal coefficients for the GAA

Grids

Greece

Greater Athens Area (GAA)

General Methodology

SNAPS 1, 3, 4, 5, 9:

➢Top Down Industrial activity data for the period 2007 - 2011 were collected by the European Pollutant Release and Transfer Register (E-PRTR, eprtr_v5.1, http: //prtr.ec.europa.eu/)

SNAP 2 - Small combustion

➢Top down: Data from the National Energy Data System of the Ministry of Reconstruction of Production, Environment and Energy (NEDS-MRPEE) and Odyssee - Mure (Odyssee - Mure project, 2014)

SNAP 7 – Road Transport

➢Bottom-up for the GAA: Tier 3 approach (COPERT 4), Total number of vehicles (DoT, ELSTAT etc), Min. Max. T, RH, Annual fuel consumption (MRPEE).

General Methodology

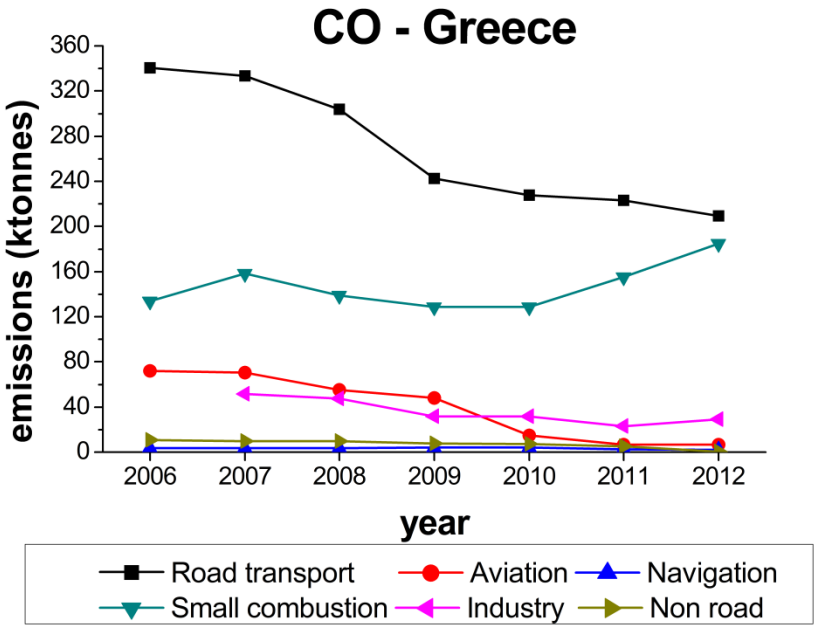
SNAP 8 – Navigation, Aviation, Off-road vehicles

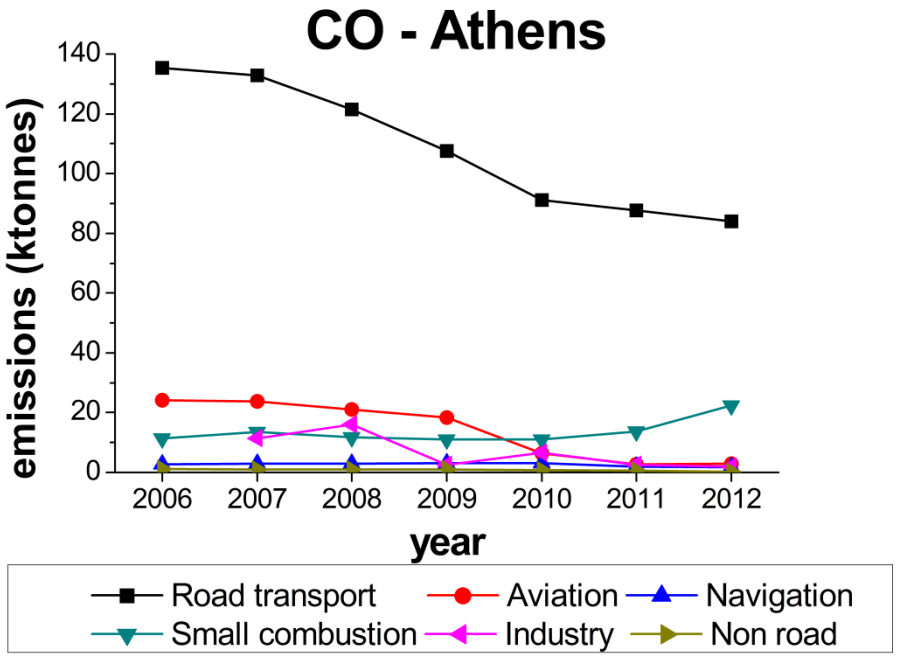
- Bottom-up: Tier 2, Seasonal emissions estimation (10 ship types, 85 Greek ports) EUROSTAT
- Bottom-up: Tier 2, emissions estimated on a monthly scale for the 38 Greek airports (Eurostat Database, Greek Civil Aviation Authority)
- Top-down: Tier 1 (Eurostat Database)

SNAP 10- Agriculture

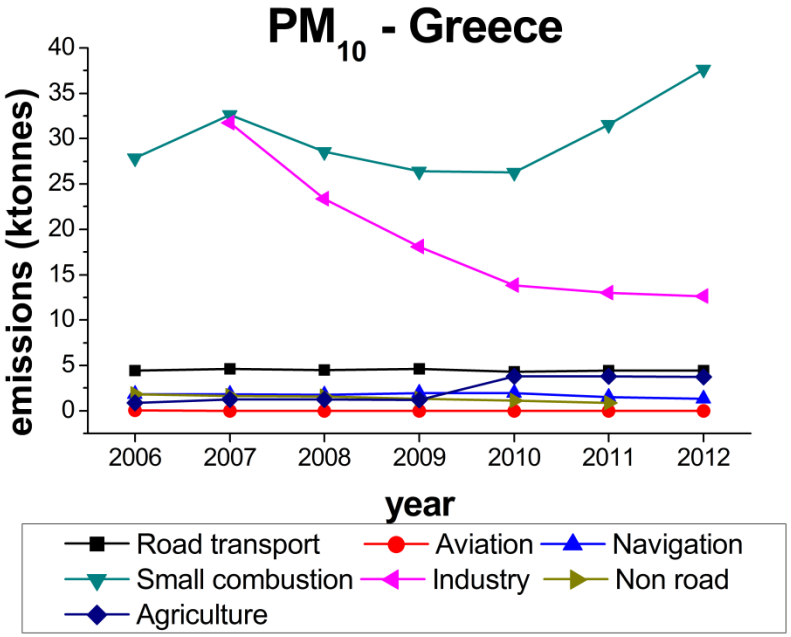
- Bottom-up: Tier 1, annual population of animals by prefectures, amount of N applied, agricultural crop areas (Eurostat, ELSTAT)

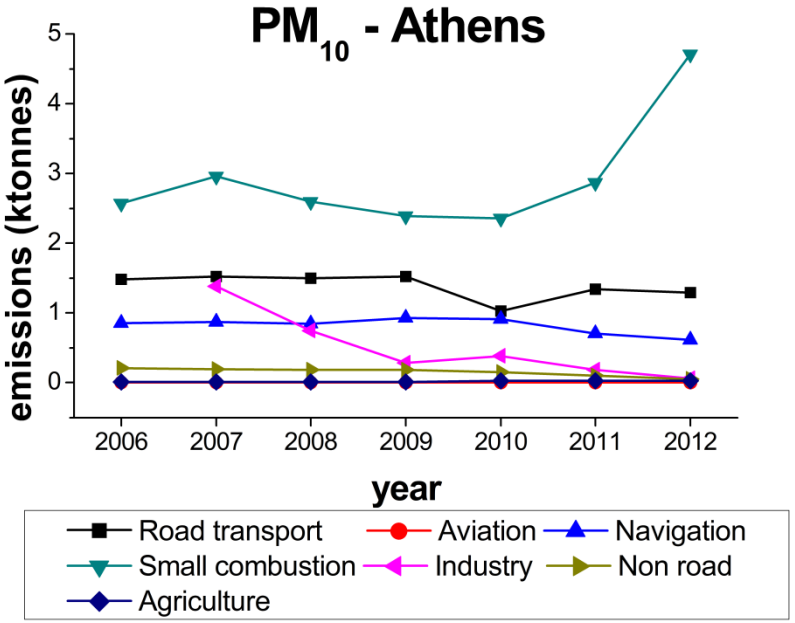
Annual variation of emissions



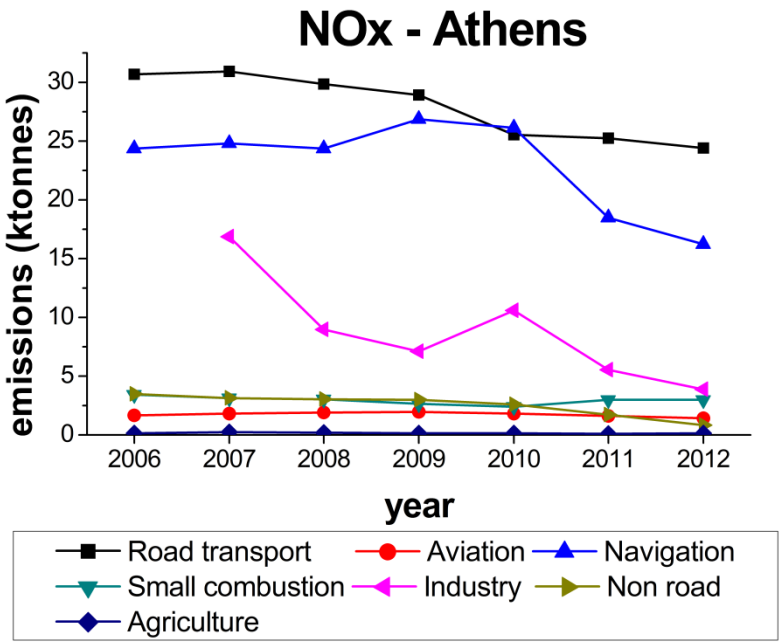


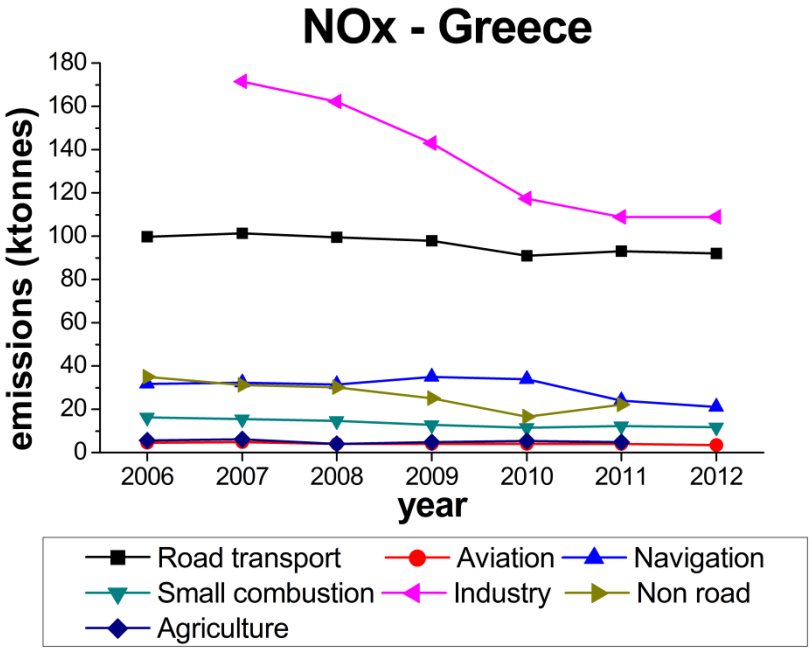
Annual variation of emissions



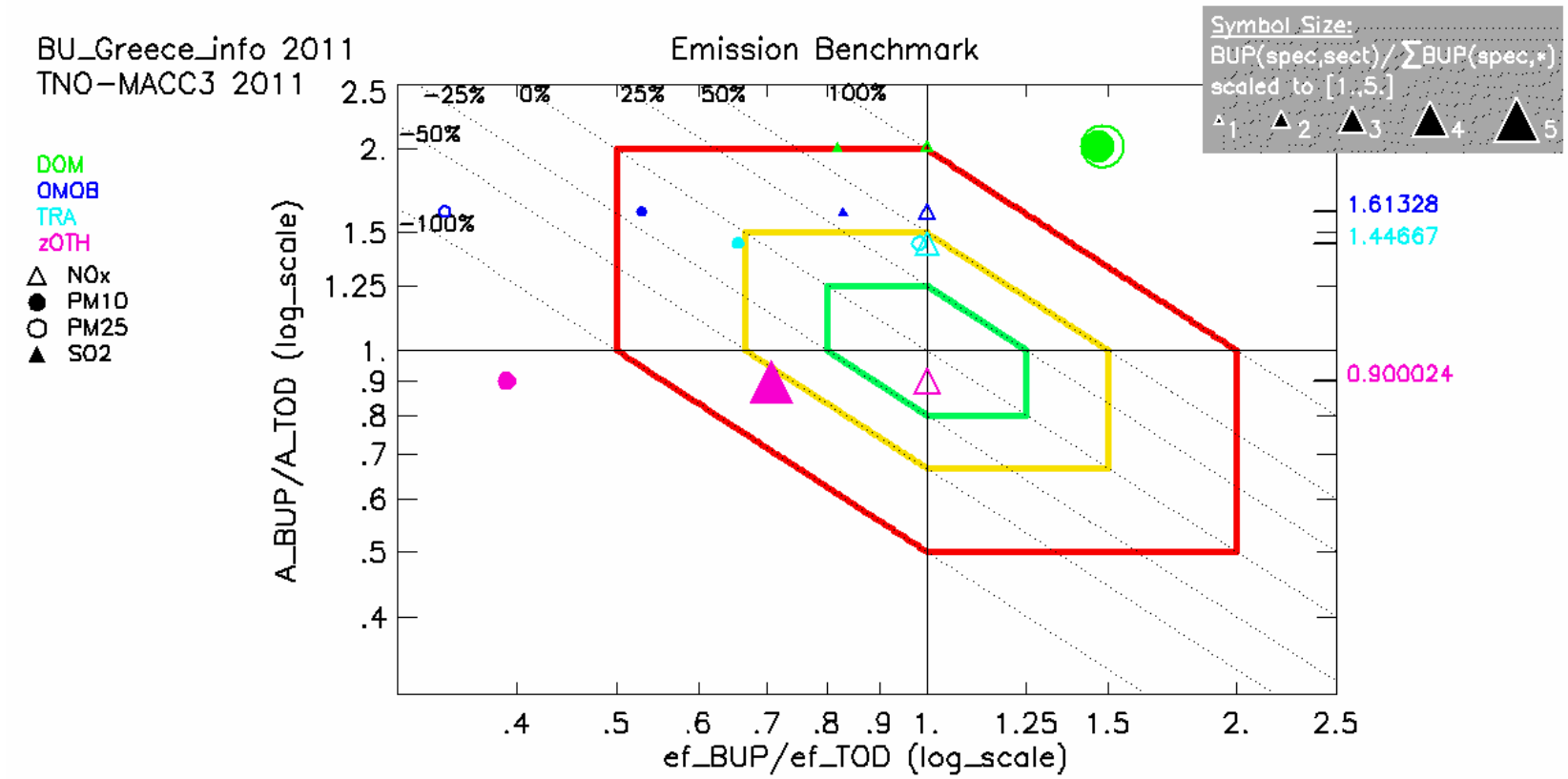


Annual variation of emissions





FEI-GREGAA vs TNO-MACCIII



Results

DOMESTIC SECTOR

- **VOC:** Falls on the red line of the diamond graph, Underestimation of emission factors, Overestimation of activity
- **NOx:** Emission factors coincide, falls on red line of diamond, overestimation of activity
- **PM_{10}:** Falls on the Adding up region of the graph, overestimation of emission factors and activity, biomass burning (?)
- **SO_2:** falls on red line of diamond, in the compensation area, overestimation of activity – underestimation of emission factor

Results

TRAFFIC SECTOR

- ❑ All pollutants lie within the diamond
- ❑ $PM_{2.5}$ and NOx comparisons indicate overestimation of activity from FEI-GREGAA
- ❑ VOC and PM_{10} show underestimation of emission factor and overestimation of activity

OMOB

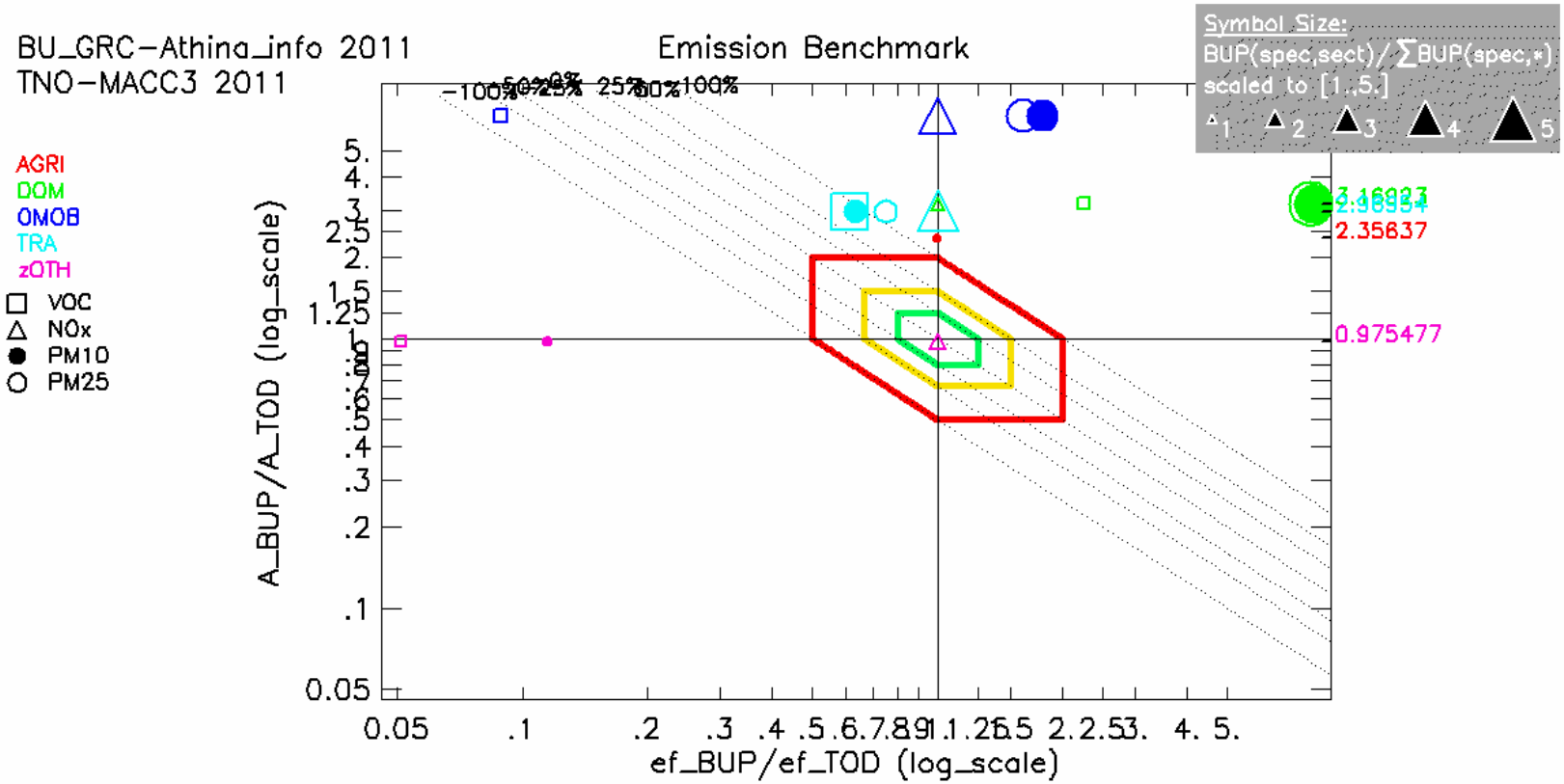
- ❑ Overestimation of activity for all pollutants
- ❑ VOC and PM2.5 lie outside the diamond
- ❑ Emission factor underestimated

Results

zOTH

- Activity results for all pollutants are slightly underestimated in FEI-GREGAA
- Emission factor ratios are underestimated especially for VOC
- SO2 has the greatest contribution compared to other sectors.

FEI-GREGAA vs TNO-MACCIII



Results

- **Traffic sector:** Overestimation of activity for all pollutants, results are in the compensation zone
- **Domestic sector:** Adding up zone, great overestimation (>5) of PM emission factor, activity overestimation the same as traffic
- **OMOB:** PM emission factors and activity are overestimated, VOC activity is underestimated a pollutant that depends on national and international navigation.
- **zOTH:** comparisons show good agreement for all pollutants in terms of activity, PM and VOC emission factors are underestimated

Concluding Remarks

✓Road transport and domestic sectors contribute more to national and local emissions.

✓OMOB sector values in Athina indicate its importance for the air quality (Port of Piraeus)

✓Comparisons for Greece and Athina show better agreement for the traffic sector

✓Results for Greece fall mostly within the diamond (expected) as compared to local scale Athina emission estimations

✓Better knowledge of TNO-MACCIII database of emissions is required.

Concluding Remarks – NOx FEI-GREGAA -EMEP

Year	Road transport	Aviation	Navigation	Small combustion	Industries	Non road transport	Agriculture	Total
2006	99.83	4.64	31.61	16.38	-	34.86	5.54	*192.85*
2007	101.42	4.67	32.14	15.36	171.38	31.28	6.02	*362.27*
2008	99.41	4.03	31.56	14.76	162.22	30.17	4.10	*346.26*
2009	97.98	4.10	34.82	12.70	142.82	24.97	4.92	*322.31*
2010	90.95	3.95	33.87	11.53	117.32	16.64	5.34	*279.60*
2011	92.99	3.90	23.95	12.21	108.93	22.01	4.76	*268.75*
2012	92.05	3.57	21.01	11.77	108.71	0.00	0.00	*237.12*

Year	Road transport	Other transport	Small combustion	Industries	Agriculture	Total
2006	122.69	80.07	11.13	169.23	1.39	*384.51*
2007	116.95	78.38	10.67	179.85	1.39	*387.25*
2008	111.21	76.70	10.22	168.50	1.39	*368.00*
2009	105.46	75.01	9.76	152.37	1.39	*343.99*
2010	99.72	73.32	9.30	139.27	1.39	*323.00*
2011	92.96	72.00	9.18	102.56	1.39	*278.10*
2012	86.21	70.68	9.06	98.83	1.39	*266.18*

Concluding Remarks –PM10 FEI-GREGAA - EMEP

Year	Road transport	Aviation (as PM2.5)	Navigation	Small combustion	Industries	Non road transport	Agriculture	Total
2006	4.42	0.0110	1.80	27.84	-	1.80	0.86	*36.73*
2007	4.60	0.0087	1.83	32.65	31.71	1.62	1.25	*73.66*
2008	4.48	0.0049	1.78	28.55	23.36	1.56	1.24	*60.98*
2009	4.64	0.0044	1.96	26.39	18.09	1.31	1.21	*53.60*
2010	4.30	0.0047	1.92	26.28	13.86	1.15	3.80	*51.30*
2011	4.43	0.0041	1.48	31.52	12.98	0.86	3.80	*55.09*
2012	4.44	0.0038	1.3	37.64	12.61	0.00	3.72	*58.42*

Year	Road transport	Other transport	Small combustion	Industries	Agriculture	Total
2006	7.29	6.18	13.25	41.65	11.86	*80.22*
2007	7.00	5.97	12.71	37.75	11.89	*75.32*
2008	6.71	5.75	12.17	34.45	11.93	*71.01*
2009	6.42	5.54	11.63	31.16	11.96	*66.71*
2010	6.14	5.33	11.09	27.86	11.98	*62.39*
2011	5.71	5.13	10.68	26.60	11.94	*60.07*
2012	5.29	4.93	10.27	25.35	11.90	*57.74*

General Methodology

The FEI-GREGAA database was constructed on a GIS platform following three main steps:

1. **The calculation of annual emissions**, according to the equation:

$$E_i = \Sigma (EF_{i,j,k} \times A_{j,k})$$

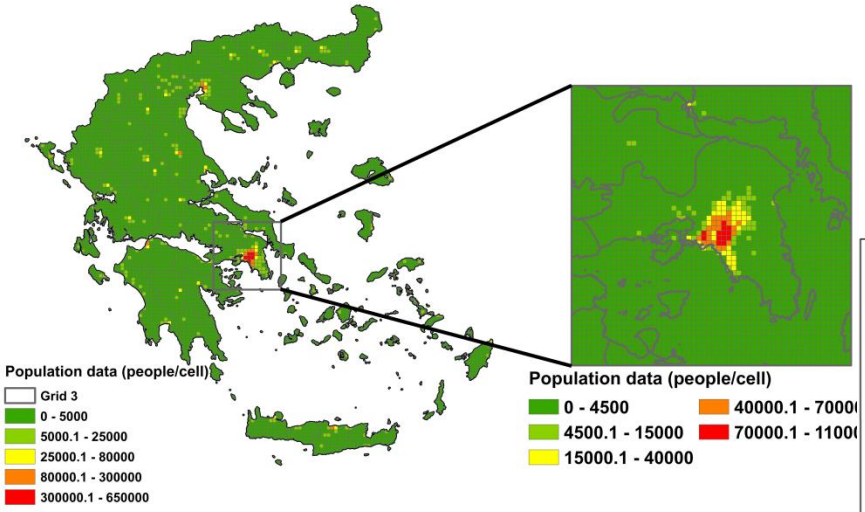
2. **The spatial allocation of emissions** in cells with the use of representative coefficients for each source. In this step thematic maps (see section 2.1) were made withthe ArcView program based on the general equation:

$$E_{i,x} = E_i \times (value_x)/(value_{tot})$$

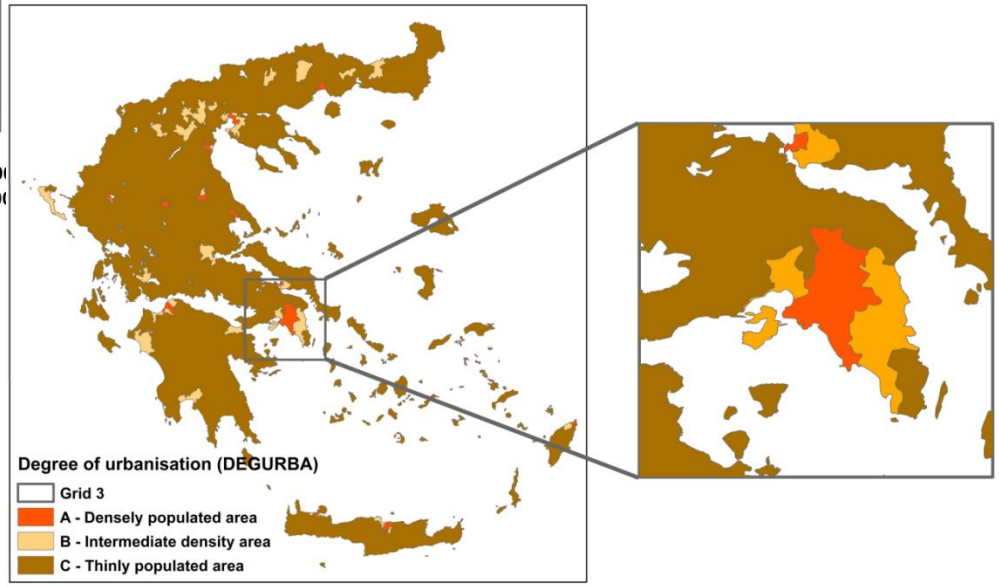
3. The **temporal disaggregation** of the gridded emissions to monthly, weekly and diurnal values based on the equation:

$$E_{h,i,x} = E_{i,x} \times M_i \times D_i \times H_i$$

Spatial allocation of emissions



The 2011 population census data (Source: Eurostat)



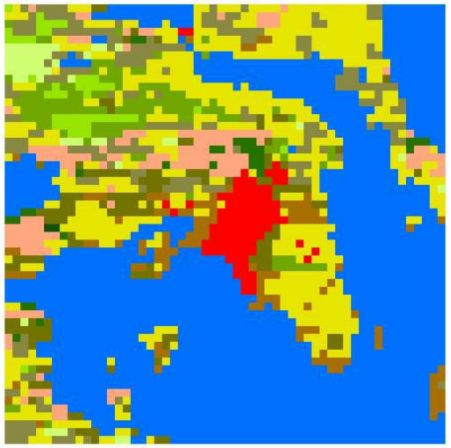
The degree of urbanisation (Source: Eurostat)

Spatial allocation of emissions

Land use

USGS LULC Categories

- 1 Urban and Built-Up Land
- 2 Dryland Cropland and Pasture
- 3 Irrigated Cropland and Pasture
- 4 Mixed Dryland/Irrigated Cropland and Pasture
- 5 Cropland/Grassland Mosaic
- 6 Cropland/Woodland Mosaic
- 7 Grassland
- 8 Shrubland
- 9 Mixed Shrubland/Grassland
- 10 Savanna
- 11 Deciduous Broadleaf Forest
- 14 Evergreen Needlelleaf Forest
- 15 Mixed Forest
- 16 Water Bodies



USGS LULC Categories

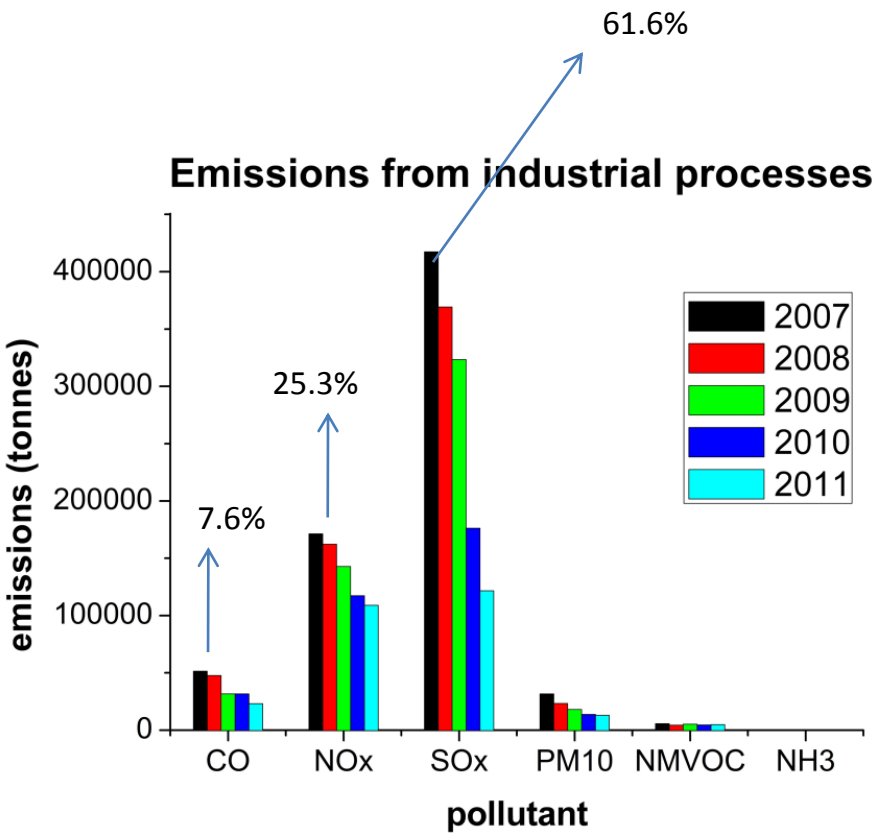
- 1 Urban and Built-Up Land
- 2 Dryland Cropland and Pasture
- 3 Irrigated Cropland and Pasture
- 4 Mixed Dryland/Irrigated Cropland and Pasture
- 5 Cropland/Grassland Mosaic
- 6 Cropland/Woodland Mosaic
- 8 Shrubland
- 9 Mixed Shrubland/Grassland
- 10 Savanna
- 14 Evergreen Needleleaf Forest
- 15 Mixed Forest
- 16 Water Bodies

SNAPS 1+3+4+5+9

Results

Methodology

Industrial activity data for the period 2007 - 2011 were collected by the European Pollutant Release and Transfer Register (E-PRTR, eprtr_v5.1, http://prtr.ec.europa.eu/)



SNAP 2 - Small combustion

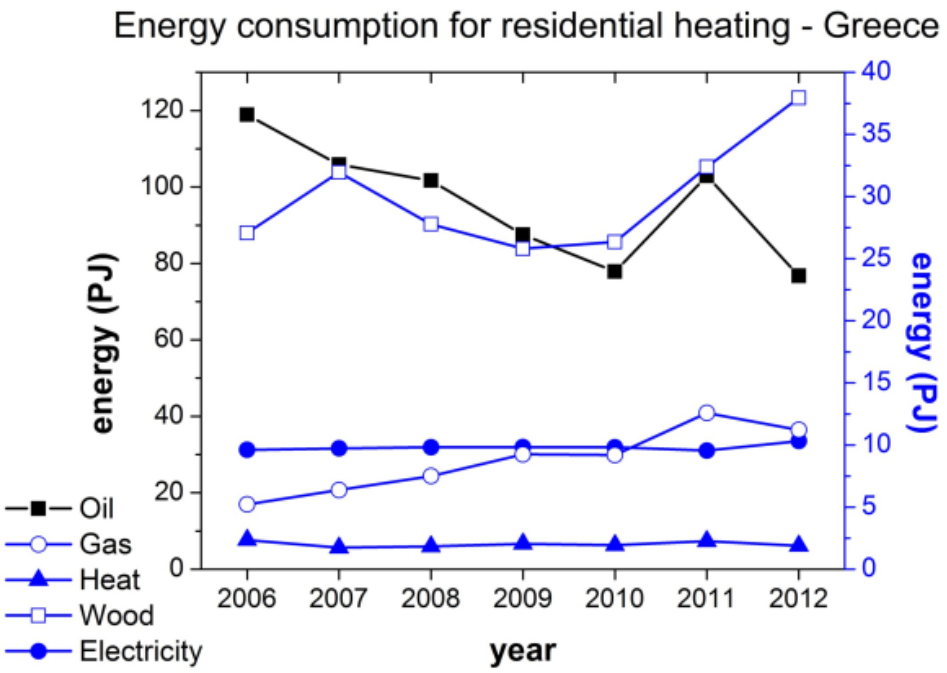
Methodology (Top-down)

The Tier 1 approach was used

Data from
✓the National Energy Data System of the Ministry of Reconstruction of Production, Environment and Energy (NEDS-MRPEE) and

✓the program Odyssee - Mure (Odyssee - Mure project, 2014)

$$E_i = \sum_{j,k} EF_{i,j,k} \times A_{j,k}$$



Biomass consumption for residential heating increased by 37% while the oil consumption decreased by 24%.

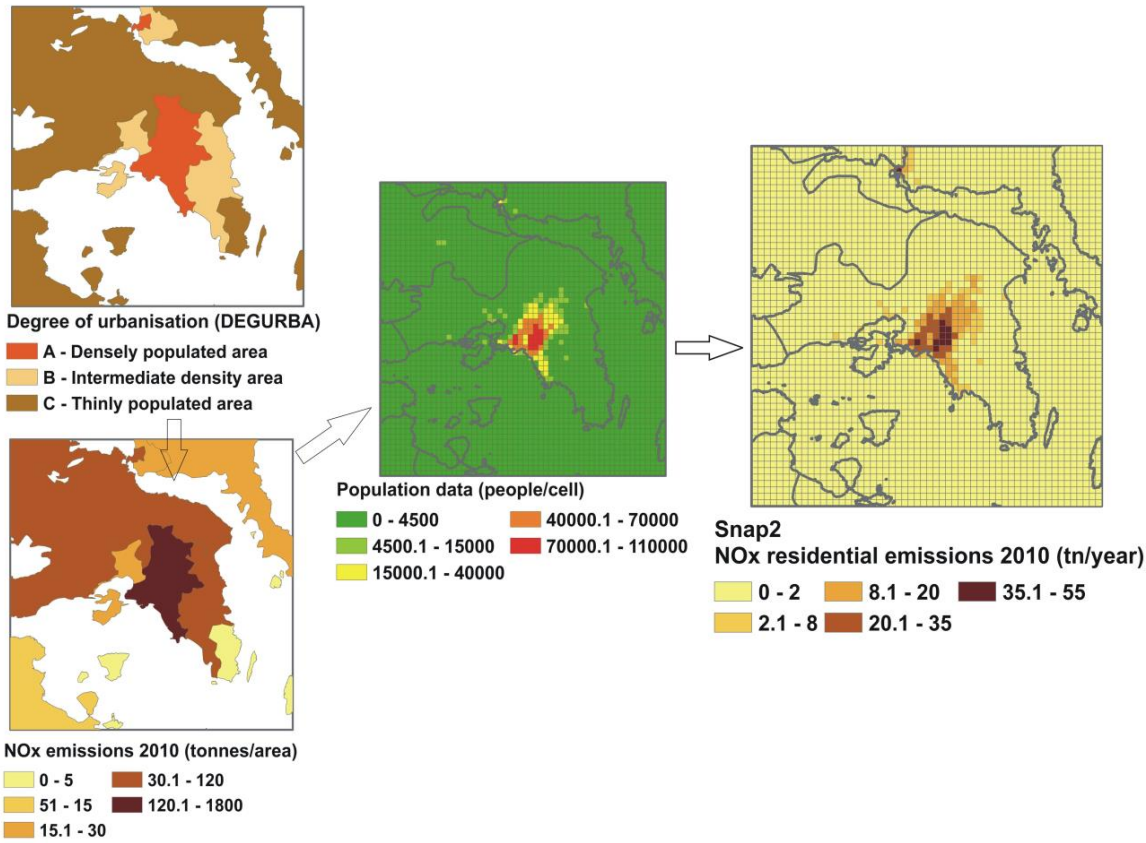
SNAP 2 - Small combustion

Spatial allocation

✓The degree of urbanization (DEGURBA),

✓The population density data (Eurostat) and

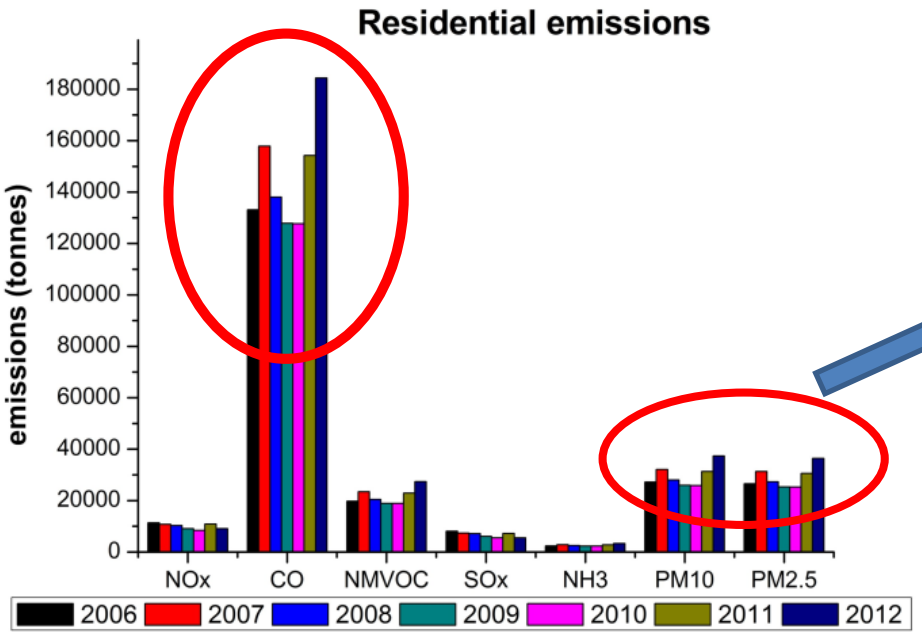
✓A survey conducted by the Greek Statistical Authority (EL.STAT.) regarding the residential energy consumption for the period Octobe 2011 - September 2012

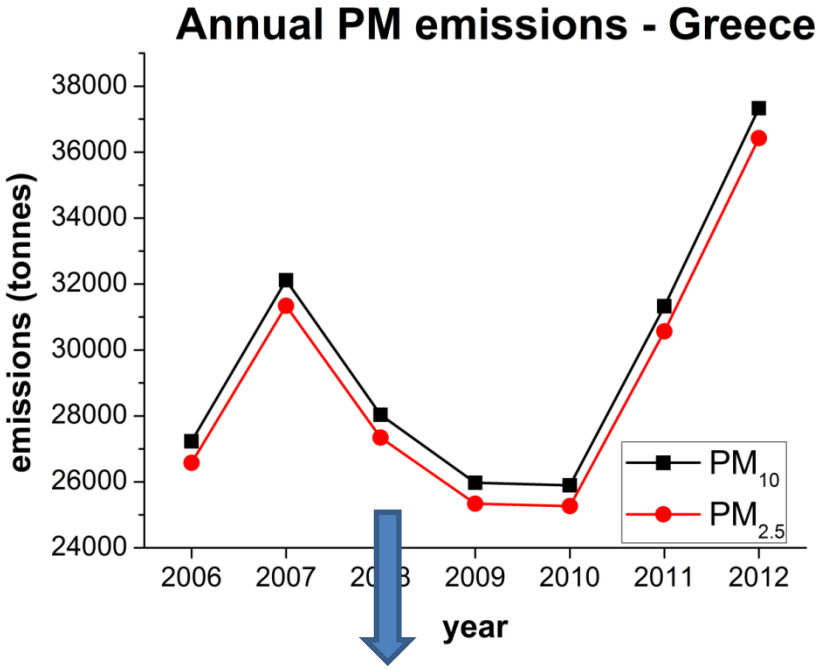


temporal allocation

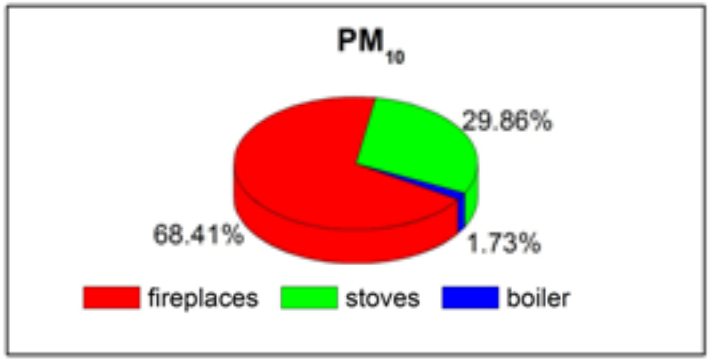
monthly, daily and hourly coefficients were used provided by the TNO database (TNO, 2005)

SNAP 2 - Small combustion

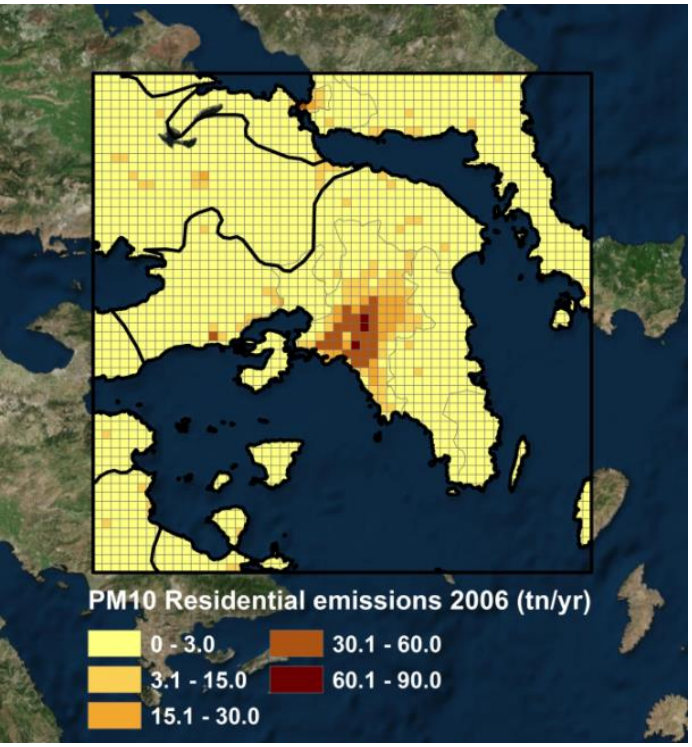


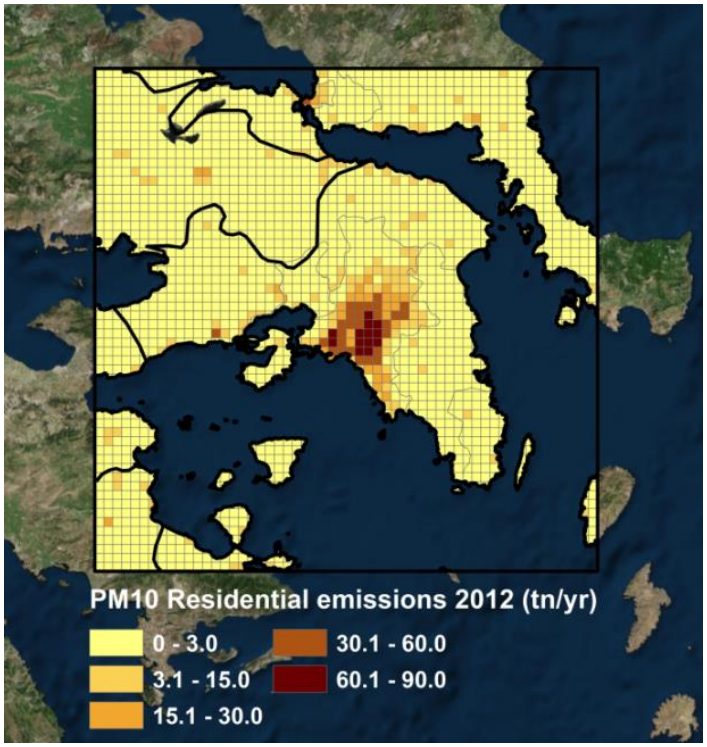


Annual variation of residential emissions for Greece.



SNAP 2 - Small combustion





2006-2011: 8.5% and 9.0% of national CO and PM_{10} emissions are attributed to the GAA, because they are related to biomass burning which is very popular at the rural areas in Greece.

2012: the specific percentages were 12.0% and 12.5% respectively revealing the fact that wood burning increased.

SNAP 7 – Road transport

Methodology (Bottom-up for the GAA)

The Tier 3 approach was used
(COPERT 4)

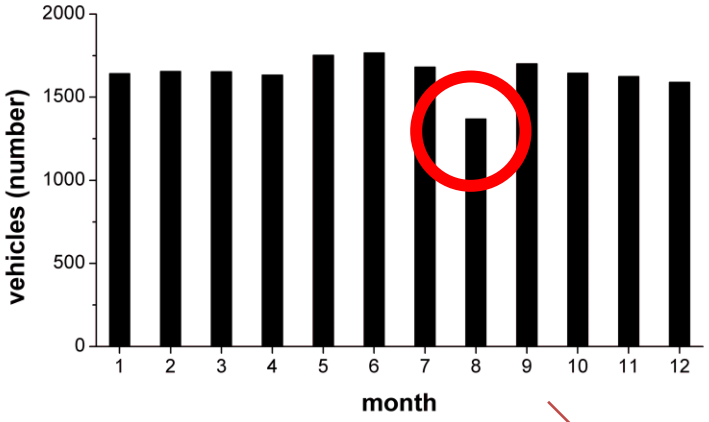
✓Total number of vehicles (source: Ministry of Transport),
✓New vehicles sold in Greece (source: ACEA, ICCT, ELSTAT),
✓Minimum and maximum monthly temperatures (source: National Meteorological Service for Greece, www.meteo.gr for the GAA),
✓Relative Humidity (source: www.meteo.gr),
✓Annual fuel consumption (source: MRPEE).

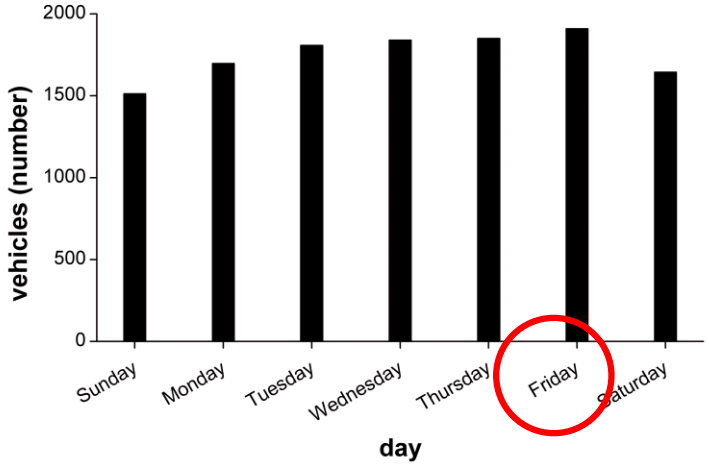
Spatial allocation Road network (OpenStreetMap).

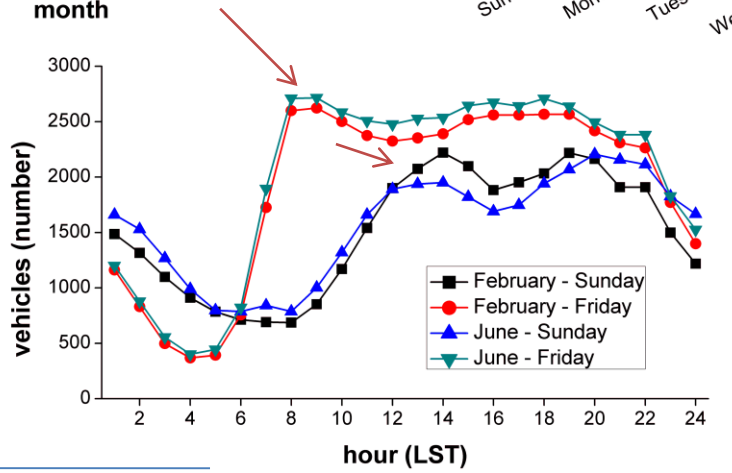
Temporal disaggregation hourly traffic flow profiles for the period 2006-2012.
New more accurate temporal coefficients were developed for the GAA highlighting the special characteristics of the area

SNAP 7 – Road transport

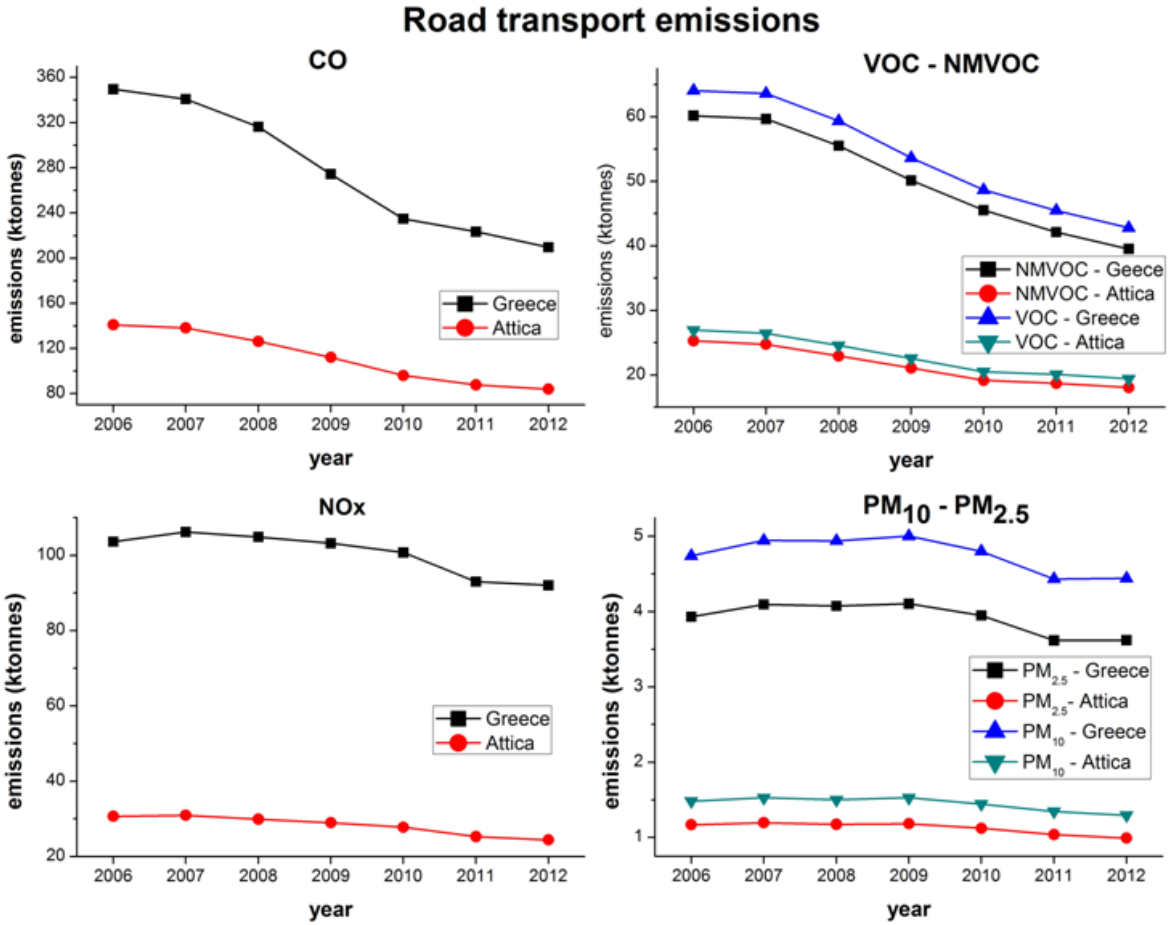
Monthly, daily and hourly mean traffic flows
Attica 2010



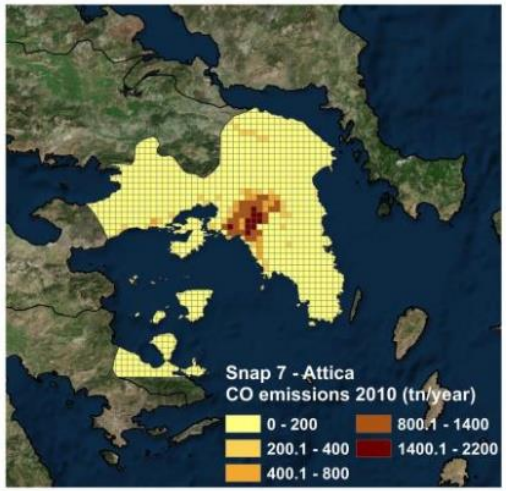


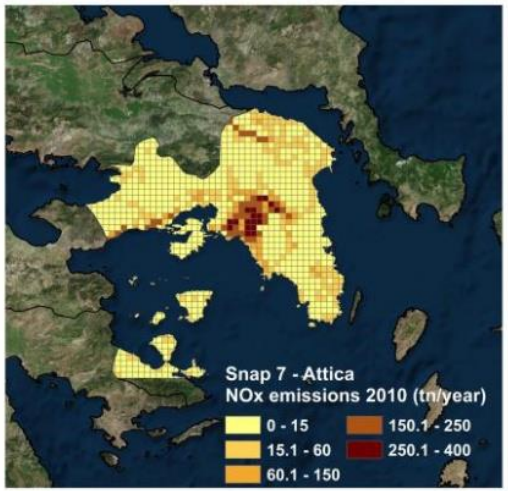


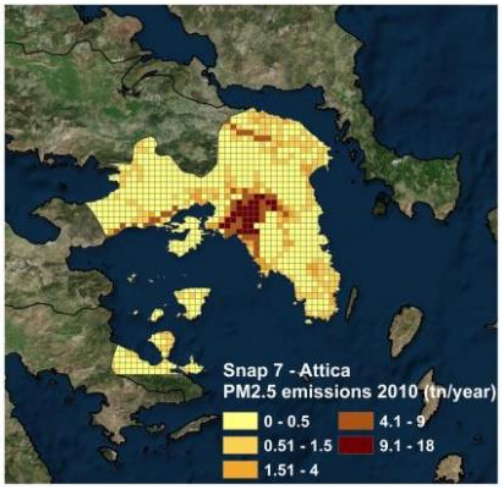
SNAP 7 – Road transport



SNAP 7 – Road transport







SNAP 8 - Navigation

Methodology (Bottom-up)

The Tier 2 approach was used
Emissions were estimated on a seasonal scale for 10 ship types and 85 Greek ports

Data from the Eurostat Database

Spatial allocation

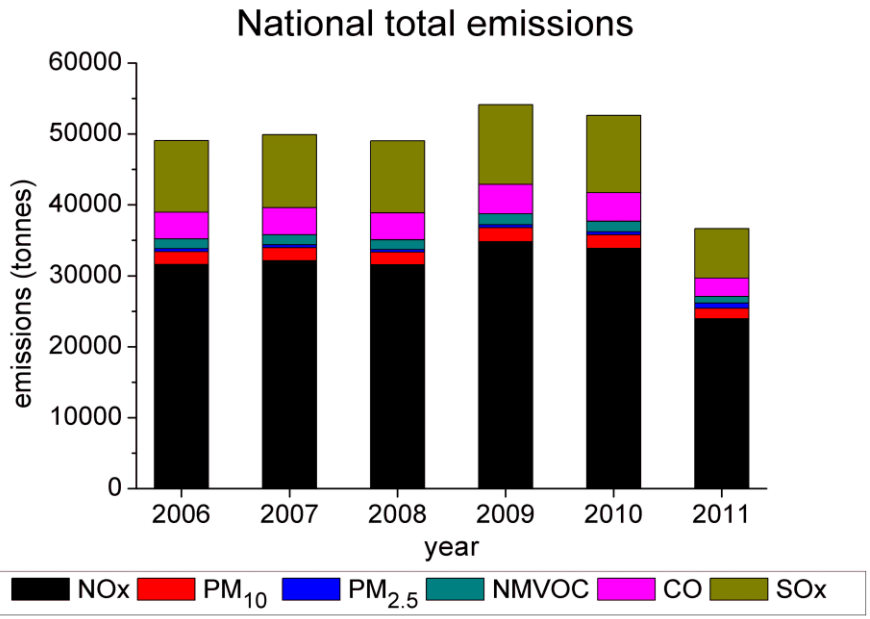
Emissions from passenger ships were allocated in a detailed Geographic Information System (GIS) route network (source:OpenStreetMap) based on the arrival port.

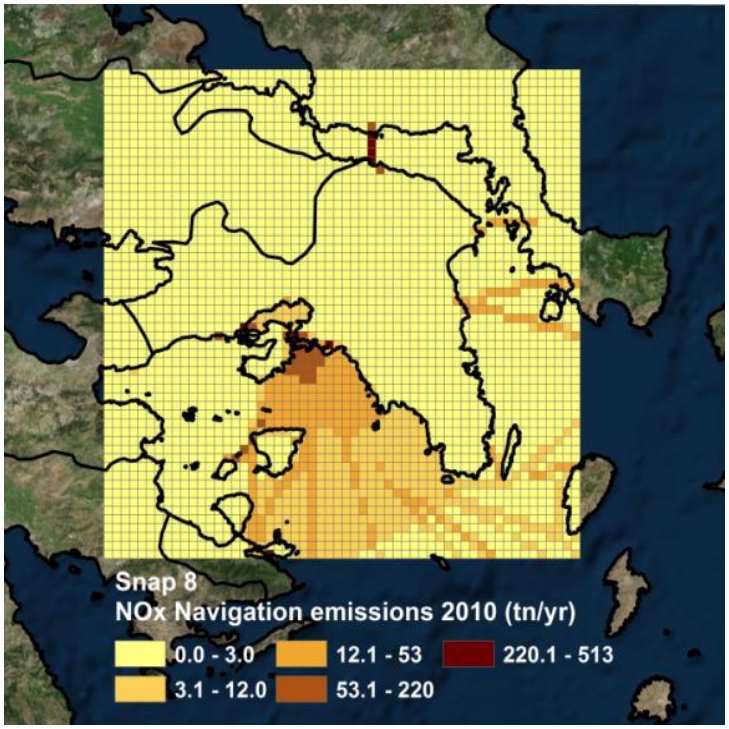
Emissions from the other vessel categories were allocated to coastal zones around the respective ports considering the probability of moving in these zones.

Temporal disaggregation

seasonal emissions were equally distributed to hourly values.

SNAP 8 - Navigation





SNAP 8 - Aviation

Methodology (Bottom-up)

The Tier 2 approach was used
Emissions were estimated on a monthly scale for the 38 Greek airports

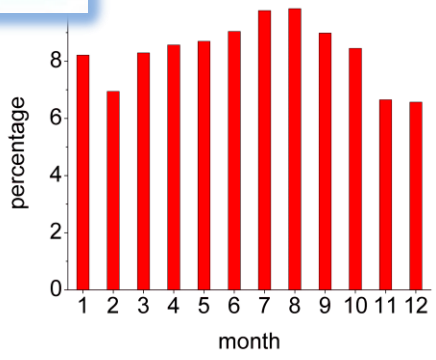
Data from the Eurostat Database and the Greek Civil Aviation Authority

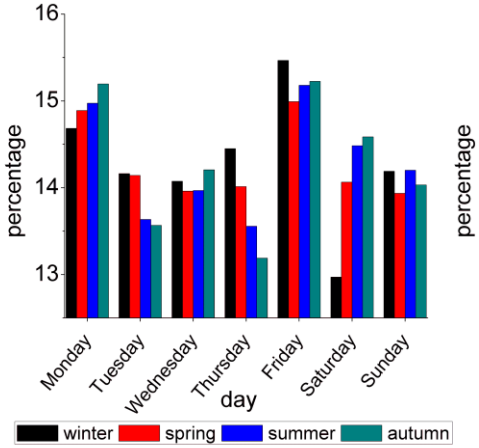
Spatial allocation on the grids having the airport's coordinates and area as surrogate data.

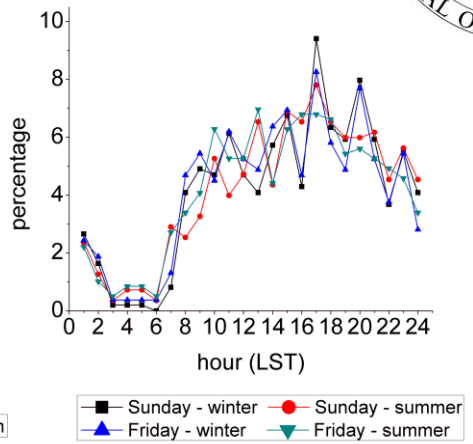
Temporal disaggregation
Weekly, daily and hourly disaggregation coefficients were **developed as part of this work** for each airport for each year separately, based on the number of flights derived from historical flight data (www.flightstats.com).

SNAP 8 - Aviation

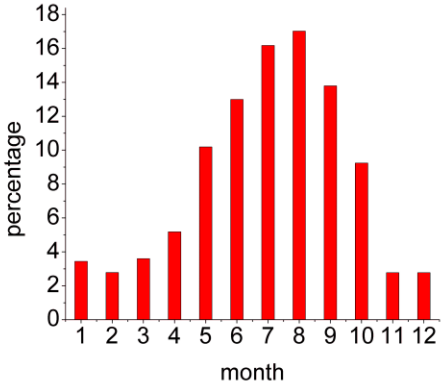
Athens airport - temporal profiles

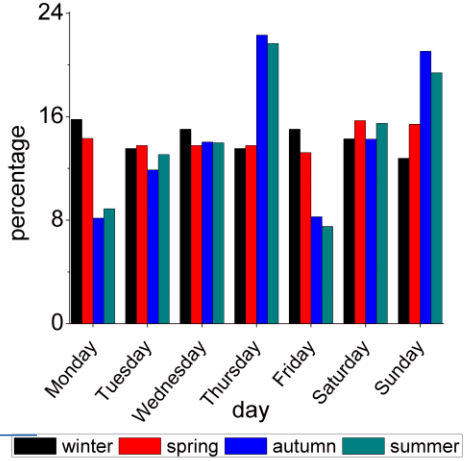


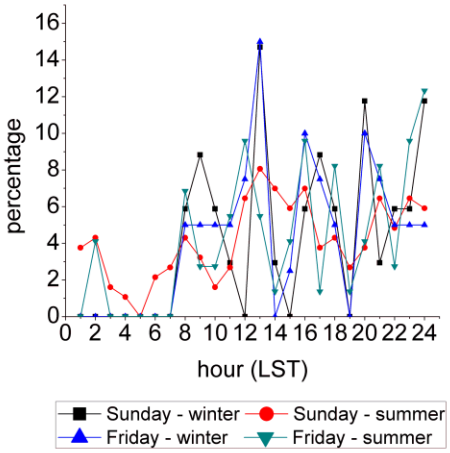




Rodos airport - temporal profiles

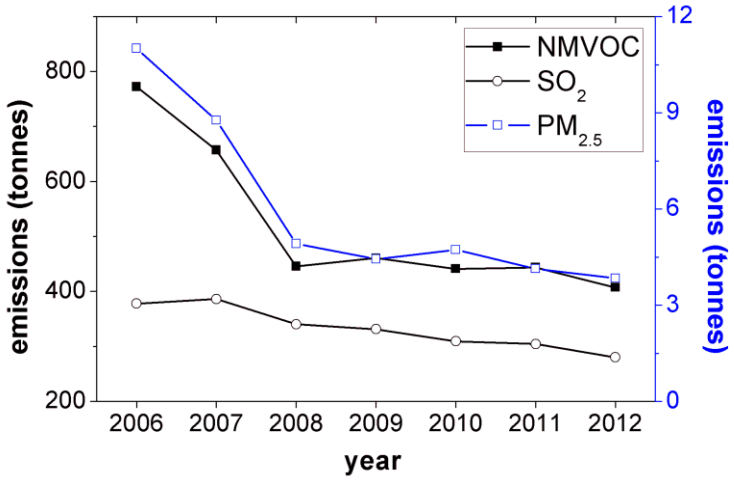


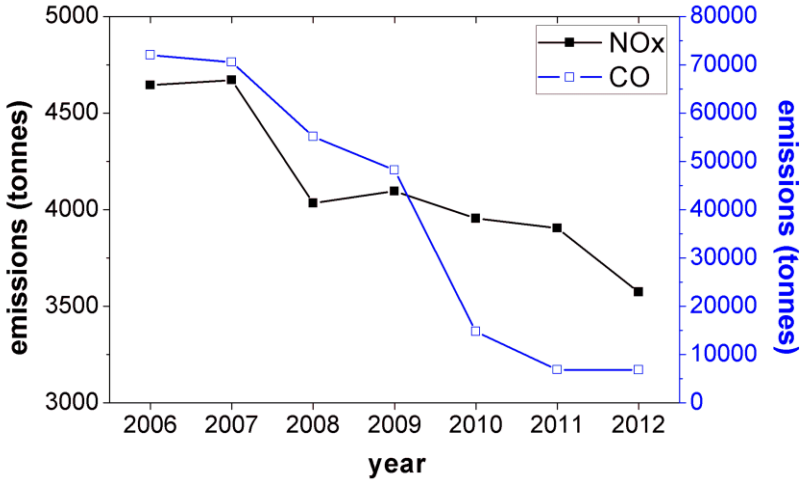




SNAP 8 - Aviation

Annual national emissions from all the Greek airports for the period 2006 – 2012.





SNAP 8 – Off road transport

Methodology (Top-down)

The Tier 1 approach was used
Data from the Eurostat Database

Spatial allocation

Emissions attributed to agricultural works: irrigated areas.
Emissions from activity in the industrial units and the construction sector: urban areas.

Temporal disaggregation

coefficients proposed by TNO

Results

✓NOx emissions prevail due to the extended use of diesel vehicles.

✓Significant decrease (about 52%) was observed from 2006 to 2012 for all pollutants due to the continuous reduction in fuel consumption.

✓In the GAA, 11.7% (2,575tn), 12.0% (834tn), 12.2% (262tn) and 13.6% (156tn) of total national emissions for NOx, CO, NMVOC and PM_{10} emissions respectively were released in 2010.

SNAP 10 – Agriculture

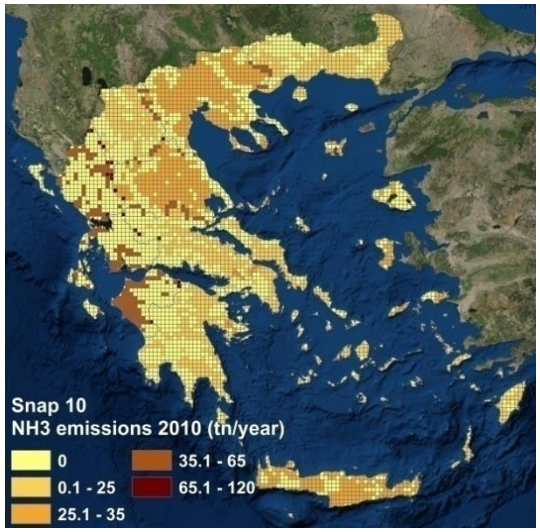
Methodology (bottom-up) – Tier 1 approach

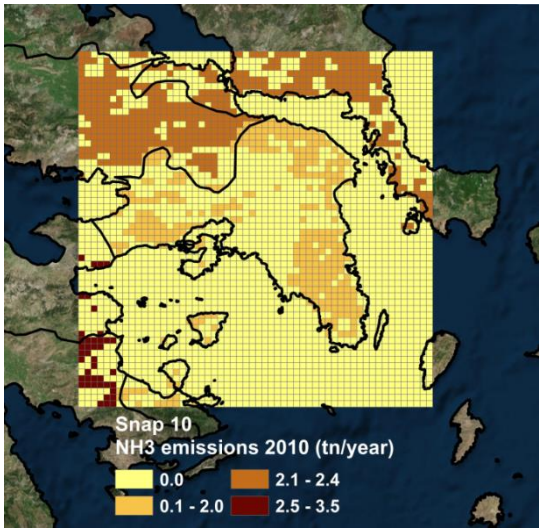
✓The annual population of animals by geographical area (prefectures of Greece) was provided by the Eurostat database for the period 2007-2012.
✓For the year 2006 data from the Hellenic Statistical Authority (EL.STAT.) were used.

✓The amount of N applied was provided by the pesticide consumption data emerged from the Eurostat database (aei_fm_usefert) on an annual level for Greece.

✓The agricultural crop areas were provided by the Eurostat database for each geographical region.

SNAP 10 – Agriculture





Annual variation of NH_3 emissions and spatially distributed NH_3 emissions for the year 2010 in Greece (left) and the GAA (right)

FEI-GREGAA vs TNO-MACCIII