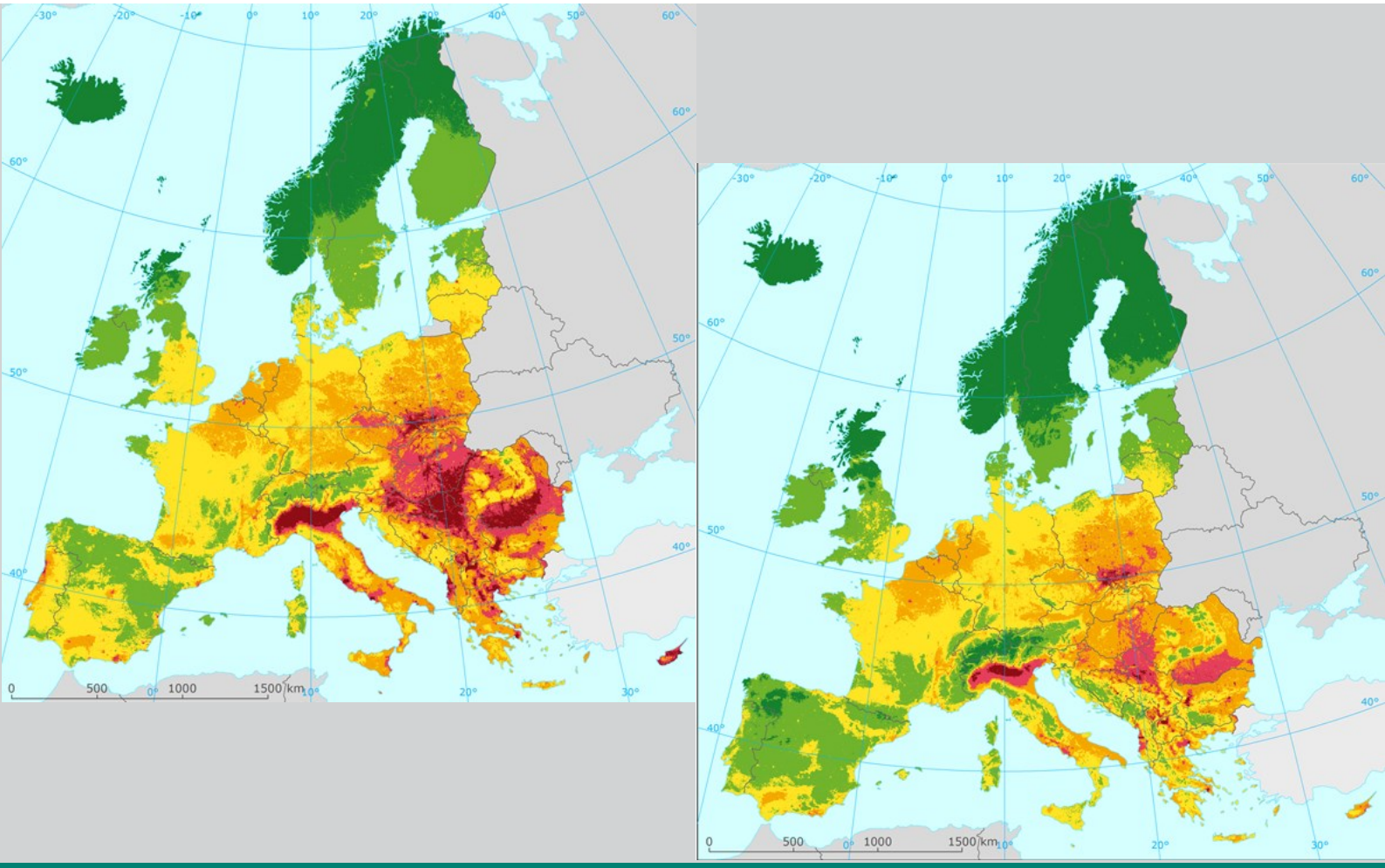
Reference air quality maps 2005 and 2009

PM_{10}, $PM_{2.5}$, ozone and NO_2
spatial maps and population exposure

July 2020



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European Environment Agency
European Topic Centre on Air pollution, transport, noise and industrial pollution

Cover picture: *Concentration maps of $PM_{2.5}$ annual average for 2005 (left) and 2009 (right). Units: $\mu g \cdot m^{-3}$. (Map 2.2 of this paper.)*

The withdrawal of the United Kingdom from the European Union did not affect the production of the report.
Data reported by the United Kingdom are included in all analyses and assessments contained herein, unless otherwise indicated.

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Reference maps for 2005 were prepared under the ETC/ACM consortium in 2018, within the scope of the subtask lead by Frank de Leeuw (NL, RIVM).

1 Introduction

Under the ETC/ATNI consortium (and its predecessors ETC/ACM and ETC/ACC) European-wide air quality maps of annual indicators have been routinely produced for years (Horálek et al. 2020 and references therein), by combining air quality measurement data with modelling results and other supplementary data. The maps are being used as an input for population exposure and health impact estimates, as routinely presented in the EEA's annual Air Quality in Europe reports (EEA, 2019).

Apart from showing the current situation, the maps are also beneficial to compare it with the situation in previous years, in order to see the development throughout the relevant period. In the near future, such a comparison of the present situation with two specific years will be performed by the EEA, namely for the years 2005 and 2009.

In its Clean Air Programme for Europe (EC, 2013) the European Commission has laid out a complex approach to further improve the air quality in Europe. In this program, objectives for reducing the health and environmental impacts of air pollution by 2030 have been established. The objectives are related to the 2005 situation: the aim is to reduce the health impacts (premature mortality attributable to particulate matter and ozone) by 52% compared to 2005. In order to evaluate the progress towards this objective, a comparison of health impacts in the present and in the year 2005 will be considered.

Furthermore, on the occasion of the 10th anniversary of the first Air Quality in Europe annual report, a comparison of the health impacts in 2009 (i.e. first year covered in EEA, 2011) and in 2018 is planned to be produced.

In order to compare the state of the air quality and the relevant health impacts in different years, consistent air quality maps (based on which the health impacts are calculated) should be used. The aim of this paper is to present 2005 and 2009 maps produced using the same methodology and the same data sources as the current 2017 and 2018 maps, and based on the input data representative for 2005 and 2009. The pollutants and their indicators as routinely used for the health impacts calculations are considered, i.e. the $PM_{2.5}$ annual average, the ozone indicator SOMO35 and the NO_2 annual average. Next to this, the PM_{10} annual average is also presented, since it is normally used for population exposure estimates.

Chapter 2 presents maps and population exposure estimates for PM_{10} and $PM_{2.5}$, Chapter 3 shows the same for ozone and Chapter 4 for NO_2. The Annex gives the details on the mapping methodology and the data used.

2 Particulate matter

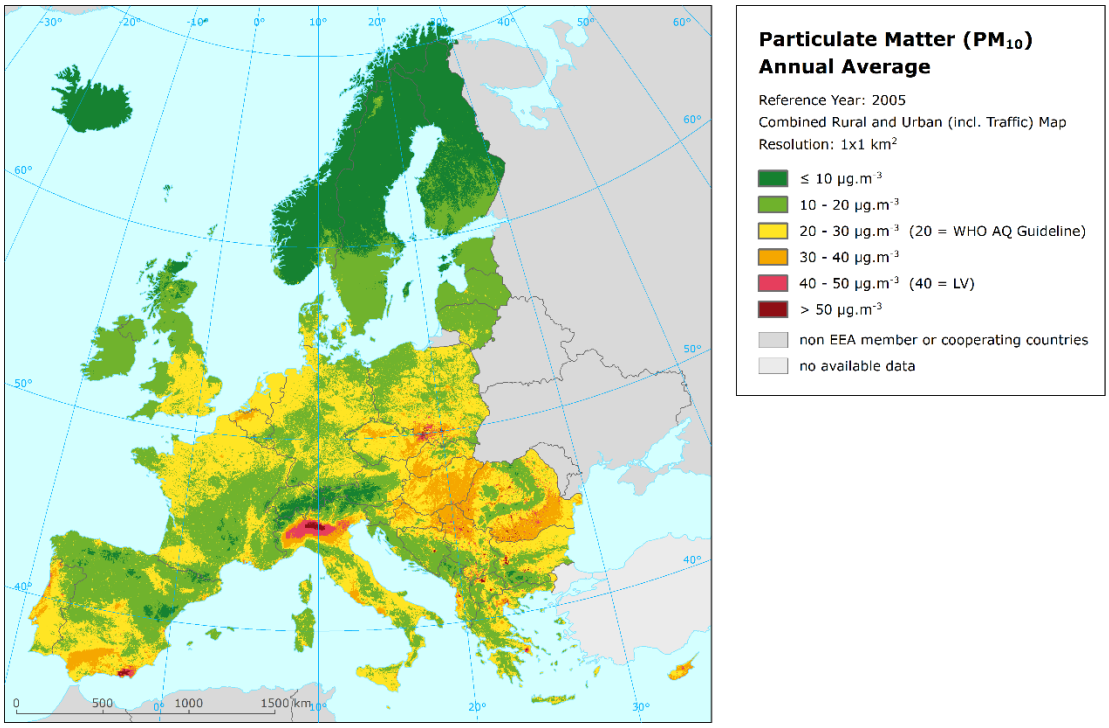
2.1 PM_{10} annual average

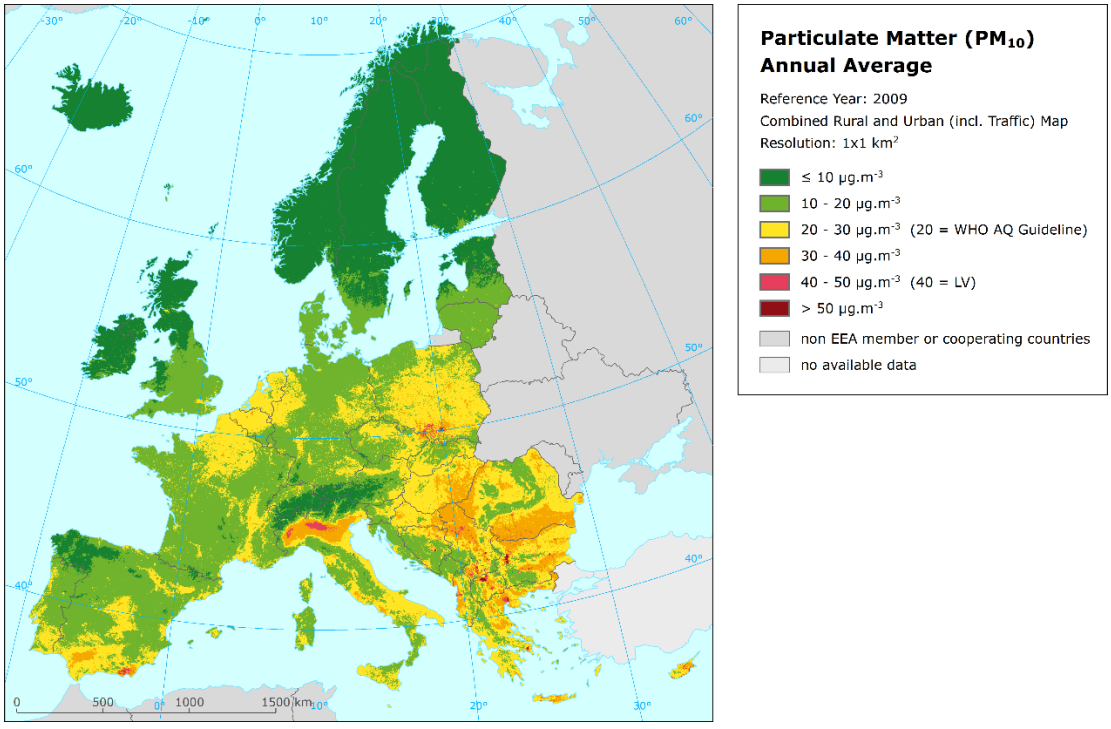
The Ambient Air Quality Directive (EC, 2008) sets limit values for long-term and for short-term PM_{10} concentrations. The long-term annual PM_{10} limit value (LV) is set at 40 $\mu g \cdot m^{-3}$. The Air Quality Guideline recommended by the World Health Organization (WHO, 2005) for the PM_{10} annual average is 20 $\mu g \cdot m^{-3}$. This section presents PM_{10} annual average maps and population exposure estimates for 2005 and 2009.

2.1.1 Concentration maps

Map 2.1 presents the concentration maps of PM_{10} annual average for 2005 and 2009. Red and purple areas indicate LV exceedances. One can see higher concentration values in 2005. In both years, LV exceedances occur in the Po valley in northern Italy, in the Ostrava – Katowice region in the Czech – Polish border area, in urban areas in Balkan countries and in southern Spain near Almeria.

Map 2.1: Concentration map of PM_{10} annual average, 2005 (above) and 2009 (below)





2.1.2 Population exposure

Tables 2.1 and 2.2 give, for 2005 and 2009, respectively, the population frequency distribution for several exposure classes, as well as the population-weighted concentration for individual countries and for Europe as a whole.

Table 2.1: Population exposure and population-weighted concentration, PM_{10} annual average, 2005

Country	ISO	Population [inhbs·1000]	PM_{10} – annual average, exposed population, 2005 [%]						PM_{10} ann. avg.
			< 10	10 - 20	20 - 30	30 - 40	40 - 50	> 50	Pop. weighted
Albania	AL	3 020		4.1	15.7	44.1	26.1	10	38.5
Andorra	AD	77	0.2	1.6	97.7	0.5			26.8
Austria	AT	8 201	0.5	15.3	69.3	14.4	0.5		25.6
Belgium	BE	10 446		0.9	59.3	39.9			29.0
Bosnia & Herzegovina	BA	3 843		7.3	26.9	48.4	7.5	10	34.3
Bulgaria	BG	7 689		1.9	27.1	17.7	18.5	34.8	42.0
Croatia	HR	4 311		5.9	26.6	62.3	5.2		32.3
Cyprus	CY	953			2.2	16.1	75.4	6.4	43.0
Czechia	CZ	10 199		0.7	28.7	60.1	7.7	2.7	32.7
Denmark	DK	5 411	0.1	14.6	83.2	2			22.5
Estonia	EE	1 359	1.2	64.5	34.3				18.2
Finland	FI	5 237	8.2	89.9	2				14.5
France (metropolitan)	FR	60 963		9.5	78.2	10.7	1.6		25.1
Germany	DE	82 501		7.1	89.6	3.3			23.5
Greece	GR	10 970		1.8	17	28.8	35.6	16.8	40.1
Hungary	HU	10 098			12.1	84.5	3.3		33.9
Iceland	IS	294	6.7	80.3	13				16.7
Ireland	IE	4 112		98.1	1.9				15.7
Italy	IT	57 875		2	33.3	40.6	16.6	7.6	34.5
Latvia	LV	2 250		31.6	53.6	13.4	1.5		23.2
Liechtenstein	LI	35		4.6	95.4				23.9
Lithuania	LT	3 355		24.3	71.6	4.1			22.1
Luxembourg	LU	461		4.9	89.9	5.2			22.5
Malta	MT	403			7.2	82.6	10.2		34.3
Monaco	MC	33				100			31.9
Montenegro	ME	613	0.1	15.5	11.7	69.2	3.5		30.7
Netherlands	NL	16 306			91.8	8.2			27.7
North Macedonia	MK	2 035		0.6	2.8	11.1	37.5	48	55.1
Norway	NO	4 606	13.9	49.8	35.6	0.7			17.6
Poland	PL	38 174		5.1	45	31.1	12.8	6	31.8
Portugal (excl. Az., Mad.)	PT	9 994		2.6	28.9	57.7	10.5	0.2	32.5
Romania	RO	21 382		1.1	10	28.6	45.6	14.6	41.0
San Marino	SM	30		0.4	95.1	4.5			26.2
Serbia (incl. Kosovo*)	RS	9 497		1.7	8.5	19.5	61.5	8.7	42.3
Slovakia	SK	5 373		0.2	12	78.5	9.1	0.1	33.9
Slovenia	SI	1 998		8.2	43.6	46.3	1.9		29.3
Spain (excl. Canarias)	ES	41 443		4.5	30.1	58.7	6.5	0.2	32.0
Sweden	SE	9 011	4.6	74.6	19.6	1.1			17.5
Switzerland	CH	7 415	0.4	18.2	78.8	2.6			22.1
United Kingdom (& dep.**)	UK	60 182		20.3	77.1	2.6			22.1
Total		**522 152**	**0.3**	**10.7**	**53.8**	**23.7**	**8.3**	**3.2**	**28.6**
			11.0				**11.5**		
EU-28		**490 655**	**0.2**	**10.4**	**55.0**	**24.1**	**7.4**	**2.9**	**28.4**
			10.6				**10.3**		
Kosovo*	KS	2 041		1.7	13.0	16.0	64.8	4.6	41.2
Serbia (excl. Kosovo*)	RS	7 456		1.8	7.4	20.4	60.7	9.7	42.5

(*) under the UN Security Council Resolution 1244/99 (**) Crown dependencies
Note 1: The value "0.0" indicates that an exposed population exists, but it is small (less than 0.05 %). Empty cells mean no exposed population.
Note 2: Turkey is not included due to the lack of air quality data.

Table 2.2: Population exposure and population-weighted concentration, PM_{10} annual average, 2009

Country	ISO	Population [inhbs·1000]	PM_{10} – annual average, exposed population, 2009 [%]						PM_{10} ann. avg.
			< 10	10 - 20	20 - 30	30 - 40	40 - 50	> 50	Pop. weighted
Albania	AL	2 936		0.7	13.4	48.8	34.4	2.6	38.2
Andorra	AD	84	0.1	10.4	89.1	0.4			26.5
Austria	AT	8 335	1.2	29.3	69.1	0.4			21.7
Belgium	BE	10 753		2.1	90.5	7.4			26.9
Bosnia & Herzegovina	BA	3 844		4.8	21.7	35.8	27.4	10.3	37.2
Bulgaria	BG	7 467		0.6	7	32.8	35.4	24.2	43.6
Croatia	HR	4 310		4.6	36.6	56.9	2		30.3
Cyprus	CY	1 081			6.2	9.7	6.2	77.9	49.6
Czechia	CZ	10 426		7.1	78.7	10.9	3.3		26.1
Denmark	DK	5 511	0.2	92.7	7.1				17.9
Estonia	EE	1 336	16.5	83.4	0.2				12.6
Finland	FI	5 326	35.4	64.6					11.0
France (metropolitan)	FR	62 466		18.2	72.4	8.2	1.2		24.1
Germany	DE	82 002		35.2	64	0.8			21.3
Greece	GR	11 095		0.3	25.5	32.4	27.4	14.4	38.5
Hungary	HU	10 031		0.1	36.1	63.9			31.3
Iceland	IS	319	71.8	24.8	3.4				9.7
Ireland	IE	4 521	29.4	70.6					12.1
Italy	IT	59 001	0.1	5.7	52.8	31.8	9.5		29.3
Latvia	LV	2 163	1.4	58.5	29.3	10.8			19.9
Liechtenstein	LI	36	0.3	93.9	5.9				18.6
Lithuania	LT	3 184		47.3	52.7				20.0
Luxembourg	LU	494		41.8	58.2				20.4
Malta	MT	411		0.2	89.6	10.2			28.3
Monaco	MC	35			100				25.9
Montenegro	ME	617		9.7	13.7	70.9	5.7		33.4
Netherlands	NL	16 486		0.8	99	0.2			25.1
North Macedonia	MK	2 049		0.1	1.8	24.9	36.2	37.1	53.4
Norway	NO	4 799	27.6	59.2	13.2				13.7
Poland	PL	38 136		3.7	42.4	39.8	11.5	2.6	30.9
Portugal (excl. Az., Mad.)	PT	10 051	0.1	23.5	62.6	13.8			24.0
Romania	RO	20 440		1.2	40.9	51.3	6.4	0.2	31.7
San Marino	SM	31		1.2	94.3	4.5			25.8
Serbia (incl. Kosovo*)	RS	9 516		0.8	5.3	33.6	50.9	9.5	40.8
Slovakia	SK	5 382		1.6	61.5	34.1	2.5	0.3	28.8
Slovenia	SI	2 032		9	70.3	20.7			26.0
Spain (excl. Canarias)	ES	44 214	0.7	13.4	65.7	20	0.3		25.5
Sweden	SE	9 256	25.1	72.3	2.3	0.3			12.5
Switzerland	CH	7 702	1.5	32.5	66				20.8
United Kingdom (& dep.**)	UK	71 517	1.6	80.2	18.1				18.4
Total		**529 921**	**1.7**	**25.8**	**49.9**	**16.3**	**4.9**	**1.4**	**25.3**
				27.5				**6.2**	
EU-28		**497 952**	**1.5**	**26.2**	**51.5**	**16.0**	**3.7**	**1.0**	**24.9**
				27.7				**4.7**	
Kosovo*	KS	2 181	0.3	5.4	21.0	49.4	23.9	0.3	44.1
Serbia (excl. Kosovo*)	RS	7 335		0.9	5.2	36.6	51.3	5.9	39.9

(*) under the UN Security Council Resolution 1244/99 (**) Crown dependencies

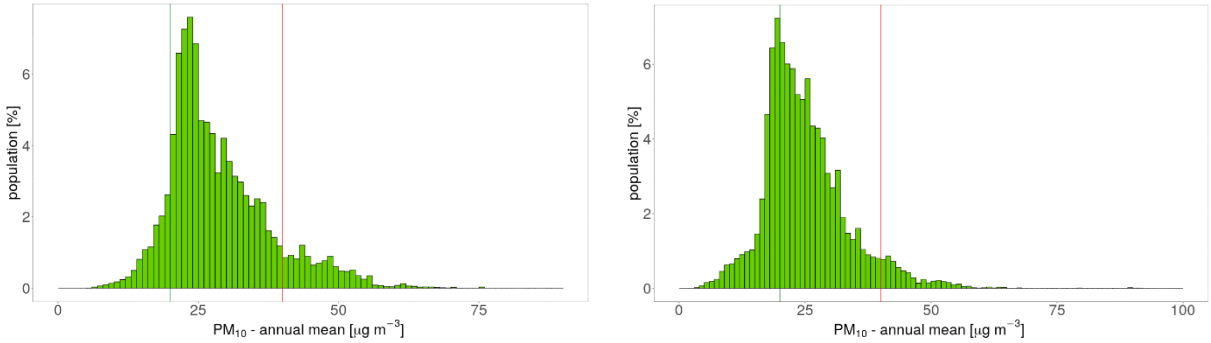
Note 1: The value "0.0" indicates that an exposed population exists, but it is small (less than 0.05 %). Empty cells mean no exposed population.

Note 2: Turkey is not included due to the lack of air quality data.

In 2005, about 89 % of both the European and the EU-28 population has been exposed to annual average concentrations above the Air Quality Guideline of 20 µg·m^{-3} recommended by the World Health Organization (WHO, 2005). In 2009, it was 72 % of both the European and the EU-28 population. Approximately 12 % (in 2005) resp. 6 % (in 2009) of the European population was exposed to concentrations exceeding the EU annual limit value of 40 µg·m^{-3}. The European-wide population-weighted concentration of the PM_{10} annual average was about 29 µg·m^{-3} in 2005 and about 25 µg·m^{-3} in 2009.

Figure 2.1 shows, for the whole mapped area (that is, all the EEA member and cooperating countries apart from Turkey, plus the microstates of Andorra, Monaco and San Marino) the population frequency distribution for exposure classes of 1 µg·m^{-3}. One can see the highest population frequency for classes between 21 and 25 µg·m^{-3} (for 2005), resp. between 18 and 21 µg·m^{-3} (for 2009). In 2005, the histogram also have a much longer right tail, meaning more population in higher concentration classes, compared to 2009.

Figure 2.1: Population frequency distribution, PM_{10} annual average, 2005 (left) and 2009 (right)



Note: Apart from the population distribution shown in graphs, it was estimated that 0.025 % (2005) resp. 0.004 % (2009) of population lived in areas with PM_{10} annual average concentration in between 80 and 200 µg.m^{-3} resp. 100 and 220 µg.m^{-3}.

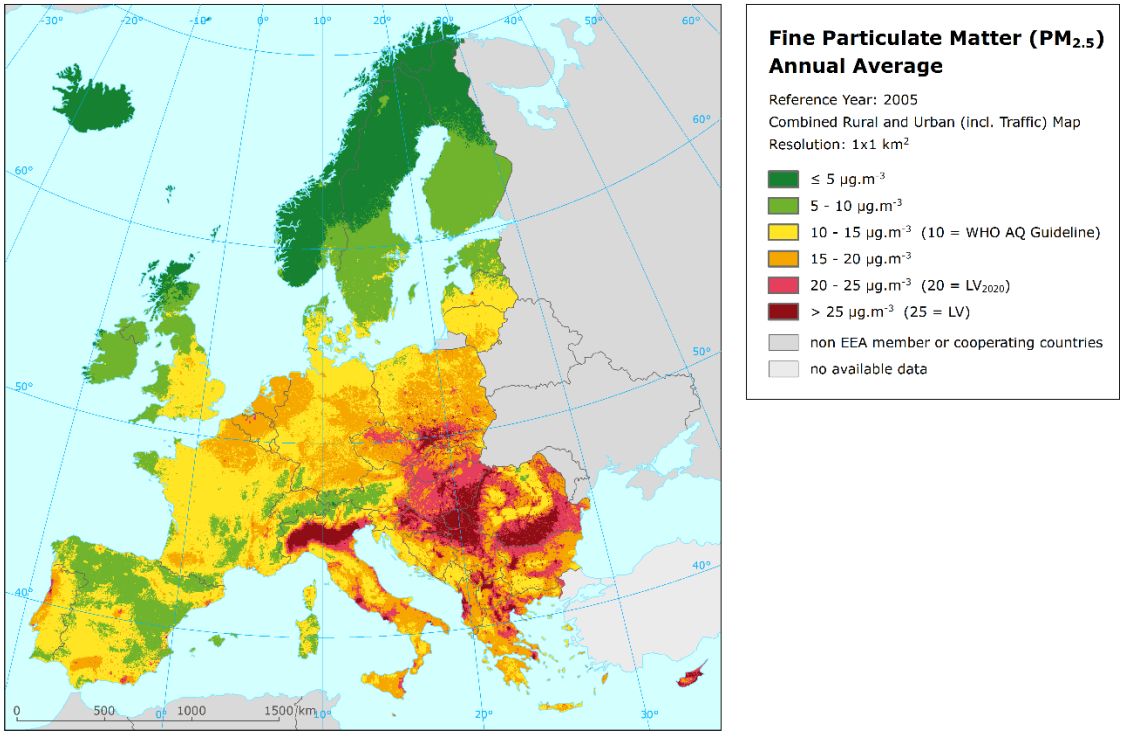
2.2 $PM_{2.5}$ annual average

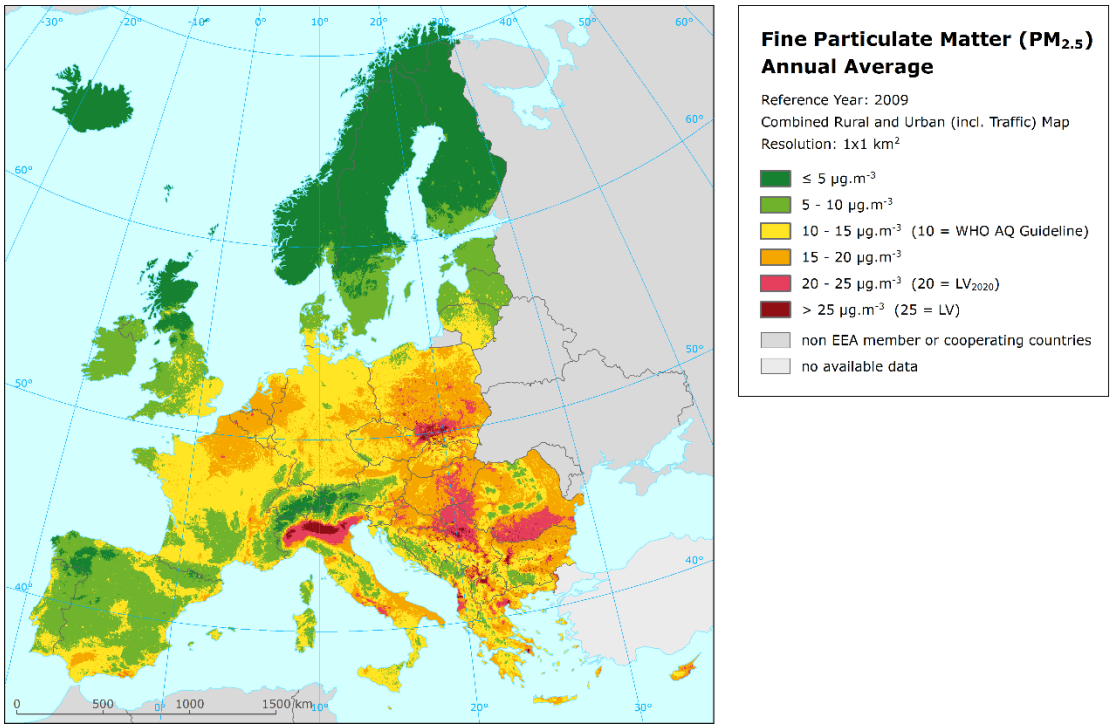
In the Ambient Air Quality Directive (EC, 2008), the limit value (LV) for the annual average $PM_{2.5}$ concentrations was set at 25 µg·m^{-3}. In the AQ directive there is also an indicative limit value (LV_{2020}) of 20 µg·m^{-3} aimed to be met by 2020. The Air Quality Guideline recommended by the World Health Organization (WHO, 2005) for the $PM_{2.5}$ annual average is 10 µg·m^{-3}.

2.2.1 Concentration maps

Map 2.1 presents the concentration maps of $PM_{2.5}$ annual average for 2005 and 2009. The purple areas exceed the LV of 25 µg·m^{-3}. Red areas show exceedances of the indicative limit value of 20 µg·m^{-3} (LV_{2020}). Like for PM_{10}, higher concentration values in 2005 are observed, compared to 2009. In both years, LV exceedances occur in Po valley in northern Italy, in the Ostrava – Katowice region in the Czech – Polish border area, in urban areas in Balkan countries and in the central Italy around Rome. In 2005, the LV was also exceeded in large areas in the Balkan region, specifically in Romania and Serbia.

Map 2.2: Concentration map of $PM_{2.5}$ annual average, 2005 (above) and 2009 (below)





2.2.2 Population exposure

Tables 2.3 and 2.4 show, for 2005 and 2009, respectively, the population frequency distribution for several exposure classes, as well as the population-weighted concentration for individual countries and whole Europe.

Table 2.3: Population exposure and population-weighted concentration, $PM_{2.5}$ annual average, 2005

Country	ISO	Population [inhbs·1000]	$PM_{2.5}$ – annual average, exposed population, 2005 [%]						$PM_{2.5}$ ann. avg.
			< 5	5 - 10	10 - 15	15 - 20	20 - 25	> 25	Pop. weighted
Albania	AL	3 020			0.2	10	22.9	66.9	27.5
Andorra	AD	77		1.8	97.7			0.5	13.5
Austria	AT	8 201		2.1	11.7	37.6	39	9.6	19.1
Belgium	BE	10 446			3.1	82.1	9.4	5.5	18.4
Bosnia & Herzegovina	BA	3 843			1.1	16.5	40	42.3	25.9
Bulgaria	BG	7 689			0.6	14.3	16.3	68.8	30.8
Croatia	HR	4 311			4.4	19.2	21	55.4	23.9
Cyprus	CY	953				0.1	6.3	93.6	28.6
Czechia	CZ	10 199			0.6	15.2	61.8	22.3	23.3
Denmark	DK	5 411	0.4	4.2	92.6		0.1	2.8	12.6
Estonia	EE	1 359		19.3	74.6	0.1	1.8	4.2	11.6
Finland	FI	5 237	1.3	74.9	19.4	2.4	1.4	0.5	8.8
France (metropolitan)	FR	60 963		1.7	33.6	54.9	3.7	6.1	16.0
Germany	DE	82 501		0.1	20.2	72.6	1.4	5.7	16.5
Greece	GR	10 970			0.7	16.7	23.3	59.2	26.6
Hungary	HU	10 098				1.1	46.3	52.6	25.0
Iceland	IS	294	14.5	78.8	0.7	2.1	3.9		7.1
Ireland	IE	4 112	0.8	90.9	1.9	4.6	1.9		8.3
Italy	IT	57 875		0.2	2.1	26.7	31.5	39.5	23.7
Latvia	LV	2 250		1	37.1	34.8	11.8	15.3	17.1
Liechtenstein	LI	35		0.1	4.9	93.8	0.1	1.2	17.9
Lithuania	LT	3 355			22.2	71.1		6.7	16.4
Luxembourg	LU	461			40.8	48.3		10.9	15.7
Malta	MT	403			0.2	18.5	71.1	10.2	21.2
Monaco	MC	33				78.5		21.5	18.9
Montenegro	ME	613			8	15.5	45.2	31.2	22.1
Netherlands	NL	16 306			1.1	91.9	1.3	5.7	17.7
North Macedonia	MK	2 035			0.1	0.9	2.8	96.2	38.9
Norway	NO	4 606	15.1	36.2	37.9	5.3	2.7	2.8	9.3
Poland	PL	38 174			4.3	35.8	31.2	28.7	22.5
Portugal (excl. Az., Mad.)	PT	9 994		0.7	19.4	50.8	20.6	8.5	18.0
Romania	RO	21 382			0.7	3.9	12.4	82.9	29.9
San Marino	SM	30				95.5		4.5	18.3
Serbia (incl. Kosovo*)	RS	9 497			0.1	2.4	8.1	89.3	30.9
Slovakia	SK	5 373				2.1	61.6	36.3	24.5
Slovenia	SI	1 998			3.5	27.1	44.9	24.5	21.8
Spain (excl. Canarias)	ES	41 443		2.1	19.9	34.6	34.1	9.3	18.4
Sweden	SE	9 011	2.1	32	61.9	0.2	0.6	3.2	10.3
Switzerland	CH	7 415		1.8	19.6	68.9	3.1	6.7	16.3
United Kingdom (& dep.**)	UK	60 182	0.2	9.9	76.7	5.7	1.8	5.7	13.1
Total		**522 152**	**0.2**	**4.3**	**22.7**	**36.1**	**15.8**	**20.9**	**19.0**
			4.5				**36.8**		
EU-28		**490 655**	**0.1**	**4.1**	**23.4**	**37.0**	**16.1**	**19.4**	**18.8**
			4.2				**35.5**		
Kosovo*	KS	2 041			0.0	2.0	10.4	87.6	30.6
Serbia (excl. Kosovo*)	RS	7 456			0.1	2.5	7.6	89.7	30.9

(*) under the UN Security Council Resolution 1244/99 (**) Crown dependencies

Note 1: The value "0.0" indicates that an exposed population exists, but it is small (less than 0.05 %). Empty cells mean no exposed population.

Note 2: Turkey is not included due to the lack of air quality data.

Table 2.4: Population exposure and population-weighted concentration, $PM_{2.5}$ annual average, 2009

Country	ISO	Population [inhbs·1000]	$PM_{2.5}$ – annual average, exposed population, 2009 [%]						$PM_{2.5}$ ann. avg.
			< 5	5 - 10	10 - 15	15 - 20	20 - 25	> 25	Pop. weighted
Albania	AL	2 936		0.1	6.3	17.9	40.8	34.9	23.3
Andorra	AD	84		1.8	98.2				13.4
Austria	AT	8 335	0.2	4.2	24.7	67.6	3.3		16.0
Belgium	BE	10 753			2	89.5	8.6		18.6
Bosnia & Herzegovina	BA	3 844		0.8	8.2	19.7	29.1	42.2	23.9
Bulgaria	BG	7 467		0.2	2.6	9.8	21.7	65.7	27.2
Croatia	HR	4 310		0.2	9.6	30.9	54.7	4.6	20.1
Cyprus	CY	1 081			1	34.3	56.4	8.3	20.6
Czechia	CZ	10 426		0.1	6.1	69.7	15.7	8.4	19.0
Denmark	DK	5 511	0.4	14.8	84.6	0.1			10.9
Estonia	EE	1 336	0.5	93.7	5.8				7.5
Finland	FI	5 326	16.5	83.5					6.7
France (metropolitan)	FR	62 466		2.9	32.9	55	7.9	1.3	16.1
Germany	DE	82 002		0.3	37.2	61.9	0.7		15.5
Greece	GR	11 095			3.6	32.4	27.6	36.4	23.1
Hungary	HU	10 031			0.1	41.5	58.4		20.2
Iceland	IS	319	28.4	66.4	2.9	2.2			6.0
Ireland	IE	4 521	0.1	83.5	16.4				8.7
Italy	IT	59 001		0.9	20.3	39.3	23.6	15.9	19.2
Latvia	LV	2 163		21.4	49.5	18.5	10.6		13.3
Liechtenstein	LI	36		2.3	97.7				13.3
Lithuania	LT	3 184		5	92.3	2.6			12.7
Luxembourg	LU	494			10	90			16.3
Malta	MT	411			2.9	86.9	10.2		16.5
Monaco	MC	35				100			15.9
Montenegro	ME	617		3.3	13.2	9.7	48.9	24.9	21.0
Netherlands	NL	16 486			7.1	92.9			17.1
North Macedonia	MK	2 049			0.8	2.6	16.9	79.7	33.0
Norway	NO	4 799	25.6	54.9	19.6				7.4
Poland	PL	38 136		0.1	6.8	32.1	41.2	19.8	21.6
Portugal (excl. Az., Mad.)	PT	10 051	0.2	18.7	64.8	15.4	0.9		12.4
Romania	RO	20 440			4	48.7	40.2	7	20.1
San Marino	SM	31			9.5	90.5			16.7
Serbia (incl. Kosovo*)	RS	9 516		0.1	2	5.8	24.2	67.9	26.7
Slovakia	SK	5 382			1.4	52.6	34.5	11.5	20.4
Slovenia	SI	2 032			9.8	52.6	37.6		18.8
Spain (excl. Canarias)	ES	44 214	0.2	7.3	49.2	41.3	2		14.5
Sweden	SE	9 256	8.7	81.6	9.7				7.5
Switzerland	CH	7 702	0.5	5.6	42.5	51.4			14.6
United Kingdom (& dep.**)	UK	71 517	0.6	12.5	84	3			12.0
Total		**529 921**	**0.7**	**7.2**	**31.8**	**39.8**	**12.9**	**7.6**	**16.6**
				7.9				**20.5**	
EU-28		**497 952**	**0.4**	**7.0**	**32.8**	**41.1**	**12.7**	**6.0**	**16.4**
				7.4				**18.7**	
Kosovo*	KS	2 181		0.0	2.0	7.8	15.6	74.6	27.5
Serbia (excl. Kosovo*)	RS	7 335		0.1	2.0	5.3	26.3	66.3	26.5

(*) under the UN Security Council Resolution 1244/99 (**) Crown dependencies

Note 1: The value "0.0" indicates that an exposed population exists, but it is small (less than 0.05 %). Empty cells mean no exposed population.

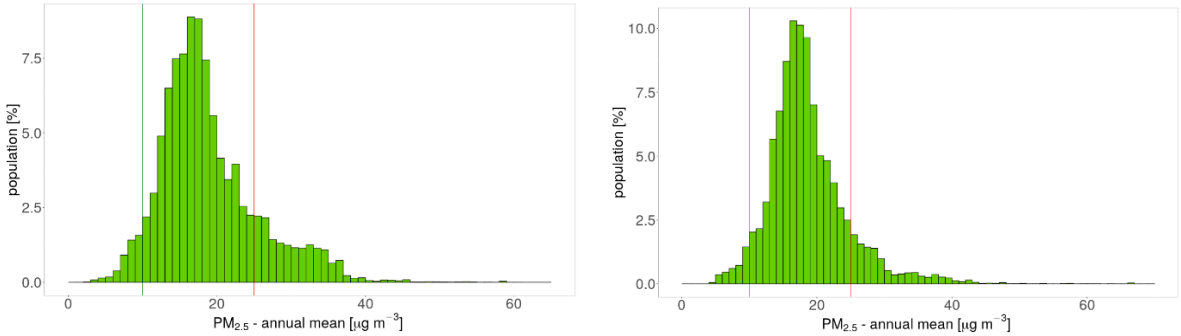
Note 2: Turkey is not included due to the lack of air quality data.

In 2005, 95 % of the European population has been exposed to $PM_{2.5}$ annual mean concentrations above the Air Quality Guideline of 10 µg·m^{-3} as defined by the World Health Organization (WHO, 2005), while in 2009 it was 92 %. The European wide population exposure exceeding the EU limit value (LV) of 25 µg·m^{-3} was about 21 % in 2005 and about 8 % in 2009. The indicative limit value LV_{2020} of 20 µg·m^{-3} was exceeded for about 37 % of the population in 2005 and about 21 % of the population in 2009.

The European-wide population-weighted concentration of the $PM_{2.5}$ annual means is estimated at about 19 µg·m^{-3} for 2005 and at about 17 µg·m^{-3} for 2009.

Figure 2.2 shows, for the whole mapped area, the population frequency distribution for exposure classes of 1 µg·m^{-3}. One can see a larger proportion of the population living in classes above the LV in 2005, compared to 2009, as pointed out above.

Figure 2.2: Population frequency distribution, $PM_{2.5}$ annual average, 2005 (left) and 2009 (right)



Note: Apart from the population distribution shown in graphs, it was estimated that 0.005 % (both in 2005 and 2009) of population lived in areas with $PM_{2.5}$ annual average concentration in between 65 and 150 µg.m^{-3} resp. 70 and 190 µg.m^{-3}.

3 Ozone

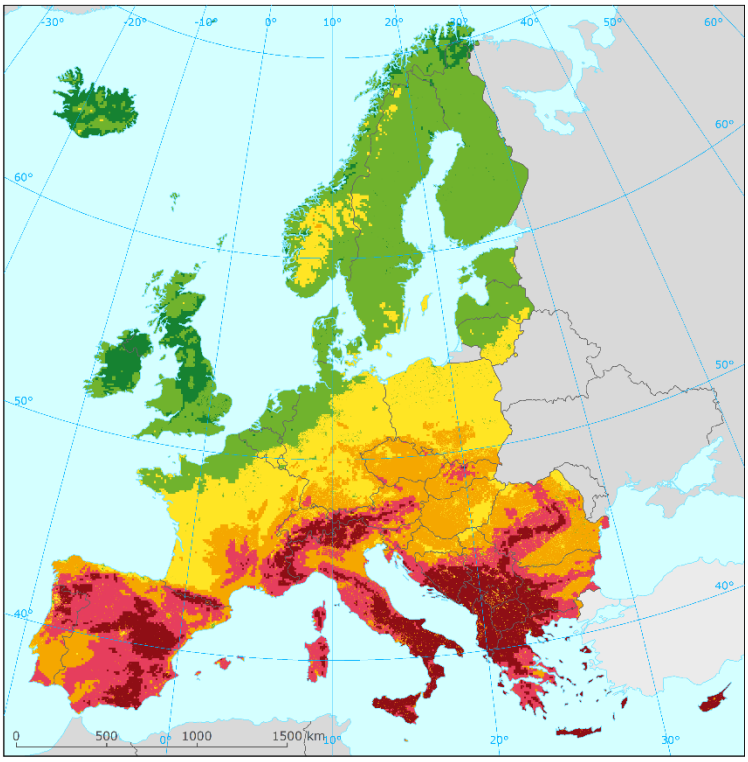
3.1 SOMO35

SOMO35 is the annually accumulated ozone maximum daily 8-hourly means in excess of 35 ppb (i.e. 70 µg·m^{-3}). It is not subject to any of the EU air quality directives and there are no limit or target values defined. However, this indicator is commonly used in health impact assessments, following WHO recommendations (WHO, 2013).

3.1.1 Concentration maps

Map 3.1 shows the maps of ozone indicator SOMO35 for 2005 and 2009. The red and purple areas show values above 8 000 µg·m^{-3}·d, while the orange areas show values above 6 000 µg·m^{-3}·d. In most of the European area, SOMO35 values were higher in 2005, compared to 2009. As usual, the southern parts of Europe show higher SOMO35 values than the northern parts. In 2005, the highest concentrations were found in the Balkan region, southern Italy, central and southern Spain, and in mountainous areas like the Alps and the Pyrenees. In 2009, the highest SOMO35 values were observed in the Alps and northern Italy, in Greece, and in south-western Spain.

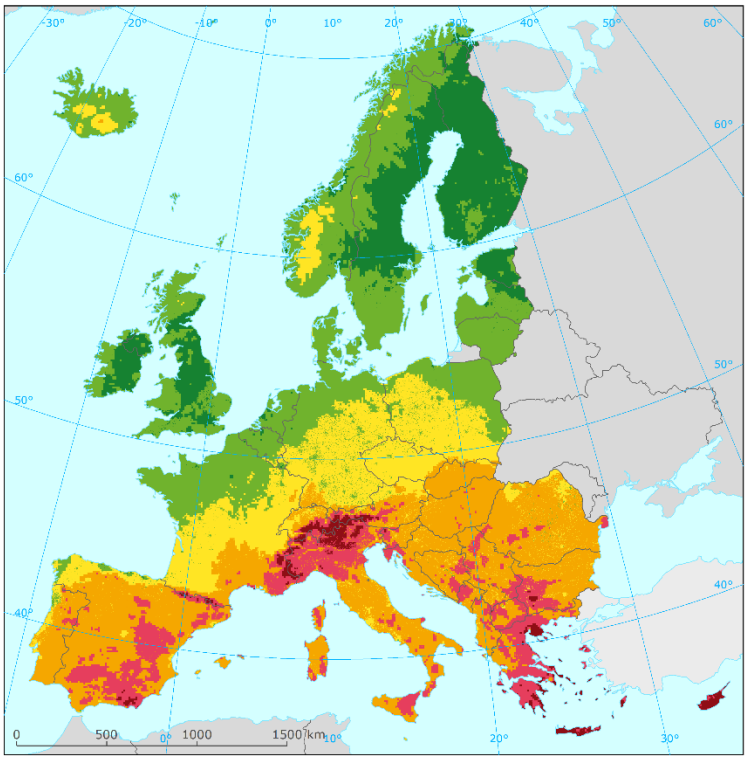
Map 3.1: Concentration map of ozone indicator SOMO35, 2005 (above) and 2009 (below)



Ozone
SOMO35

Reference Year: 2005
Combined Rural and Urban Background Map
Resolution: 1x1 km²

- ≤ 2 000 µg.m⁻³.d
- 2 000 - 4 000 µg.m⁻³.d
- 4 000 - 6 000 µg.m⁻³.d
- 6 000 - 8 000 µg.m⁻³.d
- 8 000 - 10 000 µg.m⁻³.d
- > 10 000 µg.m⁻³.d
- non EEA member or cooperating countries
- no available data



Ozone
SOMO35

Reference Year: 2009
Combined Rural and Urban Background Map
Resolution: 1x1 km²

- ≤ 2 000 µg.m⁻³.d
- 2 000 - 4 000 µg.m⁻³.d
- 4 000 - 6 000 µg.m⁻³.d
- 6 000 - 8 000 µg.m⁻³.d
- 8 000 - 10 000 µg.m⁻³.d
- > 10 000 µg.m⁻³.d
- non EEA member or cooperating countries
- no available data

3.1.2 Population exposure

Tables 3.1 and 3.2 give, for 2005 and 2009, respectively, the population frequency distribution for several SOMO35 exposure classes, as well as the population-weighted concentration for individual countries and for Europe as a whole.

Table 3.1: Population exposure and population-weighted concentration, O_3 indicator SOMO35, 2005

Country	ISO	Population [inhbs·1000]	Ozone – SOMO35, exposed population, 2005 [%]						Ozone, SOMO35
			< 2000	2000 - 4000	4000 - 6000	6000 - 8000	8000 - 10000	> 10000	Pop. weighted
Albania	AL	3 020			10.3	60.4	7.9	21.4	7 867
Andorra	AD	77				96.7	1.5	1.8	7 672
Austria	AT	8 201		4.1	47.4	43.7	4.4	0.4	5 858
Belgium	BE	10 446	2.1	93.9	4.0				2 915
Bosnia & Herzegovina	BA	3 843			58.4	24.2	10.7	6.8	6 590
Bulgaria	BG	7 689		27.0	55.6	10.8	4.8	1.9	4 804
Croatia	HR	4 311			42.9	49.0	6.2	1.9	6 426
Cyprus	CY	953				76.9	7.7	15.4	8 226
Czechia	CZ	10 199			54.2	45.8	0.1		5 926
Denmark	DK	5 411	31.1	66.5	2.4				2 386
Estonia	EE	1 359	26.5	73.3	0.2				2 441
Finland	FI	5 237	19.5	80.4	0.0				2 374
France (metropolitan)	FR	60 963	1.1	38.7	39.5	16.4	4.0	0.2	4 623
Germany	DE	82 501	0.4	46.7	50.7	2.0	0.1	0.0	3 947
Greece	GR	10 970		5.1	14.8	40.7	32.1	7.3	7 427
Hungary	HU	10 098			76.4	23.6	0.0		5 666
Iceland	IS	294	99.8	0.2					717
Ireland	IE	4 112	84.8	15.2					1 581
Italy	IT	57 875		0.1	3.5	75.5	18.3	2.6	7 429
Latvia	LV	2 250	32.3	66.1	1.6				2 305
Liechtenstein	LI	35			92.0	6.6	1.3	0.1	5 250
Lithuania	LT	3 355		89.6	10.4				3 415
Luxembourg	LU	461		73.0	27.0				3 465
Malta	MT	403				85.4	13.6	1.0	7 186
Monaco	MC	33					100.0		8 949
Montenegro	ME	613			67.3	6.5	5.6	20.5	7 039
Netherlands	NL	16 306	6.5	93.5	0.0				2 540
North Macedonia	MK	2 035			74.0	18.8	2.0	5.1	5 954
Norway	NO	4 606	46.4	52.8	0.7				2 031
Poland	PL	38 174	0.3	17.1	78.2	4.4	0.0	0.0	4 733
Portugal (excl. Az., Mad.)	PT	9 994		11.3	56.7	20.3	10.2	1.5	5 729
Romania	RO	21 382		17.5	63.5	14.3	4.5	0.2	4 978
San Marino	SM	30				86.5	13.5		7 595
Serbia (incl. Kosovo*)	RS	9 497		13.3	63.6	7.4	8.1	7.7	5 718
Slovakia	SK	5 373			58.9	40.2	0.9	0.0	6 024
Slovenia	SI	1 998			37.9	58.8	3.3	0.0	6 419
Spain (excl. Canarias)	ES	41 443		17.8	27.7	46.2	7.7	0.6	5 989
Sweden	SE	9 011	16.4	82.2	1.4				2 591
Switzerland	CH	7 415			80.9	13.0	5.4	0.7	5 610
United Kingdom (& dep.**)	UK	60 182	72.3	27.5	0.1	0.0			1 664
Total		**522 152**	**11.4**	**28.9**	**33.0**	**21.0**	**4.8**	**1.0**	**4 622**
			40.2			**26.8**			
EU-28		**490 655**	**11.6**	**29.9**	**31.8**	**21.4**	**4.7**	**0.7**	**4 573**
			41.4			**26.8**			
Kosovo*	KS	2 041			65.8	9.1	8.7	16.4	6 877
Serbia (excl. Kosovo*)	RS	7 456		16.6	63.0	6.9	7.9	5.6	5 435

(*) under the UN Security Council Resolution 1244/99 (**) Crown dependencies

Note 1: The value "0.0" indicates that an exposed population exists, but it is small (less than 0.05 %). Empty cells mean no exposed population.

Note 2: Turkey is not included due to the lack of air quality data.

Table 3.2: Population exposure and population-weighted concentration, O_3 indicator SOMO35, 2009

Country	ISO	Population [inhbs·1000]	Ozone – SOMO35, exposed population, 2009 [%]						Ozone, SOMO35
			< 2000	2000 - 4000	4000 - 6000	6000 - 8000	8000 - 10000	> 10000	Pop. weighted
Albania	AL	2 936			22.5	74.8	2.6		6 513
Andorra	AD	84					98.4	1.6	9 211
Austria	AT	8 335		16.6	67.9	14.3	1.1	0.2	5 062
Belgium	BE	10 753	18.2	81.2	0.5				2 688
Bosnia & Herzegovina	BA	3 844		14.6	58.7	24.8	1.9		5 183
Bulgaria	BG	7 467		2.8	76.0	18.4	2.8	0.0	5 248
Croatia	HR	4 310		1.9	58.1	37.6	2.3	0.0	5 858
Cyprus	CY	1 081					63.6	36.4	9 866
Czechia	CZ	10 426		31.9	66.0	2.1			4 461
Denmark	DK	5 511	16.0	83.6	0.5				2 446
Estonia	EE	1 336	84.5	15.5					1 790
Finland	FI	5 326	95.2	4.8					1 576
France (metropolitan)	FR	62 466	9.5	48.8	27.5	12.6	1.5	0.0	4 018
Germany	DE	82 002	0.4	81.5	17.7	0.4	0.0		3 536
Greece	GR	11 095			1.0	45.1	41.5	12.4	8 293
Hungary	HU	10 031			9.9	90.0	0.1		6 838
Iceland	IS	319	88.4	11.6	0.0				1 138
Ireland	IE	4 521	78.9	21.1	0.1				1 650
Italy	IT	59 001		1.2	26.8	49.1	22.4	0.5	6 908
Latvia	LV	2 163	54.3	45.7					1 843
Liechtenstein	LI	36			92.9	7.0	0.1		4 970
Lithuania	LT	3 184	6.9	93.1	0.0				2 293
Luxembourg	LU	494	23.8	70.4	5.7				2 712
Malta	MT	411			75.3	12.9	11.9		6 152
Monaco	MC	35				100.0			7 567
Montenegro	ME	617			46.5	50.5	3.0		6 097
Netherlands	NL	16 486	23.7	76.2	0.1				2 343
North Macedonia	MK	2 049		14.0	27.1	49.9	9.0		6 062
Norway	NO	4 799	62.2	37.3	0.4				1 903
Poland	PL	38 136	1.0	64.5	34.2	0.3	0.0		3 695
Portugal (excl. Az., Mad.)	PT	10 051		30.9	45.3	23.0	0.8		4 898
Romania	RO	20 440		20.1	57.8	22.0	0.1		4 938
San Marino	SM	31			84.6	15.4			5 663
Serbia (incl. Kosovo*)	RS	9 516		0.5	43.5	53.7	2.2		6 115
Slovakia	SK	5 382			19.6	80.4	0.0		6 341
Slovenia	SI	2 032			61.1	35.9	3.0	0.0	5 633
Spain (excl. Canarias)	ES	44 214	3.0	16.1	30.9	45.7	4.3	0.0	5 636
Sweden	SE	9 256	46.9	53.1	0.0				2 050
Switzerland	CH	7 702		3.3	82.4	10.8	3.0	0.4	5 119
United Kingdom (& dep.**)	UK	71 517	81.2	18.8	0.0				1 501
Total		**529 921**	**16.1**	**36.3**	**24.4**	**18.5**	**4.3**	**0.4**	**4 233**
			52.4			**23.2**			
EU-28		**497 952**	**16.5**	**38.0**	**23.1**	**17.7**	**4.4**	**0.4**	**4 179**
			54.5			**22.5**			
Kosovo*	KS	2 181			66.4	32.8	0.8		5 909
Serbia (excl. Kosovo*)	RS	7 335		0.6	37.9	58.8	2.6		6 165

(*) under the UN Security Council Resolution 1244/99 (**) Crown dependencies

Note 1: The value "0.0" indicates that an exposed population exists, but it is small (less than 0.05 %). Empty cells mean no exposed population.

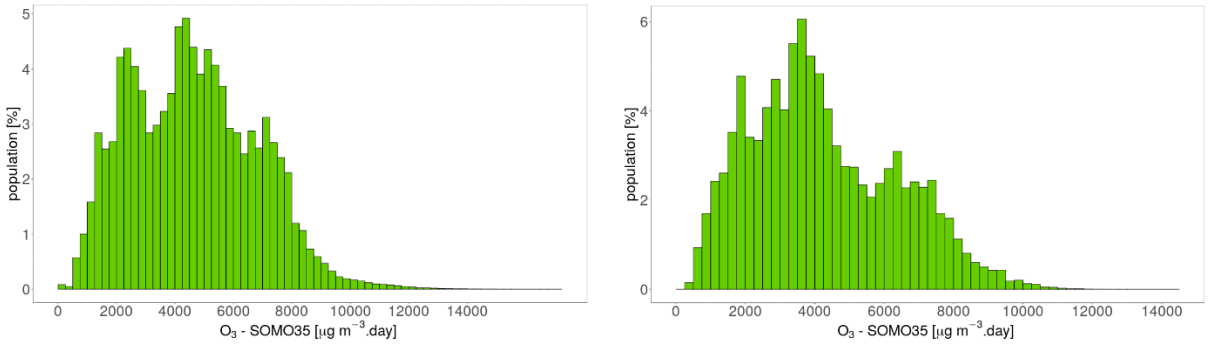
Note 2: Turkey is not included due to the lack of air quality data.

It has been estimated that in 2005 about 27 % of both the European population and the EU-28 population lived in areas with SOMO35 values above 6 000 µg·m^{-3}·d. In 2009, that was the case for 23 % of both the European and the EU-28 population.

In 2005, both the total European and the EU-28 population-weighted ozone concentrations, in terms of SOMO35, were estimated to be around 4 600 µg·m^{-3}·d. In 2009, the population-weighted concentration was about 4 200 µg·m^{-3}·d, for both all of Europe and the EU-28.

Figure 3.1 shows, for the whole mapped area, the frequency distribution of SOMO35 for population exposure classes of 250 µg·m^{-3}.d. The highest frequencies are found for classes between 2000 and 5500 µg·m^{-3}·d for 2005, resp. between 1500 and 5000 µg·m^{-3}·d for 2009

Figure 3.1: Population frequency distribution, ozone indicator SOMO35, 2005 (left) and 2009 (right)



4 Nitrogen dioxide

4.1 NO_2 annual average

The AQ Directive (EC, 2008) sets two limit values (LV) for NO_2 for the human health protection, i.e. the annual LV and the hourly LV. The annual LV is set at the level of 40 µg·m^{-3}. This is the same concentration level as recommended by the World Health Organization for the NO_2 annual average as the Air Quality Guideline (WHO, 2005).

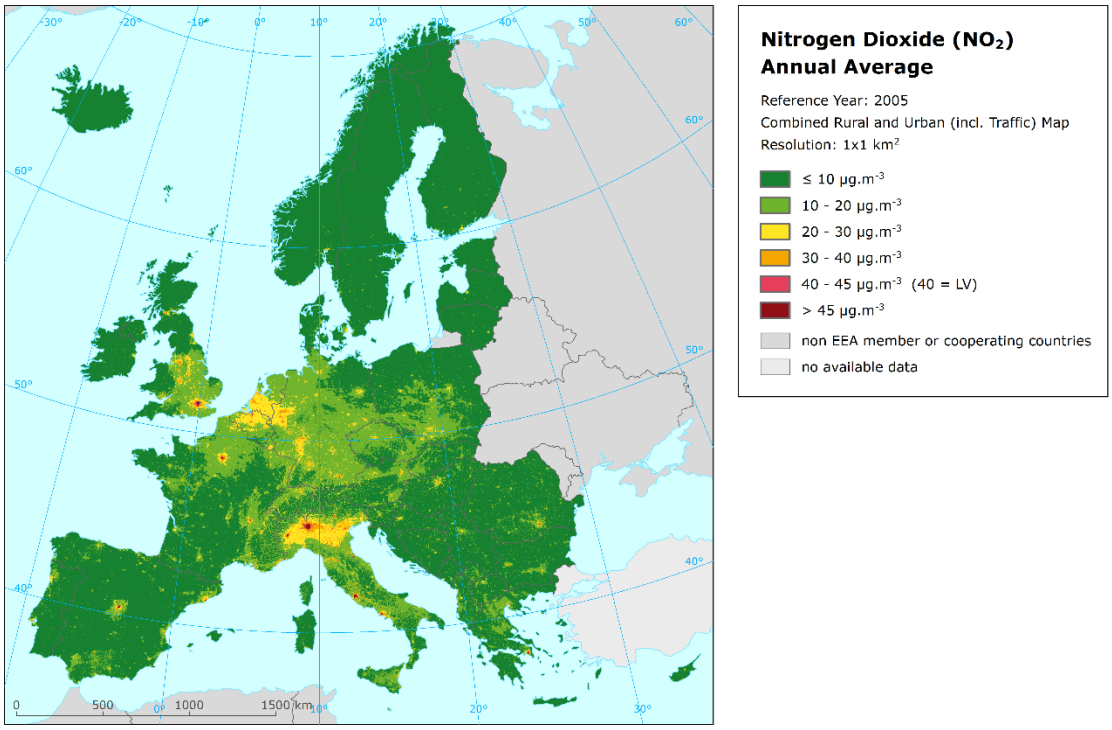
4.1.1 Concentration maps

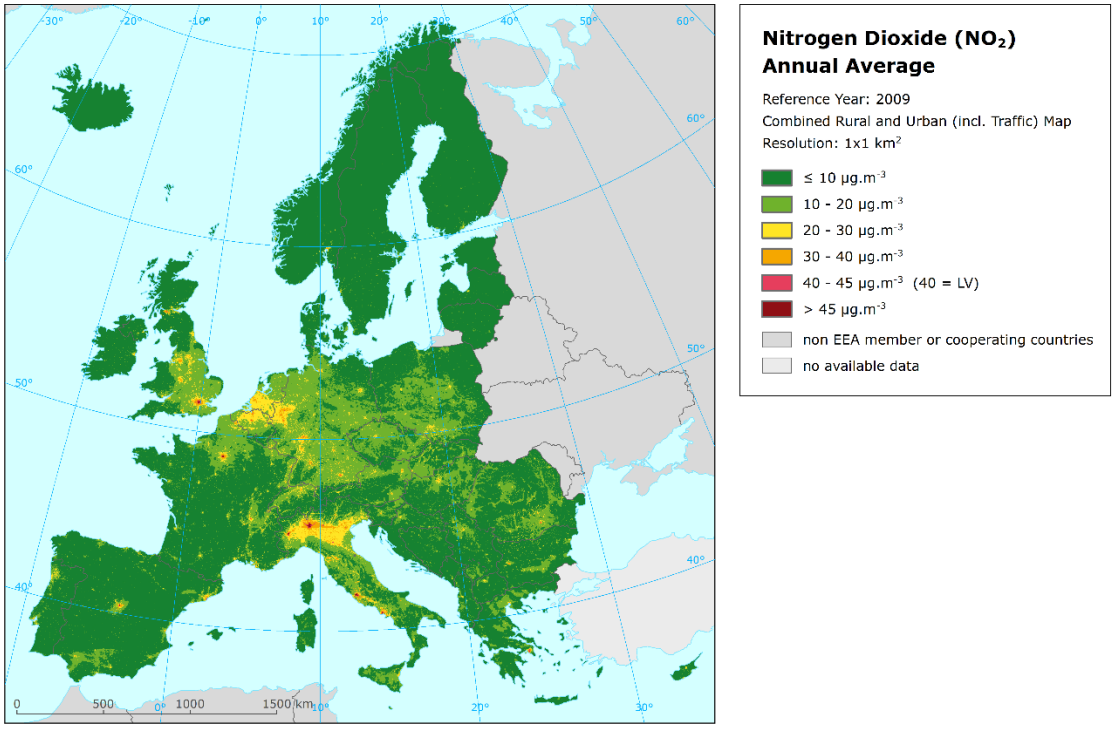
Map 4.1 presents annual average concentration maps of NO_2 for 2005 and 2009. Red and purple areas indicate LV exceedances.

As can be seen, the areas where the LV of 40 µg·m^{-3} was exceeded in both years primarily include large urban agglomerations, particularly Milan, Naples, Rome, Turin, Paris, Barcelona, Madrid, London, Athens, Munich and Bucharest.

It should be noted that the interpolated map is created at 1x1 km^2 only and as such refers to the rural and urban *background* situations only, while the exceedances of the NO_2 limit values occur mostly at local *hotspots* such as dense traffic locations and densely urbanised and industrialised areas. Although the urban traffic map layer is used in the map creation (see Annex), the traffic locations are smoothed to spatial resolution of 1x1 km^2.

Map 4.1: Concentration map of NO_2 annual average, 2005 (above) and 2009 (below)





4.1.2 Population exposure

Tables 4.1 and 4.2 show, for 2005 and 2009, respectively, the population frequency distribution for several exposure classes, as well as the population-weighted concentration for individual countries and for Europe as a whole.

Table 4.1: Population exposure and population-weighted concentration, NO_2 annual average, 2005

Country	ISO	Population [inhbs·1000]	NO_2 – annual average, exposed population, 2005 [%]						NO_2 ann. avg.
			< 10	10 - 20	20 - 30	30 - 40	40 - 45	> 45	Pop. weighted
Albania	AL	3 020	10.5	42.9	41.0	5.6			19.5
Andorra	AD	77	1.1	78.6	19.8	0.4			17.6
Austria	AT	8 201	5.1	36.8	36.1	18.5	1.2	2.2	22.9
Belgium	BE	10 446	0.1	11.3	60.2	21.8	5.0	1.5	27.4
Bosnia & Herzegovina	BA	3 843	22.8	51.7	23.2	2.3			16.1
Bulgaria	BG	7 689	14.0	51.3	22.7	11.0	1.0		18.6
Croatia	HR	4 311	20.9	37.2	35.0	5.6	1.2	0.2	18.6
Cyprus	CY	953	21.0	57.1	17.3	4.6			15.7
Czechia	CZ	10 199	2.3	51.6	38.1	7.3	0.4	0.4	20.2
Denmark	DK	5 411	26.5	49.0	22.1	1.6	0.4	0.4	15.3
Estonia	EE	1 359	37.4	56.1	6.0	0.4			11.9
Finland	FI	5 237	29.2	50.7	18.5	1.6			14.3
France (metropolitan)	FR	60 963	10.7	37.2	28.4	14.6	3.8	5.3	22.9
Germany	DE	82 501	1.6	33.3	45.0	16.5	1.7	2.0	23.8
Greece	GR	10 970	14.6	29.3	20.6	13.4	11.4	10.7	25.5
Hungary	HU	10 098	8.8	52.5	25.1	12.6	0.3	0.6	19.6
Iceland	IS	294	27.1	66.9	5.9	0.1			12.2
Ireland	IE	4 112	45.8	39.2	12.8	1.8	0.3		11.7
Italy	IT	57 875	1.5	16.8	30.2	30.1	7.7	13.6	31.2
Latvia	LV	2 250	31.6	39.9	24.2	4.3			14.7
Liechtenstein	LI	35	0.2	9.9	88.6	1.0	0.3		23.4
Lithuania	LT	3 355	31.6	48.5	17.4	2.5			13.8
Luxembourg	LU	461	0.0	23.6	51.5	20.6	1.3	3.0	25.3
Malta	MT	403	7.0	40.9	42.3	9.9			20.8
Monaco	MC	33			1.7	76.7		21.5	36.7
Montenegro	ME	613	15.8	40.1	41.9	2.3			18.0
Netherlands	NL	16 306	0.1	11.0	49.4	35.3	3.7	0.5	28.3
North Macedonia	MK	2 035	1.5	40.3	46.2	11.9	0.1		21.8
Norway	NO	4 606	32.7	33.4	24.3	8.0	0.9	0.7	15.8
Poland	PL	38 174	16.7	49.7	27.1	5.7	0.5	0.2	17.4
Portugal (excl. Az., Mad.)	PT	9 994	18.0	37.6	29.3	12.8	0.9	1.4	19.6
Romania	RO	21 382	15.9	52.3	20.7	9.1	0.8	1.2	18.3
San Marino	SM	30		13.6	81.9		4.5		23.6
Serbia (incl. Kosovo*)	RS	9 497	13.8	67.4	18.4	0.4			15.8
Slovakia	SK	5 373	6.7	73.6	17.9	1.7			16.6
Slovenia	SI	1 998	18.6	39.1	35.5	5.6	1.2		18.4
Spain (excl. Canarias)	ES	41 443	5.4	26.5	34.7	18.0	7.3	8.0	26.6
Sweden	SE	9 011	25.4	60.1	11.4	2.4	0.6		14.4
Switzerland	CH	7 415	0.9	22.9	59.0	14.1	1.5	1.6	24.5
United Kingdom (& dep.**)	UK	60 182	5.1	23.6	42.7	16.5	5.5	6.6	26.1
Total		**522 152**	**8.7**	**34.2**	**33.9**	**15.4**	**3.5**	**4.4**	**23.3**
			42.9				**7.9**		
EU-28		**490 655**	**8.3**	**33.5**	**33.9**	**15.9**	**3.7**	**4.6**	**23.6**
			41.9				**8.3**		
Kosovo*	KS	2 041	10.4	71.4	18.1				**15.7**
Serbia (excl. Kosovo*)	RS	7 456	14.6	66.4	18.5	0.5			**15.9**

(*) under the UN Security Council Resolution 1244/99 (**) Crown dependencies

Note 1: The value "0.0" indicates that an exposed population exists, but it is small (less than 0.05 %). Empty cells mean no exposed population.

Note 2: Turkey is not included due to the lack of air quality data.

Table 4.2: Population exposure and population-weighted concentration, NO_2 annual average, 2009

Country	ISO	Population [inhbs·1000]	NO_2 – annual average, exposed population, 2009 [%]						NO_2 ann. avg.
			< 10	10 - 20	20 - 30	30 - 40	40 - 45	> 45	Pop. weighted
Albania	AL	2 936	16.5	48.6	30.1	4.7			14.1
Andorra	AD	84	3.9	95.6		0.5			17.7
Austria	AT	8 335	6.1	43.7	33.3	14.4	2.0	0.4	21.2
Belgium	BE	10 753	0.8	16.8	58.4	20.3	3.2	0.5	15.1
Bosnia & Herzegovina	BA	3 844	23.0	57.6	18.9	0.5			25.9
Bulgaria	BG	7 467	8.8	27.8	46.0	15.0	1.2	1.1	22.2
Croatia	HR	4 310	18.3	49.6	29.5	2.4	0.2		23.1
Cyprus	CY	1 081	15.4	34.5	44.5	5.6			18.8
Czechia	CZ	10 426	3.2	61.4	31.4	3.3	0.8		18.6
Denmark	DK	5 511	36.5	51.0	10.5	1.4	0.4	0.1	23.3
Estonia	EE	1 336	54.7	40.4	4.8				12.7
Finland	FI	5 326	44.8	48.0	5.9	1.3			9.3
France (metropolitan)	FR	62 466	16.2	37.4	26.7	12.5	3.0	4.2	23.6
Germany	DE	82 002	2.1	36.7	43.7	13.2	1.3	3.0	10.9
Greece	GR	11 095	16.2	30.5	19.8	16.6	10.4	6.6	21.2
Hungary	HU	10 031	6.0	55.9	29.8	7.9	0.5		24.0
Iceland	IS	319	22.9	65.5	11.3	0.4			16.9
Ireland	IE	4 521	40.1	38.4	17.4	2.9	1.1	0.1	19.2
Italy	IT	59 001	2.4	21.9	32.2	28.3	6.3	8.9	13.9
Latvia	LV	2 163	40.7	40.7	17.5	1.1			13.7
Liechtenstein	LI	36	0.3	14.4	84.0	0.2	1.1		28.6
Lithuania	LT	3 184	39.3	54.9	4.8	1.1			22.0
Luxembourg	LU	494	1.6	36.4	51.0	3.9	3.4	3.6	11.9
Malta	MT	411	41.1	48.7	0.5	9.7			23.0
Monaco	MC	35			3.4	75.1		21.5	12.4
Montenegro	ME	617	21.2	52.4	24.5	1.9			35.6
Netherlands	NL	16 486	1.0	16.2	54.9	26.2	1.2	0.6	15.9
North Macedonia	MK	2 049	3.0	58.9	32.8	4.8	0.5		19.6
Norway	NO	4 799	36.5	35.4	19.2	7.0	0.6	1.3	12.7
Poland	PL	38 136	13.2	56.9	26.5	2.7	0.5	0.3	26.1
Portugal (excl. Az., Mad.)	PT	10 051	17.2	39.8	31.5	9.6	1.0	1.0	15.1
Romania	RO	20 440	7.0	41.9	37.0	12.7	0.3	1.1	17.0
San Marino	SM	31		31.1	64.4		4.5		19.0
Serbia (incl. Kosovo*)	RS	9 516	11.1	52.1	33.9	3.0			20.9
Slovakia	SK	5 382	4.0	51.8	40.0	3.8	0.4	0.0	18.1
Slovenia	SI	2 032	13.3	58.6	24.0	3.1	1.0		12.6
Spain (excl. Canarias)	ES	44 214	7.9	33.4	34.1	15.7	5.1	3.8	17.1
Sweden	SE	9 256	33.1	57.0	8.3	1.5	0.1		19.5
Switzerland	CH	7 702	1.7	29.2	55.6	10.6	1.7	1.1	21.4
United Kingdom (& dep.**)	UK	71 517	4.9	27.2	45.7	15.3	3.4	3.4	24.6
Total		**529 921**	**9.5**	**36.7**	**34.8**	**13.4**	**2.6**	**3.0**	**22.1**
			46.2				**5.6**		
EU-28		**497 952**	**9.2**	**36.2**	**34.8**	**13.9**	**2.7**	**3.1**	**22.3**
			45.4				**5.9**		
Kosovo*	KS	2 181	10.7	70.4	18.9	0.1			15.7
Serbia (excl. Kosovo*)	RS	7 335	11.2	47.6	37.6	3.7			18.7

(*) under the UN Security Council Resolution 1244/99 (**) Crown dependencies

Note 1: The value "0.0" indicates that an exposed population exists, but it is small (less than 0.05 %). Empty cells mean no exposed population.

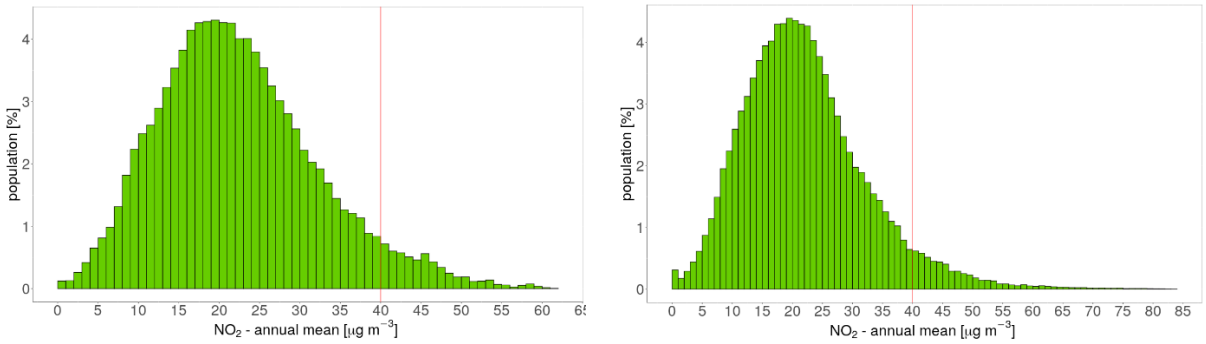
Note 2: Turkey is not included due to the lack of air quality data.

It has been estimated that about 8 % (in 2005) resp. about 6 % (in 2009) of both the European and the EU-28 population lived in areas with NO_2 annual average concentrations above the EU limit value of 40 µg·m^{-3}.

The population-weighted concentration of the NO_2 annual average is estimated to be about 23 µg·m^{-3} in 2005 and about 22 µg·m^{-3} in 2009 for both the total European and the EU-28 populations.

Figure 4.1 shows, for the whole mapped area, the population frequency distribution for exposure classes of 1 µg·m^{-3}. The frequency distribution is centred around 20 µg·m^{-3}, in both years.

Figure 4.1: Population frequency distribution, NO_2 annual average, 2005 (left) and 2009 (right)



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Annex
Mapping method, data used and technical details

A.1 Mapping method

The method used here is *Regression – Interpolation – Merging Mapping*, which is the data fusion method combining the monitoring data with supplementary data (such as the results from a chemical transport model, land cover, meteorological data and altitude) using a linear regression model followed by kriging of the residuals produced from that model (residual kriging). For PM_{10}, $PM_{2.5}$ and NO_2, separate rural, urban background and urban traffic map layers are created in 1x1 km^2 resolution, the map layers are merged into one final map using population density and road data. For ozone, separate rural and urban background map layers are created in 10x10 km^2 resolution, the final map is created based on their merge using population density in 1x1 km^2 resolution. In the case of $PM_{2.5}$, the actual measurements of $PM_{2.5}$ are supplemented with so-called pseudo $PM_{2.5}$ data, i.e. estimates based on PM_{10} measurement data and different supplementary data.

For a detailed methodology description, see Horálek et al. (2020).

A.2 Input data

A.2.1 Air quality monitoring data

The measurement data from the AirBase v8 database (EEA, 2014) is used. This data set is supplemented with several rural stations from the database EBAS (NILU, 2017) not reported to the Air Quality e-Reporting database, successor of AirBase. Specifically, 7 stations for PM_{10} and 6 stations for $PM_{2.5}$ were added for 2005, while 6 stations for both PM_{10} and $PM_{2.5}$ were added for 2009. Table A2.1 shows the number of the measurement stations selected for the individual pollutants.

Table A.1 Number of stations selected for each pollutant indicator and area type, 2005 and 2009

Station type	PM_{10}		$PM_{2.5}$		Ozone		NO_2	
	2005	2009	2005	2009	2005	2009	2005	2009
Rural background	217	280	40	105	443	511	320	384
Urban/suburban background	850	1120	78	299	915	1025	1047	1222
Urban/suburban traffic	505	718	55	133			645	838

For the $PM_{2.5}$ mapping, additional 181 resp. 196 rural background, 773 resp. 713 urban/suburban background and 456 resp. 598 urban/suburban traffic PM_{10} stations (at locations without $PM_{2.5}$ measurement) were also used for the purpose of calculating the pseudo $PM_{2.5}$ station data for 2005 and 2009, respectively.

It should be noted that the PM_{10} and $PM_{2.5}$ data for 2005 were corrected where non-reference measurement methods have been used (de Leeuw and Fiala, 2009). This applies specifically for French stations; the data were multiplied by a factor of 1.4 for rural stations, by a factor of 1.34 for urban/suburban background stations and by a factor of 1.24 for urban/suburban traffic stations.

A.2.2 EMEP MSC-W model output

For the modelling data, we used the most recent version of EMEP model data as available at the www.emep.int web page when the maps were constructed, i.e. EMEP MSC-W model version rv4.17a for 2005 and rv4.33 for 2009. For both years, the relevant emissions and meterology (i.e. 2005 resp. 2009) were used in the model run.

A.2.3 Other supplementary data

Meteorological data produced by the ECMWF has been used. For 2005, meteorological data at a spatial resolution of 0.25° x 0.25° has been used as described in Horálek et al. (2020) and as used in routine mapping until 2017 maps. For 2009, the meteorological data was extracted from the CDS (Climate Data Store, https://cds.climate.copernicus.eu/cdsapp#!/home). The data come from the reanalysed data set ERA5-Land at 0.1°x0.1° resolution, which has been supplemented in the coastal areas with the reanalysed data set ERA5-Land in 0.25°x0.25° resolution. This data is being used in routine mapping starting with 2018 maps. The reason of different sources used is that the second source was not available yet during the preparation of the 2005 maps.

For NO_2 mapping, annual average data of the tropospheric NO_2 column acquired by the OMI instrument for the years 2005 and 2009 has been used. As land cover information, data from the Corine dataset CLC2006 has been used.

National population totals presented in the exposure tables of this paper are based on Eurostat national population data for 2005 and 2009 (Eurostat, 2020).

Other supplementary data (altitude, road data, population density) as described in Horálek et al. (2020) has been used. All supplementary data for PM_{10}, $PM_{2.5}$ and NO_2 mapping have been transformed to a spatial resolution of 1x1 km^2, whereas for ozone mapping a 10x10 km^2 spatial resolution has been used. For a detailed methodology description, see Horálek et al. (2020).

A.3 Technical details and mapping uncertainties

This section present the parameters of the linear regression models and of the residual kriging and includes the statistical indicators of both the regression and the kriging. Uncertainties are estimated using the cross-validation method, see Horálek et al. (2020).

Table A.2 shows technical details and mapping uncertainties for the map of PM_{10} annual average.

Table A.2 Parameters and statistics of linear regression model and ordinary kriging of PM_{10} annual average for 2005 (left) and 2009 (right) in rural, urban background and urban traffic areas

Parameters and statistics of linear regression model and ordinary kriging		PM_{10}, Annual average 2005			PM_{10}, Annual average 2009		
		Rural areas	Urb. b. ar.	Urb. tr. ar.	Rur. ar.	Urb. b. ar.	Urb. tr. ar.
Linear regresion model (LRM, Horálek et al., 2020, Eq. A1.3)	c (constant)	1.94	2.35	2.50	2.25	2.13	2.39
	a1 (log. EMEP model)	0.592	0.350	0.41	0.627	0.461	0.41
	a2 (altitude GMTED)	-0.00025		non signif.	-0.00028		n.sign.
	a3 (wind speed)	-0.088		-0.045	-0.070		-0.040
	a4 (rel. humidity)	*non signif.*			-0.728		
	a5 (CLC, NAT_1km)	-0.0022			-0.0020		
	Adjusted R^2	**0.69**	**0.27**	**0.42**	**0.62**	**0.19**	**0.31**
	Stand. Error [µg.m^{-3}]	**0.24**	**0.37**	**0.29**	**0.24**	**0.34**	**0.24**
Ordinary kriging (OK) of LRM residuals	nugget	0.019	0.014	0.018	0.018	0.016	0.019
	sill	0.048	0.051	0.049	0.065	0.061	0.044
	range [km]	330	400	310	1000	480	380
LRM + OK of its residuals	**RMSE [µg.m^{-3}]**	**4.6**	**5.4**	**7.2**	**3.9**	**5.1**	**6.1**
	Relative RMSE [%]	**21.4**	**18.8**	**21.4**	**20.3**	**19.0**	**20.7**
	Bias (MPE) [µg.m^{-3}]	**0.0**	**0.0**	**-0.2**	**-0.1**	**0.0**	**-0.1**
	R^2 of regr. equation	**0.62**	**0.66**	**0.57**	**0.68**	**0.75**	**0.59**
	Slope of regr. eq.	**0.66**	**0.69**	**0.57**	**0.74**	**0.76**	**0.61**
	Intercept of regr. eq.	**7.2**	**9.0**	**14.1**	**5.0**	**7.0**	**11.3**

Table A.3 presents the regression coefficients determined for pseudo $PM_{2.5}$ stations data estimation and Table A.4 gives technical details and mapping uncertainties for the map of $PM_{2.5}$ annual average.

Table A.3 Parameters and statistics of linear regression model for generation of pseudo $PM_{2.5}$ data, for $PM_{2.5}$ annual average for 2005 (left) and 2009 (right)

Parameters and statistics of linear regression model for pseudo stations generation		$PM_{2.5}$, Annual average 2005		$PM_{2.5}$, Annual average 2009	
		Rural and urban background areas	Urban traffic areas	Rural and urban background areas	Urban traffic areas
Linear regresion model (LRM, Horálek et al., 2020, Eq. A1.1)	c (constant)	45.6	79.8	43.8	61.5
	b (PM_{10} measur. data)	0.583	0.328	0.617	0.516
	a1 (surf. solar radiation)	-1.405	-2.309	-1.421	-1.753
	a2 (latitude)	-0.593	-0.926	-0.516	-0.753
	a3 (longitude)	0.142	*n. sign.*	0.056	*n. sign.*
	Adjusted R^2	**0.83**	**0.57**	**0.79**	**0.71**
	Standard Error [µg.m^{-3}]	**3.0**	**3.7**	**3.0**	**2.7**

Table A.4 Parameters and statistics of linear regression model and ordinary kriging of $PM_{2.5}$ annual average for 2005 (left) and 2009 (right) in rural, urban background and urban traffic areas

Parameters and statistics of linear regression model and ordinary kriging		$PM_{2.5}$, Annual average 2005			$PM_{2.5}$, Annual average 2009		
		Rural areas	Urb. b. ar.	Urb. tr. ar.	Rur. ar.	Urb. b. ar.	Urb. tr. ar.
Linear regresion model (LRM, Horálek et al., 2020, Eq. A1.3)	c (constant)	1.26	1.90	1.94	1.32	1.99	1.75
	a1 (log. EMEP model)	0.703	0.400	0.406	0.677	0.375	0.476
	a2 (altitude GMTED)	*non signif.*			-0.00025		-0.0001
	a4 (wind speed)	-0.055			-0.036		-0.0001
	a5 (CLC, NAT_1km)	-0.0019			-0.0013		0.00
	Adjusted R^2	**0.56**	**0.20**	**0.40**	**0.70**	**0.18**	**0.39**
	Stand. Error [µg.m^{-3}]	**0.24**	**0.27**	**0.21**	**0.23**	**0.28**	**0.25**
Ordinary kriging (OK) of LRM residuals	nugget	0.012	0.011	0.007	0.013	0.019	0.015
	sill	0.054	0.042	0.028	0.055	0.053	0.040
	range [km]	740	380	310	830	530	530
LRM + OK of its residuals	**RMSE [µg.m^{-3}]**	**4.4**	**2.9**	**5.1**	**2.5**	**3.3**	**4.8**
	Relative RMSE [%]	**33.2**	**15.9**	**24.0**	**20.0**	**19.3**	**27.5**
	Bias (MPE) [µg.m^{-3}]	**-0.2**	**0.4**	**-1.2**	**0.1**	**-0.2**	**-0.1**
	R^2 of regr. equation	**0.74**	**0.76**	**0.84**	**0.82**	**0.70**	**0.63**
	Slope of regr. eq.	**0.64**	**0.78**	**0.67**	**0.85**	**0.66**	**0.56**
	Intercept of regr. eq.	**0.6**	**4.4**	**5.8**	**1.9**	**5.6**	**7.5**

Tables A.5 and A.6 give technical details and mapping uncertainties for ozone indicator SOMO35 and NO_2 annual average.

Table A.5 Parameters and statistics of linear regression model and ordinary kriging of ozone indicator SOMO35 for 2005 (left) and 2009 (right) in rural and urban background areas

Parameters and statistics of linear regression model and ordinary kriging		Ozone, SOMO35, 2005		Ozone, SOMO35, 2009	
		Rural areas	Urban b. areas	Rural areas	Urban b. areas
Linear regresion model (LRM, Horálek et al., 2020, Eq. A1.3)	c (constant)	-2544	-1443	-625	-1672
	a1 (EMEP model)	0.41	0.38	0.75	0.57
	a2 (altitude GMTED)	2.45		0.49	
	a3 (wind speed)		-181.0		*n.sign.*
	a4 (s. solar radiation)	426.1	367.8	133.3	239.9
	Adjusted R^2	**0.53**	**0.51**	**0.57**	**0.53**
	Stand. Error [µg.m^{-3}]	**2214**	**1575**	**1758**	**1612**
Ordinary kriging (OK) of LRM residuals	nugget	2.5E+06	1.2E+06	2.2E+06	1.2E+06
	sill	3.3E+06	1.8E+06	3.2E+06	1.7E+06
	range [km]	500	140	270	210
LRM + OK of its residuals	**RMSE [µg.m^{-3}]**	**2149**	**1417**	**1696**	**1452**
	Relative RMSE [%]	**34.5**	**30.8**	**30.5**	**32.9**
	Bias (MPE) [µg.m^{-3}]	**-29**	**22**	**-12**	**-8**
	R^2 of regr. equation	**0.55**	**0.60**	**0.60**	**0.62**
	Slope of regr. eq.	**0.55**	**0.62**	**0.63**	**0.64**
	Intercept of regr. eq.	**2752**	**1774**	**2022**	**1593**

Table A.6 Parameters and statistics of linear regression model and ordinary kriging of NO_2 annual average for 2005 (left) and 2009 (right) in rural, urban background and urban traffic areas

Parameters and statistics of linear regression model and ordinary kriging		NO_2, Annual average 2005			NO_2, Annual average 2009		
		Rural areas	Urb. b. ar.	Urb. tr. ar.	Rur. ar.	Urb. b. ar.	Urb. tr. ar.
Linear regresion model (LRM, Horálek et al., 2020, Eq. A1.3)	c (constant)	8.0	22.8	39.38	9.5	23.2	32.88
	a1 (EMEP model)	0.303	0.189	0.128	0.485	0.188	0.156
	a2 (OMI satellite)	1.249	1.109	0.875	1.103	1.439	1.879
	a3 (altitude GMTED)	-0.0126	-0.0135	*non signif.*	-0.0109	-0.0033	*non signif.*
	a4 (altitude_5km_rad)	0.0132	0.0126	*non signif.*	0.0096	*non signif.*	*non signif.*
	a5 (wind speed)	-1.25	-2.79	-3.62	-1.60	-3.69	-3.41
	a6 (population*1000)	2.47	0.20		2.25	0.22	
	a7 (CLC, NAT_1km)		-0.0442			-0.0604	
	a8 (CLC, AGR_1km)		-0.0320			-0.0353	
	a9 (CLC, NAT_5km_rad)	-0.0316			-0.0513		
	a10 (CLC, LDR_5km_rad)	0.0937	0.0881	0.2116	*n. sign.*	0.0561	0.1936
	a11 (CLC, HDR_5km_rad)		0.1304	0.5864		0.136	0.3929
	a12 ((T1buf75m_1km)		16.11			12.092	
	Adjusted R^2	**0.73**	**0.52**	**0.40**	**0.75**	**0.51**	**0.31**
	Stand. Error [µg.m^{-3}]	**3.48**	**6.59**	**13.09**	**3.34**	**6.20**	**13.00**
Ordinary kriging (OK) of LRM residuals	nugget	8	22	100	10	21	120
	sill	14	35	150	11	30	180
	range [km]	740	140	370	470	130	100
LRM + OK of its residuals	**RMSE [µg.m^{-3}]**	**3.2**	**5.6**	**11.8**	**3.2**	**5.4**	**11.4**
	Relative RMSE [%]	**29.1**	**21.9**	**26.5**	**29.3**	**22.7**	**27.4**
	Bias (MPE) [µg.m^{-3}]	**0.0**	**0.0**	**0.2**	**0.0**	**0.1**	**0.0**
	R^2 of regr. equation	**0.77**	**0.65**	**0.52**	**0.77**	**0.63**	**0.47**
	Slope of regr. eq.	**0.78**	**0.65**	**0.53**	**0.80**	**0.64**	**0.48**
	Intercept of regr. eq.	**2.4**	**8.9**	**21.2**	**2.2**	**8.8**	**21.8**

Comparing the uncertainties presented in Tables A.2 and A.4–A.6 with those of 2017 (Horálek et al., 2020), results of a similar magnitude can be seen in most cases. However, for $PM_{2.5}$ in urban background areas, the slope of the scatterplot regression equation is notably smaller in 2009 compared to 2017, showing higher level of underestimation in areas with high concentration levels. This underestimation is true especially for Poland, where it was caused mainly by a low number of true $PM_{2.5}$ stations compared to the number of the pseudo $PM_{2.5}$ stations in this area in 2009 and by the higher $PM_{2.5}/PM_{10}$ ratio in Poland compared to the rest of Europe, leading to underestimated $PM_{2.5}$ values at the pseudo stations in Poland.

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