MADRID

urbanismo,
medio ambiente
y movilidad

INVENTORY OF MADRID CITY GREENHOUSE GAS EMISSIONS 2021

Directorate General for Sustainability and Environmental Control

INVENTORY OF MADRID CITY GREENHOUSE GAS EMISSIONS 2021

DG for Sustainability and Environmental Control

October 2023

Prepared by:

Fundación para el Fomento de la Innovación Industrial (F2I2)

Escuela Técnica Superior de Ingenieros Industriales

Technical University of Madrid (U.P.M.)

1 INTRODUCTION

1.1 Background

Tackling climate change, due to the complex nature of the phenomenon, requires designing a wide range of measures continuously over time, both to mitigate greenhouse gas (GHG) emissions and to minimize the negative impacts arising from the phenomenon itself, and to take advantage of the opportunities that the process offers in terms of efficiency and improved quality of life.

In order that climate change mitigation measures can be properly implemented and planned, so that they are as effective as possible, it is absolutely necessary to have the information required. In this respect, two strategic information tools are essential for planning actions and being able to track progress: an energy balance and an emissions inventory.

The Air Pollutant Emissions Inventory relies on the CORINAIR methodology, which is coordinated by the European Environment Agency (EEA), and meets the requirements established by the Intergovernmental Panel on Climate Change (IPCC) and the Task Force on Emission Inventories and Projections of the United Nations Economic Commission for Europe (TFEIP - UNECE).

The Energy Balance of the municipality of Madrid, from its first edition in 2006, is compiled according to a methodology developed by the working team of the *Fundación para el Fomento de la Innovación Industrial* (F2I2), following the guidelines of the International Energy Agency and the Spanish Ministry for the Ecological Transition (MITECO), specifically adapted to the singularities of Madrid city (Pérez et al., 2019).

The City Council of Madrid is firmly committed to tackling climate change and, some years ago, acquired these two instruments, whose different editions made it possible to more precisely draw up the *Plan for the Sustainable Use of Energy and Climate Change Prevention 2008* that Council Meeting adopted in June 2008. This Plan has been applied to strengthen the actions that, for years, the City Council has been successfully implementing in this field, as shown by the results achieved so far in the framework of the targets of the Kyoto Protocol. With the *Plan for the Sustainable Use of Energy and Climate Change Prevention - Horizon 2020*, which sets more ambitious goals, Madrid was able to continue progressing in the fight against climate change and be in a position to meet future GHG reduction targets. In September 2017, the city adopted the so-called *Plan A: The Air Quality and Climate Change Plan for the City of Madrid* (hereinafter Plan A). It is a municipal tool aimed at reducing air pollution, helping to prevent climate change, and defining adaptation strategies. The Plan A fixed the GHG emissions reductions to be achieved in 2030. In September 2019, the City Council started developing a new air quality and sustainability strategy (*M360 Strategy*), which has not set new targets for reducing GHG emissions. In March of 2021, the city of Madrid presented its *"Roadmap towards Climate Neutrality for 2050"*, which aligns municipal policies aimed at the fight against climate change with European and national policies. The main goals of this Roadmap are to reduce the GHG emissions of the city of Madrid by 65% in 2030, compared to 1990, and to achieve climate neutrality in 2050.

1.2 Boundary setting and gases

The boundary of the inventory comprises the boundary of the Madrid municipality, where the Madrid City Council has the jurisdictional authority.

The GHG emissions sources are:

- Direct or “Scope 1” emissions: All direct emissions from sources within the boundary of the municipality

- Indirect or “Scope 2 + Scope 3” emissions: Energy-related emissions that occur outside the boundary of the municipality as a consequence of consumption of grid-supplied electricity (Scope 2 emissions), including associated transmission and distribution losses (Scope 3 emissions)

Regarding Scope 1, emission sources have been grouped according to the Selected Nomenclature for sources of Air Pollution (SNAP), shown in Table 1. Direct emissions of GHG from these activities include: carbon dioxide (CO_2), nitrous oxide (N_2O), methane (CH_4), hydrofluorocarbons (HFCs), perfluorocarbons (PFCs) and Sulphur hexafluoride (SF_6). Emission figures are expressed in terms of CO_2 equivalent (CO_2-eq). For this purpose, the emissions of each GHG have been weighted by their corresponding global warming potential (GWP, Table 2), in accordance with the Fifth Assessment Report of Intergovernmental Panel on Climate Change (IPCC, 2013).

Table 1. SNAP Nomenclature. Activity Groups

01	Combustion in energy and transformation industries (*)
02	Non-industrial combustion plants
03	Combustion in manufacturing industry
04	Production processes
05	Extraction and distribution of fossil fuels and geothermal energy
06	Solvent and other product use
07	Road transport
08	Non-road transport
09	Waste treatment and disposal
10	Agriculture
11	Other sources and sinks (nature)

(*) Without emissions in the municipality of Madrid.

Table 2. Individual GHG Global Warming Potential

SPECIES	CHEMICAL FORMULA	IPCC GWP, 2013
Carbon dioxide	CO_2	1
Methane	CH_4	28
Nitrous oxide	N_2O	265
HYDROFLUOROCARBONS		
HFC-23	CHF_3	12 400
HFC-32	CH_2F_2	677
HFC-125	C_2HF_5	3 170
HFC-134a	$C_2H_2F_4$ (CH_2FCF_3)	1 300
HFC-152a	$C_2H_4F_2$ (CH_3CHF_2)	138
HFC-143a	$C_2H_3F_3$ (CF_3CH_3)	4 800
HFC-227ea	C_3HF_7	3 350
HFC-236fa	$C_3H_2F_6$	8 060
PERFLUOROCARBONS		
Perfluoromethane (PFC-14)	CF_4	6 630
Perfluoroethane (PFC-116)	C_2F_6	11 100
Perfluoropropane (PFC-218)	C_3F_8	8 900
Perfluorobutane (PFC-410)	C_4F_{10}	9 200
SF_6		
Sulphur hexafluoride	SF_6	22 800
NF_3		
Nitrogen trifluoride[1]	NF_3	16 100

Source: IPCC (2013), https://www.ipcc.ch/site/assets/uploads/2018/02/WG1AR5_Chapter08_FINAL.pdf

[1] Currently, there is no evidence of nitrogen trifluoride emissions in the municipality and therefore they are not estimated.

For Scope 2 and Scope 3 emissions, only carbon dioxide emissions were considered since reliable information is only available at national level for this pollutant. These emissions are calculated using electricity consumption data and electricity emission factors (EF) (Table 3). The electricity EF correspond to national values and were obtained from the emission of carbon dioxide attributable to electricity generation, according to the National Emissions Inventory 1990-2012 (MAPAMA, 2014) and the Spanish Power Transmission Grid (REE, 2023), and the national electricity consumption (MITECO, 2023; REE, 2023).

Table 3. Electricity emission factors

Year	EF (tCO_2/MWh)	Year	EF (tCO_2/MWh)
1990	0.536	**2006**	0.456
1991	0.532	**2007**	0.469
1992	0.573	**2008**	0.401
1993	0.530	**2009**	0.362
1994	0.508	**2010**	0.292
1995	0.556	**2011**	0.350
1996	0.433	**2012**	0.374
1997	0.481	**2013**	0.301
1998	0.464	**2014**	0.305
1999	0.542	**2015**	0.348
2000	0.521	**2016**	0.284
2001	0.458	**2017**	0.326
2002	0.524	**2018**	0.283
2003	0.462	**2019**	0.222
2004	0.476	**2020**	0.171
2005	0.495	**2021**	0.164

2 GHG EMISSIONS

2.1 Direct (Scope 1) emissions

The trends of Scope 1 emissions in Madrid city are showed in Table 4 and Figure 1.

Table 4. Scope 1 emissions in the municipality of Madrid (kt CO_2 eq)*

YEAR	CH_4	CO_2	HFC	N_2O	PFC	SF_6	TOTAL
1990	*1 057.7*	*7 200.5*	*0.0*	*119.2*	*0.0*	*4.3*	***8 381.7***
1999	1 331.3	8 044.8	209.1	219.5	0.0	6.5	**9 811.3**
2000	1 336.8	8 071.0	284.8	225.4	0.0	6.7	**9 924.7**
2001	1 262.4	7 927.5	363.7	212.0	0.0	7.1	**9 772.8**
2002	1 185.2	7 975.7	433.8	210.0	0.0	7.5	**9 812.3**
2003	1 041.4	8 103.5	529.8	212.9	0.0	8.1	**9 895.9**
2004	556.7	8 444.9	603.8	205.5	0.0	9.1	**9 820.0**
2005	582.1	8 476.0	699.9	216.2	0.0	10.2	**9 984.3**
2006	575.1	8 333.4	841.8	234.7	0.0	11.0	**9 996.0**
2007	544.4	8 159.9	980.7	229.6	0.0	11.9	**9 926.5**
2008	543.7	7 965.6	1 054.8	228.4	0.1	12.7	**9 805.2**
2009	548.0	7 529.5	981.2	218.0	0.0	13.2	**9 289.9**
2010	556.3	7 132.8	981.3	214.5	0.0	13.9	**8 898.8**
2011	531.5	6 538.1	974.6	202.6	0.0	13.6	**8 260.5**
2012	519.4	6 364.0	970.2	175.2	0.0	13.9	**8 042.8**
2013	488.7	6 170.9	969.7	158.4	0.0	13.8	**7 801.5**
2014	459.9	5 852.4	960.4	154.4	0.1	13.8	**7 440.9**
2015	446.2	6 043.2	534.1	148.5	0.5	14.3	**7 186.7**
2016	457.8	6 278.9	524.7	152.8	0.4	14.6	**7 429.2**
2017	392.0	6 254.1	400.8	157.4	0.5	14.6	**7 219.4**
2018	433.3	6 611.8	291.9	148.7	0.5	15.1	**7 501.2**
2019	400.8	6 379.9	286.5	146.6	0.8	15.3	**7 230.0**
2020	400.3	5 081.6	238.1	143.3	0.5	15.7	**5 879.5**
2021	411.0	5 541.3	240.8	145.7	1.5	15.8	**6 356.4**

(*) CO_2 removals by sinks are not included (SNAP activity Group 11)

Scope 1 emissions were 24% lower in 2021 than in 1990. Since 2008, a significant reduction is observed, with the road transport sector as the largest driver (Table 5). The most important GHG contributor is CO_2, with an average contribution around 83% in 1999 – 2021.

Table 5 presents Scope 1 emissions grouped according to the activity sectors, considered in the Energy Balance of the city (AM, 2023a).

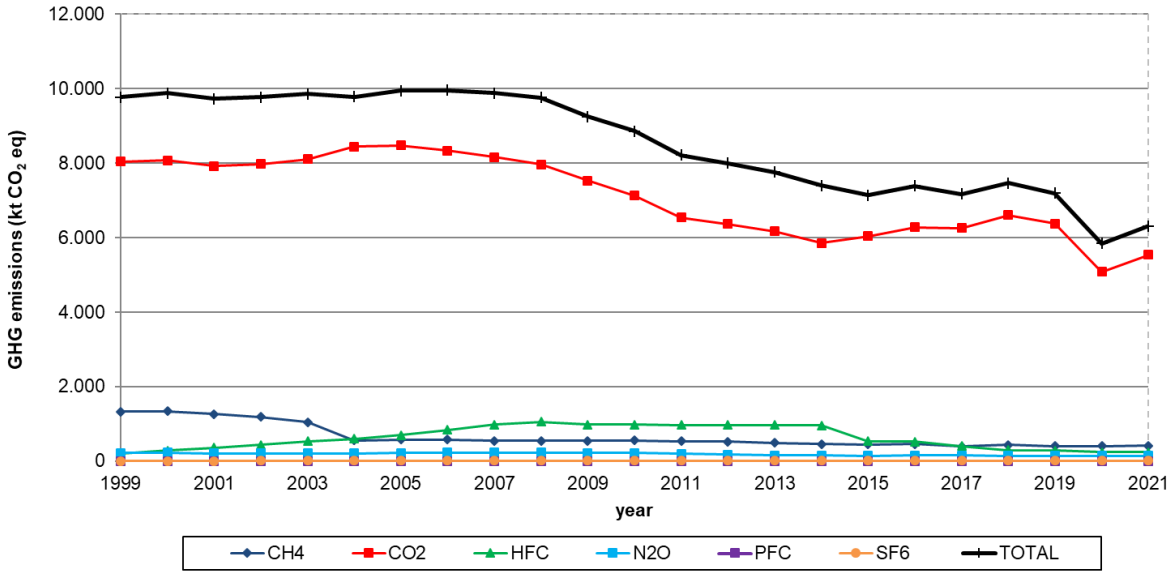

Figure 1. Scope 1 emissions trend by compound

Table 5. Scope 1 emissions by sector (kt CO_2 eq)

YEAR	Residential/ Commercial/ Institutional	Industry*	Road transport	Non-road transport	Waste treatment and disposal**	Others***	TOTAL
1999	2 595.5	623.0	3 996.9	675.2	1 537.4	383.4	**9 811.3**
2000	2 550.5	578.9	4 037.1	742.0	1 555.1	461.1	**9 924.7**
2001	2 479.4	515.7	3 989.5	760.8	1 489.1	538.4	**9 772.8**
2002	2 358.2	471.5	4 130.6	717.2	1 532.9	601.9	**9 812.3**
2003	2 559.0	517.1	4 013.3	668.6	1 444.7	693.2	**9 895.9**
2004	2 676.2	485.3	4 199.7	705.0	995.4	758.5	**9 820.0**
2005	2 695.3	482.1	4 186.0	728.1	1 032.1	860.8	**9 984.3**
2006	2 557.8	491.0	4 041.1	881.0	1 011.6	1 013.5	**9 996.0**
2007	2 614.5	514.2	3 769.8	912.9	964.0	1 151.0	**9 926.5**
2008	2 611.5	506.4	3 626.9	851.9	992.6	1 215.9	**9 805.2**
2009	2 508.2	393.1	3 439.2	780.9	1 036.9	1 131.6	**9 289.9**
2010	2 372.7	384.0	3 264.3	726.2	1 026.4	1 125.2	**8 898.8**
2011	2 235.9	363.5	2 872.7	724.1	955.3	1 109.1	**8 260.5**
2012	2 326.5	323.1	2 718.3	671.7	910.6	1 092.6	**8 042.8**
2013	2 341.4	368.7	2 611.5	594.9	801.5	1 083.5	**7 801.5**
2014	2 106.8	365.1	2 629.1	602.4	666.6	1 070.9	**7 440.9**
2015	2 045.6	377.6	2 823.5	657.7	642.6	639.8	**7 186.7**
2016	2 202.5	413.7	2 791.9	724.1	663.2	633.7	**7 429.2**
2017	2 073.0	407.7	2 848.5	751.3	628.2	510.7	**7 219.4**
2018	2 309.0	439.8	2 761.3	807.5	777.3	406.3	**7 501.2**
2019	2 168.8	379.0	2 696.8	850.7	735.2	399.5	**7 230.0**
2020	2 035.4	381.1	2 004.9	404.5	709.4	344.2	**5 879.5**
2021	2 038.3	412.1	2 251.5	495.8	808.6	349.9	**6 356.4**

(*) Emissions from SNAP 3 and 4 activity Groups
(**) Emissions from waste disposal and wastewater treatment plants
(***) Emissions from SNAP 5, 6, 10 and 11 activity Groups (excluding CO_2 removals by sinks)

Regarding emissions by activity sectors, Figure 2 shows that 'Residential/Commercial/Institutional, RCI' and 'Road transport' are particularly relevant, accounting for approximately a 66% of Scope 1 emissions.

Figure 2. Scope 1 emissions breakdown by sector

In 2021, the main source of Scope 1 GHG emissions in the city of Madrid is 'Road Transport' (35%), followed by 'RCI' (32%). Figure 3 shows CO_2 emissions from 'Road Transport' spatially disaggregated in a regular grid for 2021 (cell size 1x1 km). The spatial pattern is strongly related to the distribution of road traffic.

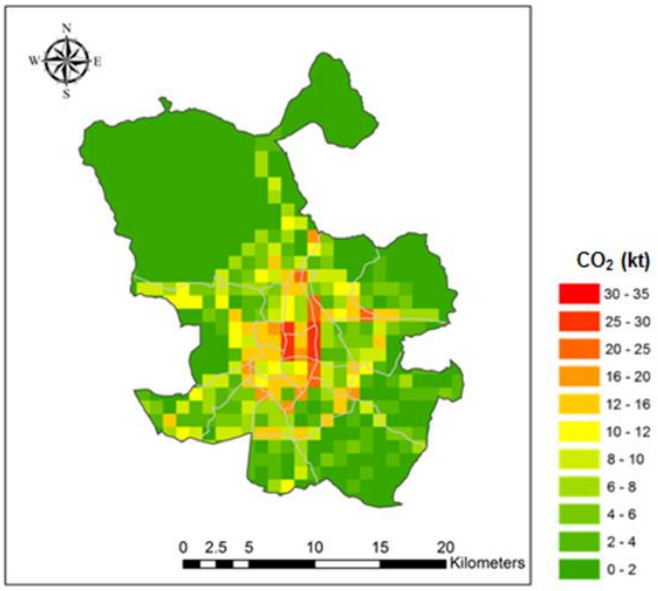

Figure 3. Spatial distribution of road transport CO_2 emissions (cell size 1x1 km)

2.2 Indirect (Scope 2 + Scope 3) emissions

Table 6 and Figure 4 include indirect electricity-related GHG emissions. Indirect (Scope 2 + Scope 3) emissions decreased by 60% in 2021 in comparison to 1990, whereas electricity consumption increased by 31% in that period.

Table 6. Scope 2 + Scope 3 emissions in the municipality of Madrid

Year	Electricity consumption, GWh	EF, $ktCO_2/GWh$	Scope 2 + Scope 3 emissions, kt CO_2
1990	8 712	0.536	**4 670.8**
1991	9 424	0.532	**5 009.5**
1992	9 393	0.573	**5 384.9**
1993	9 418	0.530	**4 989.7**
1994	9 490	0.508	**4 818.5**
1995	9 519	0.556	**5 295.3**
1996	9 737	0.433	**4 214.1**
1997	9 756	0.481	**4 690.6**
1998	10 370	0.464	**4 816.0**
1999	10 914	0.542	**5 918.1**
2000	11 462	0.521	**5 968.9**
2001	13 465	0.458	**6 173.7**
2002	12 276	0.524	**6 427.5**
2003	12 843	0.462	**5 925.5**
2004	13 271	0.476	**6 321.4**
2005	13 614	0.495	**6 760.8**
2006	13 871	0.456	**6 360.2**
2007	14 115	0.469	**6 662.7**
2008	14 590	0.401	**5 845.5**
2009	14 413	0.362	**5 211.9**
2010	14 217	0.292	**4 148.6**
2011	13 862	0.350	**4 847.0**
2012	13 716	0.374	**5 131.5**
2013	13 005	0.301	**3 916.5**
2014	12 576	0.305	**3 832.1**
2015	12 630	0.348	**4 391.0**
2016	12 573	0.284	**3 570.7**
2017	12 846	0.326	**4 027.2**
2018	13 091	0.283	**3 708.2**
2019	12 836	0.222	**2 846.2**
2020	11 360	0.171	**1 943.6**
2021	11 453	0.164	**1 867.6**

Sources: Electricity consumption: CM, 2023 (1990-2002); AM, 2023c (2003-2005); AM, 2023b (2006-2021)
Emission factors estimated from MAPAMA, 2014, MITECO, 2023, REE, 2023

This trend is explained by a decrease of 69% in the electricity EF, as a result of the increasing penetration of renewable energy and the decreasing importance of coal-fuelled power plants in the national electricity mix.

In 2021, electric consumption increased by approximately 1% in comparison to that of 2020 while indirect emissions decreased by 4%. This is due to the decrease in the electricity EF (4%), as a consequence of a lower contribution of high-emitting energy sources (coal) to the electricity mix in 2021 (REE, 2023).

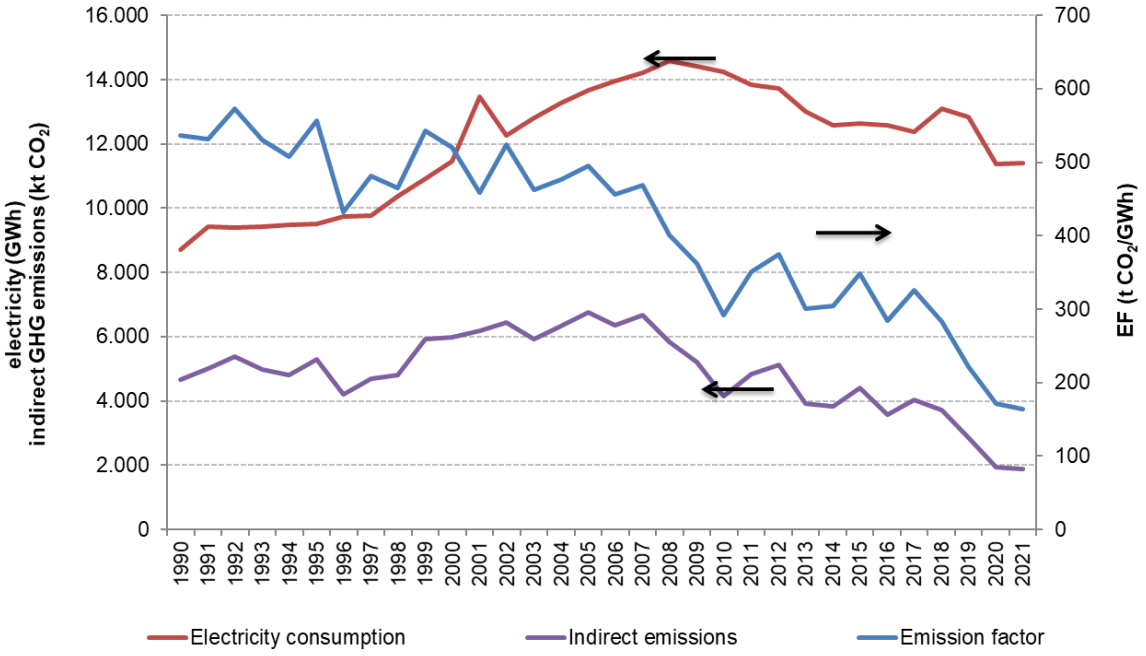

Figure 4. Evolution of indirect emissions (Scope 2+3), electricity consumption and electricity EF

Table 7 shows indirect (Scope 2+3) emissions results by activity sectors:

Table 7. Scope 2 + Scope 3 emissions by sector

Year	Residential/ Commercial/ Institutional	Industry	Road transport	Non-road transport	Waste treatment and disposal	Wastewater treatment	TOTAL
2006	5 187.6	733.8	0.0	406.6	0	32.2	**6 360.2**
2007	5 421.2	725.7	0.0	479.3	0	36.5	**6 662.7**
2008	4 802.8	572.0	0.1	442.0	0	28.6	**5 845.5**
2009	4 502.5	414.3	0.1	268.2	0	26.8	**5 211.9**
2010	3 439.0	347.8	0.1	343.7	0	18.1	**4 148.6**
2011	4 017.1	379.7	0.1	430.0	0	20.1	**4 847.0**
2012	4 373.5	300.6	0.1	436.9	0	20.4	**5 131.5**
2013	3 363.9	218.6	0.1	320.1	0	13.9	**3 916.5**
2014	3 295.2	213.7	0.1	311.5	0	11.6	**3 832.1**
2015	3 773.9	244.5	0.1	360.1	0	12.4	**4 391.0**
2016	3 064.0	196.0	0.1	300.2	0	10.3	**3 570.7**
2017	3 444.4	214.5	0.8	354.5	0	13.0	**4 027.2**
2018	3 254.1	197.5	1.4	242.8	0	12.4	**3 708.2**
2019	2 450.8	153.9	2.2	229.8	0	9.5	**2 846.2**
2020	1 728.3	92.5	1.5	113.6	0	7.7	**1 943.6**
2021	1 610.1	91.6	1.9	157.8	0	6.3	**1 867.6**

A breakdown of each activity sector is shown in Figure 5. The "RCI" sector accounts for 81-89% of indirect emissions in the evaluated period. The share of “Industry” decreases from 12% in 2006 to 5% in 2021 (as a result of a lower electricity consumption of this sector) while "Non-road transport" has a contribution between 5 and 9% in the period 2006-2021.

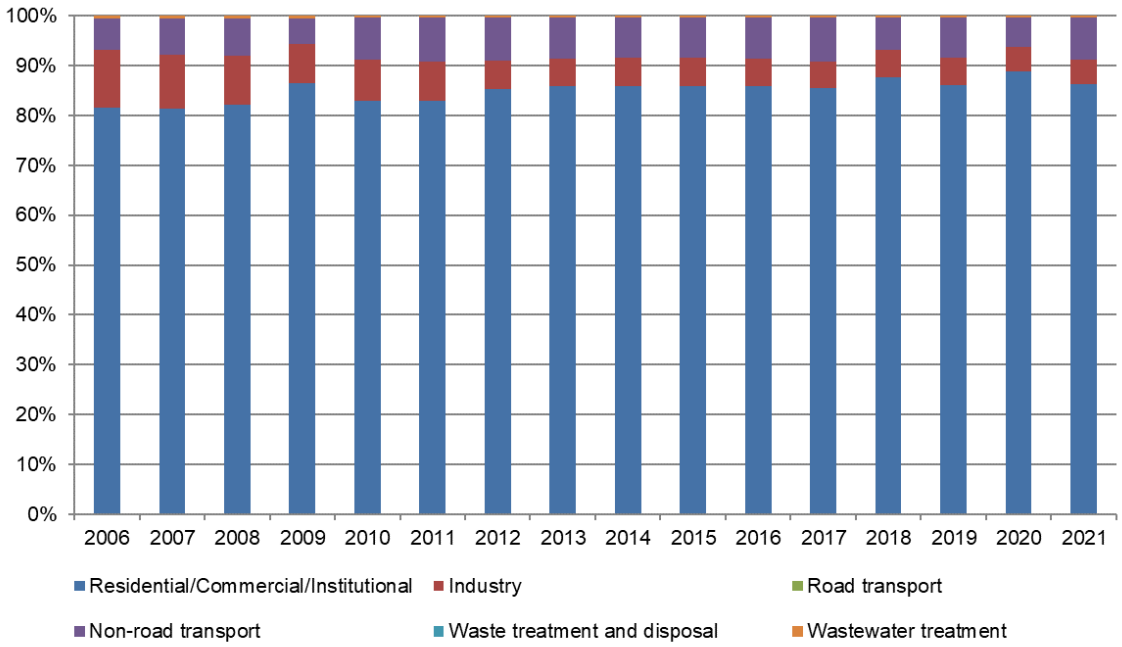

Figure 5. Scope 2+3 emissions breakdown by sector

2.3 Total Emissions

Table 8 and Figure 6 show the Scope 1, Scope 2+3 and Total GHG emissions trends in Madrid city. The dashed orange line in Figure 6 shows the emissions target set by the Roadmap towards Climate Neutrality for 2050 of the City of Madrid, which aims to reduce the emissions of the city of Madrid by 65% in 2030, compared to 1990, achieving climate neutrality in 2050. It can be observed that total GHG emissions in 2021 are 80% above the 2030 goal.

Table 8. Scope 1, Scope 2+3 and Total GHG emissions (kt CO_2 eq)

Year	Emissions			Contribution (%)		
	Scope 1	Scope 2+3	TOTAL	Scope 1	Scope 2+3	TOTAL
1990	8 381.7	4 670.8	**13 052.5**	64.2	35.8	**100**
1999	9 811.3	5 918.1	**15 729.4**	62.4	37.6	**100**
2000	9 924.7	5 968.9	**15 893.6**	62.4	37.6	**100**
2001	9 772.8	6 173.7	**15 946.5**	61.3	38.7	**100**
2002	9 812.3	6 427.5	**16 239.7**	60.4	39.6	**100**
2003	9 895.9	5 925.5	**15 821.4**	62.5	37.5	**100**
2004	9 820.0	6 321.4	**16 141.5**	60.8	39.2	**100**
2005	9 984.3	6 760.8	**16 745.2**	59.6	40.4	**100**
2006	9 996.0	6 360.2	**16 356.3**	61.1	38.9	**100**
2007	9 926.5	6 662.7	**16 589.2**	59.8	40.2	**100**
2008	9 805.2	5 845.5	**15 650.7**	62.7	37.3	**100**
2009	9 289.9	5 211.9	**14 501.9**	64.1	35.9	**100**
2010	8 898.8	4 148.6	**13 047.4**	68.2	31.8	**100**
2011	8 260.5	4 847.0	**13 107.5**	63.0	37.0	**100**
2012	8 042.8	5 131.5	**13 174.3**	61.0	39.0	**100**
2013	7 801.5	3 916.5	**11 718.1**	66.6	33.4	**100**
2014	7 440.9	3 832.1	**11 273.0**	66.0	34.0	**100**
2015	7 186.7	4 391.0	**11 577.6**	62.1	37.9	**100**
2016	7 429.2	3 570.7	**10 999.9**	67.5	32.5	**100**
2017	7 219.4	4 027.2	**11 246.6**	64.2	35.8	**100**
2018	7 501.2	3 708.2	**11 209.4**	66.9	33.1	**100**
2019	7 230.0	2 846.2	**10 076.2**	71.8	28.2	**100**
2020	5 879.5	1 943.6	**7 823.1**	75.2	24.8	**100**
2021	6 356.4	1 867.6	**8 224.0**	77.3	22.7	**100**

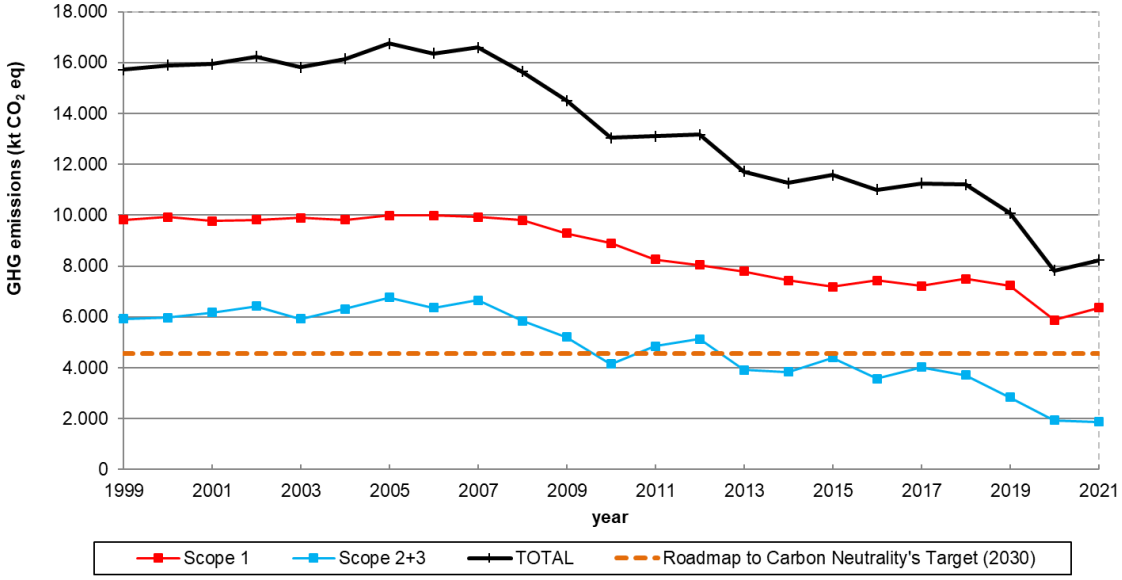

Figure 6. GHG emissions trends in Madrid city

As shown in Figure 6, Scope 1 emissions are higher than Scope 2+3. Between 1999 and 2021, the contribution of Scope 1 to total emissions ranged between 60 to 77%. Over this period of time, total emissions have decreased by 48%, Scope 1 emissions by 35% and Scope 2+3 emissions by 68%.

Table 9 shows GHG emissions results by activity sector in 2021.

Table 9. Scope 1, Scope 2+3 and Total GHG emissions by sector (2021)

Emissions	Residential/ Commercial/ Institutional	Industry*	Road transport	Non-road transport	Waste treatment and disposal**	Others***	TOTAL
kt CO_2 eq							
Scope 1	2 038.3	412.1	2 251.5	496.0	808.6	349.9	**6 356.4**
Scope 2+3	1 610.1	91.6	1.9	157.8	0.0	6.3	**1 867.6**
TOTAL	3 648.4	503.7	2 253.4	653.6	808.6	356.2	**8 224.0**
Breakdown by sector (%)							
Scope 1	32.1	6.5	35.4	7.8	12.7	5.5	**100**
Scope 2+3	86.2	4.9	0.1	8.4	0.0	0.3	**100**
TOTAL	44.4	6.1	27.4	7.9	9.8	4.3	**100**

(*) Emissions from SNAP 3 and 4 activity Groups
(**) Emissions from waste disposal and wastewater treatment plants
(***) Emissions from SNAP 5, 6, 10 and 11 activity Groups (excluding CO_2 removals by sinks)

Considering GHG Total emissions, 'RCI' is the most important source, accounting for 44%, followed by 'Road transport' (27%). This is partially explained by the high electricity consumption in 'RCI' (with the highest share of Scope 2+3 emissions, 86%).

2.4 GHG emissions by Scope and sector

Table 10 and Figure 7 show GHG emissions by sector distinguishing between "Scope 1" (direct emissions), "Scope 2" (energy-related emissions that occur outside the boundary of the municipality as a consequence of consumption of grid-supplied electricity), and "Scope 3" (emissions concerning transmission and distribution losses).

Table 10. GHG emissions by Scope and sector (kt CO_2)

Year	Residential/ Commercial/ Institutional	Industry*	Road transport	Non-road transport	Waste treatment and disposal**	Others***	TOTAL
Scope 1 emissions (direct)							
2006	2 557.8	491.0	4 041.1	881.0	1 011.6	1 013.5	**9 996.0**
2007	2 614.5	514.2	3 769.8	912.9	964.0	1 151.0	**9 926.5**
2008	2 611.5	506.4	3 626.9	851.9	992.6	1 215.9	**9 805.2**
2009	2 508.2	393.1	3 439.2	780.9	1 036.9	1 131.6	**9 289.9**
2010	2 372.7	384.0	3 264.3	726.2	1 026.4	1 125.2	**8 898.8**
2011	2 235.9	363.5	2 872.7	724.1	955.3	1 109.1	**8 260.5**
2012	2 326.5	323.1	2 718.3	671.7	910.6	1 092.6	**8 042.8**
2013	2 341.4	368.7	2 611.5	594.9	801.5	1 083.5	**7 801.5**
2014	2 106.8	365.1	2 629.1	602.4	666.6	1 070.9	**7 440.9**
2015	2 045.6	377.6	2 823.5	657.7	642.6	639.8	**7 186.7**
2016	2 202.5	413.7	2 791.9	724.1	663.2	633.7	**7 429.2**
2017	2 073.0	407.7	2 848.5	751.3	628.2	510.7	**7 219.4**
2018	2 309.0	439.8	2 761.3	807.5	777.3	406.3	**7 501.2**
2019	2 168.8	379.0	2 696.8	850.7	735.2	399.5	**7 230.0**
2020	2 035.4	381.1	2 004.9	404.5	709.4	344.2	**5 879.5**
2021	2 038.3	412.1	2 251.5	496.0	808.6	349.9	**6 356.4**
Scope 2 emissions (indirect, electricity generation)							
2006	4 704.2	665.4	0.0	368.7	29.2	0.0	**5 767.5**
2007	4 717.7	631.5	0.0	417.1	31.8	0.0	**5 798.0**
2008	4 139.8	493.0	0.1	381.0	24.7	0.0	**5 038.6**
2009	3 853.9	354.6	0.1	229.6	23.0	0.0	**4 461.2**
2010	2 917.2	295.1	0.1	291.5	15.3	0.0	**3 519.2**
2011	3 501.0	331.0	0.1	374.7	17.5	0.0	**4 224.3**
2012	3 710.7	255.1	0.1	370.7	17.3	0.0	**4 353.8**
2013	2 831.6	184.0	0.1	269.4	11.7	0.0	**3 296.9**
2014	2 804.9	181.9	0.1	265.1	9.9	0.0	**3 262.0**
2015	3 273.7	212.1	0.1	312.3	10.7	0.0	**3 808.9**
2016	2 720.5	174.1	0.1	266.5	9.2	0.0	**3 170.3**
2017	3 139.1	195.5	0.7	323.1	11.8	0.0	**3 670.2**
2018	2 972.8	180.4	1.3	221.8	11.3	0.0	**3 387.6**
2019	2 203.3	138.4	2.0	206.6	8.6	0.0	**2 558.8**
2020	1 509.8	80.8	1.3	99.2	6.7	0.0	**1 697.9**
2021	1 410.9	80.3	1.6	138.3	5.5	0.0	**1 636.5**
Scope 3 emissions (indirect, transmission and distribution losses)							
2006	483.5	68.4	0.0	37.9	3.0	0.0	**592.7**
2007	703.5	94.2	0.0	62.2	4.7	0.0	**864.6**
2008	663.0	79.0	0.0	61.0	4.0	0.0	**807.0**
2009	648.5	59.7	0.0	38.6	3.9	0.0	**750.7**
2010	521.7	52.8	0.0	52.1	2.7	0.0	**629.4**
2011	516.1	48.8	0.0	55.2	2.6	0.0	**622.7**
2012	662.9	45.6	0.0	66.2	3.1	0.0	**777.7**
2013	532.2	34.6	0.0	50.6	2.2	0.0	**619.7**
2014	490.3	31.8	0.0	46.3	1.7	0.0	**570.1**
2015	500.3	32.4	0.0	47.7	1.6	0.0	**582.1**
2016	343.6	22.0	0.0	33.7	1.2	0.0	**400.4**
2017	305.3	19.0	0.1	31.4	1.2	0.0	**356.9**
2018	281.3	17.1	0.1	21.0	1.1	0.0	**320.6**
2019	247.5	15.5	0.2	23.2	1.0	0.0	**287.4**
2020	218.5	11.7	0.2	14.4	1.0	0.0	**245.7**
2021	199.2	11.3	0.2	19.5	0.8	0.0	**231.1**
TOTAL emissions							
2006	7 745.4	1 224.8	4 041.1	1 287.7	1 043.7	1 013.5	**16 356.3**
2007	8 035.8	1 239.9	3 769.8	1 392.1	1 000.6	1 151.0	**16 589.2**
2008	7 414.3	1 078.3	3 627.0	1 293.9	1 021.2	1 215.9	**15 650.7**
2009	7 010.7	807.4	3 439.3	1 049.1	1 063.7	1 131.6	**14 501.9**
2010	5 811.6	731.8	3 264.4	1 069.9	1 044.5	1 125.2	**13 047.4**
2011	6 253.0	743.2	2 872.7	1 154.1	975.4	1 109.1	**13 107.5**
2012	6 700.1	623.7	2 718.4	1 108.6	930.9	1 092.6	**13 174.3**
2013	5 705.3	587.2	2 611.6	915.0	815.4	1 083.5	**11 718.1**
2014	5 402.0	578.8	2 629.3	913.9	678.2	1 070.9	**11 273.0**
2015	5 819.5	622.0	2 823.6	1 017.8	654.9	639.8	**11 577.6**
2016	5 266.5	609.8	2 792.0	1 024.3	673.5	633.7	**10 999.9**
2017	5 517.3	622.3	2 849.2	1 105.8	641.2	510.7	**11 246.6**
2018	5 563.1	637.3	2 762.7	1 050.3	789.7	406.3	**11 209.4**
2019	4 619.7	532.9	2 699.0	1 080.4	744.8	399.5	**10 076.2**

Year	Residential/ Commercial/ Institutional	Industry*	Road transport	Non-road transport	Waste treatment and disposal**	Others***	TOTAL
2020	3 763.6	473.6	2 006.4	518.1	717.1	344.2	**7 823.1**
2021	3 648.4	503.7	2 253.4	653.8	814.8	349.9	**8 224.0**

(*) Emissions from SNAP 3 and 4 activity Groups (**) Emissions from waste disposal and wastewater treatment plants
(***) Emissions from SNAP 5, 6, 10 and 11 activity Groups (excluding CO_2 removals by sinks)

It can be seen that in "Road Transport", "Waste treatment and disposal" and "Others", total GHG emissions are almost entirely direct emissions (Scope 1). Scope 1 emissions in "Non-road transport" account for 2 and 3 times indirect emissions (Scope 2 + Scope 3). 'RCI' is the only sector where Scope 2 emissions are higher than Scope 1 emissions although in the last year both emissions are practically the same.

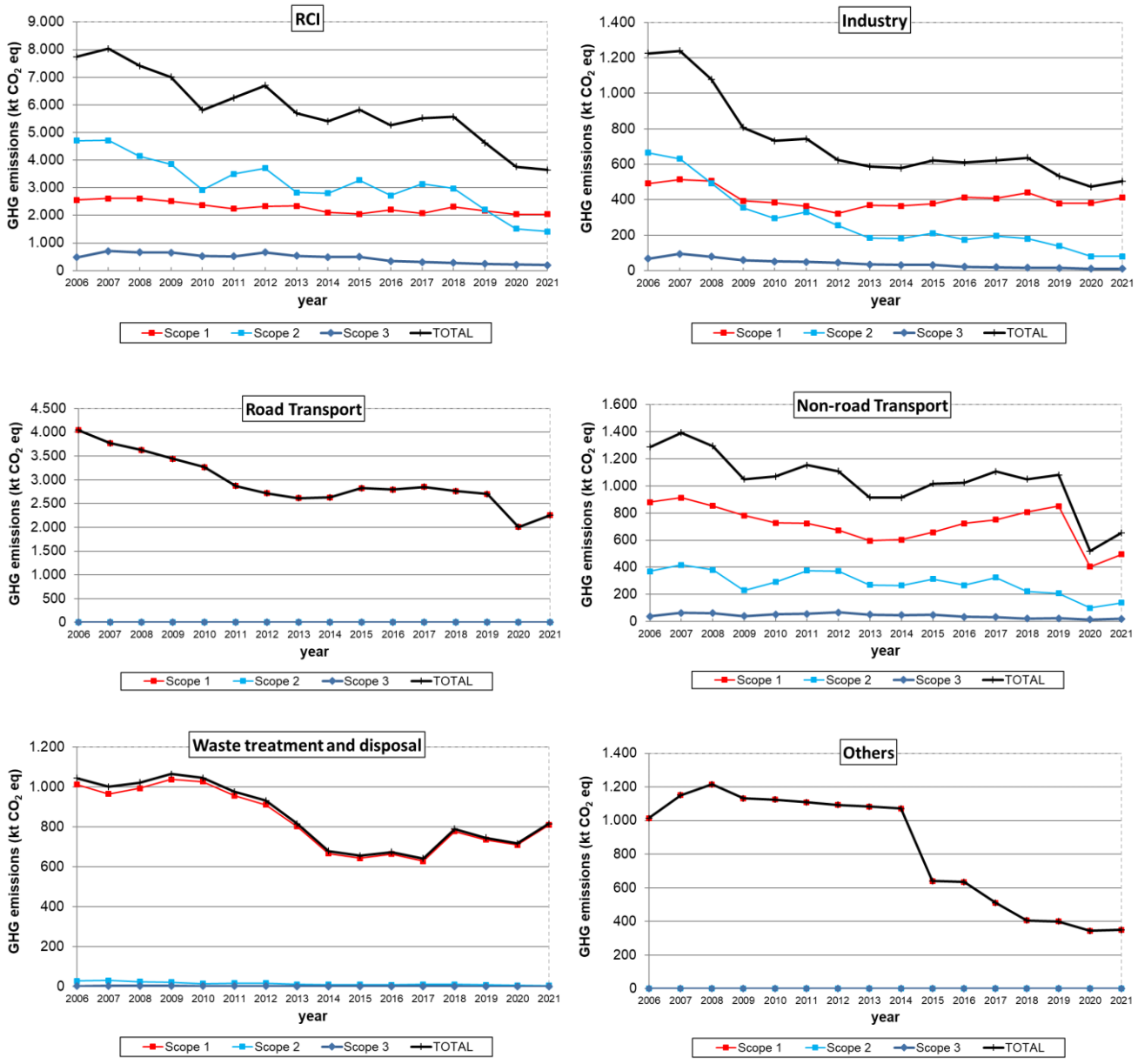

Figure 7. GHG emissions by scope and sector

3 INDICATORS

Table 11 and Figure 8 show the evolution of the population, the Gross Domestic Product (GDP) and the GHG emissions in Madrid city from 2000 to 2021. Additionally, the trend of two emission indicators is presented: the emission *per capita* (tonnes of CO_2 equivalent per inhabitant and year) and the emission per unit of GDP (tonnes of CO_2 equivalent per million euro of GDP).

Table 11. Emission and economic indicators (period 2000-2021), Madrid

Year	Population	GDP, million €$_{2010}$	Scope 1 emissions (kt CO_2 eq)	Scope 2+3 emissions (kt CO_2 eq)	Total GHG emissions (kt CO_2 eq)	Emissions *per capita* (t CO_2 eq/inhab)	Emissions per unit of GDP (t CO_2eq / million €$_{2010}$)
2000	2.882.860	95.262	9.924,7	5.968,9	15.893,6	5,5	167
2001	2.957.058	101.067	9.772,8	6.173,7	15.946,5	5,4	158
2002	3.016.788	104.194	9.812,3	6.427,5	16.239,7	5,4	156
2003	3.092.759	107.467	9.895,9	5.925,5	15.821,4	5,1	147
2004	3.099.834	111.036	9.820,0	6.321,4	16.141,5	5,2	145
2005	3.155.359	116.922	9.984,3	6.760,8	16.745,2	5,3	143
2006	3.128.600	122.043	9.996,0	6.360,2	16.356,3	5,2	134
2007	3.132.463	126.669	9.926,5	6.662,7	16.589,2	5,3	131
2008	3.213.271	129.351	9.805,2	5.845,5	15.650,7	4,9	121
2009	3.255.944	125.970	9.289,9	5.211,9	14.501,9	4,5	115
2010	3.273.049	125.339	8.898,8	4.148,6	13.047,4	4,0	104
2011	3.265.038	126.276	8.260,5	4.847,0	13.107,5	4,0	104
2012	3.233.527	123.495	8.042,8	5.131,5	13.174,3	4,1	107
2013	3.207.247	121.276	7.801,5	3.916,5	11.718,1	3,7	97
2014	3.165.235	123.019	7.440,9	3.832,1	11.273,0	3,6	92
2015	3.141.991	127.266	7.186,7	4.391,0	11.577,6	3,7	91
2016	3.165.541	132.071	7.429,2	3.570,7	10.999,9	3,5	83
2017	3.182.981	137.004	7.219,4	4.027,2	11.246,6	3,5	82
2018	3.223.334	141.144	7.501,2	3.708,2	11.209,4	3,5	79
2019	3.266.126	144.480	7.230,0	2.846,2	10.076,2	3,1	70
2020	3.334.730	130.451	5.879,5	1.943,6	7.823,1	2,3	60
2021	3.305.408	140.501	6.356,4	1.867,6	8.224,0	2,5	59

The emission per capita rate decreased by 55% in the period 2000-2021, as a result of population growth (15%) and a decrease of total GHG emissions (48%). Likewise, the "emission intensity per unit of GDP" fell 65% in that period of time.

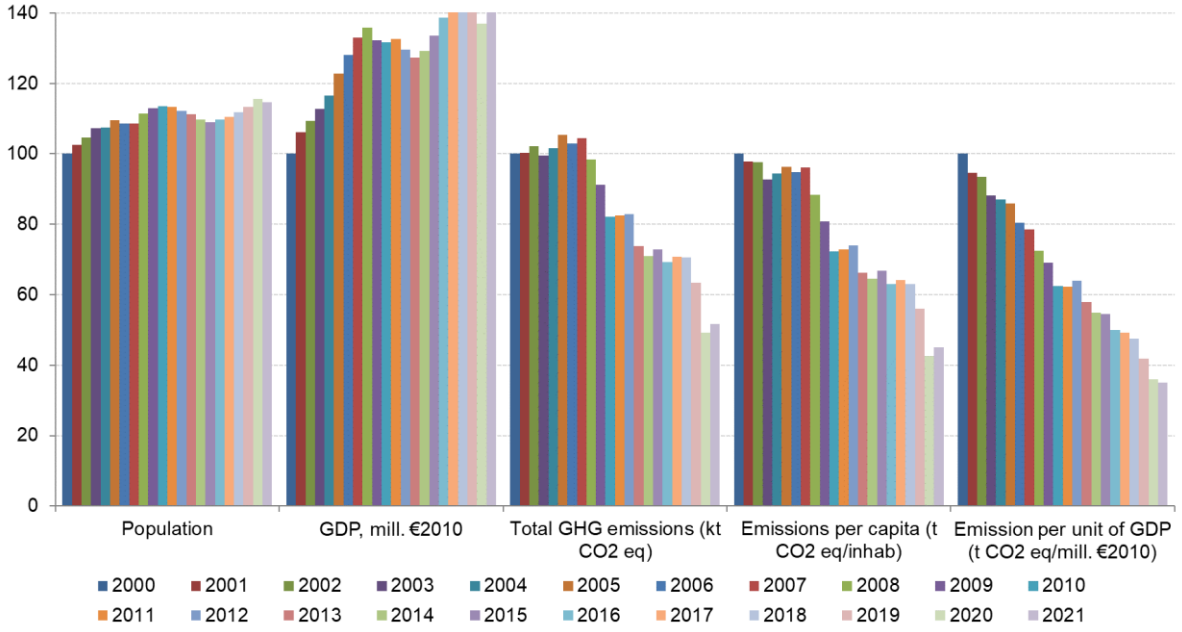

Figure 8. Trends of municipal GHG emissions and main indicators (year 2000=100)

Table 12 and Figure 9 compare the trend of population, GDP and total GHG emissions between 2000 and 2021 for Madrid and Spain. Directly comparable information about the emission indicators evaluated is also presented.

Table 12. Emission and economic indicators (period 2000-2021), Madrid and Spain

Year	MADRID					SPAIN				
	Population	GDP, million €$_{2010}$	Total GHG emissions (kt CO_2 eq)	Emissions *per capita* (t CO_2 eq/inhab)	Emissions per unit of GDP (t CO_2eq/mill. €$_{2010}$)	Population	GDP, million €$_{2010}$	Total GHG emissions (kt CO_2 eq)	Emissions *per capita* (t CO_2 eq/inhab)	Emissions per unit of GDP (t CO_2eq/mill. €$_{2010}$)
2000	2.882.860	95.262	15.894	5,5	167	40.499.791	781.631	383.276	9,5	490
2001	2.957.058	101.067	15.947	5,4	158	41.116.842	814.409	382.043	9,3	469
2002	3.016.788	104.194	16.240	5,4	156	41.837.894	840.246	400.722	9,6	477
2003	3.092.759	107.467	15.821	5,1	147	42.717.064	873.397	407.929	9,5	467
2004	3.099.834	111.036	16.141	5,2	145	43.197.684	909.818	423.590	9,8	466
2005	3.155.359	116.922	16.745	5,3	143	44.108.530	948.994	438.760	9,9	462
2006	3.128.600	122.043	16.356	5,2	134	44.708.964	990.951	432.097	9,7	436
2007	3.132.463	126.669	16.589	5,3	131	45.200.737	1.030.136	442.832	9,8	430
2008	3.213.271	129.351	15.651	4,9	121	46.157.822	1.041.491	409.175	8,9	393
2009	3.255.944	125.970	14.502	4,5	115	46.745.807	1.003.945	369.811	7,9	368
2010	3.273.049	125.339	13.047	4,0	104	47.021.031	1.006.119	354.652	7,5	352
2011	3.265.038	126.276	13.107	4,0	104	47.190.493	996.743	354.632	7,5	356
2012	3.233.527	123.495	13.174	4,1	107	47.265.321	976.593	347.509	7,4	356
2013	3.207.247	121.276	11.718	3,7	97	47.129.783	968.957	320.452	6,8	331
2014	3.165.235	123.019	11.273	3,6	92	46.771.341	993.830	321.937	6,9	324
2015	3.141.991	127.266	11.578	3,7	91	46.624.382	1.017.525	333.623	7,2	328
2016	3.165.541	132.071	11.000	3,5	83	46.557.008	1.055.841	321.650	6,9	305
2017	3.182.981	137.004	11.247	3,5	82	46.572.132	1.104.201	334.704	7,2	303
2018	3.223.334	141.144	11.209	3,5	79	46.722.980	1.120.147	328.905	7,0	294
2019	3.266.126	144.480	10.076	3,1	70	47.026.208	1.143.267	309.814	6,6	271
2020	3.334.730	130.451	7.823	2,3	60	47.398.695	1.017.567	272.244	5,7	268
2021	3.305.408	140.501	8.224	2,5	59	47.432.893	1.078.007	288.848	6,1	268

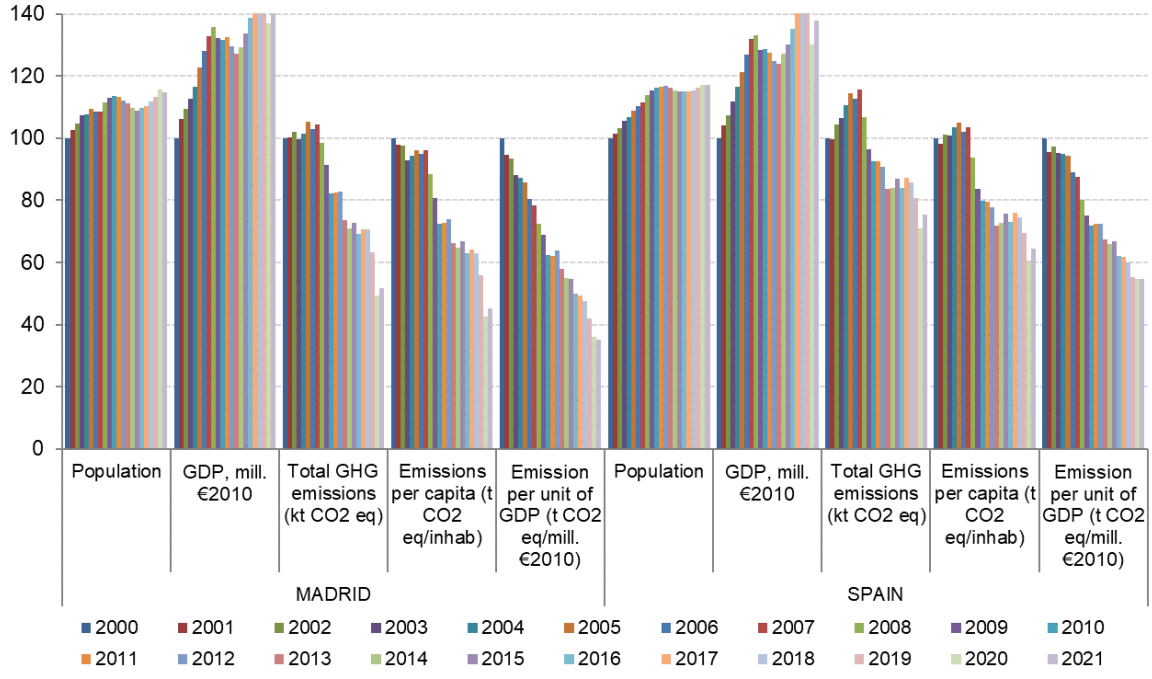

Figure 9. Trends of economic and emission indicators for Madrid and Spain (Year 2000=100)

In 2021, the city of Madrid accounted for 7% of national population but was only responsible for 3% of total GHG emissions in Spain. Thus, the local per capita emission rate is 59% lower than that of the national average (2.5 vs. 6.1 t CO_2eq/inhabitant). Similarly, Madrid accounted for 13% of national GDP in this same year, which means that local 'emission intensity per unit of GDP' was 78% lower than the corresponding national figure (59 vs. 268 t CO_2 eq/M€$_{2010}$).

These remarkable differences can be largely explained by the productive structure of the municipality, whose economy is based on the tertiary sector (services) while the industrial activity (which is more energy demanding) is less significant.

From 2000 to 2021, the decrease in the emission per capita was larger in Madrid that in Spain (55% vs. 36%), due to a relevant reduction in local emissions (48% vs 25% in Spain). The emission per unit of GDP has decreased by 65% in Madrid vs the 45% in Spain. This evolution reflects a higher decrease in local GHG emissions and a higher local GDP growth.

4 REFERENCES

- AM, 2023a. Energy Balance of the municipality of Madrid, year 2021. Madrid City Council, 2023
- AM, 2023b. Áreas de información estadística del Ayuntamiento de Madrid, 2023. Available at: http://www-2.munimadrid.es/CSE6/jsps/menuBancoDatos.jsp
- CM, 2023. Anuario Estadístico de la Comunidad de Madrid 1985-2020 -Banco de datos-. Comunidad de Madrid, 2023. Available at: http://www.madrid.org/iestadis/fijas/efemerides/anu8516nt.htm
- IPCC, 2013. IPCC Fifth Assessment Report: Climate Change 2007. Working Group, I: The Physical Science Basis. https://www.ipcc.ch/reports/
- MAPAMA, 2014. Spain GHG Inventory 1990-2012, Edition 2014. Ministry of Agriculture, Fishing, Food and the Environment, 2014. Available at: http://cdr.eionet.europa.eu/es/eu/colqfqaq/envu0z10a/
- MITECO, 2023. Balance energético 2021 y perspectivas 2022. Ministerio para la Transición Ecológica y el Reto Demográfico, 2023. Available at: https://energia.gob.es/balances/Balances/Paginas/Balances.aspx
- Pérez. J., Lázaro, S., Lumbreras, J., Rodríguez, M.E., 2019. A methodology for the development of urban energy balances: Ten years of application to the city of Madrid. Cities, 91, 126-136. https://doi.org/10.1016/j.cities.2018.11.012
- REE, 2023. El sistema Eléctrico Español 2021. Red Eléctrica de España, 2023. Available at: https://www.ree.es/es/datos/publicaciones/informe-anual-sistema/informe-del-sistema-electrico-espanol-2018
- REE, 2023. Series estadísticas del sistema eléctrico español, September 2023. Available at: http://www.ree.es/es/estadisticas-del-sistema-electrico-espanol/series-estadisticas/series-estadisticas-nacionales