

Assessing the energetic and environmental impacts of the operation and maintenance of Spanish sewer networks from a life-cycle perspective

Water Resources Management

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Online Resource 1. Features of the complete set of cities and the sample selected for the analysis

System	Number of cities	Number of inhabitants			Population density (inhabitants/km ²)		
		Mean	Maximum	Minimum	Mean	Maximum	Minimum
All cities	395	23,235	1,615,448	99	601	16,449	1.9
Sample	68	49,448	443,657	632	717	3,426	5.2

Online Resource 2. Data for each city of the sample (year 2011).

City ID	Registered population	Maximum population	Tourist Equivalent Population (TEP)	Seasonal	Region	Density (inhabitants/km ²)	Coastal	Electricity consumption (kWh)*	Length of the sewer system (km)*	Stormwater catchment area (km ²)
1	24,512	24,512	25,008	No	Mediterranean	272	Yes	55,291	71	nd
2	100,085	100,085	102,256	No	Subtropical	977	Yes	363,559	305	102.4
3	632	1,264	729	Yes	Mediterranean	34	No	780	13.2	1.8
4	41,326	41,326	41,591	No	Mediterranean	2,545	No	96,422	121.7	5.4
5	28,138	28,138	28,228	No	Mediterranean	1,753	No	nd	60	2.6
6	20,728	20,728	20,765	No	Mediterranean	2,052	No	62,293	36	1.6
7	334,329	500,000	358,868	Yes	Mediterranean	1,661	Yes	670,694	625.2	48.2
8	6,007	11,500	7,267	Yes	Mediterranean	217	Yes	50,787	49.2	8
9	36,872	36,872	37,596	No	Subtropical	1,117	Yes	20,963	154.9	33
10	4,932	12,000	5,210	Yes	Mediterranean	34	No	nd	32	10.5
11	72,062	400,000	93,544	Yes	Mediterranean	1,871	Yes	23,764	203.6	10.4
12	13,537	nd	13,672	nd	Atlantic	560	No	120,326	90.3	24
13	3,086	4,230	3,108	Yes	Mediterranean	753	No	nd	27	nd
14	6,350	6,800	6,396	No	Mediterranean	73	No	22,299	30	87
15	27,000	40,227	38,655	Yes	Mediterranean	1,338	Yes	1,400,000	200	nd
16	33,008	150,000	44,146	Yes	Mediterranean	941	Yes	39,893	215	8.3
17	218,210	313,568	242,428	Yes	Mediterranean	391	Yes	1,952,983	999.3	143.5
18	7,019	7,019	7,065	No	Mediterranean	1,614	No	1830	56.9	2.6
19	9,065	9,097	9,194	No	Subtropical	495	Yes	nd	14.1	nd
20	230,354	230,354	242,030	No	Mediterranean	707	Yes	65,688	477.3	36.1
21	443,657	443,657	446,779	No	Mediterranean	501	No	4,279,034	1,481.6	275.4
22	6,800	20,000	8,414	Yes	Mediterranean	161	Yes	nd	92.5	6.2
23	5,315	5,315	5,374	No	Mediterranean	443	No	1,705	28	2
24	2,108	2,500	2,143	No	Mediterranean	31	No	nd	11	1

25	9,818	11,000	9,934	No	Mediterranean	13	No	nd	50	3.5
26	144,800	144,800	148,258	No	Subtropical	1,419	Yes	88,146	412.6	67
27	21,708	24,400	22,052	No	Mediterranean	656	No	nd	67.7	6
28	32,733	79,673	37,702	Yes	Mediterranean	553	Yes	155,093	81.9	10.5
29	3,115	3,115	3,161	No	Mediterranean	237	No	1,289	34.7	nd
30	16,738	30,000	17,070	Yes	Mediterranean	1,909	No	5,111	123.4	8.9
31	3,055	4,448	3,237	Yes	Mediterranean	203	No	1,061	28.8	nd
32	42,560	42,560	42,806	No	Mediterranean	121	No	nd	139.4	8
33	13,810	33,000	18,024	Yes	Mediterranean	388	Yes	nd	153.9	nd
34	19,310	20,000	19,417	No	Mediterranean	51	No	nd	90	nd
35	23,870	23,870	24,102	No	Mediterranean	142	No	38,111	78.1	4.7
36	1,400	2,500	1,476	Yes	Atlantic	13	No	nd	30	nd
37	14,134	14,123	14,432	No	Atlantic	165	No	116,545	nd	nd
38	13,345	13,345	13,462	No	Mediterranean	1,931	No	2,168	88.1	5.5
39	72,036	75,448	95,605	No	Mediterranean	197	Yes	432,697	449.1	nd
40	8,966	10,500	9,033	No	Mediterranean	546	No	4,531	60	2.6
41	60,000	65,000	60,599	No	Mediterranean	1,674	No	35114	300.9	45
42	14,688	20,000	15,908	Yes	Atlantic	433	Yes	962,215	105.4	14
43	4,474	5,500	4,576	No	Mediterranean	198	No	nd	25.3	2.5
44	61,576	61,576	63,051	No	Atlantic	521	Yes	891,303	494.6	52
45	7,224	10,200	7,746	Yes	Atlantic	222	Yes	129,061	106.2	14
46	52,200	52,200	52,491	No	Mediterranean	230	No	710,173	147	226.7
47	11,550	11,550	12,196	No	Atlantic	197	Yes	319,370	127.7	31
48	21,094	28,519	21,452	Yes	Mediterranean	367	No	nd	144.2	11.8
49	32,366	91,465	52,338	Yes	Mediterranean	431	Yes	335,963	166	22
50	22,554	25,000	22,766	No	Mediterranean	2,340	No	nd	3.1	4.7
51	16,924	17,500	17,394	No	Subtropical	390	Yes	235,772	31.7	27.7
52	26,615	26,615	29,190	No	Atlantic	387	Yes	587,359	117.2	28
53	15,428	15,428	15,540	No	Mediterranean	404	No	22,754	49.4	nd
54	33,372	170,000	53,995	Yes	Mediterranean	574	Yes	526,295	107.3	12.4

55	136,415	170,000	138,456	Yes	Atlantic	620	No	561,678	659.8	190
56	17,200	17,200	18,039	No	Subtropical	572	Yes	22,769	62.7	27
57	140,184	155,000	144,926	No	Mediterranean	2,248	Yes	33,176	204	277
58	68,181	300,000	74,613	Yes	Mediterranean	3,426	Yes	267,180	152	nd
59	32,140	32,140	32,635	No	Mediterranean	170	No	55,804	242.1	184
60	102,136	395,940	155,633	Yes	Mediterranean	1,430	Yes	54,287	317.9	22
61	6,392	7,000	6,543	No	Atlantic	50	No	nd	40	nd
62	313,437	320,000	315,630	No	Mediterranean	1,587	No	157,197	690.3	57.8
63	9,102	9,102	9,215	No	Mediterranean	643	No	48.4	68.6	nd
64	2,316	2,537	2,479	No	Mediterranean	5	No	nd	80	nd
65	22,532	nd	22,788	nd	Mediterranean	148	No	nd	91	4
66	6,129	20,000	9,334	Yes	Mediterranean	303	Yes	7,764	35.4	30
67	6,810	9,000	6,909	Yes	Mediterranean	42	No	nd	26.9	3.6
68	2,870	3,000	2,902	No	Mediterranean	62	No	nd	11	1.3

* Values equal to zero were excluded from the analysis, as it was not known whether they were real zeros or unrecorded parameters. nd: No Data

City ID	Annual precipitation (mm)	Stormwater runoff (m ³)	Registered drinking water (m ³)	Water flow (m ³)	Income per capita (€)**	Slope (city centre – WWTP) (m)
1	196	nd	1.2E+06	nd	12,525	nd
2	324	3.0E+07	6.4E+06	3.6E+07	nd	nd
3	336	5.4E+05	1.0E+05	6.5E+05	nd	64
4	300	1.4E+06	2.1E+06	3.5E+06	10,882	-1
5	454	1.1E+06	1.2E+06	2.3E+06	nd	29
6	454	6.5E+05	9.9E+05	1.6E+06	nd	9
7	336	1.5E+07	2.2E+07	3.6E+07	nd	nd
8	442	3.2E+06	4.0E+05	3.6E+06	nd	17
9	324	9.6E+06	1.5E+06	1.1E+07	nd	nd
10	524	5.0E+06	2.2E+06	7.2E+06	23,706	nd
11	336	3.1E+06	9.7E+06	1.3E+07	nd	nd
12	1010	2.2E+07	8.5E+05	2.3E+07	15,408	23
13	336	nd	3.3E+05	nd	nd	14
14	300	2.3E+07	nd	nd	9,417	-19
15	504	nd	2.2E+06	nd	18,100	-19
16	504	3.7E+06	3.1E+06	6.8E+06	17,100	-29
17	340	4.4E+07	2.1E+07	6.5E+07	11,638	nd
18	357	8.3E+05	4.1E+05	1.2E+06	17,454	nd
19	214	nd	6.9E+05	nd	nd	nd
20	336	1.1E+07	1.3E+07	2.3E+07	nd	nd
21	300	7.4E+07	2.6E+07	1.0E+08	12,637	nd
22	336	1.9E+06	7.8E+05	2.7E+06	nd	nd
23	357	6.4E+05	4.3E+05	1.1E+06	21,047	nd
24	463	4.3E+05	1.2E+05	5.5E+05	nd	46
25	463	1.5E+06	6.0E+05	2.1E+06	11,588	-21
26	214	1.3E+07	8.9E+06	2.2E+07	nd	nd
27	454	2.4E+06	1.7E+06	4.2E+06	nd	nd
28	336	3.2E+06	2.1E+06	5.3E+06	nd	-67
29	357	nd	nd	nd	12,334	nd
30	454	3.6E+06	2.0E+06	5.6E+06	nd	26
31	336	nd	3.0E+05	nd	nd	12
32	536	3.9E+06	2.0E+06	5.9E+06	13,682	86
33	524	nd	2.0E+06	nd	16,842	100
34	534	nd	1.2E+06	nd	nd	-146
35	536	2.3E+06	nd	nd	13,314	86
36	523	nd	8.3E+04	nd	nd	nd
37	817	nd	nd	nd	15,926	11

38	357	1.8E+06	9.3E+05	2.7E+06	19,333	nd
39	336	nd	7.7E+06	nd	nd	nd
40	640	1.5E+06	5.5E+05	2.0E+06	14,300	nd
41	454	1.8E+07	2.4E+06	2.1E+07	nd	nd
42	1690	2.1E+07	1.0E+06	2.2E+07	15,930	7
43	336	7.7E+05	3.9E+05	1.2E+06	nd	171
44	1690	7.9E+07	7.9E+06	8.7E+07	17,233	13
45	1010	1.3E+07	nd	nd	13,717	4
46	396	8.1E+07	3.5E+06	8.4E+07	nd	460
47	1010	2.8E+07	4.4E+05	2.9E+07	13,962	27
48	454	4.8E+06	2.0E+06	6.8E+06	nd	nd
49	340	6.7E+06	2.4E+06	9.1E+06	13,576	-13
50	336	1.4E+06	nd	nd	nd	nd
51	214	5.3E+06	1.1E+06	6.4E+06	nd	36
52	1010	2.5E+07	2.6E+06	2.8E+07	11,552	21
53	357	nd	8.2E+05	nd	16,187	nd
54	336	3.7E+06	3.1E+06	6.8E+06	nd	-53
55	1890	3.2E+08	8.9E+06	3.3E+08	19,611	nd
56	214	5.2E+06	1.3E+06	6.5E+06	nd	nd
57	504	1.3E+08	8.9E+06	1.3E+08	18,500	32
58	524	nd	6.9E+06	nd	17,620	nd
59	340	5.6E+07	2.6E+06	5.9E+07	12,484	nd
60	336	6.7E+06	7.6E+06	1.4E+07	nd	19
61	523	nd	3.2E+05	nd	10,969	nd
62	435	2.3E+07	2.3E+07	4.6E+07	nd	21
63	357	nd	6.1E+05	nd	14,780	nd
64	196	nd	2.1E+05	nd	9,642	nd
65	463	1.6E+06	1.5E+06	3.1E+06	12,487	nd
66	454	1.2E+07	6.9E+05	1.3E+07	nd	10
67	336	1.1E+06	5.0E+05	1.6E+06	nd	180
68	463	5.2E+05	2.0E+05	7.2E+05	nd	27

** Estimations for 2011 were not found. Therefore, the analysis includes data for the period 2006-2011, when available. nd: No Data

Online Resource 3. Factors potentially influencing the electricity consumed during the pumping of wastewater and their classification criteria

		Factors	Description
Quantitative data	Physical configuration of the network	Length of the sewer	<ul style="list-style-type: none"> Total km of sewer Metres of sewer per TEP
		Altitude difference between the middle of the city and the WWTP	<ul style="list-style-type: none"> Height (metres)
		Wastewater flow	<ul style="list-style-type: none"> Total volume (m³) of wastewater produced Volume (m³) of wastewater produced per TEP
		Stormwater runoff	<ul style="list-style-type: none"> Total volume (m³) of stormwater Volume (m³) of stormwater per TEP
		Water flow (wastewater + stormwater)	<ul style="list-style-type: none"> Total volume of (m³) of water transported Volume (m³) of water transported per TEP
Qualitative data	Regional features	Population	<ul style="list-style-type: none"> Small city: ≤ 10,000 inhabitants Medium city: 10,000 – 50,000 inhabitants Large city: > 50,000 inhabitants
		Population density	<ul style="list-style-type: none"> Low density: ≤ 300 inhabitants/km² Medium density: 300-1,000 inhabitants/km² High density: >1,000 inhabitants/km²
		Income per capita	<ul style="list-style-type: none"> Medium-Low: <15,000 € per capita Medium-High: 15,001 – 24,000 € per capita
		Climate	<ul style="list-style-type: none"> Atlantic Mediterranean Subtropical
		Seasonality	<ul style="list-style-type: none"> Seasonal $\left(\frac{\text{maximum population}}{\text{registered population}} \geq 1.25\right)$ Non-seasonal $\left(\frac{\text{maximum population}}{\text{registered population}} \leq 1.25\right)$
		Location	<ul style="list-style-type: none"> Coastal Inland

Online Resource 4. Comparison of the total electricity consumption in kWh under different regional conditions

		Total kWh					
		N	Mean	Median	Minimum	Maximum	Standard Deviation
Population	Small	11	2.0E+04 _a	1.8E+03	4.8E+01	1.3E+05	3.9E+04
	Medium	21	2.5E+05 _a	9.6E+04	2.2E+03	1.4E+06	3.6E+05
	Large	16	6.6E+05 _a	3.2E+05	2.4E+04	4.3E+06	1.1E+06
Population density	Low	13	1.5E+05 _a	5.5E+04	7.8E+02	7.1E+05	2.1E+05
	Medium	20	5.6E+05 _a	2.0E+05	4.8E+01	4.3E+06	1.0E+06
	High	15	1.9E+05 _a	5.4E+04	1.8E+03	1.4E+06	3.7E+05
Climate	Atlantic	8	4.6E+05 _a	4.4E+05	1.2E+05	9.6E+05	3.4E+05
	Mediterranean	35	3.3E+05 _a	5.1E+04	4.8E+01	4.3E+06	8.0E+05
	Subtropical	5	1.5E+05 _a	8.8E+04	2.1E+04	3.6E+05	1.5E+05
Coastal	No	22	2.9E+05 _a	2.9E+04	4.8E+01	4.3E+06	9.1E+05
	Yes	26	3.7E+05 _a	2.0E+05	7.8E+03	2.0E+06	4.8E+05
Seasonal	No	29	3.0E+05 _a	5.6E+04	4.8E+01	4.3E+06	8.0E+05
	Yes	18	4.0E+05 _a	1.4E+05	7.8E+02	2.0E+06	5.5E+05
Income per capita	Medium-High	13	3.4E+05 _a	1.2E+05	1.7E+03	1.4E+06	4.7E+05
	Medium-Low	14	5.6E+05 _a	7.6E+04	4.8E+01	4.3E+06	1.2E+06

^{a,b} Values in the same row and sub-table not sharing the same subscript are significantly different at $p < 0.05$

Online Resource 5. Comparison of the electricity consumption per m³ of water flow in kWh under different regional conditions

		kWh/m ³ of water flow					
		N	Mean	Median	Minimum	Maximum	Standard Deviation
Population	Small	6	3.5E-03 _a	1.6E-03	6.0E-04	1.4E-02	5.2E-03
	Medium	16	2.1E-02 _a	1.6E-02	8.1E-04	7.7E-02	2.2E-02
	Large	14	1.0E-02 _a	3.9E-03	2.5E-04	4.3E-02	1.3E-02
Population density	Low	5	7.1E-03 _a	8.4E-03	9.5E-04	1.4E-02	5.9E-03
	Medium	18	2.0E-02 _a	1.0E-02	6.0E-04	7.7E-02	2.1E-02
	High	13	8.0E-03 _a	1.9E-03	2.5E-04	3.8E-02	1.2E-02
Climate	Atlantic	6	1.5E-02 _a	1.1E-02	1.7E-03	4.3E-02	1.5E-02
	Mediterranean	25	1.4E-02 _a	3.4E-03	2.5E-04	7.7E-02	1.9E-02
	Subtropical	5	1.1E-02 _a	4.0E-03	1.9E-03	3.7E-02	1.5E-02
Coastal	No	15	9.2E-03 _a	1.7E-03	8.1E-04	4.3E-02	1.4E-02
	Yes	21	1.7E-02 _a	1.0E-02	2.5E-04	7.7E-02	1.9E-02
Seasonal	No	21	1.1E-02 _a	3.5E-03	2.5E-04	4.3E-02	1.4E-02
	Yes	14	1.9E-02 _a	9.9E-03	6.0E-04	7.7E-02	2.2E-02
Income per capita	Medium-High	9	7.8E-03 _a	1.7E-03	2.5E-04	4.3E-02	1.4E-02
	Medium-Low	8	2.2E-02 _a	2.4E-02	9.5E-04	4.3E-02	1.6E-02

^{a,b} Values in the same row and sub-table not sharing the same subscript are significantly different at p < 0.05