Desalination and Water Treatment
www.deswater.com
doi: 10.5004/dwt.2017.11431

58 (2017) 399–405
January

Environmental performance assessment of waste-to-energy plants in Europe by using the Cleaner Treatment Concept

Lineker Max Goulart Coelho*, Hosmanny Mauro Goulart Coelho, Liséte Celina Lange

Sanitary and Environmental Engineering Department, Federal University of Minas Gerais, Av. Antônio Carlos, 6627, School of Engineering, Campus Pampulha, Bloc 2, Room 4628, Belo Horizonte, Minas Gerais, 30270-901, Brazil, email: linekermax@yahoo.com.br

Received 23 December 2015; Accepted 9 May 2016

ABSTRACT

The aim of this paper is to present the evaluation of waste-to-energy (WTE) plants concerning environmental performance in the light of the Cleaner Treatment Concept by using the Cleaner Treatment Index. This index is formed by the combination (aggregation) of several indicators. Fifty WTE plants from 12 European countries were evaluated. It is observed that the average and standard deviation of CTI are 0.73 and 0.13, respectively, which corresponds to the environmental performance class "Good". Results show that Nordic countries present a better environmental performance in terms of CTI values than the average level of the European WTE evaluated. The indicators with the worst performances for the majority of plants were related to energy recovery, indicating that this aspect needs to be better managed. In addition, from the results, it was found that the Cleaner Treatment Concept is an important tool to help environmental performance assessments of waste treatment technologies. The CTI index, in turn, allows the application of the Cleaner Treatment Concept in quantitative studies being an important instrument for practical uses of this treatment management approach.

Keywords: Cleaner treatment; Waste to energy; Environmental performance

1. Introduction

According to [1], about 1.3 billion tons of solid waste are generated annually, and it estimated that this amount will increase to 2.2 billion tons by 2025. On the other hand, waste management has gained importance because the solid waste disposal generates several impacts to the environment.

So, waste management becomes crucial to achieve sustainability because when its steps are properly executed they contribute to reducing environmental liabilities and decreasing natural resources requirements including fossil fuels and water.

In addition, according to [2], the main goal of technologies and policies for solid waste management (SWM) is to protect the environment and human health by reducing the negative impacts of waste and looking for ways to reuse them to provide benefits to society. Several studies have presented the benefits from waste management to sustainability.

The latter means a balance between economic efficiency, social equity and environmental protection. Moreover, the first definition of this term provided by the World Commission on Environment and Development (WCED) in 1991, sustainable development consists in a development that meets the needs of the present without compromising the ability of future generations to meet their own needs [3].

It is important to note that the disposal should obey the classic hierarchy principle of the solid waste management, which is organized by priority order, starting from the non-generation and ending up in the final disposal. Between these steps, there are, respectively, the minimization of waste generation, reuse, recycling and treatment. However, even with greater emphasis on pollution prevention and waste reduction, there will always be waste to be managed

* Corresponding author.

Presented at the 2015 International Environmental Engineering Conference (IEEC 2015) October 28–30, 2015, Busan, Korea.

1944-3994/1944-3986

[4]. Thus, this residual part can be recovered as energy and/or be properly disposed. According to [5], the nations who have reduced or even eliminated landfilling have done so by a combination of materials and energy recovery. The benefits of waste-to-energy (WTE) plants are waste landfilled reduction, electricity and heat generation and CO_2 emissions reduction [6].

According to [7], the potential production of energy from waste by 2020 amounts to 196 TW (76 for electricity and 120 from heat), and thence nearly double of actual figures.

Thus, to provide a technical tool for solid waste managers, it is necessary to develop methodologies and decision-making models geared to support SWM.

Two of the most used tools for assessing the environmental performance are the indexes and indicators. According to [8], an indicator is a quantitative measure that can typically be used to illustrate and communicate complex phenomena in a simple way, providing a significant clue or making perceptible a trend or phenomenon that is not immediately noted.

The Organization for Economic Cooperation and Development (OECD) was the first international organization to develop and publish a set of environmental indicators at the beginning of the 1990s. According to the model adopted by this organization, the indicators could be classified as (i) pressure, which reflect the cause of a phenomenon; (ii) state, which quantify the state of some element of the environment; (iii) response, which reflect the reaction to a pressure previously established. On the other hand, environmental indexes can be defined as a set of aggregated indicators, which provide an overview of phenomena that depend on a large number of variables.

Reference [9] describes the most common method to develop indexes which consists in the following steps: decision of the phenomenon to be studied; selection of indicators which should be based on their relevance, comprehensiveness of the chosen topic and the ease and quality of their data needed to obtain it; study of relationships between indicators; standardization and allocation of weights; and robustness and sensitivity tests which aim to evaluate the applicability and scope of the index.

There are numerous tools to support decision making such as the EPA models [10]: Waste Reduction Model (WARM), Recycled Content Tool (ReCon), and Durable Goods Calculator (DGC). However, although the concern with sustainable development and environment protection has considerably grown in the last years, it is noted that the majority of decision-making models and tools are still excessively tied to economic aspects or geared to the production process. Moreover, existing models focus on the priority steps of solid waste management, beyond waste energy recovery and disposal. So, in order to help the lack of models and tools aiming at the waste treatment and final disposal, a new concept was proposed by [11]: the Cleaner Treatment (CT), which is based on the Cleaner Production (CP) principles.

According to the concept proposed by the United Nations Environmental Programme in 1991, CP is a "continuous application of an integrated preventative environmental strategy to processes, products and services to increase efficiency and reduce risks to humans and the environment" [12].

The CT, based on the CP principles, proposes a management strategy for waste treatment plants advocating the minimization of solid waste, liquid and gas generation, the maximization of energy recovery efficiency, the reduction of fossil fuel consumption and greenhouse gas emissions; minimization of land take and chemical consumption. Reference [11] also presented and validated a quantitative application of this new concept called Cleaner Treatment Index (CTI). The same paper shows that this index consists in a simple and robust tool to assess and compare the environmental performance of different treatment plants being an excellent way to support Cleaner Treatment implementation.

The aim of this paper is to present the evaluation of European WTE plants concerning environmental performance in the light of the Cleaner Treatment Concept by using the CTI.

2. Materials and methods

Fifty WTE plants from 12 European countries were evaluated. The name of the plants will not be informed; it is provided only in the country where the WTE was installed and the operational data which are obtained from [13]. Table 1 presents the number of WTE analyzed for each country. Table 2 presents the operational data of the WTE plants analyzed.

For the evaluation of the environmental performance of the WTE plants analyzed, the CTI index was used. The CTI is formed by combination (aggregation) of several indicators as presented in Eq. (1):

$$CTI = \sum_{i=1}^{n} w_i . q_i \tag{1}$$

where w_i is weight given to each indicator whose sum is equal to 1; q_i is indicator value normalized; i is environmental indicator included in the index; and n is total number of indicators.

Table 3 presents the indicators which are considered in the CTI and their weights. Other indicators related to water, soil, air and materials presented in the standard framework of CTI were not included in this research due the lack of information about these aspects in the WTE database used.

Table 1
Number of plants analyzed per country

Country	Number of WTE plants
Austria	4
Belgium	6
Czech Republic	2
Finland	2
Denmark	11
Germany	6
Hungary	1
Norway	4
Portugal	2
Slovakia	1
Spain	3
Sweden	8

Table 2
Operational data of the WTE plants analyzed

Country	WTE plant code	Waste treated (tons)	Oil consumed (L)	Gas consumed (Nm³)	Residues generated (tons)	Electricity generated (MWh)	Heat generated (MWh)	Electricity consumed (MWh)
Austria	WTE 1	196,604	0	4,466,000	43,160	29,760	0	24,570
	WTE 2	89,123	155,000	0	24,853	49,600	0	11,700
	WTE 3	290,625	2,058	0	38,999	47,486	315,639	0
	WTE 4	146,000	0	0	48,400	116,000	0	16,000
Belgium	WTE 5	91,325	404,259	0	20,726	38,811	0	7,775
	WTE 6	98,552	147,807	28,393	18,092	9,570	0	0
	WTE 7	62,556	116,319	0	11,448	30,604	0	9,257
	WTE 8	350,692	745,800	0	87,238	226,377	0	27,314
	WTE 9	60,000	35,000	140,000	15,090	29,600	1,550	6,100
	WTE 10	139,220	0	0	34,085	0	0	0
Czech	WTE 11	232,985	0	232,170	68,699	71,174	588,130	17,677
Republic	WTE 12	94,336	0	193,072	31,798	23,168	266,812	10,005
Finland	WTE 13	320,000	0	60,700,000	78,600	500,000	750,000	500,000
	WTE 14	160,000	0	0	26,135	104,000	302,400	104,000
Denmark	WTE 15	56,334	0	188,959	10,781	30,760	84,520	5,653
	WTE 16	34,895	0	315,000	6,867	16,000	76,420	3,082
	WTE 17	127,060	0	0	36,140	165,300	479,000	17,875
	WTE 18	130,900	0	170,405	28,773	41,303	259,403	14,475
	WTE 19	408,000	0	0	103,600	156,000	841,000	18,000
	WTE 20	111,039	172,955	0	24,500	44,700	211,000	446,626
	WTE 21	235,993	1,223,000	0	47,300	154,000	487,000	17,000
	WTE 22	209,767	0	434,615	45,200	98,000	378,000	14,300
	WTE 23	54,000	0	106,000	10,600	25,000	111,800	1,300
	WTE 24	52,832	0	0	9,300	27,100	115,000	4,400
	WTE 25	189,900	0	500	40,000	132,000	374,000	19,000
	WTE 26	50,678	0	48,126	9,300	17,200	0	3,000
Germany	WTE 27	119,000	766,000	755,000	34,000	38,000	90,000	17,000
	WTE 28	227,000	0	242,000	57,000	105,000	0	30,000
	WTE 29	644,000	0	1,024,000	177,000	61,000	0	13,000
	WTE 30	111,000	160,000	180,000	30,000	61,000	30,000	13,000
	WTE 31	257,000	322,000	0	78,000	136,000	284,000	49,000
	WTE 32	366,000	2,330,000	6,400,000	113,000	140,000	345,000	60,000
Hungary	WTE 33	409,000	0	1,400,000	108,000	158,000	755,000	30,000
Norway	WTE 34	99,500	11,600	0	17,000	0	250,000	0
	WTE 35	148,000	887,000	0	27,000	53,000	507,000	0
	WTE 36	160,000	746,000	0	42,000	65,000	415,000	20,000
	WTE 37	46,800	0	42,700	10,500	8,478	105,000	0
Portugal	WTE 38	180,000	0	180,000	83,000	184,000	0	27,000
	WTE 39	121,000	758,000	647	4,000	53,000	0	14,000
Slovakia	WTE 40	123,000	0	244,000	32,000	40,000	263,000	9,000
Spain	WTE 41	340,000	0	0	77,000	170,000	0	23,000
	WTE 42	30,000	0	0	7,200	7	0	5
	WTE 43	315,000	0	0	41,000	236,000	0	65,000
Sweden	WTE 44	55,000	583,000	12,000	0	0	175,700	0
	WTE 45	91,000	155,000	0	0	33,000	203,300	33,000
	WTE 46	61,000	1,230	0	0	13,000	150,000	3,000
	WTE 47	540,000	1,000,000	0	0	220,000	1,440,000	66,000
	WTE 48	48,000	215,000	0	0	0	152,000	0
	WTE 49	549,000	792,000	0	0	234,000	1,300,000	104,000
	WTE 50	205,000	1,041,000	0	0	0	503,000	0

Table 3
Indicators considered in CTI and their weights

Aspect	Code	Indicator	Weight
Soil	SO-3	Waste or sub products generated by treated waste (kg.ton^{-1})	0.171
Materials	MA-3	Environmental liabilities avoided by treated waste (kg.ton^{-1})	0.216
Energy	EN-1	Electricity consumption by treated waste (kWh.ton^{-1})	0.161
	EN-2	Fossil fuel consumption by treated waste (kJ.ton^{-1})	0.154
	EN-3	Thermal energy generation by treated waste (kWh.ton^{-1})	0.142
	EN-4	Electricity generation by treated waste (kWh.ton^{-1})	0.156

Table 4
Minimum and maximum benchmarks values for waste-to-energy technology

Indicator code	Waste-to-energy benchmarks	
	Min	Max
SO-3	0.20	0.35
MA-3	0.65	0.80
EN-1	60	200
EN-2	20,000	700,000
EN-3	200	2,700
EN-4	150	800

Indicators' weight was determined according to the methodology described in [11].

It is important to note that indicators were normalized before aggregation, because they have different scales and units. It was used the method of Min-Max normalization that allows converting indicators to values between 0 and 1 using the maximum and minimum values of reference (benchmark). The benchmarks used in this study were obtained in [11] and they are presented in Table 4.

Two normalization equations were used. Eq. (2) is applied when an increase in the indicator acts favorably to the index raise, and Eq. (3) is used for normalization of indicators whose increase results in a reduction of the index value:

$$q = (x_{\text{variable}} - \min) / (\max - \min) \quad (2)$$

$$q = 1 - ((x_{\text{variable}} - \min) / (\max - \min)) \quad (3)$$

where q is normalized value of the indicator; x_{variable} is indicator not normalized; min is lower value of benchmarking; and max is higher value of benchmarking.

The CTI value, which could vary from 0 to 1, allows evaluating waste treatment technologies. According to the CTI value, the plant is classified in terms of environmental performance in the categories shown in Table 5. Further details about CTI methodology were described in [11].

Table 5
Environmental performance classification according to the CTI result

ICT value	Class
0.9–1.0	Excellent
0.8–0.9	Very good
0.7–0.8	Good
0.6–0.7	Regular
0.5–0.6	Tolerable
0.4–0.5	Bad
<0.4	Very bad

3. Results and discussion

Table 6 presents results of the CTI and the normalized indicator values obtained for each WTE plant. From the results, it could be noted that all the plants received maximum score for indicator EN-1, and 90% of them achieved the best score for EN-2. On the one hand, this indicates that the most part of plants have already attained low energy consumption requirements. On the other hand, the fact of the huge majority of plants to achieve the best score for these indicators suggests that the benchmark values could be changed toward more restrict limits related to energy consumption.

Moreover, Table 6 also provides the standard deviation and average values for indicators and CTI results. It is observed that the average and standard deviation of CTI are 0.73 and 0.13, respectively. From these statistics, globally it could be noted that a low variability of CTI results with 70% of the analyzed WTE plants presenting scores higher than 0.70 which corresponds to the lower limit of the category "Good".

It is also noted that EN-3 and EN-4 present the worst average scores, 0.49 and 0.41, respectively. So, this indicates that the performance of WTE plants analyzed, in terms of energy generation, could be strongly improved.

However, it is important to note that EN-3 and EN-4 are the indicators that present the higher standard deviations. This shows a high variability among WTE plants in terms of energy generation. Indeed, some plants present indicator results for EN-3 and EN-4 close to the lower benchmark limit, while others achieved the maximum reference value. So, this indicates that the WTE plants with bad scores in these indicators could also make many improvements in its energy generation rates to achieve the performance of the leading edge plants that obtained the higher scores.

Concerning SO-3 and MA-3, the average values were superior to 0.7 indicating that the demand for materials and the environmental liabilities avoided are globally with high scores. High SO-3 and MA-3 values indicate that the analyzed WTE plants were efficient in minimize waste to be landfilled, reducing land disposal demand.

Fig. 1 presents a diamond graphic in which it is made a comparison of the average indicator values with the indicator values of the WTE plants with the best and worst scores. Comparing the best plant, it is noted that it presents better scores for all indicators in relation to the average values, but the major difference is related to the performance of energy generation, comprising EN-3 and EN-4. Concerning the plant

Table 6
CTI and normalized indicator results for each WTE analyzed

Country	WTE plant code	SO-3	MA-3	EN-1	EN-2	EN-3	EN-4	CTI	Class
Austria	WTE 1	0.87	0.87	1.00	0.40	1.00	0.00	0.70	Good
	WTE 2	0.47	0.47	1.00	1.00	0.00	0.63	0.60	Regular
	WTE 3	1.00	1.00	1.00	1.00	0.35	0.02	0.76	Good
	WTE 4	0.12	0.12	1.00	1.00	0.00	0.99	0.52	Tolerable
Belgium	WTE 5	0.82	0.82	1.00	1.00	0.00	0.42	0.70	Good
	WTE 6	1.00	1.00	1.00	1.00	0.00	0.00	0.70	Good
	WTE 7	1.00	1.00	1.00	1.00	0.00	0.52	0.78	Good
	WTE 8	0.67	0.67	1.00	1.00	0.00	0.76	0.70	Good
	WTE 9	0.66	0.66	1.00	1.00	0.00	0.53	0.65	Regular
	WTE 10	0.70	0.70	1.00	1.00	0.00	0.00	0.59	Tolerable
Czech	WTE 11	0.37	0.37	1.00	1.00	0.93	0.24	0.63	Regular
Republic	WTE 12	0.09	0.09	1.00	1.00	1.00	0.15	0.51	Tolerable
Finland	WTE 13	0.70	0.70	1.00	0.00	0.86	1.00	0.71	Good
	WTE 14	1.00	1.00	1.00	1.00	0.68	0.77	0.92	Excellent
Denmark	WTE 15	1.00	1.00	1.00	1.00	0.52	0.61	0.87	Very good
	WTE 16	1.00	1.00	1.00	1.00	0.80	0.47	0.89	Very good
	WTE 17	0.44	0.44	1.00	1.00	1.00	1.00	0.78	Good
	WTE 18	0.87	0.87	1.00	1.00	0.71	0.25	0.79	Good
	WTE 19	0.64	0.64	1.00	1.00	0.74	0.36	0.72	Good
	WTE 20	0.86	0.86	1.00	1.00	0.68	0.39	0.81	Very good
	WTE 21	1.00	1.00	1.00	1.00	0.75	0.77	0.93	Excellent
	WTE 22	0.90	0.90	1.00	1.00	0.64	0.49	0.83	Very good
	WTE 23	1.00	1.00	1.00	1.00	0.75	0.48	0.88	Very good
	WTE 24	1.00	1.00	1.00	1.00	0.79	0.56	0.90	Excellent
	WTE 25	0.93	0.93	1.00	1.00	0.71	0.84	0.91	Excellent
	WTE 26	1.00	1.00	1.00	1.00	0.00	0.29	0.75	Good
Germany	WTE 27	0.43	0.43	1.00	0.85	0.22	0.26	0.53	Tolerable
	WTE 28	0.66	0.66	1.00	1.00	0.00	0.48	0.65	Regular
	WTE 29	0.50	0.50	1.00	1.00	0.00	0.00	0.51	Tolerable
	WTE 30	0.53	0.53	1.00	1.00	0.03	0.61	0.62	Regular
	WTE 31	0.31	0.31	1.00	1.00	0.36	0.58	0.58	Tolerable
	WTE 32	0.28	0.28	1.00	0.37	0.30	0.36	0.42	Bad
Hungary	WTE 33	0.57	0.57	1.00	1.00	0.66	0.36	0.69	Regular
Norway	WTE 34	1.00	1.00	1.00	1.00	0.93	0.00	0.83	Very good
	WTE 35	1.00	1.00	1.00	1.00	1.00	0.32	0.89	Very good
	WTE 36	0.58	0.58	1.00	1.00	0.96	0.39	0.74	Good
	WTE 37	0.84	0.84	1.00	1.00	0.82	0.05	0.76	Good
Portugal	WTE 38	0.00	0.00	1.00	1.00	0.00	1.00	0.47	Bad
	WTE 39	1.00	1.00	1.00	1.00	0.00	0.44	0.77	Good
Slovakia	WTE 40	0.60	0.60	1.00	1.00	0.78	0.27	0.70	Good
Spain	WTE 41	0.82	0.82	1.00	1.00	0.00	0.54	0.72	Good
	WTE 42	0.73	0.73	1.00	1.00	0.00	0.00	0.60	Regular
	WTE 43	1.00	1.00	1.00	1.00	0.00	0.92	0.85	Very good
Sweden	WTE 44	1.00	1.00	1.00	0.95	1.00	0.00	0.84	Very good
	WTE 45	1.00	1.00	1.00	1.00	0.81	0.33	0.87	Very good
	WTE 46	1.00	1.00	1.00	1.00	0.90	0.10	0.85	Very good
	WTE 47	1.00	1.00	1.00	1.00	0.99	0.40	0.90	Excellent
	WTE 48	1.00	1.00	1.00	1.00	1.00	0.00	0.84	Very good
	WTE 49	1.00	1.00	1.00	1.00	0.87	0.42	0.89	Very good
	WTE 50	1.00	1.00	1.00	1.00	0.00	0.00	0.70	Good
Average	–	0.76	0.76	1.00	0.95	0.49	0.41	0.73	–
Standard deviation	–	0.28	0.28	0.00	0.18	0.41	0.30	0.13	–

with the worst CTI score, it is noted that it scores worse than the average score values for all indicators.

Fig. 2, in turn, shows the number of WTE plants in each category. From the results, it was found that the most part of WTE analyzed (60%) have presented CTI values under 0.8 being classified as "Good" or in inferior categories.

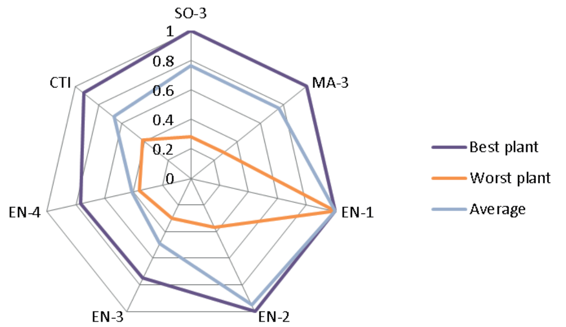

Fig. 1. Diamond graphic presenting average indicator values and indicators from the WTE plant with the worst and the best CTI scores.

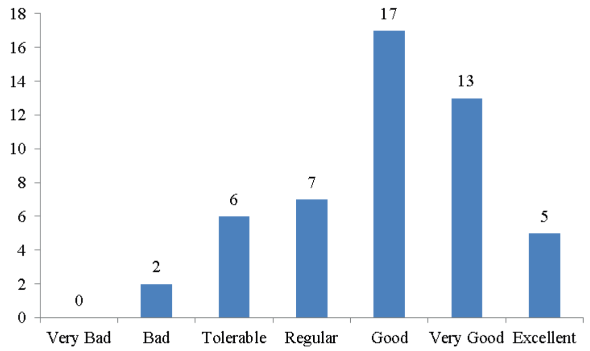

Fig. 2. Number of WTE plants in each environmental performance class, according CTI results.

Regarding each class, the most part of plants were classified as "Good" (17 plants) followed by "Very good" category with 13 WTE plants. In addition, no plant was classified as "Very bad" and only two plants are positioned in "Bad" class. It is important to note that only five WTE plants were classified as "Excellent" and all of them are located in Nordic countries.

Table 7 presents the averaged indicators and CTI values for each country. It is noted that WTE plants from Germany and Czech Republic present the lower CTI average values. The major reasons for the bad results of WTE from Czech Republic are related to the bad scores of SO-3, MA-3 and EN-4, whereas for Germany the worst ones are SO-3, MA-3 and EN-3. So, it is noted that the bad environmental performances are linked to several aspects, indicating that a more general improving in WTE system and management will be required to improve environmental performance.

On the other hand, Denmark and Sweden obtained the higher average CTI scores (0.84) followed by Finland (0.82) and Norway (0.81). Thus, it is noted that the analyzed WTE plants from Nordic countries have clearly better performances than the ones from other countries.

4. Conclusions

The results show that WTE plants from Nordic countries present a better environmental performance in terms of CTI values than the average level of European WTE evaluated. Results also indicate that EN-1 and EN-2 benchmark values need to be revised toward more restrict limits because it seems that the existent WTE plants have already achieved the current benchmark upper limit. The worst performances for the majority of plants were related to the indicators EN-3 and EN-4, which could suggest that energy recovery needs to be better managed.

In addition, from the "Results and discussion" section, it was found that the Cleaner Treatment Concept is an important tool to help environmental performance assessments of waste treatment technologies. The CTI index, in turn, makes the application of the Cleaner Treatment Concept easy in quantitative studies being an important instrument for practical uses of this treatment management approach.

Table 7
Average CTI and normalized indicators results for each country

Country	SO-3	MA-3	EN-1	EN-2	EN-3	EN-4	CTI	Class
Austria	0.62	0.62	1.00	0.85	0.34	0.41	0.65	Regular
Belgium	0.81	0.81	1.00	1.00	0.00	0.37	0.69	Regular
Czech Republic	0.23	0.23	1.00	1.00	0.97	0.20	0.57	Tolerable
Denmark	0.89	0.89	1.00	1.00	0.67	0.54	0.84	Very good
Finland	0.85	0.85	1.00	0.50	0.77	0.89	0.82	Very good
Germany	0.45	0.45	1.00	0.87	0.15	0.38	0.55	Tolerable
Hungary	0.57	0.57	1.00	1.00	0.66	0.36	0.69	Regular
Norway	0.86	0.86	1.00	1.00	0.93	0.19	0.81	Very good
Portugal	0.50	0.50	1.00	1.00	0.00	0.72	0.62	Regular
Slovakia	0.60	0.60	1.00	1.00	0.78	0.27	0.70	Good
Spain	0.85	0.85	1.00	1.00	0.00	0.49	0.72	Good
Sweden	1.00	1.00	1.00	0.99	0.80	0.18	0.84	Very good

References

[1] World Bank, What a Waste: A Global Review of Solid Waste Management, Washington, DC, USA, 2012, pp. 7–8.
[2] United States Environmental Protection Agency, Municipal solid waste (2012). Available from: http://www.epa.gov/epawaste/nonhaz/municipal/index.htm.
[3] World Commission on Environment and Development, Our Common Future, 2nd ed. Oxford, UK: Oxford University Press, 1991, pp. 50–100.
[4] S.A. Thorneloe, K.A. Weitz, Sustainability and waste management. In: Proceedings of Sustainable Waste Management, Waste Management Association of Australia, Melbourne, Nov. 2004, pp. 24–26.
[5] N.J. Themelis, M.E.D. Barriga, P. Estevez, M.G. Velasco, Guidebook for the Application of Waste to Energy Technologies in Latin America and the Caribbean, IDB – Inter-American Development Bank, 2012.
[6] A. Massarutto, Economic aspects of thermal treatment of solid waste in a sustainable WM system, Waste Manage., 37 (2015) 45–57.
[7] Confederation of European Waste-to-Energy, Plants: heating and lighting the way to sustainable future, 2012. Available from: http://www.cewep.eu/m_1073, accessed 11-28-2015.
[8] European Environment Agency, EEA Core Set of Indicators Guide, Copenhagen, Denmark, 2005, pp. 8–12.
[9] M. Saisana, S. Tarantola, State-of-the-art Report on Current Methodologies and Practices for Composite Indicator Development, European Commission–Joint Research Centre, Italy, 2002, pp. 23–45.
[10] United States Environmental Protection Agency, Solid Waste Management and Green House Gases – A Life Cycle Assessment of Emissions and Sinks, 2nd ed., 2006, pp. 45–63.
[11] H.M.G. Coelho, L.C. Lange, L.M.G. Coelho, Proposal of an environmental performance index to assess solid waste treatment technologies, Waste Manage., 32 (2012) 1473–1481.
[12] United Nations Environment Program, Environmental Agreements and Cleaner Production – Questions and Answers, 2006, p. 36.
[13] International Solid Waste Association, Waste-to-energy State-of-the-art-report Statistics, 6th ed., 2012, p. 210.