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RESP

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Assessing the current and future efficiency of OECD countries in municipal solid waste management

OECD ülkelerinin belediye katı atık yönetiminde mevcut ve gelecekteki verimliliğinin değerlendirilmesi

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ANAHTAR KELİMELER

Belediye Katı Atıkları
OECD
Öngörü
Dalgacık analizi
Burg modeli

ÖZ

Bu makalenin amacı, OECD ülkelerinin belediye katı atık yönetiminde mevcut ve gelecekteki verimliliğini değerlendirmektir. Metodoloji iki yönlüdür. Mevcut verimliliği değerlendirmek için yazarlar, GSYİH ile ölçülen daha fazla mal ve hizmet üretmenin, daha fazla belediye katı atık üretmek anlamına geldiğini varsayarak, belediye katı atıklarının GSYH'ye oranını hesaplamışlardır. Bu orana göre sonuçlar, 2020 yılında belediye katı atık yönetiminde Türkiye'nin en az verimli ülkelerden biri olduğunu, onu Kolombiya, Meksika, Şili ve Yunanistan'ın takip ettiğini göstermektedir. Norveç, 2020 yılında belediye katı atıklarında en düşük oranla en verimli yönetici olurken, onu Lüksemburg, İrlanda, İsviçre ve İsveç takip etmektedir. OECD ülkelerinin belediye katı atık yönetiminde gelecekteki verimliliğini değerlendirmek amacıyla, veri eksikliği nedeniyle Avustralya, Kanada ve Kosta Rika hariç 35 OECD ülkesi için toplanan zaman serileri dalgacık analizi ile tahmin edilerek 2100 belediye katı atık projeksiyonu sunulmaya çalışılmaktadır.

KEYWORDS

Municipal Solid Waste
OECD
Forecasts
Wavelet analysis
Burg model

ABSTRACT

The purpose of this paper is to assess the current and future efficiency of OECD countries in managing municipal solid waste. The methodology is twofold. To assess the current efficiency, the authors develop a ratio of municipal solid waste to GDP, assuming that producing more of goods and services, measured with GDP, means producing more municipal solid waste. Based on this ratio, results show that Turkey was the least efficient manager in municipal solid waste in 2020, followed by Colombia, Mexico, Chile and Greece. Norway was the most efficient manager in municipal solid waste in 2020 with the lowest ratio, followed by Luxembourg, Ireland, Switzerland, and Sweden. To assess future efficiency of OECD countries in managing municipal solid waste, 2100 projections of municipal solid waste are obtained by forecasting with wavelet analysis historical time series gathered by OECD from 35 countries excluding Australia, Canada, and Costa Rica for lack of data.

1. Introduction

This paper aims to assess the current and future efficiency of OECD countries in municipal solid waste management. Current efficiency will be measured from historical data and future efficiency from 2021-2100 municipal solid waste projections. 35 OECD countries are selected, excluding Australia, Canada, and Costa Rica for lack of data. Municipal solid waste includes items disposed by the public, such as product packaging, grass clippings, furniture, clothing, bottles, food scraps, newspapers, appliances, paint, and batteries. It comes mainly from household consumption but includes also some commercial and industrial wastes (US EPA, 2023). 2100 projections are obtained by forecasting with wavelet analysis municipal solid waste historical time series gathered by OECD from 35 countries. The Organization for Economic Co-operation and Development is an international organization of 38 countries that works to 'build better policies for better lives'. The OECD promotes 'prosperity, equality, opportunity and well-

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being for all' (OECD, 2023a). Together with governments, policy makers and citizens, the OECD works to set evidence-based international standards and find solutions to a range of social, economic and environmental challenges such as solid waste management. Looking at 2020 data of municipal solid waste produced by OECD countries gathered in Table 1 (source of the data: OECD, 2023b) and their relationship with GDP (current US$), GDP per capita, population, land and land + water superficies per country, allow researchers to identify strong relationships between municipal solid waste and GDP (correlation coefficient of +98.90%), municipal solid waste and population (+95.34%) and municipal solid waste and land area and land+water area (+93%). The higher the population, GDP and land area (or land + water area), the more municipal solid waste will be produced, which intuitively makes sense.

Table 1. 2020 municipal solid waste, Land + water area in km^2, Land area in km^2, Population, 2022 GDP (current US$) in millions USD and 2022 GDP per capita (current US$) by country

Country	(1) 2020 municipal solid waste in Tonnes, Thousands	(2) Land + water area in km^2	(3) Land area in km^2	(4) Population 2022 or 2023 estimates	(5) 2022 GDP (current US$) in millions USD	(6) 2022 GDP per capita (current US$)	(7) = (1) / (5) in %	(8) = (7) *normalized*	Ranking of (8) from highest to lowest
Correlation Coefficient ρ:		ρ(1,2) = 93.75%	ρ(1,3) = 93.44%	ρ(1,4) = 95.34%	ρ(1,5) = 98.90%	ρ(1,6) = 10.62%			
Austria	7,438.0	83,871	82,445	9,120,091	471,400.07	52,131.40	1.58%	-0.06	15.00
Belgium	8,408.0	30,528	30,278	11,755,313	578,604.10	49,582.80	1.45%	-0.22	18.00
Chile	8,177.4	756,102	743,812	19,960,889	301,025.25	15,355.50	2.72%	1.39	4.00
Colombia	12,082.5	1,141,748	1,038,700	52,215,503	343,939.45	6,630.30	3.51%	2.41	2.00
Costa Rica	1,459.3	51,100	51,060	5,213,362	68,380.84	13,198.80	2.13%	0.65	9.00
Czech Republic	5,814.0	78,871	77,171	10,827,529	290,923.53	27,638.40	2.00%	0.48	11.00
Denmark	4,744.0	2,220,093	2,220,072	5,941,388	395,403.91	66,983.10	1.20%	-0.54	25.00
Estonia	509.0	45,227	42,388	1,365,884	38,100.81	28,332.60	1.34%	-0.37	21.00
Finland	3,370.0	338,425	303,816	5,541,016	280,825.96	50,536.60	1.20%	-0.54	24.00
France	36,370.0	640,679	640,427	68,042,591	2,782,905.33	40,963.80	1.31%	-0.40	23.00
Germany	53,322.0	357,114	348,672	84,358,845	4,072,191.74	48,432.50	1.31%	-0.40	22.00
Greece	5,613.0	131,957	130,647	10,482,487	219,065.87	20,732.10	2.56%	1.20	5.00
Hungary	3,931.0	93,028	89,608	9,678,000	178,788.57	18,463.20	2.20%	0.73	8.00
Iceland	225.0	103,000	100,250	390,830	27,841.65	72,903.00	0.81%	-1.04	31.00
Ireland	3,210.0	70,273	68,883	5,149,139	529,244.87	104,038.90	0.61%	-1.30	34.00
Israel	5,976.0	20,770	20,330	9,741,000	522,033.45	54,659.80	1.14%	-0.61	26.00
Italy	28,945.0	301,339	294,140	58,803,163	2,010,431.60	34,158.00	1.44%	-0.23	19.00
Japan	41,669.0	377,976	364,546	124,500,000	4,231,141.20	33,815.30	0.98%	-0.81	29.00
Korea	22,544.6	100,210	99,909	51,439,038	1,665,245.54	32,254.60	1.35%	-0.34	20.00
Latvia	909.0	64,559	62,249	1,885,400	41,153.91	21,851.10	2.21%	0.75	7.00
Lithuania	1,350.0	65,300	62,680	2,862,274	70,334.30	24,826.80	1.92%	0.38	12.00
Luxembourg	498.0	2,586	2,586	660,809	82,274.81	126,426.10	0.61%	-1.30	35.00
Mexico	42,102.8	1,964,375	1,943,945	129,035,733	1,414,187.19	11,091.30	2.98%	1.73	3.00
Netherlands	9,304.0	41,850	33,893	17,887,100	991,114.64	55,985.40	0.94%	-0.87	30.00
New Zealand	3,705.0	270,467	262,443	5,199,100	247,234.05	48,249.30	1.50%	-0.16	17.00
Norway	3,247.0	385,207	365,957	5,504,329	579,267.37	106,148.80	0.56%	-1.35	36.00
Poland	13,117.0	312,696	311,888	37,726,000	688,176.61	18,321.30	1.91%	0.36	13.00
Portugal	5,279.0	92,226	91,119	10,467,366	251,945.38	24,274.50	2.10%	0.60	10.00
Slovak Republic	2,612.0	49,037	48,105	5,426,857	115,468.80	21,258.10	2.26%	0.82	6.00
Slovenia	1,024.0	20,273	20,151	2,116,972	62,117.77	29,457.40	1.65%	0.03	14.00
Spain	21,989.0	505,992	498,980	48,196,693	1,397,509.27	29,350.20	1.57%	-0.06	16.00
Sweden	4,460.0	447,425	407,284	10,538,026	585,939.17	55,873.20	0.76%	-1.10	32.00
Switzerland	6,096.0	41,277	39,997	8,865,270	807,706.04	92,101.50	0.75%	-1.11	33.00
Turkey	34,581.0	783,562	769,632	85,279,553	905,987.82	10,616.10	3.82%	2.80	1.00
United Kingdom	31,002.0	242,495	241,930	67,026,292	3,070,667.73	45,850.40	1.01%	-0.78	28.00
United States	265,224.5	9,833,517	9,147,593	335,038,000	25,462,700.00	76,398.60	1.04%	-0.74	27.00
						Average =	1.62%		
						Stand. Dev. Pop. =	0.78%		

Sources: OECD website at https://stats.oecd.org/index.aspx?DataSetCode=MUNW, [Time series of Municipal waste generated in Tonnes, Thousands], on the World Bank website at https://data.worldbank.org/indicator/NY.GDP.MKTP.CD [GDP (current US$), 2022 estimates], on Wikipedia website at https://en.wikipedia.org/wiki/List_of_countries_and_dependencies_by_population [Sovereign states and dependencies by population, 2022 or 2023 estimates] and on Wikipedia website at https://en.wikipedia.org/wiki/List_of_countries_and_dependencies_by_area [Countries and dependencies by area]

Table 2 confirms the positive and strong relationship between variables, except the 'GDP per capita' variable, which has a weak relationship with all other variables.

Table 2. Correlation coefficient table between 2020 municipal solid waste, Land + water area, Land area, Population, 2022 GDP (current US$) in millions USD and 2022 GDP per capita (current US$) variables

	(1) 2020 municipal solid waste in Tonnes, Thousands	(2) Land + water area	(3) Land area	(4) Population	(5) 2022 GDP (current US$) in millions USD	(6) 2022 GDP per capita (current US$)
(1) 2020 municipal solid waste in Tonnes, Thousands	100.00%					
(2) Land + water area	93.75%	100.00%				
(3) Land area	93.44%	99.98%	100.00%			
(4) Population	95.34%	86.53%	86.47%	100.00%		
(5) 2022 GDP (current US$) in millions USD	98.90%	93.16%	92.71%	91.45%	100.00%	
(6) 2022 GDP per capita (current US$)	10.62%	13.52%	13.27%	-2.26%	17.87%	100.00%

To track how effectively OECD countries are managing their municipal solid waste, the authors develop a ratio of 2020 municipal solid waste in tonnes, thousands to 2022 GDP (current USD) in USD million, assuming that producing more of goods and services, measured with GDP, means producing more municipal solid waste. The ratio is normalized for the 36 OECD countries, the more positive the ratio, the higher the ratio is than the average for OECD countries, the worse the management of municipal solid waste is. Conversely, the more negative the ratio, the lower the ratio is than the average for OECD countries, the better the management of municipal waste. Based on Table 1, with the highest normalized ratio of +2.80 (refer to the column labelled "8" in the first row and the row corresponding to Turkey), Turkey was the least efficient manager in municipal solid waste in 2020, followed by Colombia, Mexico, Chile and Greece. Norway was the most efficient manager in municipal solid waste in 2020 with the lowest normalized ratio of -1.35, followed by Luxembourg, Ireland, Switzerland and Sweden.

Section 2 reviews the literature on wavelet analysis modelling and starts with the literature on solid waste projections. Section 3 explains the forecasting method used in this paper. Section 4 presents and discusses the results. Section 5 concludes.

2. Literature Review

This research intends to assess the current and future efficiency of OECD countries in municipal solid waste management. Current efficiency will be measured from historical data and future efficiency from 2021-2100 municipal solid waste projections obtained with a forecasting model based on wavelet analysis. The first part of the literature review discusses solid waste projections in the literature, the second part presents wavelet analysis forecasting models in the literature.

2.1. Solid waste projections in the literature

Among seminal papers in the literature of solid waste projections, Kolekar et al. (2016) proposed a review of municipal solid waste generation prediction models. According to them, prediction models related to municipal solid waste generation used economic, socio-demographic or management-orientated data and identify possible factors that will help in selecting the crucial design options within the framework of mathematical modelling; most common attributes affecting waste generation being overall size of the household, income level of households, and the level of education. The World Bank was also a pioneer in the literature review of solid waste projections in its global snapshot of solid waste management to 2050 (Kaza et al., 2018). According to this study, waste generation will radically overtake population growth by more than double by 2050. By 2050, the world is expected to generate 3.40 billion tons of waste per year, a significant increase from 2.01 billion tons (2018 estimate). Although countries take action to improve and innovate in solid waste management, urgent action is still needed. Solid waste management affects all humans but first the most vulnerable ones who may lose their lives and homes from landslides of waste dumps, may work in unsafe waste-picking conditions, and suffer diseases. Plastic waste, one of the components of solid waste, is seeing its consumption increase. An example of article that describes the impact of plastic waste on the environment and humans' health in Pakistan is Sanjrani et al. (2023). In 2016, globally, 242 million tonnes of plastic waste were generated, which represents 12 percent of all municipal solid waste. In 2016, globally, about 1.6 billion tonnes of CO2-equivalent greenhouse gas emissions were generated from solid waste management, about 5 percent of total emissions. According to the World Bank study (Kaza et al., 2018), 'without action, solid waste–related emissions are anticipated to increase to 2.6 billion tonnes of CO2-equivalent by 2050.' Chen et al. (2020) studied trends and impacts of the world's growing municipal solid waste. They applied compositional Bayesian regression to produce the first estimates of past and future (1965–2100) waste generation disaggregated by composition and treatment, along with resultant environmental impacts, for every country. They found that total wastes grow at declining

speed with economic development, and that global waste generation increased from 635 Mt in 1965 to 1999 Mt in 2015 and will reach 3539 Mt by 2050. Chen et al. showed that a continuation of current trends and improvements is insufficient to reduce pressures on natural systems and achieve a circular economy. More recently, Teshome et al. (2023) proposed a multiple linear regression models to estimate the rate of household solid waste generation. They found that household solid waste generation rate is about 0.39 kilograms per capita per day and that organic waste accounted for the majority of the waste generated in the study area (71.28 percent), followed by other waste (9.77 percent), paper (6.71 percent), and plastic waste (6.41 percent). The solid waste generation rate demonstrated a positive relationship ($p<0.05$) with monthly household income and educational level. However, there was a negative association between family size and age ($p > 0.05$). The following section discusses how wavelet analysis, the model used in this paper, is applied in the literature of forecasting.

2.2. Wavelet analysis forecasting model in the literature

Wavelet analysis was first applied to physical phenomena including electrical, audio or seismic signals which propagate through space in waveforms. Wavelet analysis has also been applied in finance and economics since interest rates, exchange rates, volatility of asset returns, gross domestic product, levels of employment or consumer spending propagate through time in waveforms. Rostan and Rostan (2018a) illustrated the versatility of wavelet analysis when forecasting financial time series. To exemplify the versatility of wavelet analysis, Rostan and Rostan (2019) identified when European Muslim population will be majority in Europe with wavelet analysis. Rostan et al. (2015) assessed the financial sustainability of the Spanish pension system, and Rostan and Rostan (2018b) applied an identical methodology to Saudi pension system. Wavelet analysis was applied to the forecast of economic time series of countries such as Spain (Rostan and Rostan, 2018c) and Greece (Rostan and Rostan, 2018d), Saudi Arabia (Rostan and Rostan, 2021a and Rostan et al., 2023a), Austria (2020), countries of the Persian Gulf (2022a), Turkey (2022b), UK (2022c), Australia (2023a), South Korea (2023b), Brazil, Mexico and Argentina (2023d), Cyprus (2023e) and Eurozone (Rostan et al., 2023b). Interest rates were forecasted with wavelet analysis due to their valuable property of propagating through time in waveforms (Rostan et al., 2017). In addition, fossil fuels price estimates (Rostan and Rostan, 2021b), population estimates (Rostan et al., 2015; Rostan and Rostan, 2017) and global temperature projections (Rostan and Rostan, 2023c) were forecasted with wavelet analysis.

In this article, the authors assume that time series of the annual amount of municipal solid waste of the OECD countries propagate overtime in waveform patterns, like signals through space. Wavelet analysis focuses on the analysis, synthesis, and modification of signals. Wavelets mimic signals with specific properties that make them useful for signal processing. From a finite record of a stationary data sequence, Wavelet analysis estimates how the total power is distributed over frequency (Stoica & Moses, 2005). Wavelet analysis uses Discrete Wavelet Transform (DWT) due to several not tractable properties of Continuous Wavelet Transform (CWT) such as highly redundant wavelet coefficients (Valens, 1999), infinite number of wavelets in the wavelet transform and no analytical solutions found for most functions of the wavelet transforms. To refine wavelet-based forecasting method, Renaud et al. (2002) proposed redundant 'à trous' wavelet transform and multiple resolution signal decomposition.

Section 3 presents the methodology. Section 4 gathers the results and section 5 concludes.

3. Methodology

Table 3 gathers the information related to time series of Municipal solid waste in Tons, Thousands generated by OECD countries and collected by the OECD (2023b). The authors interpolated some data using the arithmetic average of previous and subsequent data when it was applicable. The numbers of interpolated data per country appear in Table 3

Table 3. Number of available data of historical time series of OECD countries (source of data: OECD, 2023b), number of data interpolated by the authors, level of decomposition applied in wavelet analysis (refer to step 2 of the methodology section), number of forecasted data for each OECD country

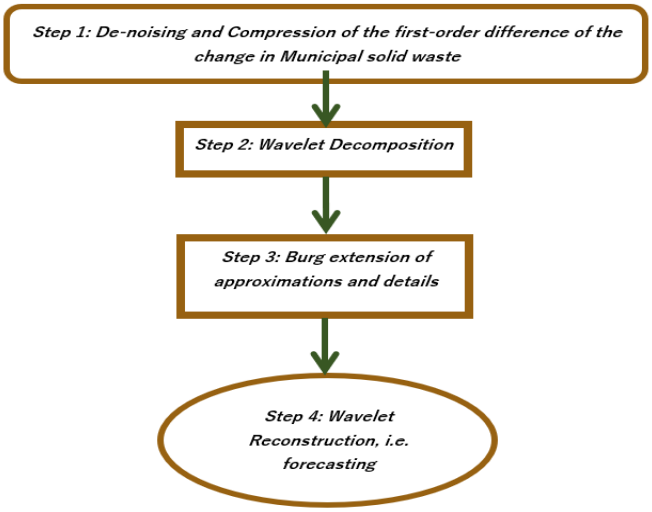
	Country	Available Data of time series of Municipal solid waste in Tons, Thousands	Number of interpolated data	Level of decomposition used in forecasting	Number of forecasted data
1	Australia	13 data from 2007 to 2019	0	No possible forecast	No possible forecasts due to a reduced number of available data
2	Austria	31 data from 1990 to 2020	0	4	80
3	Belgium	32 data from 1990 to 2021		4	79
4	Canada	No data available	0	No possible forecast	No possible forecasts with no available data
5	Chile	19 data from 2000 to 2019	2	6	81
6	Colombia	16 data from 2003 to 2018	0	7	82

7	Costa Rica	12 data from 2010 to 2021	0	No possible forecast	No possible forecasts due to a reduced number of available data
8	Czech Republic	27 data from 1995 to 2021	0	4	79
9	Denmark	28 data from 1994 to 2021	0	4	79
10	Estonia	27 data from 1995 to 2021	0	4	79
11	Finland	28 data from 1994 to 2021	0	4	79
12	France	30 data from 1992 to 2021	1	4	79
13	Germany	27 data from 1995 to 2021	0	4	79
14	Greece	30 data from 1990 to 2019	3	4	81
15	Hungary	32 data from 1990 to 2021	4	4	79
16	Iceland	26 data from 1995 to 2020	1	4	80
17	Ireland	26 data from 1995 to 2020	0	4	80
18	Israel	22 data from 2000 to 2021	0	5	79
19	Italy	31 data from 1990 to 2020	2	4	80
20	Japan	31 data from 1990 to 2020	0	4	80
21	Korea	31 data from 1990 to 2020	0	4	80
22	Latvia	27 data from 1995 to 2021	0	4	79
23	Lithuania	27 data from 1995 to 2021	0	4	79
24	Luxembourg	32 data from 1990 to 2021	0	4	79
25	Mexico	23 data from 1990 to 2012	1	5	88
26	Netherlands	32 data from 1990 to 2021	1	4	79
27	New Zealand	29 data from 1990 to 2018	14	4	82
28	Norway	32 data from 1990 to 2021	2	4	79
29	Poland	32 data from 1990 to 2021	0	4	79
30	Portugal	32 data from 1990 to 2021	1	4	79
31	Slovak Republic	32 data from 1990 to 2021	2	4	79
32	Slovenia	27 data from 1995 to 2021	0	4	79
33	Spain	27 data from 1995 to 2021	0	4	79
34	Sweden	32 data from 1990 to 2021	3	4	79
35	Switzerland	32 data from 1990 to 2021	0	4	79
36	Turkey	31 data from 1990 to 2020	3	4	80
37	United Kingdom	32 data from 1990 to 2021	4	4	79
38	United States	29 data from 1990 to 2018	0	4	82

Sources: OECD website at https://stats.oecd.org/index.aspx?DataSetCode=MUNW, [Time series of Municipal waste generated in Tonnes, Thousands]

Besides measuring the current efficiency of OECD countries in municipal solid waste management, this paper intends to measure future efficiency from 2021-2100 municipal solid waste projections obtained with a forecasting model based on wavelet analysis. The forecasting model, improved with a de-noising and compression step of the methodology presented in a seminal paper of Rostan & Rostan (2018a), requires four steps illustrated in Figure 1. The detailed methodology is available in Rostan & Rostan (2022b, *Journal of Emerging Economies & Policy*). The choice of the level of decomposition in step 2 is conditional to the number of available data, the greater the number of historical data of the time series, the lower the level of decomposition. The ideal number, as explained in Rostan & Rostan (2018a), is level-2 decomposition to generate more accurate projections. However, the constraint of a low number of historical data provided by the OECD (2023b), as detailed in Table 3, implies a minimum level of decomposition of 4 and a maximum level of 7 depending on the number of available data per country.

Figure 1. Flowchart of the methodology from steps 1 to 4.



4. Results

This paper aims to assess the current and future efficiency of OECD countries in municipal solid waste management. Current efficiency will be measured from historical data and future efficiency from 2021-2100 annual amount of municipal solid waste projections generated with wavelet analysis. In section 3, a four-step methodology is applied to the historical times series of annual amount of municipal solid waste, data recorded and disseminated by the OECD (2023b). Figures 2, 3, 4 and 5 illustrate the forecasts per OECD country obtained with the wavelet analysis forecasting model. The number of forecasted data, varying per country, is mentioned in the last column of Table 3. Table 4: 1) ranks OECD countries by 2020 ratios of efficiency in management of municipal solid waste from (1) least efficient country to (36) most efficient country and 2) ranks OECD countries by annual growth rates of 2021-2100 projections of the amount of municipal solid waste from (1) highest growth of the amount of municipal solid waste to (36) lowest growth of the amount of municipal solid waste. As mentioned earlier, with the highest normalized ratio of +2.8 (refer to the column labelled "4" in the first row of Table 4 and the row corresponding to Turkey), Turkey was the least efficient manager in municipal solid waste in 2020, followed by Colombia, Mexico, Chile and Greece. Norway was the most efficient manager in municipal solid waste in 2020 with the lowest normalized ratio of -1.35, followed by Luxembourg, Ireland, Switzerland and Sweden. With the highest annual growth rate of 2.63% (refer to the column labelled "5" in the first row of Table 4 and the row corresponding to Belgium) of its 2021-2100 projections of the amount of municipal solid waste, Belgium will have the most difficulty controlling the generation of municipal solid waste, followed by Austria, the Slovak Republic, the Czech Republic and Colombia. With the lowest annual growth rate of -1.31%, Japan will be best able to control municipal solid waste generation, followed by Sweden, Denmark, Switzerland and the UK. Switzerland and Sweden, appearing twice in the list of best-performing OECD countries in terms of current and future efficiency in the way they manage municipal solid waste, should serve as models for other countries to improve their management of municipal solid waste.

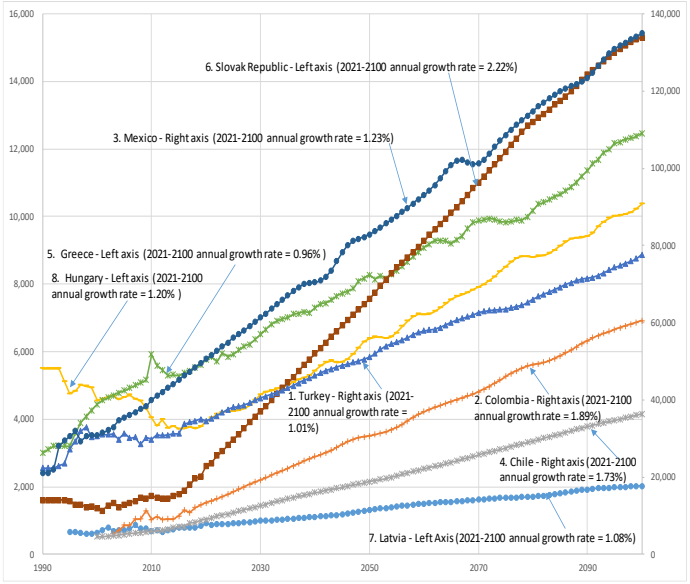
Table 4. 2020 Ranking of OECD countries by ratio of efficiency in management of municipal solid waste from (1) least efficient country to (36) most efficient country and Ranking of OECD countries in Annual Growth Rate of 2021-2100 projections of the amount of municipal solid waste from (1) highest growth of the amount of municipal solid waste to (36) lowest growth of the amount of municipal solid waste.

Country	(1) 2020 municipal solid waste in Tonnes, Thousands	(2) 2022 GDP (current US$) in millions USD	(3) = (1) / (2) in %	(4) = (3) *normalized*	Ranking of (4) from highest to lowest	(5) 2021-2100 Annual Growth Rate of municipal solid waste	Ranking of (5) from highest to lowest
Turkey	34,581.00	905,987.82	3.82%	2.8	1	1.01%	21
Colombia	12,082.50	343,939.45	3.51%	2.41	2	1.89%	5
Mexico	42,102.80	1,414,187.19	2.98%	1.73	3	1.23%	15
Chile	8,177.40	301,025.25	2.72%	1.39	4	1.73%	8
Greece	5,613.00	219,065.87	2.56%	1.2	5	0.96%	22
Slovak Republic	2,612.00	115,468.80	2.26%	0.82	6	2.22%	3
Latvia	909	41,153.91	2.21%	0.75	7	1.08%	20
Hungary	3,931.00	178,788.57	2.20%	0.73	8	1.20%	16
Costa Rica	1,459.30	68,380.84	2.13%	0.65	9	N/A	N/A
Portugal	5,279.00	251,945.38	2.10%	0.6	10	1.17%	17
Czech Republic	5,814.00	290,923.53	2.00%	0.48	11	2.18%	4
Lithuania	1,350.00	70,334.30	1.92%	0.38	12	0.73%	24
Poland	13,117.00	688,176.61	1.91%	0.36	13	1.76%	7
Slovenia	1,024.00	62,117.77	1.65%	0.03	14	1.10%	19
Austria	7,438.00	471,400.07	1.58%	-0.06	15	2.28%	2
Spain	21,989.00	1,397,509.27	1.57%	-0.06	16	0.50%	27
New Zealand	3,705.00	247,234.05	1.50%	-0.16	17	1.55%	12
Belgium	8,408.00	578,604.10	1.45%	-0.22	18	2.63%	1
Italy	28,945.00	2,010,431.60	1.44%	-0.23	19	0.43%	29
Korea	22,544.60	1,665,245.54	1.35%	-0.34	20	0.90%	23
Estonia	509	38,100.81	1.34%	-0.37	21	0.15%	30
Germany	53,322.00	4,072,191.74	1.31%	-0.4	22	0.49%	28
France	36,370.00	2,782,905.33	1.31%	-0.4	23	0.59%	26

Finland	3,370.00	280,825.96	1.20%	-0.54	24	1.62%	10
Denmark	4,744.00	395,403.91	1.20%	-0.54	25	-0.24%	33
Israel	5,976.00	522,033.45	1.14%	-0.61	26	1.54%	13
United States	265,224.50	25,462,700.00	1.04%	-0.74	27	1.40%	14
United Kingdom	31,002.00	3,070,667.73	1.01%	-0.78	28	0.09%	31
Japan	41,669.00	4,231,141.20	0.98%	-0.81	29	-1.31%	35
Netherlands	9,304.00	991,114.64	0.94%	-0.87	30	0.70%	25
Iceland	225	27,841.65	0.81%	-1.04	31	1.13%	18
Sweden	4,460.00	585,939.17	0.76%	-1.1	32	-1.20%	34
Switzerland	6,096.00	807,706.04	0.75%	-1.11	33	-0.02%	32
Ireland	3,210.00	529,244.87	0.61%	-1.3	34	1.67%	9
Luxembourg	498	82,274.81	0.61%	-1.3	35	1.59%	11
Norway	3,247.00	579,267.37	0.56%	-1.35	36	1.80%	6
		Average =	1.62%				
		Stand. Dev. Pop. =	0.78%				

Figure 2 gathers the 9 least efficient countries among 36 OECD countries based on the 2020 ratio of efficiency in municipal solid waste management ranked from (1) the least efficient country to (36) the most efficient country.

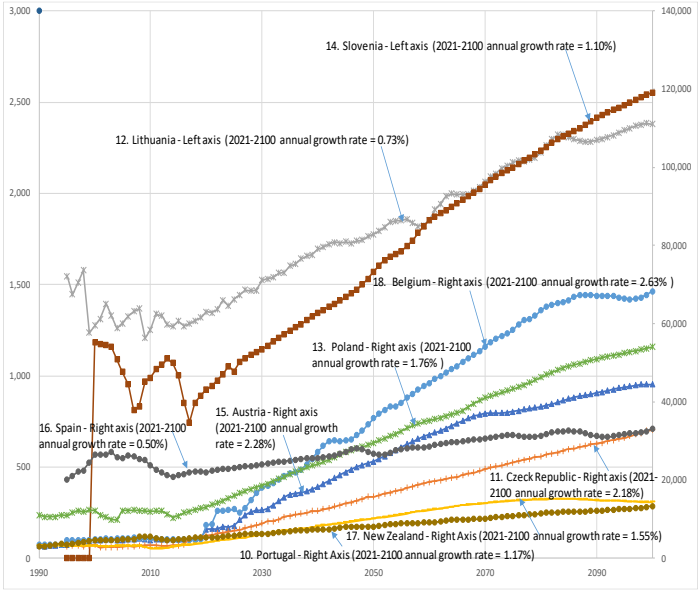
Figure 2. 2100 projections of annual amount of municipal solid waste of OECD countries ranked from 1 to 9 in Table 1 (last column)



Among 8 countries of Figure 2 (8 countries instead of 9, Costa Rica projections were not obtained due to limited historical data), the Slovak Republic will have the most difficulty controlling the generation of municipal solid waste (2021-2100 annual growth rate of +2.22%) and Greece will be best able to control municipal solid waste generation (2021-2100 annual growth rate of +0.96%).

Figure 3 gathers the 9 countries among 36 OECD countries ranked from 10 to 18 based on the 2020 ratio of efficiency in municipal solid waste management ranked from (1) the least efficient country to (36) the most efficient country.

Figure 3. 2100 projections of annual amount of municipal solid waste of OECD countries ranked from 10 to 18 in Table 1 (last column)



Among 35 countries under study (35 countries instead of 36, Costa Rica projections were not obtained due to limited historical data), Belgium will have the most difficulty controlling the generation of municipal solid waste, with a 2021-2100 annual growth rate of +2.63% of its amount of municipal solid waste. Among the 9 countries of Figure 3, Spain will be best able to control municipal solid waste generation (2021-2100 annual growth rate of +0.50%).

Figure 4 gathers the 9 countries among 36 OECD countries ranked from 19 to 27 based on the 2020 ratio of efficiency in municipal solid waste management ranked from (1) the least efficient country to (36) the most efficient country.

Figure 4. 2100 projections of annual amount of municipal solid waste of OECD countries ranked from 19 to 27 in Table 1 (last column)

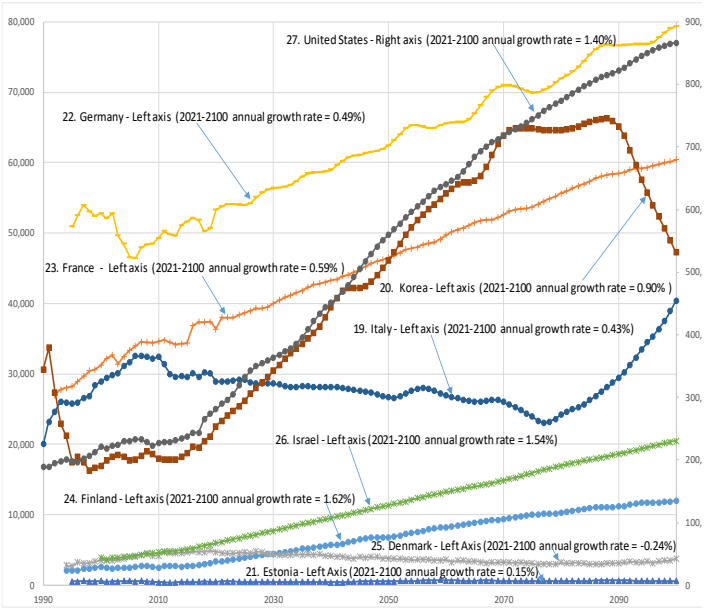
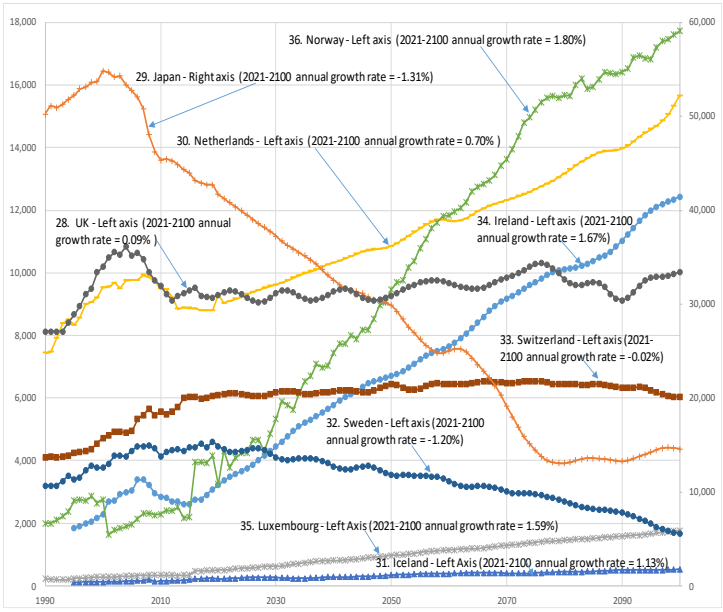


Figure 5. 2100 projections of annual amount of municipal solid waste of OECD countries ranked from 28 to 36 in Table 1 (last column)



Among the 9 countries of Figure 4, Finland will have the most difficulty controlling the generation of municipal solid waste (2021-2100 annual growth rate of +1.62%) and Denmark will be best able to control municipal solid waste generation (2021-2100 annual growth rate of -0.24%).

Figure 5 gathers the 8 countries among 36 OECD countries ranked from 28 to 36, identified as the best countries in terms of management of municipal solid waste based on the 2020 ratio of efficiency in municipal solid waste management ranked from (1) the least efficient country to (36) the most efficient country.

Among 35 countries under study (35 countries instead of 36, Costa Rica projections were not obtained due to limited historical data), Japan will be best able to control municipal solid waste generation with a 2021-2100 annual growth rate of -1.31% of its amount of municipal solid waste. Among the 9 countries of Figure 5, Norway will have the most difficulty controlling the generation of municipal solid waste (2021-2100 annual growth rate of +1.80%).

5. Conclusion

This paper measures the current and future efficiency of OECD countries in municipal solid waste management. Current efficiency was measured from 2020 historical data for 36 OECD Countries excluding Australia, and Canada for lack of data. Future efficiency was measured from 2021-2100 municipal solid waste projections for 35 OECD Countries excluding Australia, Canada and Costa Rica for lack of data. 2021-2100 municipal solid waste projections are obtained by forecasting historical data of annual amounts of municipal solid waste with wavelet analysis. Time series of annual amounts of municipal solid waste are collected by the OECD (2023b). Wavelet analysis uncovers municipal solid waste time series by transforming them into simplified time series after decomposition, extrapolating the information embedded in these simplified series and reconstructing the predicted time series.

To measure the current efficiency of OECD countries in municipal solid waste management, a 2020 ratio of efficiency is obtained by dividing 2020 municipal solid waste (in Tons, Thousands) by 2022 GDP (current US$) in millions USD, then normalized it for the 36 countries (including Costa Rica). The correlation coefficient between municipal solid waste and GDP over 36 countries is 98.90%, which suggests that the greater the production of goods and services, the greater the municipal solid waste generation. This high correlation coefficient intuitively explains the rationale for using the ratio as an indicator of current efficiency. OECD countries are ranked with their 2020 ratio of efficiency in municipal solid waste management from (1) least efficient country to (36) most efficient country. With

the highest normalized ratio of +2.80, Turkey was the least efficient manager in municipal solid waste in 2020, followed by Colombia, Mexico, Chile and Greece. Norway was the most efficient manager in municipal solid waste with the lowest normalized ratio of -1.35, followed by Luxembourg, Ireland, Switzerland and Sweden.

To measure the future efficiency of OECD countries, 35 OECD countries are ranked with their Annual Growth Rate of 2021-2100 projections of the amount of municipal solid waste from (1) highest growth of the amount of municipal solid waste (least efficient) to (35) lowest growth of the amount of municipal solid waste (most efficient). Out of 36 countries, Costa Rica was dropped from the list since Costa Rica projections were not obtained due to limited historical data. With the highest annual growth rate of 2.63% of its 2021-2100 projections of the amount of municipal solid waste out of 35 OECD countries, Belgium will have the most difficulty controlling the generation of municipal solid waste, followed by Austria, the Slovak Republic, the Czech Republic and Colombia. With the lowest annual growth rate of -1.31%, Japan will be best able to control municipal solid waste generation, followed by Sweden, Denmark, Switzerland and the UK. Switzerland and Sweden, appearing twice in the list of best-performing OECD countries in terms of current and future efficiency in the way they manage municipal solid waste, should serve as models for other countries to improve their management of municipal solid waste.

Further research could focus on identifying the secret recipes of countries like Switzerland, Sweden or Japan in their efficient management of municipal solid waste and how to implement these recipes in countries that lack efficiency.

Data availability statement: The data that support the findings of this study are openly available on OECD website at https://stats.oecd.org/index.aspx?DataSetCode=MUNW, [Time series of Municipal waste generated in Tonnes, Thousands], on the World Bank website at https://data.worldbank.org/indicator/NY.GDP.MKTP.CD [GDP (current US$), 2022 estimates], on Wikipedia website at https://en.wikipedia.org/wiki/List_of_countries_and_dependencies_by_population [Sovereign states and dependencies by population, 2022 or 2023 estimates] and on Wikipedia website at https://en.wikipedia.org/wiki/List_of_countries_and_dependencies_by_area [Countries and dependencies by area]

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