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Municipal Solid Waste and Utility Consumption in Taiwan

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Abstract: In Taiwan, 3,130,735 t of refuse for disposal and 4,113,808 t of recycled recyclable waste were generated in 2017. The government of Taiwan has been actively promoting a resource recycling program since July 1998. To pursue sustainability and locate waste minimization opportunities, the correlation between utility consumption and population and the quantity of refuse and recyclable waste from municipalities in Taiwan was studied. There are six special municipalities and 16 cities and counties covering a great variety of urbanization and settlement characteristics, such as registered populations, electricity, and water consumption. The above parameters of the municipalities were correlated with the quantities of refuse and recycled urban waste. Residential electricity consumption, overall population, and business electricity consumption were found to be major parameters correlating the generation of refuse and recycled urban waste. Due to their higher levels of business activities, the waste generation behaviours of these six special municipalities are more diverse than those of the 16 municipalities. Due to the discrepancy of the registered population system, the utility consumption values within administrative boundaries can better predict municipal solid waste, (MSW) generation than utility consumption at a per capita. Utility consumption within administrative boundaries is more convenient as a measure to predict refuse and recycled urban waste than other complex social–economic indicators.

Keywords: municipal solid waste; recycling; recyclable waste; sustainability; urban; utilities

1. Introduction

The environmental challenges facing human societies due to ever-increasing living standards have increasingly receiving attention globally. Making cities sustainable is listed as Sustainable Development Goal 11 (SDG 11) by the United Nations [1]. Target 6 of SDG 11 is to reduce the adverse per capita environmental impact of cities, which involves paying special attention to environmental and waste management issues [1]. In total, 12 out of the 17 UN SDGs relate to the issue of solid waste management [2] since 2.01 billion tonnes of municipal solid waste (MSW) are annually generated worldwide [3]. The complex nature of solid waste management issues requires an interdisciplinary approach [4,5].

Various studies have focused on the waste generation rates in connection with other socio–economic statistics. A study on China compounded household electricity consumption per capita with the urbanisation level and compared it to the annual solid waste generation, ultimately finding a good correlation [5]. Traditional forecasting methods for solid waste generation frequently count on demographic and socioeconomic factors on a per-capita basis. The per-capita coefficients may be

taken as fixed over time or projected to change over time [6]. The energy and material flows through the world's 27 megacities with populations greater than 10 million people (as of 2010) were quantified by Kennedy et al. [7]. Collectively, the resource flows through megacities were found to be largely consistent [7]. Correlations were established for electricity consumption, water consumption, waste generation, and population growth [7]. Identifying the megacities that exhibit high and low levels of consumption and those that make efficient use of resources could facilitate the pursuit of sustainability [7].

Like other developing areas, Taiwan has also experienced rapid urbanization and industrialization over the last few decades. Due to its high population density and decreasingly available land resources for waste disposal, Taiwan has been improving its measures for waste disposal and moving toward sustainability.

1.1. Background

Taiwan is a small and densely populated island, with a total area slightly less than 36,000 km^2. The average population density was 651.2 people/km^2 in 2017 [8]. The population growth of Taiwan has been stagnating, with 22,958,360 inhabitants in 2007 and 23,571,227 in 2017. There are six special municipalities and 16 counties and cities in Taiwan. The administrative regions with population of 1,250,000 or more that have special requirements in their political, economic, cultural, and metropolitan development may establish special municipalities based on the Local Government Act of Taiwan [9]. The pertinent legislation distinguishes two kinds of waste: industrial and general waste. General waste is defined as waste generated by non-industrial sources (according to the Waste Disposal Act of Taiwan [10]). General waste, originating from households and business activities and collected and administered by local government agencies, is referred to as municipal solid waste (MSW) in this study. MSW includes refuse, kitchen and food waste, bulk waste, and recyclable waste [11]. A portion of the general MSW that does not belong to food waste, bulk waste, or recyclable waste (disposed by incineration plants and landfills) is referred to as refuse in this study. The list of articles designated as recyclable waste is administered by the Taiwan Environmental Protection Administration (TEPA) and reviewed annually. According to the regulations of 2017 [12], there are 14 articles designated as recyclable waste, including paper and plastics containers, batteries, motorcycles, automobiles, batteries, tires, lubricants, electrical appliances, computer products, and others.

1.2. Resource Recycling Programs in Taiwan

During and prior to the 90's, waste recycling in Taiwan was operated by private enterprises and individuals and solely guided by market mechanisms. The Waste Disposal Plan, announced by TEPA in 1991, outlined the prospects of improving waste recycling and replacing landfill by incineration, among other issues. TEPA promulgated several laws in 1998 to enhance recycling: the establishment of a four-in-one recycled network, regulating the responsible handling of regulated recyclable waste by enterprises, and regulating recyclable waste auditing and certification. Started in July 1998, the government of Taiwan has established, owned, and managed the national recycling network. The four-in-one national recycling network is comprised of community residents, recycling enterprises, the cleaning teams of local governments, and the national recycling fund. The first three parties conduct actual recycling. The national recycling fund, administered by TEPA, regulates recycling enterprises, manages recycling fees, and subsidizes the first three parties. Enterprises designated in public announcements are obligated, before paying periodic sales tax, to pay recycling, clearance, and disposal fees to the recycling fund, a rate decided upon by the central authority. In accordance with international trends, TEPA launched the policy of "waste minimization and resource recovery" in 2003 to promote zero waste, green manufacturing, green consumption, source minimization, resource recovery, and reuse [11].

Then, TEPA formulated the Programs for General Waste Recycling and Resources and Resource Recovery in 2007, which includes seven tasks: mandatory garbage sorting, the versatile usage of

kitchen and food waste, the versatile usage of bulk waste, the reuse of household renovation waste, zero waste promotion, sewage treatment, and the recycling of scraped vehicles.

After implementation of the above programs, the waste management system captured and properly managed 99.98% of waste in 2015. Incineration replaced landfills as the principal means of waste disposal. At the end of 2019, 97.47% of refuse (waste that is not recycled) was incinerated, and 2.53% was landfilled [11]. The resource recovery rates (defined as the summation of the recycled 14 regulated recyclable articles) reached 53.5% in 2018 [11]. National resource recycling quantities are defined as the summation of the recycled 14 regulated recyclable articles. Incineration plants and sanitary landfills treated 2,969,654 and 70,382 tonnes of refuse in 2017 for Taiwan. In 2007, 4,335,770 and 504,944 tonnes of refuse were treated by incineration plants and sanitary landfills [13]. On the other hand, the recyclable waste recycled by implementing agencies totaled 2,408,429 to 4,113,808 tonnes from 2007 to 2017 [14]. The increase of recycling rates in recent decades illustrates the progress of the Resource Recycling Program in Taiwan, as illustrated in Figure S1 in the Supplementary Materials.

1.3. Objectives

The infrastructure for MSW treatments is always under pressure, despite the well-operating waste minimization and resource recycling programs in Taiwan. Natural disasters, such as typhoons and earthquakes, have frequently increased the sudden burdens of current MSW facilities. Many of the 25 operating incineration plants in Taiwan are reaching either a major service period or their end-of-life. In addition, landfills and facilities that store and treat recyclable waste are reaching their respective limits. In Taiwan, six special municipalities and 16 cities and counties cover a large variety of urbanization and settlement characteristics, such as the population areal density and electricity and water consumption, both within the administration boundary and per capita. There are many socio–economic, environmental, and MSW service factors employed to correlate or evaluate MSW systems [15], such as households [16], GDP per capita [17], and recycling rates [18]. Since all human activities require electricity and water consumption, the present study aims to compare the correlation between MSW, population, and utility consumption to identify the most pertinent factors influencing MSW generation.

Previous progress for MSW management for waste minimization in Taiwan was reviewed more than a decade ago [19]. The policy influence potential for solid waste management decision making in Taiwan was previously investigated via the analytic hierarchy process (AHP) [20]. However, the predictions of future trends under the consistent socio–economic and policy changes of the last two decades require more in depth analysis of up-to-date data. The proper prediction of refuse and recycled solid waste quantities in Taiwan is vital to strategic long-term environmental planning.

To improve the future strategies of the national resource recycling program, we investigate the overall environmental benefits of the program that promote urban sustainability management, the impact of settlement characteristics on the total quantities of regulated recycled recyclable waste, and the refuse among municipal solid waste in Taiwan.

2. Data Description and Methodology

2.1. Land Area and Population

The total registered population, population density, and land area were obtained from the Department of Statistics, Ministry of the Interior, Taiwan, ROC [21]. In the Taiwanese system, every administration unit keeps records of the registered members of each household. Figure 1 shows a map of Taiwan indicating the administrative boundaries of six special municipalities and 16 counties and cities.

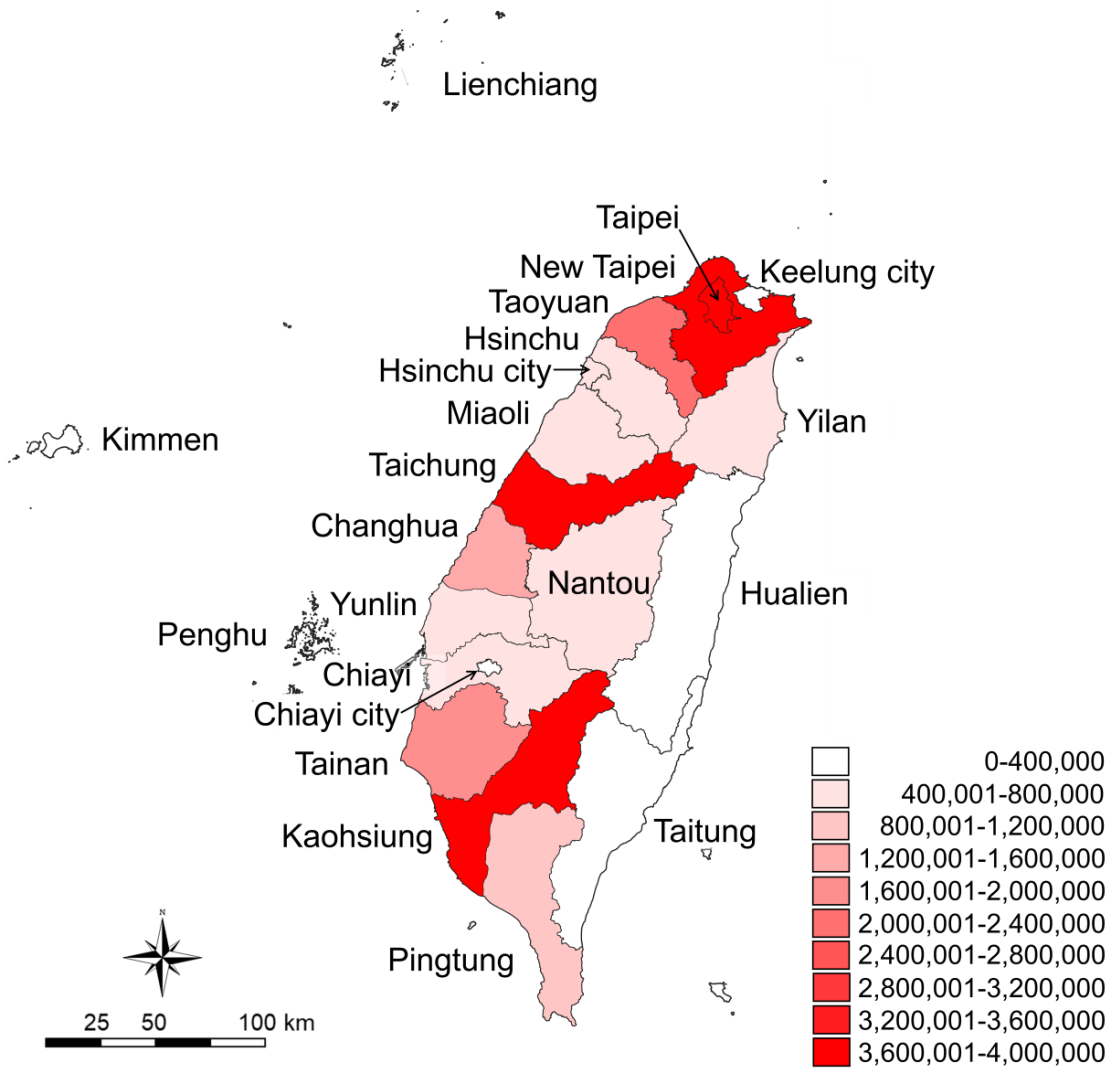

Figure 1. Map of municipalities of Taiwan.

Table 1 shows the population and land areal data of six special municipalities and 16 cities and counties in Taiwan, as well as the population densities.

Table 1. 2017 Population statistics of municipalities of Taiwan.

Distinction	Country	Population		Area *		Population Density
			percentage	km^2	percentage	Person/km^2
Special municipalities	New Taipei City	3,986,689	16.91	2053	5.67	1942
	Taichung City	2,787,070	11.82	2215	6.12	1258
	Kaohsiung City	2,776,912	11.78	2952	8.16	941
	Taipei City	2,683,257	11.38	272	0.75	9872
	Taoyuan City	2,188,017	9.28	1221	3.37	1792
	Tainan City	1,886,522	8.00	2192	6.06	861
	Subtotal	**16,308,467**	**69.19**	**10,905**	**30.13**	**1496**
Counties and cities	Changhua	1,282,458	5.44	1074	2.97	1194
	Pingtung	829,939	3.52	2776	7.67	299
	Yunlin	690,373	2.93	1291	3.57	535
	Miaoli	553,807	2.35	1820	5.03	304
	Hsinchu	552,169	2.34	1428	3.95	387

Table 1. *Cont.*

Distinction	Country	Population		Area *		Population Density
	Chiayi	511,182	2.17	1904	5.26	269
	Nantou	501,051	2.13	4106	11.34	122
	Yilan	456,607	1.94	2144	5.92	213
	Hsinchu City	441,132	1.87	104	0.29	4235
	Keelung City	371,458	1.58	133	0.37	2798
	Hualien	329,237	1.40	4629	12.79	71
	Chiayi City	269,398	1.14	60	0.17	4488
	Taitung	219,540	0.93	3515	9.71	62
	Kimmen	137,456	0.58	152	0.42	906
	Penghu	104,073	0.44	127	0.35	820
	Lienchiang	12,880	0.05	29	0.08	447
	Subtotal	**7,262,760**	**30.81**	**25,292**	**69.87**	**287**
	Total	**23,571,227**	**100**	**36,197**	**100**	**651**

*: Land area only.

2.2. Refuse and Recycled Waste

Data on refuse [13], food waste, bulk wasten and recycled waste [14] were obtained from the Environmental Protection Administration, Executive Yuan, ROC. Recyclable waste (not including kitchen and food waste and bulk waste) is referred to as recycled waste in this study. Table 2 lists the above data expressed as the total and per capita weight. The recycling rates are calculated by dividing the recycled waste by the total waste weight in Table 2. The total waste weights include refuse, kitchen and food waste, bulk waste, and recyclables. Since the present study mainly investigates recycled waste and refuse, data on kitchen and food waste, bulk waste, and the total waste weights are listed in Supplementary Table S1.

Table 2. Waste generation of Taiwan in 2017.

Distinction	Country	Refuse			Recycled Waste			Recycle Rate
		ton	%	Per capita	ton	%	Per capita	%
Special municipalities	New Taipei City	390,679	12.83	0.098	606,677	14.75	0.152	52.36
	Taichung City	357,187	11.73	0.128	457,481	11.12	0.164	53.00
	Kaohsiung City	377,711	12.40	0.136	496,185	12.06	0.179	51.16
	Taipei City	205,932	6.76	0.077	468,299	11.38	0.175	62.02
	Taoyuan City	379,199	12.45	0.173	487,301	11.85	0.223	54.74
	Tainan City	238,233	7.82	0.126	339,573	8.25	0.180	50.58
	Subtotal	**1,948,941**	**64.01**	**0.120**	**2,855,516**	**69.41**	**0.175**	**53.79**
Counties and cities	Changhua	191,519	6.29	0.149	206,098	5.01	0.161	49.20
	Pingtung	141,747	4.66	0.171	146,776	3.57	0.177	47.66
	Yunlin	86,576	2.84	0.125	83,605	2.03	0.121	44.09
	Miaoli	88,015	2.89	0.159	106,423	2.59	0.192	50.55
	Hsinchu	77,099	2.53	0.140	90,144	2.19	0.163	51.09
	Chiayi	70,917	2.33	0.139	98,629	2.40	0.193	53.58
	Nantou	86,734	2.85	0.173	81,536	1.98	0.163	45.37
	Yilan	70,451	2.31	0.154	83,769	2.04	0.183	50.51
	Hsinchu City	61,411	2.02	0.139	83,143	2.02	0.188	51.14
	Keelung City	63,942	2.10	0.172	85,461	2.08	0.230	52.22
	Hualien	50,324	1.65	0.153	59,575	1.45	0.181	51.27
	Chiayi City	42,931	1.41	0.159	47,718	1.16	0.177	48.06
	Taitung	35,319	1.16	0.161	47,229	1.15	0.215	52.02
	Kimmen	11,246	0.37	0.082	16,319	0.40	0.119	52.17
	Penghu	15,725	0.52	0.151	19,042	0.46	0.183	47.88
	Lienchiang	2052	0.07	0.159	2826	0.07	0.219	41.92
	Subtotal	**1,096,008**	**35.99**	**0.151**	**1,258,293**	**30.59**	**0.173**	**49.47**
	Total	**3,044,949**	**100**	**0.129**	**4,113,809**	**100**	**0.175**	**52.39**

2.3. Electricity Consumption

Both residential and business electricity consumption data were obtained from the Taiwan Power Company [22]. Statistics on electricity consumption do not include agricultural and industrial usage [22]. Residential electricity covers the actual in-house power usage. Business electricity covers the office, service, and tourism industries and reflects the strength and intensity of all business activities. Table 3 presents the electricity consumption in six special municipalities and 16 cities and counties in 2017. Six special municipalities, comprising 69.19% of the total population, consumed 69.89% and 77.63% of all household and business electricity, respectively.

Table 3. The electricity consumption of Taiwan in 2017.

Distinction	Country	Household Electricity			Business Electricity		
		kWh	%	Per capita	kWh	%	Per capita
Special municipalities	New Taipei City	7,595,834,139	17.02	1905	3,339,767,233	19.76	838
	Taichung City	5,418,247,516	12.14	1944	2,766,215,461	16.37	993
	Kaohsiung City	5,351,240,142	11.99	1927	1,670,322,383	9.88	602
	Taipei City	4,839,223,577	10.84	1803	2,589,705,192	15.32	965
	Taoyuan City	4,268,433,997	9.56	1951	1,653,253,956	9.78	756
	Tainan City	3,722,639,779	8.34	1973	1,056,560,140	6.25	560
	Subtotal	**31,195,619,150**	**69.89**	**1913**	**13,075,824,365**	**77.36**	**802**
Counties and cities	Changhua	2,337,148,181	5.24	1822	744,551,509	4.40	581
	Pingtung	1,601,899,674	3.59	1930	371,022,188	2.20	447
	Yunlin	1,318,486,706	2.95	1910	286,143,720	1.69	414
	Miaoli	999,761,483	2.24	1805	299,379,905	1.77	541
	Hsinchu	1,101,591,987	2.47	1995	335,795,440	1.99	608
	Chiayi	885,685,724	1.98	1733	190,640,030	1.13	373
	Nantou	846,890,618	1.90	1690	237,009,681	1.40	473
	Yilan	871,346,186	1.95	1908	279,762,822	1.66	613
	Hsinchu City	930,233,245	2.08	2109	311,348,788	1.84	706
	Keelung City	674,457,039	1.51	1816	178,774,159	1.06	481
	Hualien	640,203,090	1.43	1945	196,647,502	1.16	597
	Chiayi City	515,119,301	1.15	1912	184,537,278	1.09	685
	Taitung	391,364,701	0.88	1783	114,856,278	0.68	523
	Kimmen	118,703,468	0.27	864	35,751,807	0.21	260
	Penghu	177,424,059	0.40	1705	49,061,688	0.29	471
	Lienchiang	27,596,789	0.06	2143	11,835,090	0.07	919
	Subtotal	**13,437,912,251**	**30.11**	**1850**	**3,827,117,885**	**22.64**	**527**
	Total	**44,633,531,401**	**100**	**1894**	**16,902,942,250**	**100**	**717**

2.4. Water Consumption

Water consumption data for the total residential and business water usage within the administrative boundary were obtained from the Taiwan Water Company [23]. Statistics on water consumption do not include agricultural and industrial usage [23]. The water consumption in Taiwan in 2017 is listed in Table 4. Six special municipalities, comprising 69.19% of the total population, consumed 72.15% of the country's water supply.

Table 4. Water consumption of Taiwan in 2017.

Distinction	Country	Water Consumption		
		L	%	Per capita
Special municipalities	New Taipei City	443,475	19.35	0.111
	Taichung City	262,634	11.46	0.094
	Kaohsiung City	250,728	10.94	0.09
	Taipei City	328,476	14.33	0.122
	Taoyuan City	204,914	8.94	0.094
	Tainan City	163,462	7.13	0.087
	Subtotal	**1,653,689**	**72.16**	**0.101**

Table 4. *Cont.*

Distinction	Country	Water Consumption		
Counties and cities	Changhua	94,322	4.12	0.074
	Pingtung	80,615	3.52	0.097
	Yunlin	58,972	2.57	0.085
	Miaoli	44,448	1.94	0.08
	Hsinchu	49,543	2.16	0.09
	Chiayi	44,830	1.96	0.088
	Nantou	44,865	1.96	0.09
	Yilan	41,187	1.80	0.09
	Hsinchu City	49,056	2.14	0.111
	Keelung City	39,963	1.74	0.108
	Hualien	30,507	1.33	0.093
	Chiayi City	27,926	1.22	0.104
	Taitung	19,172	0.84	0.087
	Kimmen	5128	0.22	0.037
	Penghu	6578	0.29	0.063
	Lienchiang	829	0.04	0.064
	Subtotal	**637,941**	**27.84**	**0.088**
	Total	**2,291,630**	**100**	**0.097**

For plotting refuse, recycled waste, and the population (with respect to the sizes of the six special municipalities and 16 cities and counties shown in Figure S2 in the Supplementary Material), the ranked quantitative distribution for the amount of waste and size of the population are consistent with the patterns of international cities [7] and China [17].

Linear regression and Pearson analysis were conducted using the SPSS software.

3. Results and Discussion

3.1. Recyclable Waste vs. Refuse

Figure 2 shows refuse vs. recyclable waste for all six special municipalities and 16 cities and counties. The correlation coefficient is 0.934 for all six special municipalities and 16 cities and counties, as shown in Figure 2. The above correlation is expected, since all six special municipalities and 16 cities and counties execute an identical national program for recyclable waste management in Taiwan. All special municipalities and cities and counties in Taiwan have a similar degree of development in their MSW systems. The correlation coefficient for 16 cities and counties, 0.967, is ever higher for the 16 cities and counties shown in Figure S3 in the supplementary section. The above observation suggests that the 16 cities and counties might have more similar lifestyles. The correlation coefficient among all six special municipalities alone is only 0.513.

Taipei city has lower quantities of refuse relative to recycled waste compared to other settlements. The reason for this may be that Taipei City has operated a volume-based collection fee (VCF) system since July 2000. This VCF system charges households and citizens based on a user pays principle [19]. Before the adoption of the VCF system, waste-collection fees charged in Taipei city were based on household water usage. This system failed to provide an incentive for households to reduce their waste generation, as reflected by the annual MSW generation figures. To remediate this problem, the VCF system was introduced by Taipei City. Under the VCF system, citizens purchase officially authorized garbage bags for their refuse [19]. In addition, the MSWs of many housing complexes are collected and disposed of by specialized cleaning companies. This portion may be counted as industrial waste rather than MSW, which may also contribute to the lower figure for waste generation in Taipei City.

New Taipei city is an outlier in the other direction, with higher quantities of refuse than the others (relative to recycled waste). Interestingly, New Taipei City has also adopted a VCF system in 2010, but effects found in Taipei are not observable here. Possibly, more people commute from New Taipei

city to Taipei city and leave their refuse there during work hours. The greater number of international migrant workers residing in new Taipei city might generate more uncounted refuse and recycled waste per capita. Many international migrant workers in the manufacturing sector also reside in Taoyuan city. The above factors may contribute to the higher refuse and recyclable waste per capita for those special municipalities. The smaller de facto residing population in Tainan city might contribute to its lower refuse and recycled waste per capita. The low overall population of Tainan city (the lowest among the municipalities) contributes the least overall refuse and recyclable waste among the six special municipalities.

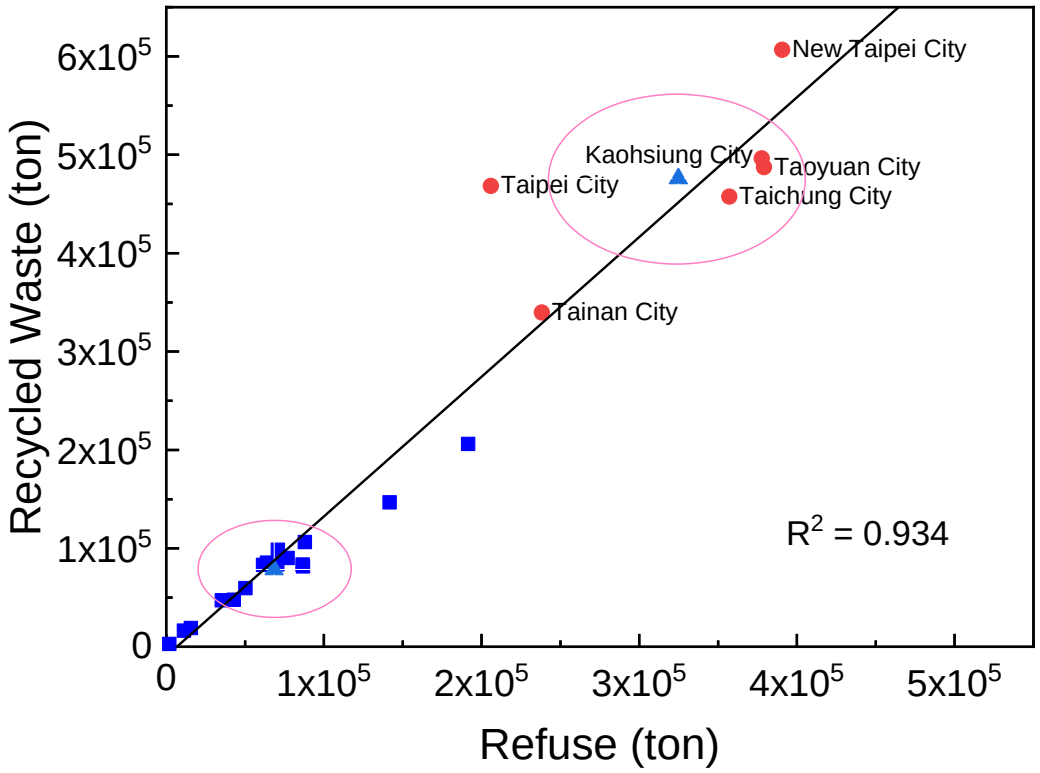

Figure 2. Refuse vs. Recycled waste correlation. Blue solid square: 16 Counties and cities; Red solid circle: six special municipalities.

The quantities of recycled waste for the five special municipalities exceed four hundred thousand tons. This observation suggests that the infrastructure for handling recycled waste may soon reach its limit. On the other hand, the quantity of recycled waste in Tainan city has some space for growth. A more rigorous program for recycled waste collection for Taipei city might contribute to an exceeding lower quantity of refuse. Tainan city has more agricultural settlements than the other special municipalities. Taoyuan city, however, has a larger manufacturing industry and thus hires the most international migrant workers. The characteristics of Taichung city are between those of Tainan city and Taoyuan city. Commuters, students, international migrant workers, and business and leisure travellers might contribute most to the disparity of the first three special municipalities.

The Pearson correlation coefficient for recyclable waste vs. refuse, listed in Table S2 in the supplementary section, is 0.952. The Pearson correlation coefficient for per capita recyclable waste vs. refuse, listed in Table S3 in the supplementary section, is 0.685. The total quantities within the administrative boundaries correlate better than the per capita quantities. The correlation coefficient for all six special municipalities and 16 counties shown in Figure 2 also suggestst a disparity in lifestyle and waste generation patterns within these administration regions. The delineation of six special municipalities is not only done by population density but also from an historical, geographical, and regional developmental perspective [9].

3.2. Registered Population

The correlation between the registered population and refuse quantity is shown in the upper panel of Figure 3, and the correlation between the registered population and recyclable waste is shown in the lower panel of Figure 3. The correlation coefficient is 0.972 and 0.893 for recyclable waste and refuse in all six special municipalities and 16 cities and counties, as shown in Figure 3. The lower correlation with refuse might have contributed to the higher level of business activities in some municipalities. The lower quantities of both refuse and recycled waste in Tainan city suggest that the actual residing population might be lower than the registered population. The higher quantities of both refuse and recycled waste in Taoyuan city suggest that many international workers and domestically migrating families might contribute to the large quantity of solid waste.

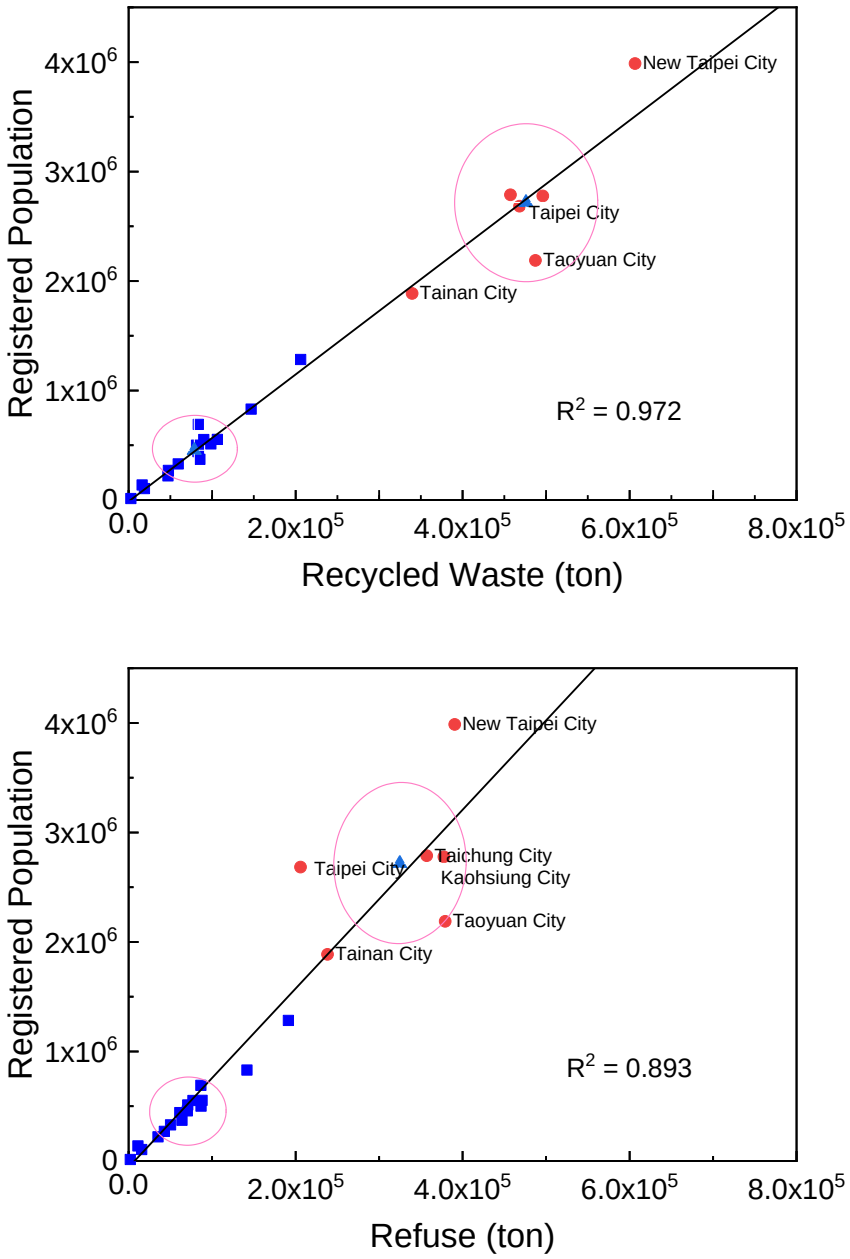

Figure 3. Registered population vs. recycled waste and refuse. Blue solid square: 16 Counties and cities; Red solid circle: six special municipalities.

The correlation coefficients are 0.943 and 0.971 for recycled waste and refuse, respectively, for the 16 cities and counties (Figure S4 in supplementary section). This observation also suggests that the 16 cities and counties might have similar lifestyles. In contrast, the correlation coefficients vs. registered population for the six special municipalities alone are only 0.47 and 0.46, respectively, which again suggests a great disparity in lifestyles, domestic and international commuting patterns, migrant populations, different levels of business activities, etc. This disparity might be caused by the presence of more agricultural communities in Taoyuan, Taichung, and Tainan. When analysing the correlations against population density, no correlations were found for the analyzed utilities, as shown in Table S2 in the supplementary section. Similarly, low correlation coefficients were found for the utility consumption per capita, as shown in Table S3 in the supplementary section.

Hence, the registered population alone cannot properly serve as an indicator. On the other hand, the overall registered population within the administrative boundary still serves as the foundation for analyses of solid waste generation.

Household registration of the population is frequently used as the basis for the environmental decision-making process. However, there are common social phenomena in every society, such as de facto migration and studying or working away-from-home. Hence, the Directorate General of Budget, Accounting and Statistics (DGBAS), of Executive Yuan conducts a Population and Housing Census once per decade. This census provides an understanding of the quantity and characteristics of the resident population, as well as the household and family formation, study and work status, and household occupation. The information derived from this census is provided to the government as the primary basis for the implementation of national policies and infrastructure development, as well as to support pertinent studies [24]. In the latest population and housing census report of 2010, 74.66% of the population lived at their nationally registered address [25]. However, there was also a great discrepancy: 84.1% and 30.5% of the population in Yunlin county and Lienchiang county, respectively, actually lived in their registered addresses in 2010. Such a discrepancy could contribute to the lower correlation between the registered population and MSW quantities. In addition, many other social activities, such as the service and tourism industries, may contribute to MSW generation. This also includes international migrant workers. Since all human activities require electricity and water consumption, the present study is meant to compare the correlation between MSW, the population, and utility consumption.

3.3. Electricity Consumption

3.3.1. Residential Electricity

Residential electricity is charged using a low base rate plus the actual kilowatts consumed per household with lower rates than those charged for business users. Hence, it could serve as an index to analyze solid waste generation.

The correlation between residential electricity and refuse is shown in the upper panel of Figure 4, and the correlation between residential electricity and recyclable waste is shown in the lower panel of Figure 4. The correlation coefficient is 0.973 and 0.907 for the recyclable waste and refuse, respectively, for all six special municipalities and 16 cities and counties, as shown in Figure 4. The lower correlation with refuse might be attributed to the higher level of business activities producing refuse for some municipalities. The linear correlation coefficient is 0.936 and 0.960 for refuse and recyclable waste, respectively, for all 16 cities and counties, as shown in Figure S5 in the supplementary section. The high correlations suggest that household activities are directly responsible for the generation of refuse and recyclable waste for all 16 cities and counties. The above observation also suggests that all six special municipalities and 16 cities and counties might have similar lifestyles regarding residential electricity consumption and MSW generation.

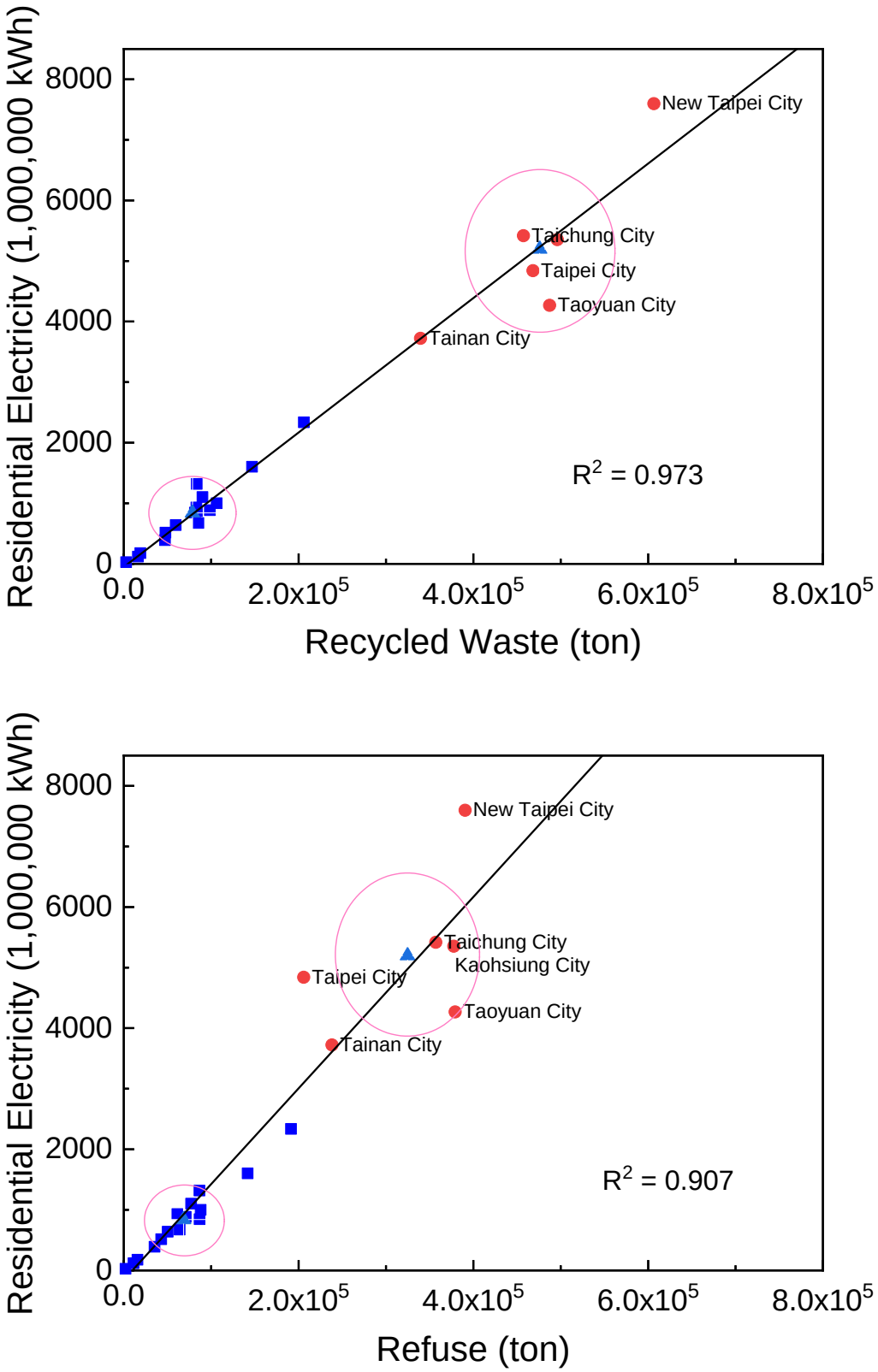

Figure 4. Refuse and recycled waste vs. residential electricity correlation. Blue solid square: 16 Counties and cities; Red solid circle: six special municipalities.

While Taoyuan city and Tainan City consumed similar levels of residential electricity, Taoyuan generated much more refuse than Tainan city. In contrast, while Taichung city had much higher residential electricity consumption than Taoyuan city, both cities generated the same level

of refuse. Taichung city had much higher residential electricity consumption than Taoyuan city, but both cities generated the same level of refuse. The linear correlation coefficient for all six special municipalities also demonstrated a great disparity in lifestyle, domestic and international commuting populations, and migrant populations, as well as different levels of business activities, etc. The above disparity, revealed by the low correlation, might be caused by the greater number of agricultural sub-municipalities in Taoyuan, Taichung, and Tainan. Even lower correlation coefficients were obtained for all per capita analyses in Table S2 in the supplementary section. A further examination of the disparity between cities could reveal more waste minimization opportunities and facilitate a better long term waste management strategy.

All Pearson correlation coefficients for residential electricity vs. refuse, business electricity, recyclable waste, and water consumption listed in Table S2 in the supplementary section are greater than 0.95. Only the two Pearson correlation coefficients for residential electricity vs. business and water consumption, listed in Table S3 in the supplementary section, are greater than 0.58. The total quantities within the administrative boundaries correlate better than the per capita quantities for residential electricity.

3.3.2. Business Electricity

Business electricity is charged per household with separate rates; hence, it could be used as an index to analyze solid waste generation.

The correlation between business electricity and refuse is shown in the upper panel of Figure 5, and correlation between business electricity and recyclable waste is shown in the lower panel of Figure 5. The correlation coefficient is 0.903 and 0.777 for recyclable waste and refuse for all six special municipalities and 16 cities and counties, as shown in Figure 5. The lower correlation with refuse might be attributed to the more random nature of solid waste generated from the business activities in some municipalities. These correlations that are lower than the values of household electricity consumption suggest that business activities generate a greater quantitative variety of refuse and recyclable waste in all six special municipalities and all 16 cities and counties. The linear correlation coefficient is 0.892 and 0.894 for refuse and recyclable waste, respectively, for all 16 cities and counties, as shown in Figure S6 in the supplementary section. Figure S6 shows better recycled waste recovering for two members among 16 cities and counties, as their data lie in the right of the correlation lines in the upper panel of Figure S6.

All Pearson correlation coefficients for business electricity vs. refuse, business electricity, recyclable waste, and water consumption (listed in Table S1 in the supplementary section) are greater than 0.9. Only the two Pearson correlation coefficients for residential electricity vs. business and water consumption (listed in Table S2 in the supplementary section) are greater than 0.58. The total quantities within the administrative boundaries also correlate better than the per capita quantities for business electricity. The high correlation among per capita utility consumption suggests a similar consumption pattern for electricity and water among the study areas. The low correlation among per capita refuse and recyclable waste suggests that the registered population alone cannot be used alone to predict the generation of refuse and recyclable waste.

Above observation also suggests that the 16 cities and counties might have similar lifestyles. The linear correlation coefficients vs. business electricity for all six special municipalities alone are only 0.405 and 0.584 for refuse and recyclable waste. The recyclable waste correlates better with business electricity consumption for all six special municipalities. Refuse correlates better with residential electricity consumption for all six special municipalities. The above comparison suggests that business activities more strongly influence recyclable waste generation, while household activities more strongly influence the refuse generation for all six special municipalities.

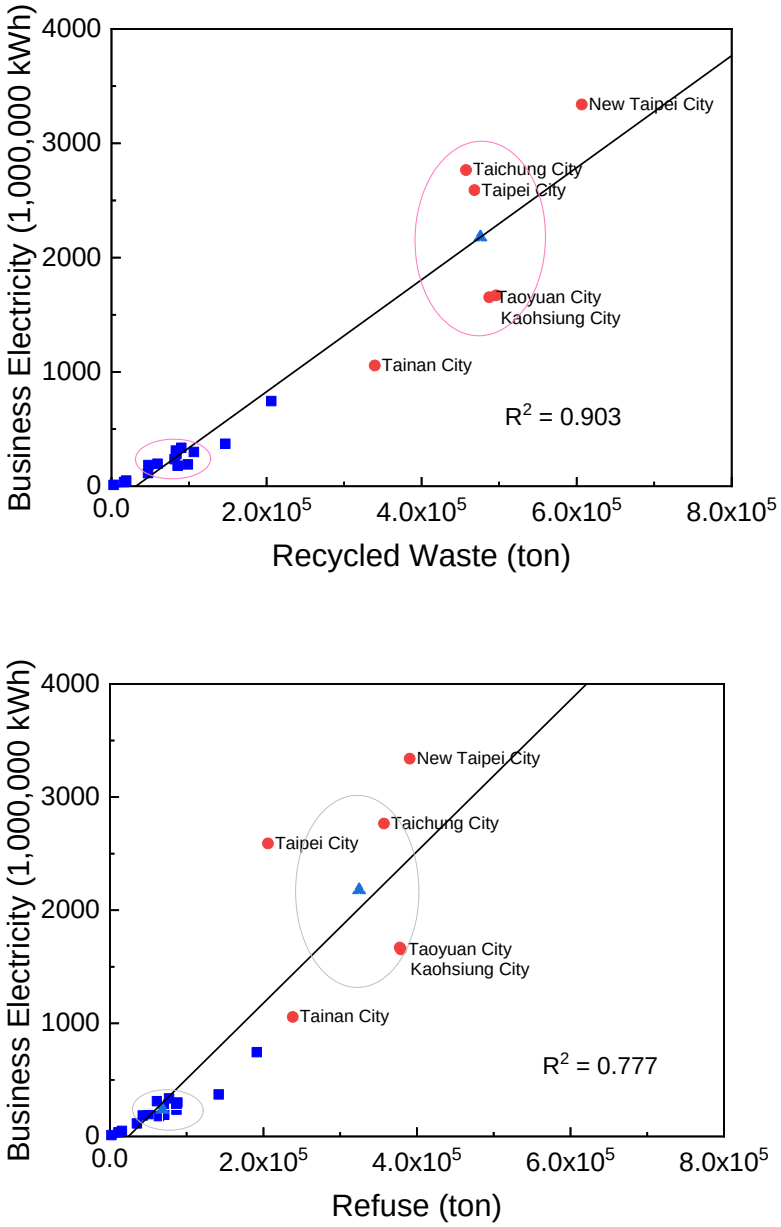

Figure 5. Refuse and recycled waste vs. business electricity correlation. Blue solid square: 16 Counties and cities; Red solid circle: six special municipalities.

3.4. Water Consumption

Water consumption is charged per household, regardless of residential or business purposes, so water consumption within the boundary of each municipality is counted in this study. The linear correlation between water consumption and refuse is shown in the upper panel of Figure 6, and the correlation between water consumption and recyclable waste is shown in the lower panel of Figure 6. The linear correlation coefficient is 0.931 and 0.790 for the refuse and recyclable waste for all six special municipalities and 16 cities and counties, as shown in Figure 6. Like electricity consumption, water consumption could be used as an indicator for refuse and recyclable waste. The correlation coefficient is 0.940 and 0.942 for the refuse and recyclable waste of all 16 municipalities, as shown in Figure S6 in the supplementary section. Like electricity consumption, the 16 municipalities demonstrated similar lifestyles in the correlation between water consumption and waste generation. The correlation coefficient vs. water consumption for all six special municipalities alone is only 0.291 and 0.471, respectively, for refuse and recyclable waste. The water consumption for all six special

municipalities is even more diverse and shows that electricity consumption within administrative boundaries could serve as a better indicator than water consumption to predict municipal solid waste generation. The linear correlation coefficient is 0.932 and 0.944 for recyclable waste and refuse, respectively, for all 16 cities and counties, as shown in Figure S7 in the supplementary section. Higher correlation among all 16 cities and counties suggests a more consistent water consuming living pattern for all 16 cities and counties.

All Pearson correlation coefficients for water consumption vs. refuse, business electricity, residential electricity, and water recyclable waste (Table S2 in the supplementary section) are greater than 0.9. Only one significant Pearson correlation coefficient per capita for water consumption vs. business and residential electricity is 0.576. The total quantities within administrative boundaries correlate better than the per capita quantities for water consumption, as well as for business and residential electricity.

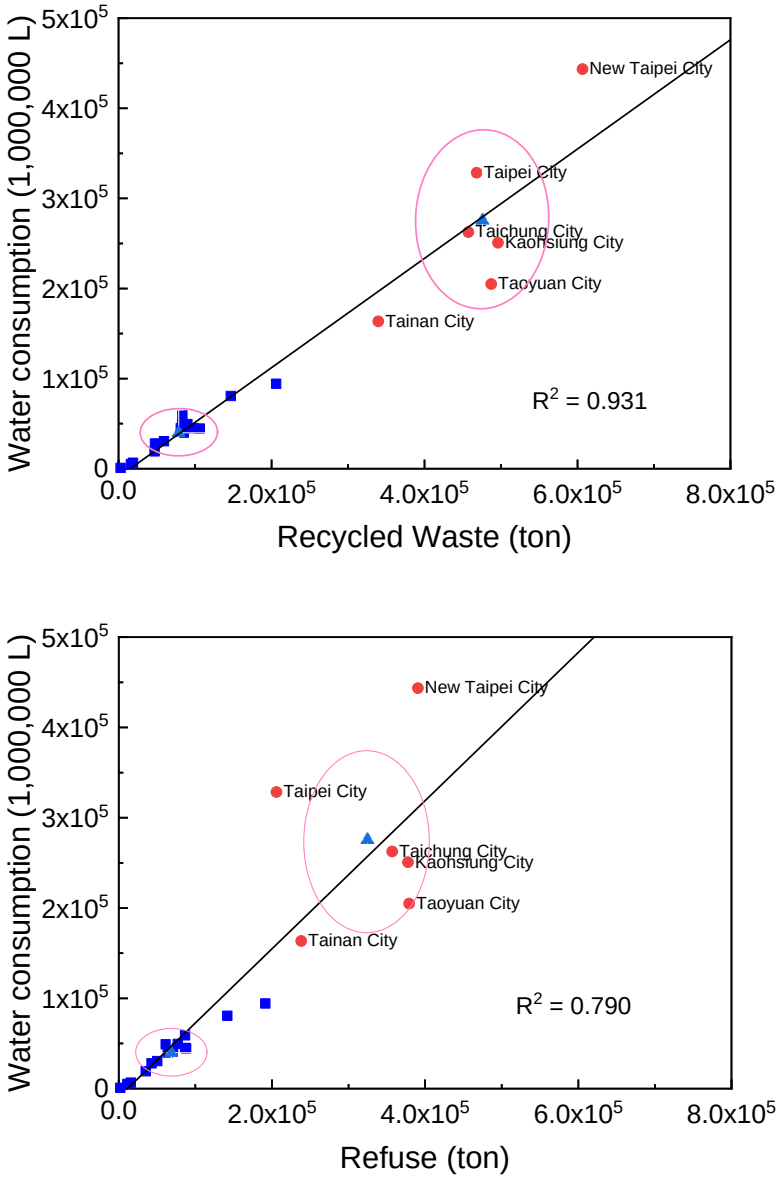

Figure 6. Refuse and recycled waste vs. water consumption correlation. Blue solid square: 16 Counties and cities; Red solid circle: six special municipalities.

4. Conclusions

Resource consumption is closely related to the lifestyles of municipal residents and has an important impact on changes in the quantity and quality of refuse and recycled municipal solid waste. The quantities of refuse and recyclable waste generation, as well as residential electricity consumption, business electricity consumption, and water consumption, are correlated. The degree of correlation for refuse and recyclable waste generation correlates with municipal utility consumption in the following order: residential electricity consumption, business electricity consumption, and water consumption within administrative boundaries. Discrepancies in the registered population were also found, which reduced the correlation between MSW generation and utility consumption per capita. A total of 16 counties and cities with similar lifestyles and degrees of business activities correlated better than the six special municipalities with higher degrees of business activities and much more diverse lifestyles. Discrepancies in the registered population were likewise found, which greatly reduced the correlation between per capita MSW generation and utility consumption. Many current incineration plants in Taiwan are aging, and many cities and counties have devised their own MSWs to be treated or disposed by the facilities of other cities and counties. The findings of the present study suggest that the trend of predicted utility consumption within administrative boundaries could be effectively employed to predict the trends of MSW generation within administrative boundaries, optimize the priority of upgrading current MSW facilities, and construct new facilities. The data on utility consumption within administrative boundaries are also much simpler to obtain and use than other complex socio–economic indicators.

Supplementary Materials: The following are available online at http://www.mdpi.com/2071-1050/12/8/3425/s1, Figure S1: MSW treatment in Taiwan, Figure S2: The correlation with population, recycled waste and refuse in Taiwan, Figure S3: Recycled waste and refuse for cities and counties, Figure S4: Registered population vs. recycled waste and refuse for cities and counties, Figure S5: Recycled waste and refuse waste vs. residential electricity for cities and counties, Figure S6: Recycled waste and refuse waste vs. business electricity for cities and counties, Figure S7: Recycled waste and refuse vs. water consumption for cities and counties; Table S1: Recycle rate of Taiwan in 2017, Table S2: Pearson correlation between utilities and MSW generation of municipalities of Taiwan, Table S3: Pearson correlation between utilities parameters and MSW generation of municipalities of Taiwan per capita based.

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