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Predicting the Generation of Municipal Solid Waste on the Islands of Malta

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I. Introduction:

Waste can be simply described as an item that is not required or does not hold any value anymore. It is a major problem in Malta because of the small territorial area and a high population density. The disposal of waste may be a source of pollution that affects everyone's health. Thus, Waste generation management in Malta is fundamental to enhance a country's quality of life. However, more and more waste is generated and the quantity of Municipal Solid Waste (MSW) has to be assessed and foreseen for effective waste management.

II. Literature Review

P. Beigl et al [1] developed a socio-economic model for forecasting MSW generation in Major European cities, based on the statistical analysis of MSW data based on an annual time series up to 32 years from 55 European cities and 32 countries. The model consists of three equations as follows below. To determine the prosperity of a city they set thresholds for three criteria, namely GPD, Infant mortality rate and percentage of labour force in agriculture.

For cities with very high prosperity,

$$MSW^t = 359.5 + 0.014 \cdot GDP^t - 197.1 \cdot \log(INF^t_{urb}) \quad \textbf{Equation 1}$$

For cities with high prosperity

$$MSW^t = 276.3 + 0.016 \cdot GDP^t - 126.5 \cdot \log(INF^t_{urb}) \quad \textbf{Equations 2}$$

For cities with low or medium prosperity

$$MSW^t = -360.7 - 375.6.\log(INF^t_{nat}) + 8.93.POP^t_{15\text{-}59} - 123.9 .HHSIZE^t + 11.7\ LIFEEXP^t$$

Equation 3

Where $\mathbf{MSW^t}$ is the municipal solid waste generated per capita and year, $\mathbf{GDP^t}$ is the national gross domestic product per capita at 1995 purchasing power parities, **INF** is the infant mortality rate per 1,000 births in the city **(INFurb)** or in the country **(INFnat)**, $\mathbf{POP_{15\text{-}59}}$, is the percentage of the population aged 15 to 59 years, $HHSIZE^t$ is the average household size and $LIFEEXP^t$ is the life expectancy at birth and **t** is the year [1].

On the other hand, Striebing B. et al [2] quote an equation proposed by Paul Ehrlich in the early 1970s, called the IPAT equation:

$$I = P.A.T \quad \textbf{Equation 4}$$

where I = environmental impact
P = population

A = affluence
T = technology

These equations will be tested using historical data about MSW generation in Malta.

III. Historical data about MSW generation in Malta

Waste Management can be defined as the activities and measures undertaken to tackle and deal with all varieties of waste from the first stage, generation of waste, until the last phase, disposing of it. This management process consists of several essential actions being storage, collection, recycling, processing, energy recovery and final disposal of waste, along with monitoring and regulation of it [3].

Nevertheless, waste management practices are important as well, and have to be carefully planned for future needs and assessments. Moreover, effective waste management is usually proposed to reduce harmful effects and minimise environmental contamination and reduce, possibly eliminate, human health risks [4]. Many environmental and health issues have been related either directly or indirectly to non-implementation of EMS [5] [6].

In February 2018, the NSO of Malta prepared data on Municipal Waste Generation (MWG) that is expressed in kg/cap, as shown in Table 1 [7]. It should be noted that the data for 2016 were provisional at the time.

MSW in Malta was recorded to be 282,709 tonnes in 2016, an increase of 4.8% over the previous year, which was the highest amount generated in Malta till then. The average municipal waste was 642 kg/cap. in 2016 [7] [8]. See Table 1. In the same year (2016), waste from black bag collection, green/grey bag including glass which comprised **68.8 %** (194,577 tonnes) of the total amount of the MWG, decreased by 1.5 % over the previous year. Bring-in sites and civic amenity sites made up **7.4 %**, (20,763 tonnes) of the total waste generation, which is an increase of 5.7 % over 2015. The rest of the amount of MSW includes hazardous waste that amounted to **23.8 %** (67,369 tonnes) [7].

No		2011	2012	2013	2014	2015	2016
1	Municipal Waste Generation – (total tonnes)	**245,199**	**247,997**	**246,521**	**256,630**	**269,660**	**282,709**
2	Bring-in sites	4,955	3,447	4,043	3,740	2,652	2,527
3	Civic amenity sites	12,396	12,338	13,050	14,370	16,994	18,236
4	Green/Grey bag and glass collection Rec.)	10,111	10,720	11,729	12,891	14,926	17,113
5	Black bag collection – local councils	134,108	132,075	133,528	139,837	144,993	136,619
6	Black bag collection - other	30,216	42,914	34,922	34,224	37,679	40,845
7	Street cleaning	3,215	3,659	3,607	3,039	3,649	4,633
8	Other * (Waste not otherwise specified in the list)	40,198	42,844	45,642	48,528	48,767	62,736
9	Municipal waste generation, Kg/cap.	**587**	**589**	**580**	**598**	**621**	**642**

Source: Wasteserv Malta Ltd.; ERA; NSO * includes hazardous waste

Table 1, Municipal waste generation.

The amount of waste generated is closely connected to the Gross Domestic Product (GDP) per capita, given unaltered waste intensities in the economy and human activities, see Figure 1, which is based on the data in table 2. Figure 1 illustrates the trends of MSW generation, GDP and population growth over the past 17 years. It is clear from the graphs that, although not strong, a positive relationship is present., that is, MSW generation is affected by both the GDP and the population growth rates, not necessarily vice versa.

Year	MSW Generation projection (Tonnes/Yr.)	GDP (constant 2010 US$)	Total Population
2000	212181	7141192053	390087
2001	215990	7184635762	393028
2002	235469	7398940397	395969
2003	241430	7587152318	398582
2004	249710	7620794702	401268
2005	251447	7909139073	403834
2006	252833	8053774834	405308
2007	265940	8374834437	406724
2008	273094	8655099338	409379
2009	264619	8441986755	412477
2010	244361	8741059603	414508
2011	243178	8856688742	416268
2012	247997	9096953642	420028
2013	246521	9516423841	425967
2014	256630	10288609272	434558
2015	269660	11278543046	445053
2016	282709	11868476821	455356
2017	-	12630728477	465292

Table 2

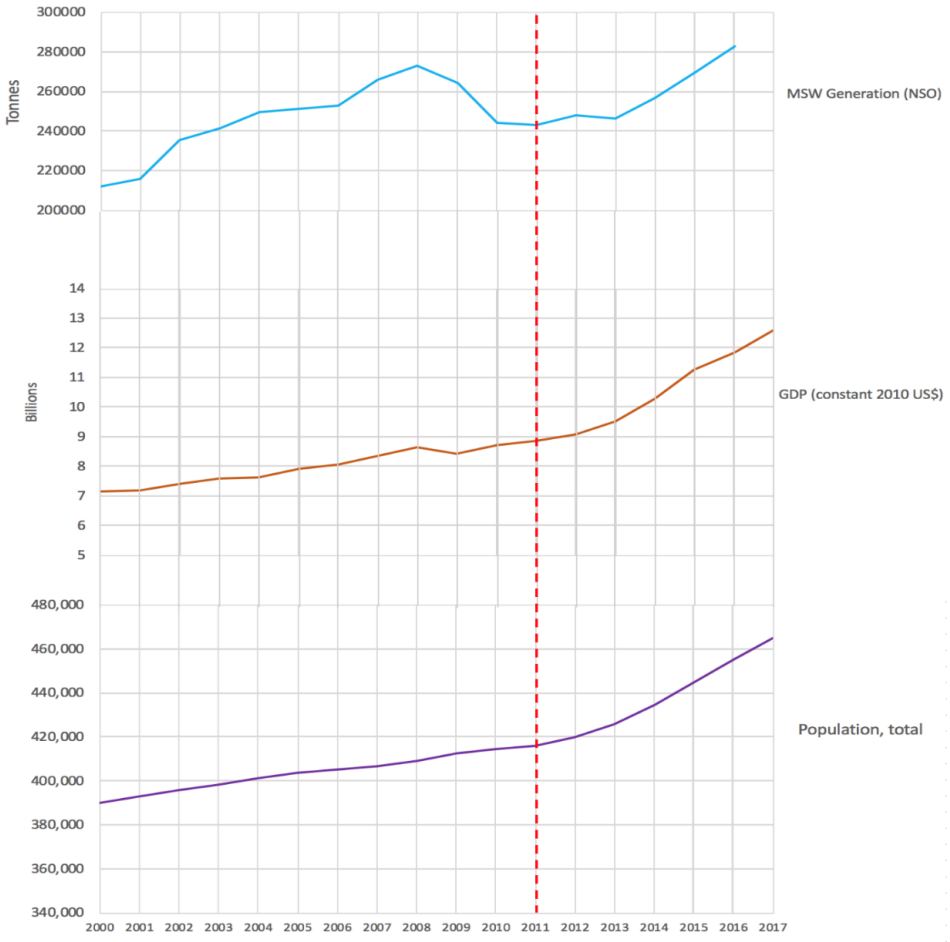

Figure 1

IV. Using the Beigl equations to predict the generation of waste in Malta

Malta is a very high prosperity country according to the criteria adopted by P. Beigl and colleagues for forecasting MSW generation in Major European cities. Hence their equation 1 should be used to predict the MSW generated by Malta, the results of which are tabulated below, see Table 3. A graph, see Figure 2, of the actual MSW generation vs the equation's output of MSW generation was plotted to visually understand the differences [1].

$MSW^t = 359.5 + 0.014 \cdot GDP^t - 197.1 \cdot \log(INF^t_{urb})$ *very high* prosperity …**Equation 1**

Where MSW^t is the municipal solid waste generated per capita and year, GDP^t is the national gross domestic product per capita at 1995 purchasing power parities, INF is the infant mortality rate per 1,000 births in the city (INF_{urb}).

Year	INF	GDP per capita (€)	MSW Generation Equation kg / cap / yr.	MSW Generation Tonnes / yr. (NSO)	MSW Generation kg / y (NSO)	MSW Generation kg / y (NSO)	MSW Generation Diff between theoretical and actual
2000	5.9	18,306.7	463.9	212,181	212,181,000	544	80.1
2001	5.8	18,280.2	465.0	215,990	215,990,000	550	84.6
2002	5.7	18,685.7	472.1	235,469	235,469,000	595	122.5
2003	5.6	19,035.4	478.5	241,430	241,430,000	606	127.2
2004	3.9	18,991.8	508.9	249,710	249,710,000	622	113.4
2005	3.9	19,585.1	517.2	251,447	251,447,000	623	105.5
2006	3.9	19,870.8	521.2	252,833	252,833,000	624	102.6
2007	3.8	19,375.6	516.5	265,940	265,940,000	648.1	170.7
2008	3.8	21,928.7	552.2	273,094	273,094,000	662.6	149.5
2009	3.8	20,675.6	534.7	264,619	264,619,000	639.1	143.5
2010	3.7	21,089.8	542.8	244,361	244,361,000	587.3	84.4
2011	3.7	22,821.8	567.0	243,178	243,178,000	581.3	54.2
2012	3.7	21,930.8	554.5	247,997	247,997,000	589.4	76.2
2013	3.6	23,930.2	584.9	246,521	246,521,000	582.5	41.3
2014	3.6	26,180.9	616.4	256,630	256,630,000	603	30.4
2015	3.5	23,819.5	585.7	269,660	269,660,000	630.6	91
2016	3.5	25,058.2	603.1	282,709	282,709,000	658.4	101.7

Table 3

As can be seen from the Table 3, the difference between the actual MSW generation in Malta and the theoretical (i.e. that as calculated using equation 1) is worrying when considering Malta to be of very high prosperity [1]. The MSW Generation Difference between the theoretical and actual is highest in 2007, at 170.7 kg per capita per year, however, the table also illustrates that this difference decreases as time passes which is assuring, since Malta inhabitants should theoretically be producing approximately 93.5 kg less waste per person per year in the past decade.

On the other hand, assuming Malta to be a low or medium prosperity country, equation 3 can be used, i.e.
$MSW^t = -360.7 - 375.6.\log(INF^t_{nat}) + 8.93.POP^t_{15\text{-}59} - 123.9 .HHSIZE^t + 11.7\ LIFEEXP^t$
(Low or medium prosperity) …..**Equation 3**

where MSW^t is the municipal solid waste generated per capita and year, GDP^t is the national gross domestic product per capita at 1995 purchasing power parities, INF is the infant mortality rate per 1,000 births in the city (INFurb) or in the country (INFnat), $POP_{15\text{-}59}$, is the percentage of the population aged 15 to 59 years, $HHSIZE^t$ is the average household size and $LIFEEXP^t$ is the life expectancy at birth and **t** is the year [1].

The results are shown in Table 4. Again a graph, see Figure 3, of the actual MSW generation vs the equation's output of MSW generation was plotted to visually understand the differences,

Year	INF	POP_{15-64}	HHSIZE	LIFEEXP	MSW Generation Equation Kg / cap / yr.	MSW Generation (NSO) Tonnes / yr.	MSW Generation (NSO) Kg / yr.	MSW Generation (NSO) Kg / cap / yr.	MSW Generation Diff between theoretical and actual
2006	3.9	69.09	2.8	79.2	543.7	252833	252833000	623.8	80.1
2007	3.8	69.36	2.8	79.4	548.5	265940	265940000	648.1	99.6
2008	3.8	69.49	2.7	79.6	564.4	273094	273094000	662.6	98.3
2009	3.8	69.47	2.7	79.7	568.1	264619	264619000	639.1	71
2010	3.7	69.29	2.7	79.9	568.8	244361	244361000	587.3	18.4
2011	3.7	69.03	2.6	80.1	578.5	243178	243178000	581.3	2.8
2012	3.7	68.67	2.6	80.2	576.4	247997	247997000	589.4	13
2013	3.6	68.21	2.6	80.4	574.7	246521	246521000	582.5	7.8
2014	3.6	67.71	2.6	80.6	572.5	256630	256630000	603	30.5
2015	3.5	67.22	2.6	80.7	569.3	269660	269660000	630.6	61.3
2016	3.5	66.65	2.6	80.7	582.7	282709	282709000	658.4	75.8

Table 4

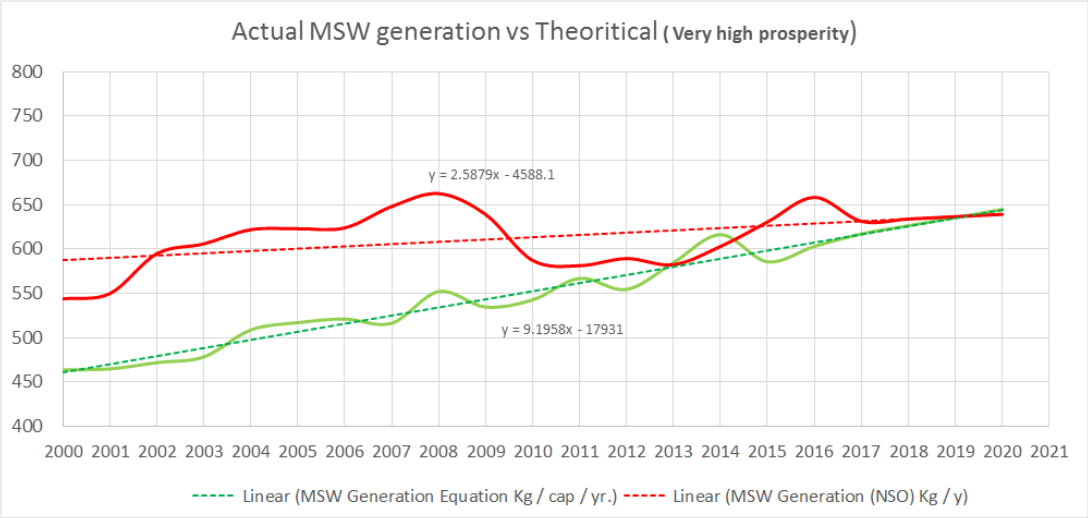

Figure 2

$$MSW^t = 359.5 + 0.014 \cdot GDP^t - 197.1 \cdot \log(INF^t{}_{urb}) \quad \textit{very high} \text{ prosperity} \qquad \textbf{Equation 1}$$

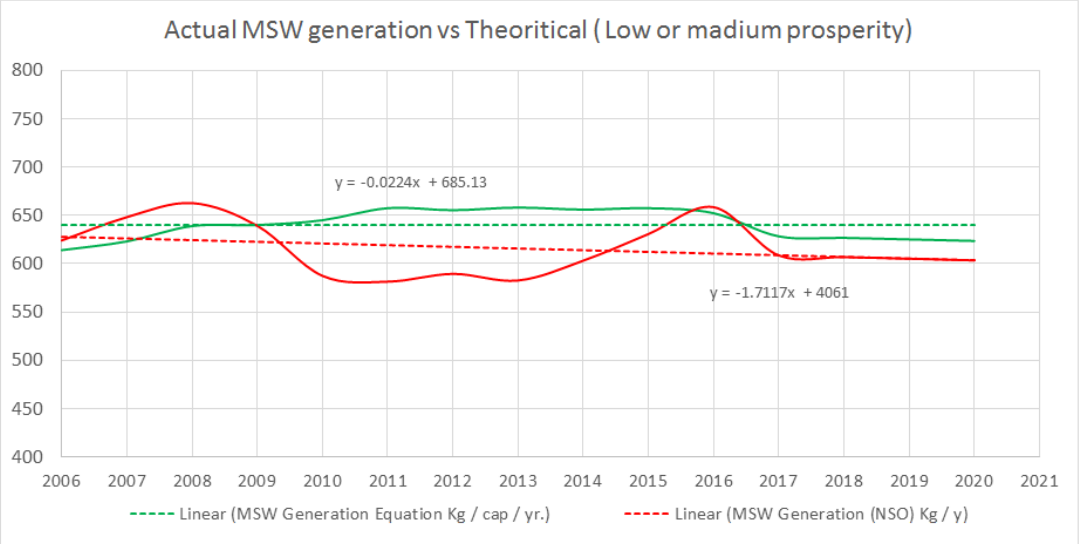

Figure 3

$$MSW^t = -360.7 - 375.6.\log(INF^t_{nat}) + 8.93.POP^t_{15\text{-}59} - 123.9.HHSIZE^t + 11.7\ LIFEEXP^t$$ *Low or medium prosperity*

Equation 2

V. Applying the IPAT equation to the historical data

The IPAT equation is routinely utilized for examining the relationship between economics population and technological development and their effect on the environment. The MSW forecasting equation considers key players such as regional characteristics, human processes and long-term socio-economic trends in the prediction of the MSW generation.

To test the applicability of using the IPAT equation to predict future generation of MSW, we take the Impact I as representing the change in quantity of MSW. To represent the Affluence, A, one could use a number of economic factors, such as GDP, and average salary. All these three indicators will be tried so as to establish the strongest factor of these that will produce a similar change to that of MSW during a given period. The technology term, T, of the equation proved challenging to quantify, but it was considered reasonable to assume that it had not changed in Malta over the short period considered, i.e. 2010 to 2016. Thus it shall be considered as a constant. However, to keep this factor as close to constant as reasonably possible a short comparison period from 2010 till 2016 was chosen.

IPAT equation

I = impact P = population A = affluence T = technology

	Parameters	2010	2016	Percentage change	2016/2010
I	**MSW (Tonnes / yr.)**	244,361	282,709	(38,348 / 244,361)*100 = 15.7 %	**1.16**
P	**Population**	414,508	455,356	(40,848 / 414,508)*100 = 9.8%	**1.10**
A_1	**GDP /capita (€)**	21,089.79	25,058.17	(3,968.38 / 21,089.79)*100 = 18.8%	**1.19**
A_2	**Average Salary (€ p.a.)**	14,455	16,882	(2,427/14455)*100 = 16.8 %	**1.17**
T	**Technology**			0% (assumption)	**1.0**

Figure 3

Table 6

I = PAT T (constant) = 1 P = 1.10 MSW = 1.16

For A_1 = GDP I = 1.10*1.19* 1.0 = 1.31

For A_2 = Average Salary I = 1.10*1.17*1.0 = 1.29

Two observations can be made from these results. One is that the average salary as a measure of affluence gives a result that is closer to the actual (1.29 vs 1.16) than the GDP (1.31 vs 1.16). This is reasonable since MSW would be related to what people can spend and this depends on salaries rather than what the nation as a whole is producing. Secondly, the actual MSW is much lower than that predicted by the equation. That may be due to the fact that the factor for technology (T) was taken as constant. However, if one factors in an increase in awareness of the need to reduce MSW and also concrete measures taken by individuals and firms to reduce

waste and considers these as part of (T), then it can be seen that a 10% improvement (T = 0.9) is all that is needed for IPAT to correctly predict the future generation of MSW.

VI. Discussion

The prediction equations in section 4 showed that Malta during the past 10 years was performing as a low prosperity country, see figure 3, while in fact it is a country of very high prosperity as per GDP, INF and percentage of labour force in agriculture. Nonetheless, a positive trend illustrates that Malta will maintain a healthy MSW generation by 2020 if the GDP continue at the same rate, INF is kept low and waste management efforts are preserved. From the results of the IPAT equation, it can be seen that MSW was influenced more by Average salary than GDP and that if T is taken to represent an increase in awareness rather than an impermeant in technology, it takes only a 10% reduction in T for the equation to accurately predict the amount of MSW generated. .

VII. Conclusion

Universities, centers of excellence and research centers have a crucial role in the making of professionals and technicians that understand the principles of and the proper way of implementing environmental sustainability as well as waste management techniques. Positive returns have already been achieved by some developing countries that have invested in research and the education of the growing generations. The manifestation of such paybacks was in having cleaner cities, more responsible citizens and higher status of solid waste workers [9] [10].

Like any service provision, MSW services have a cost tag as well. However, the expenditures are not regained, in most of the cases. Resources are needed with the goal of attaining appropriate equipment, skilled personnel, proper maintenance, right infrastructure and operation. Moreover, support of the central government in the form of grants and incentives, the attention of the municipal leaders towards waste management issues, the input of the customers and a proper administration of the funds are critical for contemporary sustainable systems [11].

References

[1]. Forecasting Municipal Solid Waste Generation in Major European Cities P. Beigl, G. Wassermann, F. Schneider and S. Salhofer Institute of Waste Management, BOKU – University of Natural Resources and Applied Life Sciences, Vienna, Austria.

[2]. Striebing B., Ogundipe, A., and Papadakis, M. (2016) Engineering Applications in Sustainable Design and Development. 6th ed. Nelson Engineering. Pp. 496-510

[3]. Ginige, T., Sparks, N. and Formosa, S. (2010). Waste Not Want Not-Sustainable Waste Management in Malta. Lead - Law, Environment and Development Journal.

[4]. Eea.europa.eu. (2017). [online] Available at: https://www.eea.europa.eu/publications/managing-municipal-solid-waste/malta-municipal-waste-management [Accessed 16 Jun. 2017].

[5]. Reinhart, D., Bolyard, S., & Berge, N. 2016. Grand Challenges – Management of municipal solid waste. Waste Management, 49: 1-2. https://www-sciencedirect-com.ejournals.um.edu.mt/science/article/pii/S0956053X16000027 April 10, 2018.

[6]. Dereinda, F., & Greenwood, L. (2015). Environmental Management System Risks and Opportunities: A Case Study in Pertamina Geothermal Energy Area Kamojang. In Proceedings World Geothermal Congress 2015: 2-3. https://pangea.stanford.edu/ERE/db/WGC/papers/WGC/2015/02018.pdf , February 15, 2018, Melbourne.

[7]. NSO.gov.mt. (2018). [online] Available at: https://nso.gov.mt/en/News_Releases/View_by_Unit/Unit_B3/Environment_Energy_Transport_and_Agriculture_Statistics/Documents/2018/News2018_019.pdf [Accessed 21 Mar. 2018].

[8]. Sustaining Our World. (2018). The past, present, and future of solid waste disposal. [online] Available at: http://sustainingourworld.com/2011/09/22/the-past-present-and-future-of-solid-waste-disposal/ [Accessed 20 Jan. 2018].

[9]. Eea.europa.eu. (2017). [online] Available at: https://www.eea.europa.eu/publications/managing-municipal-solid-waste/malta-municipal-waste-management [Accessed 16 Jun. 2017].

[10]. Chapter 5 – Municipal Solid Waste Management: Turning Waste Into Resources (Shanghai Manual – A Guide for Sustainable Urban Development in the 21st Century).

[11]. Sustaining Our World. (2018). The past, present, and future of solid waste disposal. [online] Available at: http://sustainingourworld.com/2011/09/22/the-past-present-and-future-of-solid-waste-disposal/ [Accessed 20 Jan. 2018].