

**Output Analysis of Using Mathematical Modelling (IWM-2 Model) for Municipal Solid Waste Management (MSWM) in the State of Kuwait:
A Life Cycle Inventory (LCI) of Polymeric Based Waste**

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Abstract

Waste is a by product of human activity, which physically contains the same materials found in useful products, it only differs by its lack of value. In this communication, the outcome of a mathematical model (IWM-2 model) designed as a Life Cycle Inventory (LCI) tool was analysed. Data regarding Municipal Solid Waste (MSW) stream of the state of Kuwait were fed into the model. The emphasis was on polymeric based waste. However, all MSW streams were considered in the Life Cycle Assessment (LCA). In terms of environmental burdens, Global Warming Potential (GWP) was found to be higher in the recycling stream, when compared to the other stages in the boundaries of the cycle. Air and water emissions associated with the case study were also at their peak at the recycling stage. An integrated waste management scheme is recommend for the case, considering the lack of mechanical recycling and waste to energy (W/E) development in Kuwait.

Keywords: IWM-2 model, MSW, GWP, Kuwait, Mechanical Recycling.

Abbreviations

C	Composting
GL	Glass
GWP	Global Warming Potential
I	Incineration
IWM	Integrated Waste Management
KM	Kuwait Municipality
L	Landfill
LFG	Landfill Gas
LCA	Life Cycle Assessment
LCI	Life Cycle Inventory
MRF	Materials Recovery Facility
ME	Metal
MSW	Municipal Solid Waste
MSWM	Municipal Solid Waste Management
PA	Paper
PL	Plastic
PSW	Plastic Solid Waste
R	Recycling
RDF	Refuse Derived Fuel
TE	Textiles
TS	Transfer Station
W/E	Waste to Energy

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1. Introduction

Life Cycle Inventories (LCI) are a part of a much broader picture, which are Life Cycle Assessments (LCA). Although, considered the main part of such studies, it is evident to study full cycles of products. In other terms, 'Cradle to Grave' assessment has become an essential part of any engineering application or process. LCIs and LCAs are both applied in order to estimate the outcome of processes and products fate in the environment. These approaches to Municipal Solid Waste Management (MSWM) technologies will aid in the identification of environmental burdens associated with given processes leading to a more enviro-friendly choices, when it comes to sustainable options considered. MSWM is one of the most important and challenging issues for sustainable development. It is also one of the most controversial issues and has been a subject of an ongoing debate amongst decision makers and stakeholders (Kirkby et al., 2004).

Waste could be classified by a mixture of schemes, most commonly by physical state (solid, liquid, gaseous), and then within solid waste by: original use (packaging waste, food waste, etc ...), by material (glass, paper, etc ...), or physical properties (combustible, compostable, recyclable, etc ...), by origin (domestic, commercial, etc ...), or by safety level (hazardous, non hazardous). MSW composition varies, both seasonally and geographically from country to country, and urban to rural areas. As communities are getting wealthier, MSW is growing annually in elevated proportions.

In 1990, each individual in the world produced an average of 250 Kg of MSW, generating in total 1.3×10^9 tonnes of MSW (Beede and Bloom, 1995). Ten years later, this amount almost doubled, reaching 2.3×10^9 tonnes produced worldwide. In EU countries, over 250×10^6 tonnes of MSW are produced each year and with the annual growth of 3%. It was projected that 290×10^6 tonnes/year of MSW will be produced in the EU-27 by 2010, and 336×10^6 tonnes/year by 2020 (ETC/RWM, 2008). Currently each person is producing an annual average of 500 Kg of MSW in the EU (Rand et al., 2000), where back in 1995, each individual produced 400 Kg/year (ETC/RWM, 2008). Developed countries produce twice as much as countries in the developing world. In the UK, the average citizen generates ten times their own body weight as MSW. The current predominant solution for MSW is landfilling, which generates a number of burdens on the environment, including CH₄ and CO₂ emissions into the atmosphere and leaching chemicals into soils and ground water. By 2020, the Organization for Economic Co-operation and Development (OECD)

estimates world population to generate 45% more MSW than in 1995 (OCD, 2005).

The EU wants to reduce waste quantities going to landfills by 20% from 2000 to 2010 with a projected reported diversion of 34% by 2020 (ETC/RWM, 2008), and by 50% in the year 2050. Currently, 67% of MSW is landfilled in the EU countries. Unfortunately, no clear plan issued by the government of Kuwait exists yet although MSW treatment is of an extreme importance.

In Kuwait, MSW poses a serious threat to the community. Yet still, little has been done in terms of a drastic governmental solution. Al-Meshan and Mahros (2001) estimated MSW in Kuwait at a rate of 984,000 tons/year back in 2000. Compared to other neighbouring countries, Kuwait's MSW generation was found to be considerably at a higher rate. Keeping in mind, surrounding countries are larger in size with fewer resources (Table 1).

A great percentage of final waste streams in Kuwait consist of polymeric based waste, *i.e.* Plastic Solid Waste (PSW). Generation of PSW was found to be 150,000 tonnes/year in Kuwait; making up 13% of the final waste stream (Al-Meshan and Mahros, 1997; Al-Salem, 2008a). In other countries, W/E solutions and recycling (mechanical or chemical) reduced these percentages and diverted efforts towards biomass and bio-waste treatments. In the UK, reports show that dense and film plastic add up to 7% of the final waste line (Parafit, 2002); whilst in the US and Mexico, it makes up 11 and 4% (USEPA, 2002). Many researchers have studied and come up with solutions to PSW problems using mathematical modelling techniques. Nepal et al. (1999) suggested plastic recycling in India would be improved by establishing deposit centres for post-consumer plastic waste. Over the past two decades, detailed models have been adopted regarding economics of materials recovery resulting from MSW, and their environmental burdens (Boustead, 1992), as well as broader methods including cost, public acceptance and ease of operation and maintenance (Sushil, 1990). Clark (1978) used modelling techniques to optimise collection methods and predict most efficient collection routes for waste management facilities.

In this study, a mathematical modelling tool, namely Integrated Waste Management (IWM-2) model was used to assess the environmental burdens and costs of the current situation of MSW processing in Kuwait. All MSW streams were considered in the study, although the emphasis was on PSW. The model was set-up as a LCI for an Integrated Waste Management (IWM) solution.

Table 1: Waste generation rate (per individual) in Kuwait and other neighbouring countries. Source: Al-Salem, 2007.

Country	MSW generation per individual (Kg/day)	Country	MSW generation per individual (Kg/day)
Kuwait	1.4	Oman	0.7
Qatar	1.3	Egypt	0.81
UAE	1.2	Tunisia	0.41
Bahrain	1.3	Jordan	0.6

2. Model Description and Implementation

2.1. Integrated Waste Management (IWM-2)

Model

The main tool used in this study was IWM-2 (Integrated Waste Management) model developed by McDoughall et al. (2008); which is a modified version of the White et al. (1995) model of IWM. The model is a Visual Basic graphical interface. The original function of the model was to give municipalities around the world abroad indication of environmental and economical burdens of waste management decisions. The solid waste stream through its life cycle was followed in the model. Each stage in the life cycle was represented by a series of input questions, answers of which define the system considered. Those inputs were divided within the model into seven categories (*i.e.* Waste inputs, Waste collection, MRF& RDF sorting, Biological treatment, Thermal treatment, Landfilling, Recycling). Even though waste materials are physically commingled, the different waste materials were kept separate in the model, which will be needed in characterizing the material composition of the waste, its calorific value and effectiveness of any treatment process, at any time in the life cycle.

The basic idea behind the IWM-2 model is to subtract the amount of materials going through different process from the original waste input, which entered into a reclaimed materials stream thereafter. By the end of the life cycle, all of wasted materials will have left the materials stream and have been entered into either the emissions calculation or product columns. What differentiates the IWM-2 model from any other LCA simulation tool is its capability of implementing IWM into any

scenario designed or desired. The costing features were also capable of calculating the affordability of the scheme studied.

2.2. Scope Definition

The scenario modelled in this study included different MSW processes with the same disposal method, which reflects the current situation of Kuwait. Although the focus was on polymeric based solid waste (*i.e.* PSW), all sorts of MSW were considered in the life cycle, *i.e.* organics, textiles, wood, paper, pulp ... etc. The output of the model included all environmental burdens and economical costing.

The current scenario run in the model was based on the following components: waste collection and transportation, sorting, landfilling and recycling. Biological and thermal treatments (although existing in some processing lines but not in full-scale for the benefit of the municipality) were excluded.

2.3. Functional Unit and System Boundaries

Following the previous work performed on the city of Ankara, Turkey by Ozeler et al. (2006) using the IWM model, the functional unit in this study has been defined as the amount of MSW generated in the whole of the state of Kuwait, *i.e.* urban, suburban and beyond city borders. The system boundaries selected for the life cycle of the wasted articles was defined as the moment when material ceases to have value, becoming evidently labelled as waste. The scenario considered in this study and the system boundaries are illustrated in Fig. 1.

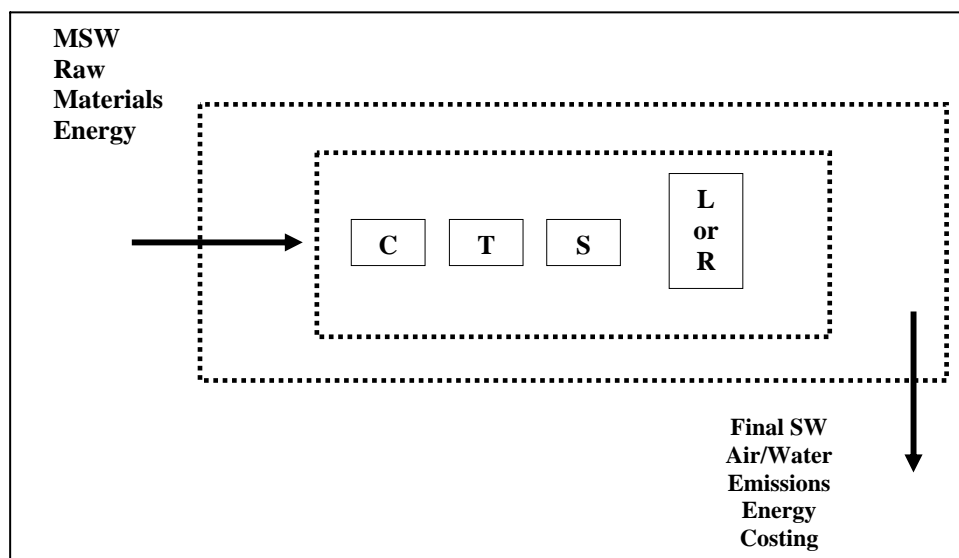


Fig. 1. The modelled scenario considered in the study. C: Collection, T: Transportation, L: Landfilling, S: Sorting, R: Recycling, (---) system boundary, (→) input/output

2.4. Life Cycle Inventory (LCI) and Model Inputs

The data secured and eventually considered as inputs for the model were gathered from previous work on MSW in the state of Kuwait (Al-Salem,

2007; Al-Salem, 2008a; Al-Salem, 2008b). The data gathered included population projections, waste characteristics and weight composition, waste management applications and operational recommendations for landfills in Kuwait. Table 2

summarises the main inputs considered in the model for the waste collection and waste sorting stages. The model asks for a number of input data regarding delivered household waste. This part of the model deals with central collection sites. For simplicity, the materials were divided in the model into *Bulky* waste (*i.e.* furniture and appliances) and *Garden* waste. Fig.2 shows the delivered waste tab in the modelled scenario. Amounts considered were gathered from Al-Salem (2007); Al-Salem and Al-Samhan (2007). For the case of PSW delivered, a 1:1 ratio was assumed between film and dense plastic (including rigid) to calculate the amount delivered and wasted. Based on the knowledge that PSW amounts to 150,000 ton/year in the state of Kuwait (13% of the total MSW), ∴ delivered PSW will amount to 128571.5 Kg/household/year, which was fed to the model as 9999.9 Kg/household/year as default value not exceeding 10,000 Kg/household/year. This condition satisfies the model restrictions. Commercial solid waste was excluded in many previous attempts of assessing MSW in Kuwait, as well as waste collected from outer sources, *i.e.* not produced in Kuwait. These amounts were included in this study in the commercial waste section. The input summary of

the input waste section gave a total 12,188,858 tonnes of MSW.

Waste Collection was given in a different section in the model, basically divided into two sections; Kerbside Collection Systems (KCS) and Material Bank Collection System (MBCS). For the case of Kuwait, MBCS doesn't exist and the only governing board responsible for collection (or sub contracting the deal) is Kuwait Municipality (KM), which gives one KCS with 100% distribution to all households served. Table 3 shows the summary of the collected commercial and household waste produced by the model. The cost of kerbside collection and central site and transport were fed to the model as 4.5 m£ (1.89 mKD) and 0.85 £/tonne handled (0.4 KD/tonne handled) (Al-Salem, 2008a).

Regarding the MRF (Materials Recovery Facilities) and RDF (Refuse Derived Fuel) section, destination with percentages of processing and costs were fed to the model, as well as residue treatment details, revenue from sale to re-processor, MRF process data including electricity consumption and efficiency. Recycling costs and sales revenue were obtained from market quotes (Table 4) (RW, 2008).

Table 2: Main input parameters for the IWM-2 model in the waste collection and sorting stages

Category	Value
Population ¹	3.5 million
Avg. residents in household ¹	6
%Petrol operated automobiles	95
Amount SW generated/person/year	146
Fraction of PSW ²	13
Fraction of Ferrous Metal Waste in amount of Metal solid waste	75%

¹ Source: Koushki, and Al-Humoud, (2002a); Koushki, and Al-Humoud, (2002b).

²Source: Al-Meshan, and Mahros, (1997); Al-Meshan, and Mahros, (2001).

Table 3: Waste collection summary for collected household and commercial waste displayed by the model as outputs of stage 2, including input amount, transferred and rest (remaining) waste

Collected Household Waste	Paper	Glass	F Metal	non F Metal
Input (tonnes)	107,310	15,330	11,498	3,833
Transferred (tonnes)	166	111	0	0
Restwaste (tonnes)	107,144	15,219	11,498	3,833
Collected Household Waste	Plastic Film	Plastic Rigid	Organics	Other
Input (tonnes)	33,215	33,215	250,390	56,210
Transferred (tonnes)	55	55	10	10
Restwaste (tonnes)	33,160	33,160	250,380	56,200
Collected Commercial Waste	Paper	Glass	F Metal	non F Metal
Input (tonnes)	11	2	1	0
Transferred (tonnes)	0	0	0	0
Restwaste (tonnes)	11	2	1	0
Collected Commercial Waste	Plastic Film	Plastic Rigid	Organics	Other
Input (tonnes)	3	3	25	6
Transferred (tonnes)	0	0	0	0
Restwaste (tonnes)	3	3	25	6

2.5. Integrated Waste Management (IWM) Scope

In this study, with the focus being on PSW, the Life Cycle Assessment (LCA) angle was established via an Integrated Waste Management (IWM) scope. No longer should the process, of which was chosen, be an individual line but integrated within the W/E schemes. MSW composition varies, both seasonally and geographically from country to country, and urban to rural areas. In that aspect, the IWM should satisfy sustainable management in terms of 1) affordability (*i.e.* MSWM should 1) reduce emissions to land, air and water), 2) social acceptance, and 3) environmental effectiveness.

3. Results and Discussion

The final inputs/outputs of the model are displayed in Fig.3. 511,000 tonnes of collected household waste with a delivery waste estimate of 12,188,858 tonnes resulted in a sorted amount of 112 tonnes of MSW. This shows a high percentage of accuracy with less than 5% error on the model's results. Since the actual amount of first stage sorting was estimated to be 116.3 tonnes of MSW (Al-Salem and Al-Samhan, 2007). The majority of the output; as expected was landfilled giving 85.59% of the final waste stream. Combusted waste and untreated materials resulted in a 0.01 and 14.40% of the final solid waste stream, respectively. A more detailed breakdown of the final solid restwaste stream is displayed in Table 5.

Table 4: International market quotes used in the model for glass, non ferrous metal, ferrous metal, plastics, paper and municipal recycling index. Source: *Spot market prices on 23rd October, 2008*

	Type of Scrap	Price £ (KD)/tonne
Glass Index	Mixed Scrap Glass	2.77 (1.16)
	Mixed Bottle Scrap	3.70 (1.55)
	Clear Bottle Scrap	14.64 (6.14)
Paper Recycling Index	Boxboard	59.47 (24.97)
	Mixed Paper	17.38 (7.30)
	White Envelope	225.7 (94.79)
Plastic Index	Mixed PET Scrap	0.135 (0.05) /lb
	Mixed LDPE Scrap	0.135 (0.05) /lb
	Mixed HDPE Scrap	0.14 (0.6) /lb
	PVC Scrap	0.12(0.05) /lb
	Mixed PP Scrap	0.14(0.5) /lb
	Polystyrene Scrap	0.17(0.07) /lb
Scrap Metal	No.2 Steel	188.75 (79.27)
	Stainless Scrap	0.51 (0.21) /lb
	Old Mixed Zinc Scrap	0.20 (0.08) /lb
Municipal Recycling Index	Old News Papers	63.44 (26.64)
	OCC	62.0 (26.04)
	Office Paper	63.44 (26.64)
	PET	0.13 (0.05) /lb
	HDPE	0.14 (0.06) /lb
	UBC	0.42 (0.17) /lb
	Steel Cans	103.7 (43.55)
	Scrap Glass	2.74 (1.15)

The screenshot shows a software interface for waste input management. It features a table for 'Bulky Waste Delivered' with columns for Glass, Ferrous metal, Non-ferrous metal, Film plastic, Rigid plastic, and Other. The values are 3.0, 7.5, 2.8, 9,999.9, 9,999.9, and 1.3 respectively. Below this is a section for 'Garden Waste Delivered' with a value of 4.7. At the bottom, there are navigation buttons: Streams, Results, Advanced, << Back, Main, Next >>, Print, Glossary, and Help.

	Glass	Ferrous metal	Non-fe metal	Film plastic	Rigid plastic	Other
Amounts delivered (kg/household/year)	3.0	7.5	2.8	9,999.9	9,999.9	1.3

Amount delivered (kg/household/year) 4.7

Fig. 2. Waste Inputs screen to the modelled scenario of the state of Kuwait showing the delivered waste tab.

Table 5: Integrated Waste Management Model IWM-2 restwaste (tonnes/year) stream output from the modelled case of the state of Kuwait

Des	Dest.	Glass	F-Metal	PL Film	PL Rigid	Organics	Other
CHW	-	15,330	11,498	33,215	33,215	250,390	56,210
DHW	-	1,750	4,375	5,833,275	5,833,275	2,742	758
CCW	-	2	1	3	3	24	6
DGW	B	n/a	n/a	n/a	n/a	-2,742	n/a
KCS DR	S	-111	Zero	-55	-55	-10	-10
BHWR	M	-1,138	-3,062	-874,991	-874,991	n/a	n/a
BHWR	T/L	-612	-1,312	-4,958,284	-4,958,284	n/a	-758
MTLS	L	-15,221	-11,499	-33,163	-33,163	-250,404	-56,205

CHW: Collected Household Waste; DHW: Delivered Household Waste; CCW: Collected Commercial Waste; DGW: Delivered Garden Waste, KCS DR: Kerbside Collection System Dry Recyclables, BHWR: Bulky Household Waste Recovered, BHWR: Bulky Household Waste Residue, MTLS: Material to Landfill Stream, Des: Destination, b: Biological, S: Sorting, C: cRDF, d: dRDF, T: Thermal, L: Landfill, M: Material, Des: Description.

Table 6: Integrated Waste Management Model IWM-2 sorting (tonnes/year) stream output from the modelled case of the state of Kuwait

Description	PA	GL	PL Film	PL Rigid	Organics
KCSI Dry Recyclables	166	111	55	55	10
MRF Process Recycled	-76	-78	-3	-3	n/a
MRF Process To PPDF Burning	-41	n/a	-36	-36	n/a
MRF Process Residue To Landfill	-50	-33	-17	-17	-10

Table 7 Integrated Waste Management Model IWM-2 Costs (£/year) stream output from the modelled case of the state of Kuwait

	Collection	Sorting	Landfill	Recycling	Total
Outgoings	14,426,137	545	43,814,469	3,639,674	61,880,826
Revenue	-2,866,719	-697	Zero	-1,833,292	-4,700,709
Total	11,559,418	-152	43,814,469	1,806,382	57,180,117
Cost/household	20	Zero	75	3	98
Cost/person	3	Zero	13	1	16

Table 8: Integrated Waste Management Model IWM-2 Costs (KD/year) stream output from the modelled case of the state of Kuwait

	Collection	Sorting	Landfill	Recycling	Total
Outgoings	6,058,978	228.9	18,402,077	1,528,663	25,989,947
Revenue	-1,204,022	-292.74	Zero	-769,983	-1,974,298
Total	4,854,956	-63.84	18,402,077	758,680	24,015,649
Cost/household	8.4	Zero	31.5	1.26	41.16
Cost/person	1.26	Zero	5.46	0.42	6.72

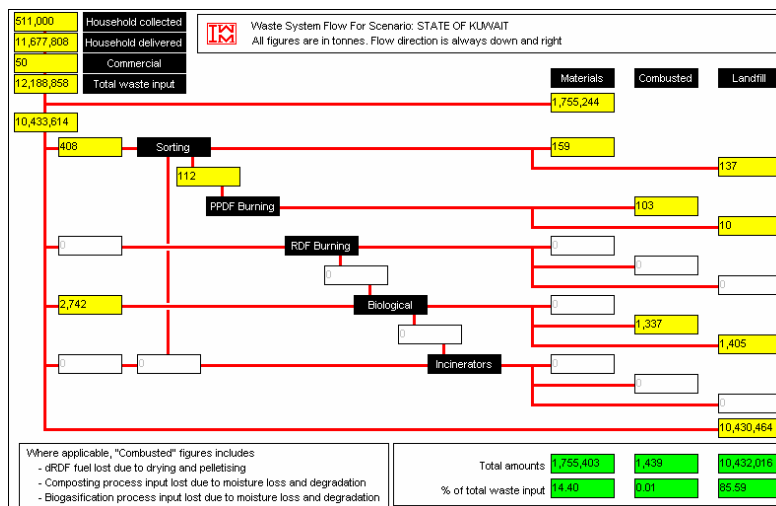


Fig. 3. Waste flow chart (tonnes/annum) adapted from IWM-2 model for the case of the state of Kuwait

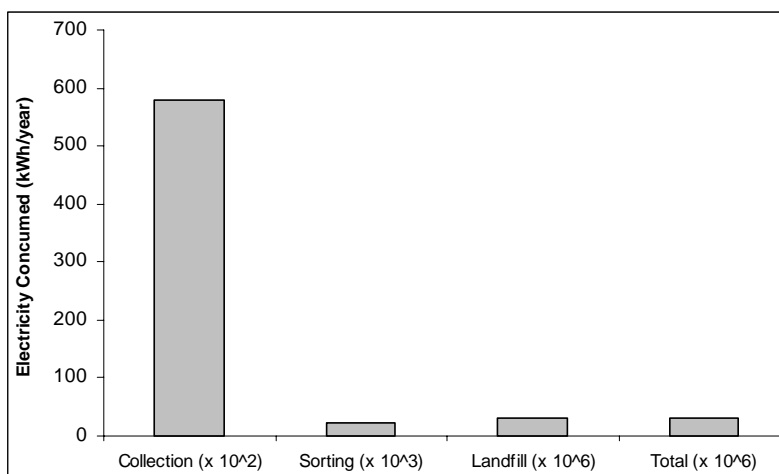


Fig. 4. Electricity consumption (output) for the state of Kuwait case, considering collection, sorting, landfilling and the total burden

Sorting in Kuwait is considered a kerbside one, especially for the case of recyclates. The majority of sorting occurs for rigid plastics in the estimated amount of 55 tonnes/year for kerbside sorting (Table 6). Plastic films were estimated at the rate of 55 tonnes/year of sorted MSW. The major environmental burdens associated with waste collection systems will be due to the transport required, which consumes energy and results in significant air emissions. The function of the collection system, after all, is to transport the waste from households or commercial properties to sorting or treatment sites. There may be other burdens, however, such as the production of plastic bags used in the collection, or the cleaning of bins. Inputs to the waste collection system of the model are energy, raw materials and waste. Outputs of the system consist of air/water emissions, residual waste and secondary materials considered as inputs to other relevant processes (*i.e.* central sorting, biological treatment ... etc). The MRF lines process a mere amount of 3 tonnes/year, considered very low with respect to the waste amount being generated.

It was expected from previous reports that the government of Kuwait had enormous burdens in terms financially, in terms of municipal waste. The output confirmed the governmental estimated budget drop resulting in a loss in revenue, an excess of 2 mKD (4 m£). The costing is detailed in Table 7 and 8. Fuels stream was calculated using the model as well. For the recycling process, a consumption rate of almost 31.5×10^6 kWh/year, of electrical power was consumed. In terms of petrol consumption, the only process involving such fuel was collection. This is due to the fact that other processes are mainly operated by diesel operated vehicles, which along side lorry trucks are the only left in the country. Petrol consumption was in

excess of 41.5×10^6 litres, agreeing with actual estimates in 2005 of 43.5×10^6 litres.

In terms of electrical supply used, it was estimated that KM consumes an excess of 31.5×10^9 kWh. This amount could be manipulated and redesign of the structure could be considered with the aid of IWM. In the UK, MSW generated annually has a potential energy value equivalent to 30×10^6 tonnes of coal which is about 10% of the UK energy demand (Barron, 1995). Fig.4 shows the electricity consumed by the different process considered in our case. Collection and sorting seems to be behind landfilling (30.33×10^6 kWh), which was also expected in the case of Kuwait. This is due to the fact that landfills in the state operate with a low efficiency electrical cycles compared to other processes involved. Also, sorting is done manually in many cases, which will influence labour costs but not electrical consumption. One of the most important outcomes in an LCA study is the environmental burden assessment of the process line or series of processes (IWM).

In this study, major air and water emissions were assessed as an outcome of the model (Table 9 and 10). Regarding air emissions, particulates (*aka* PM_{10} or particulate matter with an aerodynamic diameter of $\leq 10 \mu m$) were highest when it came to recycling processes (1×10^9), which was the case for the rest of the air pollutants estimated. GWP was calculated at its peak unexpectedly, water emissions followed a similar pattern of the air emissions, in terms of being considerably higher associated with the recycling process. However, Furans/Dioxins were estimated at their minimal levels in landfilling, but no traces were associated with recycling. This is due to the fact that no biological or thermal treatments were involved in this scenario. Such treatment of MSW usually results in further breakdown of Dioxin and CH_4 particles.

Table 9: Integrated Waste Management Model IWM-2 Air Emissions (gm) Results from the modelled case of the state of Kuwait.

	C	S	L	R	Total
PM ₁₀	52x10 ³	6,462	48x10 ³	-1x10 ⁶	-1x10 ⁶
CO	813x10 ³	17,109	361x10 ³	-211 x10 ³	961x10 ³
CO ₂	130x10 ³	7x10 ³	162x10 ³	-2x10 ⁶	-1x10 ⁶
CH ₄	159x10 ³	14,243	35x10 ³	-12x10 ⁶	35x10 ⁶
NOx	2x10 ⁹	63,657	1x10 ⁹	-10x10 ⁹	-7x10 ⁹
GWP	133x10³	7x10³	903x10³	-2 x10⁶	-1x10⁶
N ₂ O	3,463	43	175,385	37x10 ⁶	38x10 ⁹
SOx	195x10 ⁶	27,611	192x10 ⁶	1x10 ⁹	1x10 ⁹
HCl	280,007	783	9x10 ⁶	-581,185	8x10 ⁶
HF	29	76	1x10 ⁶	-768,590	710,465
H ₂ S	Zero	Zero	17x10 ⁶	-27,697	17x10 ⁶
Total HC	Zero	Zero	179x10 ⁶	Zero	179x10 ⁶
Chl. HC	Zero	Zero	3x10 ⁶	Zero	3x10 ⁶
Dioxins/F	Zero	Zero	Zero	Zero	Zero
Ammonia	4	12	50,793	-18,524	32,384
Arsenic	Zero	Zero	Zero	-72,828	-72,828
Cadmium	Zero	Zero	877	-549	328
Chromium	Zero	Zero	59	141	200
Copper	Zero	Zero	Zero	761	761
Lead	13	1	4,311	68,373	72,705
Manganese	Zero	Zero	1,659	Zero	1,663
Mercury	Zero	Zero	510	-88	424
Nickel	65	6	24,029	-12,694	11,454
Zinc	41	1	12,273	-2,530	9,796

Table 10: Integrated Waste Management Model IWM-2 Water Emissions (gm) Results from the modelled case of the state of Kuwait.

	C	S	L	R	Total
BOD	177	1	170x10 ⁶	1x10 ⁹	1x10 ⁹
COD	5,794	21	170x10 ⁶	3x10 ⁹	3x10 ⁹
Suspended Solids	112x10 ⁶	4,064	64x10 ⁶	7x10 ⁶	183x10 ⁶
TOC	18,164	351	4x10 ⁶	-500,151	3x10 ⁶
AOX	Zero	0	3x10 ⁶	17x10 ⁶	21x10 ⁶
Chl. HC	Zero	0	1x10 ⁶	1,320	1x10 ⁶
Dioxins/Furans	Zero	Zero	1	Zero	1
Phenols	Zero	2	604,168	-1x10 ⁶	-410,648
Aluminium	4,319	1,862	7x10 ⁶	-7x10 ⁶	619,134
Ammonium	543,468	48	33x10 ⁶	-32,696	33x10 ⁶
Arsenic	3	4	37,122	-95,943	-58,785
Barium	4,977	186	764,684	-749,399	21,941
Cadmium	Zero	0	22,400	24,768	47,170
Chloride	1x10 ⁹	44,910	705x10 ⁶	-346x10 ⁶	1x10 ⁹
Chromium	22	19	169,632	-643,608	-473,787
Copper	6	9	121,941	1x10 ⁶	1x10 ⁶
Cyanide	Zero	0	501	-83,493	-82,991
Fluoride	Zero	Zero	610,223	-2,733	607,490
Iron	1x10 ⁶	2,508	159x10 ⁶	-1x10 ⁶	159x10 ⁶
Lead	5	11	144,589	-408,344	-263,648
Mercury	Zero	0	952	3,194	4,147
Nickel	8	9	304,084	-265,262	38,914
Nitrate	1,296	54	223,870	-6x10 ⁶	-6x10 ⁶
Phosphate	53	110	448,103	-418,678	30,465
Sulphate	37x10 ⁶	21,808	104x10 ⁶	-26x10 ⁶	115x10 ⁶
Sulphide	Zero	1	2,249	79,451	81,705
Zinc	23	19	1x10 ⁶	-71,386	1x10 ⁶

There have been numerous reports calculating the energy consumption and emissions associated with the production of specific virgin plastic resins (Kindler and Mosthaf, 1989; Lundholm and Sundstrom, 1986; Habersatter, 1991). Comparable details are very rare in the case of plastics, however, for the process of recycling probably due to its relatively recent introduction and rapid rate of development. Clark and New (1991) suggest that the energy saving from plastic recycling vary from 27 to 215 GJ/tonne, depending resin type. A more

detailed study by Henstock (1992) reports that energy consumption and some emissions associated with the reprocessing with low-density polyethylene film collected from supermarkets into recycled LDPE granules and then into recycled polyethylene bags. The primary energy consumption of the reprocessing from recovered LDPE film into recycled LDPE granules is presented between 25.4 and 32.2 GJ/tonne. The air emissions that result from the electrical power and propane consumption during the process are presented in Table 11.

Table 11: Energy consumption and emissions from recycled and virgin plastic production. Source: McDoughall et al., 2008.

Category	Virgin LDPE /tonne produced	Recycled LDPE /tonne produced	LDPE savings/tonne recycled	Virgin HDPE/tonne produced
Energy consumption (GJ)	40.828	25.4	15.42	33.258
Air emissions (gm)				
Particulates	3000			2000
CO	900			600.0
CO ₂	2 x10 ⁶	1.2 x10 ⁶	2.6 x10 ⁶	3.53 x10 ⁶
NOx	12000	6390	5610	10000
Water emissions (gm)				
BOD	200			100.0
COD	1500			200.0
Solid waste (Kg)	39.1	132.0	-92.9	31.9

For the production of virgin LDPE and HDPE, data (averaged across Europe) give a total primary energy consumption of 88.55 and 80.98 GJ per tonne, respectively. These include the inherent energy of the feed-stock material used (47.73 GJ/tonne), and it can be argued whether this should be included when comparisons are made.

4. Proposed Futuristic Work and Recommendations

From the above mentioned and current undertaken research priorities, a clear state plan should be enforced on concerned parties. W/E treatments do not exist in a proper scale in Kuwait, which by itself is an issue. The same efforts must be driven towards chemical and mechanical recycling options as well. Work with involved parties should be commenced in term of PSW (MSW generally) re-use.

More awareness should be promoted with the public regarding the opportunities W/E treatments will create in terms of a more safe and environment-friendly living. Rules and regulations must be stated clearly and worked upon with both major and mediocre scale industries, with no exceptions. Scenarios using models designed specifically for the benefit of IWM, should be run constantly with the aid of KM. Thermal, biological and mechanical treatments must be integrated by law with industries producing MSW in Kuwait.

Later stages of this work will commence in two paths, modelling scenarios best seen fit for a number of case studies, and studying recycling opportunities of PSW in an attempt to produce useful fuel.

5. Conclusion

A full assessment in the form of a Life Cycle Inventory (LCI) was carried out, with the aid of IWM-2 model, to evaluate the current situation of Plastic Solid Waste (PSW) in Kuwait. All MSW streams were considered for the benefit of the model input, which the mere recycling efforts resulted in high values in terms of Global Warming Potential (GWP). 511,000 tonnes of collected household waste with a delivery waste estimate of 12,188,858 tonnes resulted in a sorted amount of 112 tonnes (< 2.4% of collected household waste) of MSW. With the current KCS on site sorting occurring in Kuwait, it was estimated that 55 tonnes/year of plastic films were handled. The MRF lines process a mere

amount of 3 tonnes/year, considered very low with respect to the waste amount being generated. Model output showed an excess of 4 m£ (2 mKD) budget drop resulting in a loss in revenue, due to the current MSW handling system.

The most important aspect of an LCA study is the assessment of environmental burdens associated with the different activities in the processes studied. In terms of air emissions, most of the parameters evaluated were at their peak at the recycling step of the process, showing the lack of environmental control. Global Warming Potential (GWP) was estimated at around 1,000 Kg CO₂ eq/ tonne waste managed. Whilst, CH₄ and CO₂ were estimated at 35,000 and 1,000 Kg CO₂ eq/ tonne waste managed. A clear plan needs to be executed by the government to control the associated emissions of landfilling, recycling and other processes studied.

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