V. RESULTS ANS DISCUSSION

Part I. Case Study Alexandria Fiber Company

In the current study two management systems were implemented in a local plant for acrylic fiber manufacturing called Alexandria Fiber Company. One system was for managing energy and the other for waste management. Both systems were designed and implemented as a continues improvement cycle. Furthermore, the environmental impact of the acrylic fiber manufacturing was investigated and analyzed, details are illustrated in next section.

V.1.Analysis of Present Status of Energy and Waste

V.1.1.Power consumption

In order to assess the efficiency of power consumption in the plant, four years data from 2009 to 2012 were collected for power consumption. Total power consumption for 2012 was 26.3 GWh and total production was 16,556 ton. Power consumption ratios were calculated for energy consumed in relation to produced fiber in each month. Ratios were calculated by dividing the total power consumed on that month by total tow produced. Data are shown in Table (1) and Figure (13).

A number of studies cited the power consumption in textile industry like Ozturk (2005) but not per ton production. The power consumption ratio is normally related to the production, however, this relation is not in direct proportion as in cases of production shut down, several machines and utilities would be running. Figure (13) shows that the highest power consumption ratio was on February 2011 which is attributed to low production in that month due to instability of the county during that period. At the same time, trend of power consumption ratio in 2012 increased due to several reasons: the decrease in monthly production, the high amount of power consumption required for process machine start-up after forced stops by frequent steam failures or machine break downs, additions of new motors and modification in utility area.

V.1.2. Steam Consumption

According to process engineering design steam consumption ratio was 9.8 T/TF, consumed in material preparation and production areas. The steam consumption was distributed as follow: polymerization (1.1T/TF), dope preparation (1.0 T/TF), solvent recovery (3.0 T/TF) and production (4.7 T/TF).

Total steam consumption in 2012 was 222,473 ton, consumed for the production of 16,556 ton fiber. Further, steam consumption data was limited due to non-availability of steam flow meters. Only total steam consumption data for all the plant was available. Steam consumption ratio is calculated by dividing the total steam consumption by the total tow produced. Table (2) and Figure (14) show steam consumption ratio in 2011 and 2012.

Data indicate that highest steam consumption ratio was in January as additional steam was required for heating purpose during the cold ambient conditions. Lowest consumption was in August. Steam consumption ratio, as related to actual production, increased twice in April 2011 and September 2011 due to frequent production shut downs.

Table 1: Power consumption ratio (kW/TF $_{produced}$) from 2009 to 2012

Year	Jan.	Feb.	Mar.	Apr.	May.	Jun.	Jul.	Aug.	Sep	Oct.	Nov	Dec.	Avg.
2009	1,360	1,319	1,387	1,394	1,345	1,340	1,359	1,351	1,347	1,347	1,346	1,345	1,353
2010	1,386	1,338	1,325	1,327	1,322	1,323	1,325	1,327	1,320	1,237	1,254	1,253	1,311
2011	1,325	1,852	1,358	1,312	1,338	1,440	1,425	1,322	1,502	1,321	1,340	1,333	1,406
2012	1,528	1,595	1,519	1,504	1,488	1,582	1,691	1,629	1,650	1,628	1,651	1,635	1,592

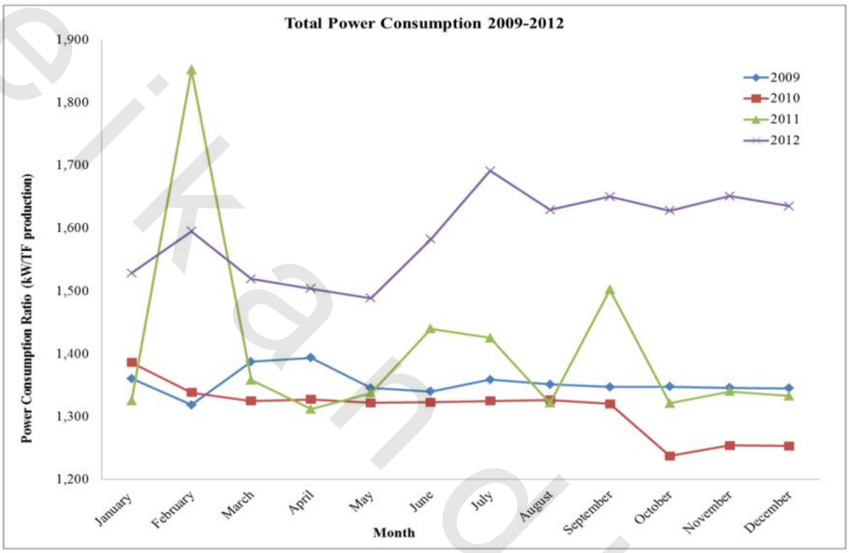


Figure 13: Ratio of electrical power consumption to fiber production from 2009 to 2012

Table 2: Steam consumption ratio (T/TF $_{produced}$) in 2011 and 2012

Year	Jan.	Feb.	Mar.	Apr.	May.	Jun.	Jul.	Aug.	Sep	Oct.	Nov	Dec.	Avg.
2011	13.6	12.6	13.1	14.7	13.8	14.3	13.4	13.1	14.6	13.7	13.3	14.0	13.7
2012	15.3	14.1	13.7	14.2	14.1	13.9	13.0	11.9	12.1	12.6	13.0	13.5	13.4

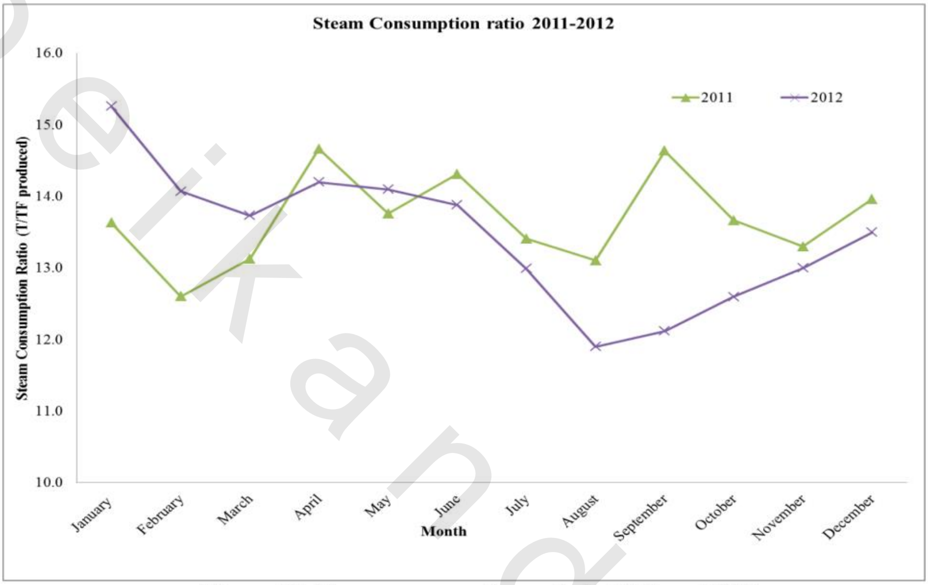


Figure 14: Steam consumption ratio in 2011 and 2012

V.1.3. Waste generation

The main purpose of the waste management is to give an outline of waste streams and treatment options (ECE, 2003). In this respect air emissions, liquid and solid wastes were included. Regarding air emissions, two sources of air emissions were found: a) water vapors from the washing, gel dyeing and stretching which are sucked and vented through duct to the atmosphere and b) vapors from the vessels and reactor in the polymerization area which are scrubbed in a monomer gas absorber and recycled back to the process. As for liquid in the current case study the raw water for the plant is received from the Nubariya canal. According to the AFCO-EIA the plant consumes about 9000 m^3/day of additional water. The following Table (3) provides details of the distribution and consumption of raw water. The total raw effluent generated is 3600 m^3/day. The inflows to the treatment plant are generated from two major streams: inflow generated from process plant areas and inflow generated from utilities. Table (4) presents liquid waste sources in plant and generated amount (AFCO-EIA, 2007).

The inflow generated from process plant represent 43.3% of the total raw generated effluent and the rest 56.7 % are generated from the utilities. Process plant inflow is generated from: washing of polymer cake containing low molecular weight polymer 1440 m^3/day, 1080 m^3/day from the stretching machine, part of the liquid waste generated in the solvent recovery area is recycled back to washing machine in the production line and 72 m^3/day is sent to the treatment plant. They represent 40%, 30% and 2% of process plant stream, respectively. The generated flow from the utilities is a mix from: cooling towers blow down 300 m^3/day, DW water regeneration 80 m^3/day, ROreject water 920 m^3/day and 140 m^3/day liquid effliuent from horticulture irrigation and sanitation, they represent 8.3%, 2.2%, 25.6 %, 16.7% and 3.9% from utilities stream, respectively.

Both steams are treated through an effluent treatment plant. On actual inventory it was found that available flow meters only exist for monitoring the overall effluent to the treatment plant. Table (5) illustrates the water quality parameters of process effluent to E.T.P. (AFCO-EIA, 2007). It was found that pollution levels for treated effluent from the E.T.P were within Egyptian environmental regulations shown in Appendix (C), consequently more focus was addressed to handling of solid waste generation.

Concerning solid wastes, the textile industry produces a variety of solid waste by volume it is the second largest waste stream after liquid effluent. Table (6) shows the description of different solid wastes and the generated amount from plant (Tantri, 2010). The source of solid waste includes waste fiber, residues from finishing chemicals, hydrocarbons, dyes and chemicals from solvent recovery systems, sludge from effluent treatment plant, dye containers, chemical containers, pallets, fly ash and general paper trash. In agreement with US EPA (1996) the quantity and type of solid waste produced depends on the nature of the operation, the efficiency of the processes and the level of awareness about solid waste management.

It was observed that the domestic solid waste runs an independent system. Solid wastes of chemical empty bags and dye empty cans were collected and disposed by a government recognized contractor (Al-Nasria). The filter pads and waste water treatment sludge are being disposed off by government recognized sites for toxic material. As for the wet and dry fiber waste from the production line, it was recovered and utilized again as dope solution. The fiber with lowest grade was liquefied in the gel dissolving unit using sodium thiocyanate.

Table 3: Distribution and consumption of raw water in plant.

Details	Water Consumption (m^3/day)
Horticulture and sanitation	500
Cooling tower (make up), Filter back wash	1500
RO	920
DW plant	80
Process water for plant supply	6000
Total	**9000**

Table 4: Liquid waste sources and generated amount.

Sr.	Source	Generated waste flow (m^3/day)
1	**Process waste effluent**	**1560**
1.1	Washing of polymer cake	1440
1.2	Stretching machine	1080
1.3	Solvent recovery area	72
2	**Effluent from utilities**	**2040**
2.1	Cooling towers blow down	300
2.2	DW water regeneration	80
2.3	RO reject	920
2.4	Filter back wash	600
2.5	Horticulture irrigation and sanitation	140
Total		**3600**

Table 5: Water quality parameters of process effluent to the E.T.P.

	Parameters	Concentration (mg/l)	Load (kg/hr)
1	pH	5 - 9	----
2	BOD	200 - 300	19.5
3	COD	550 - 750	49.0
4	Monomers of acrylic fiber	15 - 20	1.3
5	Sodium Thiocyanate	20 - 30	2.0

Table 6: Solid waste description and generated amount from plant(Tantri, 2010)

Department	Waste Description	Quantity per day	Unit
Production	TiO_2 Empty Bags	1.0	No
	Dye Empty Tot	1.0	No
	Acid Empty Drums	1.0	No
	Dye Empty Drums	4.0	No
	NSO Empty Bags	1.0	No
	Finish Empty Drums	1.0	No
	Anti Foam Empty Drums	1.0	No
	Pigment Waste	60.0	Kg
	Waste Gelled Dope	60.0	Kg
	Dye waste	30.0	Kg
	TiO_2 waste	60.0	Kg
	Sodium thiocyanate waste	60.0	Kg
	Unusable fiber waste	5.0	Kg
	Cotton Waste	2.5	Kg
Material Preparation	Spillage Polymer	0.1	Tots
	Methyl acrylate Bags	2.0	Bags
	Sodium thiocyanate Bags	30.0	Bags
	Acid Drums	1.0	Drums
	Carbon	0.1	Tots
	Silica Bags	0.5	Bags
Utility	Flocculants Empty Bags	0.1	No
	Filter Aid Polymer Empty Tots	0.1	No
	Chemical Empty Plastic Cans	2.0	No
	Chemical Sludge	50.0	Kg
	Cartridge Filter Candles	3.0	No

V.2. Development of Energy and Waste Management Systems

In accordance to ISO 50001:2011 and ISO 14001:2004 the policy states that organization is committed to achieve energy performance improvement, continual improvement and prevention of pollution. Energy policy and waste policy were defined according to the nature and scale of the organization's use and consumption. The planned policy for energy management aimed to achieve at least 15% reduction in energy consumption. Table (7) illustrates power consumption planned and actual.

In spite of applying anenergy management program the actual power consumption in 2012 was higher than the power consumption in 2011, however, a significant reduction in power consumption happened in 2013.The reasons for that were: first of all, the energy management program started in January 2012, conducted audits and reviews was done till April 2012, implementation of targeted goals in the plan was done during the rest of 2012. Consequently, reflection of creation and implementation of energy management program in terms of power savings was not measurable till 2013. Next, the increase of power consumption in 2012 was due to: the decrease in monthly production, high amount of power consumption required for process machine start-up after forced stops by frequent steam failures or machine break downs, additions of new motors and modification in utility area. Gutowski *et al.,* (2006) reported similarly that high amount of power consumption is required for process machine start-up after forced stops by frequent steam failures or machine break downs. There is a significant energy requirement to start-up and maintain the equipment in a "ready" position.The monthly reduction in power consumption within 2013 was 3.9% which achieved a direct saving of 919,500 EGP/Year. It is expected to reach the goal of 15% reduction in power consumption gradually.

The major solid wastes generated by the textile sector are fiber wastes. The planned policy focused on solid waste generation aiming to reduce solid waste generated in form of waste fiber to reach less than 1% of the production. The implemented actions in order to achieve that were: providing a new liquefaction unit to liquefy the solid wastes and reduce waste generation through training operators on waste reduction practices. Shown in Table (8) the generated waste in 2011 reached 5.4% of the production (average per month), after the implementation of the waste management program the generated waste reduced till 2.9% of the production (average per month), it is expected to reach the targeted reduction gradually. In terms of money the monthly direct saving of this reduction is equal to 854,700 EGP/Year as calculated below by equation (1).

Direct saving from waste reduction (EGP/Year)
= Cost of 1 ton Acrylic fiber (EGP) x Amount of reduced waste (Actual 2012 – Present 2011) (Ton)…………(1)

Table 7: Power consumption planed and actual (average per month).

	Power Consumption			
	2011	Planed	2012	2013
KWh	72258.9	61419.1	73876.3	69460.4
Consumption (%)	100.0	85.0	102.2	96.1

Table 8: Generated waste planned and actual (average per month).

	Generated Waste		
	2011	Planed	2012
Ton waste/month	80.9	15.0	40.2
Generated (%)	5.4	1	2.9

V.3.Implementation of Energy and Waste Management Systems

V.3.1. Monitoring and performance assessment

Evaluating performance involves the regular review of both energy use data and the activities carried out as part of the action plan. Ozturk (2005), Nagesha (2005) and Hasanbeigi (2010) stated that monitoring the use of energy is necessary to reduce energy losses and recover lost energy. Moreover, performance assessment and goals setting cannot be done without data collection and analysis. This was best achieved through an effective and efficient system of reporting. In agreement with William *et al.,* (2003) the objective of the energy reporting system was to measure energy consumption and compare it either to company goals or to standard energy consumption, using historical data showed how much energy was utilized.

After launching the energy management system in 2012, daily power consumption for different areas was monitored. Daily power consumption ratio was calculated and plotted against the norm. Root cause of any deviation was investigated and reported. Finally the report was circulated to all concerned persons to take the necessary actions. In order to find the major power consumer in the facility Figure (15) shows average power consumption within 2012 in different areas against the norm. Table (9) and Figure (16) present actual monthly power consumption in 2012. Data indicated that utility area was the highest with a percentage of 68.1 % of the total consumption followed by production section (19.7 %) then material preparation (11.4 %). Further investigation of power consumption was done by analyzing monthly power consumption in sub areas.

Table (10) and Figure (17) present the monthly power consumption for polymerization, dope preparation and solvent recovery in material preparation area. Data collected indicated that highest consumption was in polymerization with a percentage of (45.2%) of the total consumption in the area followed by solvent recovery (44.3%) and lowest consumption was in dope preparation sub area (10.5%).Table (11) and Figure (18) present the monthly power consumption for the sub areas within production area: spinning machine, tow dryer, apron dryer and baler. Highest consumption was in spinning machine section and lowest was in baler section. Percentage of consumption in each sub area was: spinning machine (72.9%), tow dryer (14.1%), apron dryer (13.1%) and baler (4.5%).

Table 9: Monthly power consumption in 2012 in different areas (kWh)

Area		Material Preparation	Production	Utility	Total
Norm (kWh)		9750.0	17800.0	35700.0	63250.0
Month		Actual Consumption			
	January	8366.5	14688.1	43955.4	67010.0
	February	8042.1	13863.9	46844.6	68750.6
	March	8680.6	15319.8	50645.3	74645.7
	April	8002.3	14388.9	45773.5	68164.6
	May	8415.7	15218.3	48570.6	72204.6
	June	8845.7	14763.8	50556.4	74166.0
	July	8226.2	14794.5	50398.7	73419.3
	August	8810.1	14660.0	59432.1	82902.2
	September	8787.8	13130.8	57498.0	79416.7
	October	8143.6	14717.5	57527.0	80388.1
	November	8331.0	14454.2	51090.6	73875.8
	December	8222.6	14389.3	48960.0	71571.9
Average		8406.2	14532.4	50937.7	73876.3

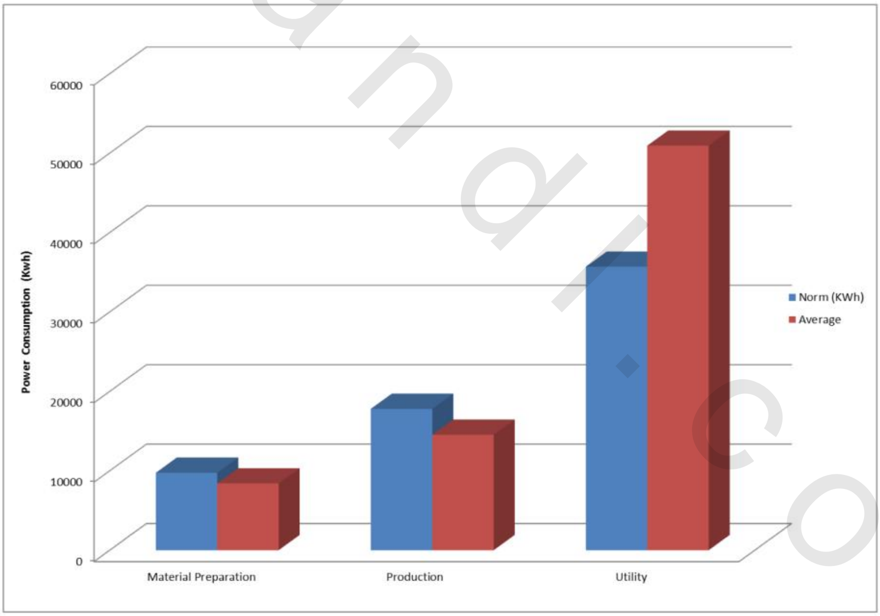


Figure 15: Average power consumption in acrylic fiber in 2012 in different areas as compared to the norm (kWh)

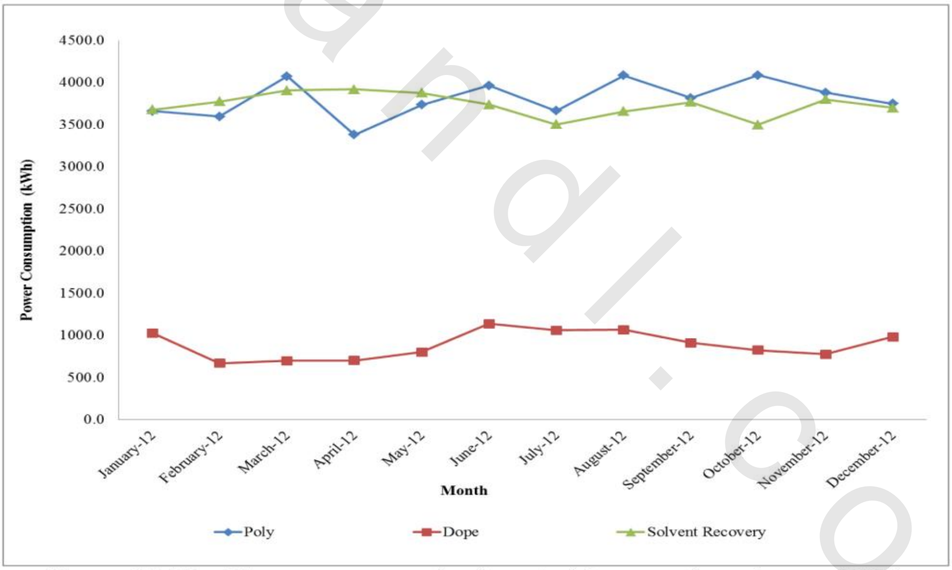
Table 10: Monthly power consumption in 2012 in material preparation sub areas (kWh).

Area		Polymerization	Dope Preparation	Solvent Recovery	Total
Norm (kWh)		4300.0	1200.0	4250.0	9750.0
Month		Actual Consumption			
	January	3660.5	1029.2	3677.4	8367.1
	February	3596.1	669.7	3776.3	8042.1
	March	4075.6	698.8	3906.2	8680.6
	April	3380.0	702.9	3919.4	8002.3
	May	3736.7	802.2	3876.9	8415.7
	June	3965.4	1139.7	3740.7	8845.8
	July	3663.9	1059.8	3502.6	8226.3
	August	4083.2	1067.1	3659.9	8810.1
	September	3817.5	911.7	3767.6	8496.8
	October	4088.5	825.5	3500.0	8413.9
	November	3882.0	777.0	3800.0	8459.0
	December	3750.0	985.0	3700.0	8435.0
Average		3808.3	889.0	3735.6	8432.9

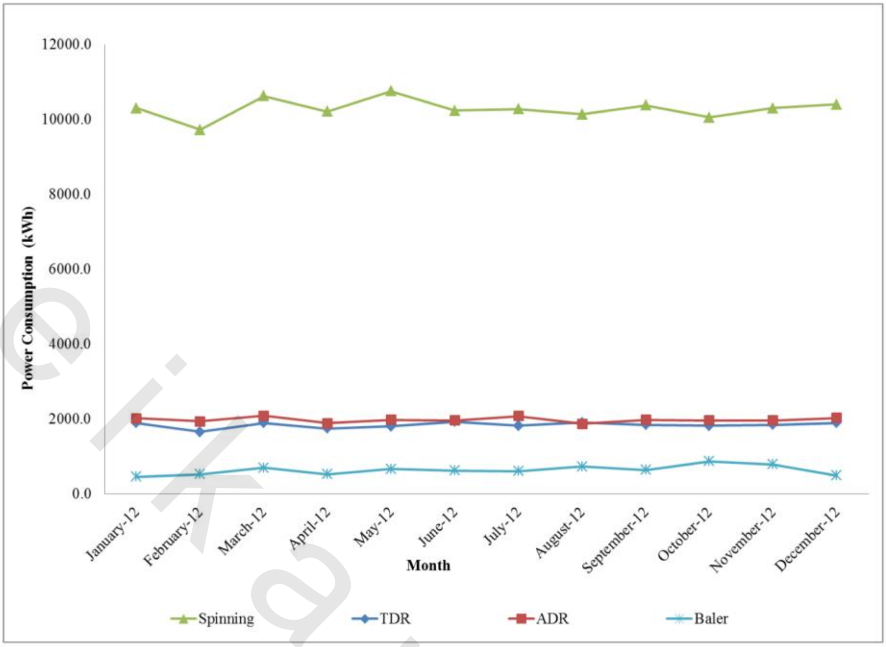
Figure 16: Power consumption in different areas of the plant (kWh).

Table 11: Monthly power consumption in 2012 in production sub areas (kWh).

Area		Spinning Machine	Tow Dryer	Apron Dryer	Baler	Total
Norm (kWh)		**11800.0**	**2700.0**	**2700.0**	**600.0**	**17200.0**
		Actual Consumption				
Month	January	10302.7	2020.5	1902.5	462.4	14225.7
	February	9725.1	1942.6	1665.1	531.1	13332.7
	March	10621.1	2092.2	1901.5	705.0	14614.8
	April	10212.1	1891.6	1755.9	529.4	13859.5
	May	10757.3	1980.4	1807.6	673.0	14545.3
	June	10234.4	1967.2	1932.0	630.3	14133.6
	July	10279.5	2082.0	1824.5	608.6	14186.0
	August	10134.8	1876.7	1908.6	739.9	13920.1
	September	10373.2	1981.7	1855.0	647.7	14209.9
	October	10049.0	1966.5	1827.1	875.0	13842.5
	November	10300.0	1970.0	1850.0	790.0	14120.0
	December	10400.0	2030.0	1900.0	500.0	14330.0
Average		**10282.4**	**1983.4**	**1844.1**	**641.0**	**14110.0**



Figures 17: Monthly power consumption in material preparation sub areas (kWh)

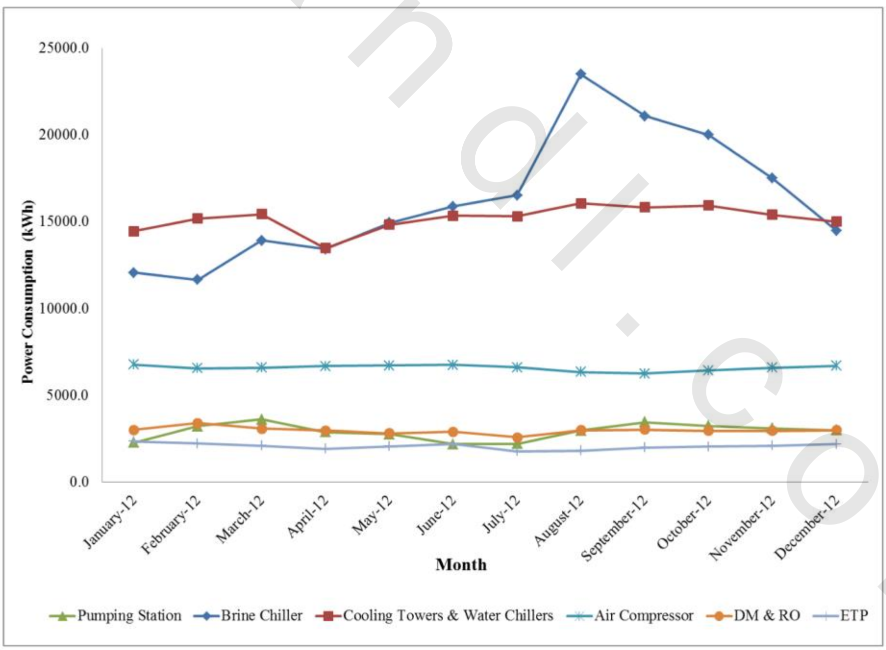


Figures 18: Monthly power consumption in production sub areas (kWh)

Table (12) and Figure (19) present detailed analysis of monthly power consumption for all major units in the utility area. The area contains of six major units: pumping station, brine chillers, air compressors, cooling towers & water chillers, RO & DW plant, and E.T.P. Data indicated that within the utility area the highest power consumption was by the brine chillers (42.7%) of total consumption in the area, brine chillers consumption increased in a noticeable way during the summer months in order to provide the necessary subzero temperature required for the processes in the production line. The following highest power consumers in the plant were the cooling towers & water chillers (39.9%). The next major consumers were the air compressors (17.3%) and the lowest power consumptions were by RO & DW plant (7.8%), pumping station (7.7%) and at last E.T.P. (5.4%). According to this analysis utility area was considered the focus area for further improvements.

Table 12: Monthly power consumption in 2012 in Utility units (kWh).

Area		Air Compressors	Cooling Towers & Water Chillers	Brine Chillers	Pumping Station	DM & RO	E.T.P.	Total
Norm (KWh)		3300.0	7200.0	14200.0	1800.0	3800.0	2100.0	24700.0
	Actual Consumption							
Month	January	6781.0	14449.5	12064.5	2291.8	3014.3	2360.9	33295.0
	February	6555.7	15184.8	11655.5	3231.8	3399.4	2226.4	33396.0
	March	6605.2	15430.6	13912.8	3615.3	3093.5	2100.7	35948.6
	April	6689.0	13475.4	13413.9	2892.9	2974.0	1934.9	33578.3
	May	6729.4	14832.1	14940.2	2765.5	2820.2	2069.8	36501.7
	June	6764.6	15347.2	15874.2	2191.7	2903.7	2193.4	37985.9
	July	6617.4	15304.1	16524.3	2219.4	2587.7	1777.1	38445.8
	August	6356.3	16052.1	23490.3	2971.7	3005.4	1820.7	45898.6
	September	6253.2	15824.0	21076.8	3457.5	3030.7	2007.8	43154.0
	October	6436.0	15933.2	20000.0	3246.7	2953.6	2052.6	42369.2
	November	6600.0	15400.0	17500.0	3100.0	2970.0	2100.0	39500.0
	December	6710.0	15000.0	14500.0	3000.0	3000.0	2200.0	36210.0
Average		6591.5	15186.1	16246.0	2915.4	2979.4	2070.4	38023.6



Figures 19: Monthly power consumption in utility units (kWh)

Total steam consumption started to be monitored on daily basis since the initiation of the energy management system on January 2012. Daily steam consumption ratio was being calculated and plotted against the norm. The monitoring system of solid waste included daily data collection of production, waste fiber generated from production line, low grade fiber and daily liquefied fiber. The low grade fiber is a final produced fiber that cannot be sold for high quality textile applications, however, it is sold for low quality applications like padding material. Table (13) and Figure (20) presentthe amount of generated waste from production within 2012. It can be noticed that the generated waste was more than 1% in all months, highest percentage in April, July and December due to repeated steam failures and forced shut downs in line. When a forced shut down takes place, all the fiber in process in the manufacturing machines is considered waste fiber and is sent to recovery.

Figure (21) shows the percent of low grade fiber. Figure (21) is closely similar to Figure (20) as low grade fiber is part of the generated waste. Both wastes should be minimized by reducing the generated waste from production. This can be achieved by reducing machine breakdowns through improving planned maintenance. Furthermore, Figure (22) shows the liquefied waste. The generated fiber waste is liquefied in a special unit using sodium thiocyanate and used once again in the production line. The monthly liquefied amount is independent of the generated waste from the production line; it depends on the operation stability of liquefying unit. It can be noticed that the liquefied amount of waste increased within the last quarter of the year. This was achieved by installing a new unit for waste liquefaction. The installation of this unit was one of the goals set in the action plan for waste reduction. As indicated previously in Table (8) the monthly average of generated waste fiber in 2012 was 2.9% in comparison to 5.4% in 2011. The implementation if waste management action plans reduced the generated waste.

Table 13: Generated waste from production line in 2012

	Unit	Jan.	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Production	Ton	1316.0	1283.5	1468.0	1326.0	1487.0	1419.0	1332.0	1427.0	1307.0	1433.0	1431.0	1326.0
Generated waste	Ton	30.3	30.1	42.8	56.6	39.0	35.2	49.0	35.2	34.3	35.9	39.0	55.0
	%	2.3	2.4	2.9	4.3	2.6	2.48	3.7	2.5	2.6	2.5	2.7	4.2
Liquefied waste	Ton	13.6	5.7	35.5	14.2	31.0	44	26.7	44.0	50.0	65.8	60.0	55.0
	%	1.0	0.4	2.4	1.1	2.1	3.10	2.0	3.1	3.8	4.6	4.2	4.2
Low grade fiber	Ton	14.6	5.4	10.8	21.5	13.3	8.4	14.4	15.6	10.9	12.6	19.0	12.5
	%	1.1	0.4	0.7	1.6	0.9	0.59	1.1	1.1	0.8	0.9	1.3	0.9

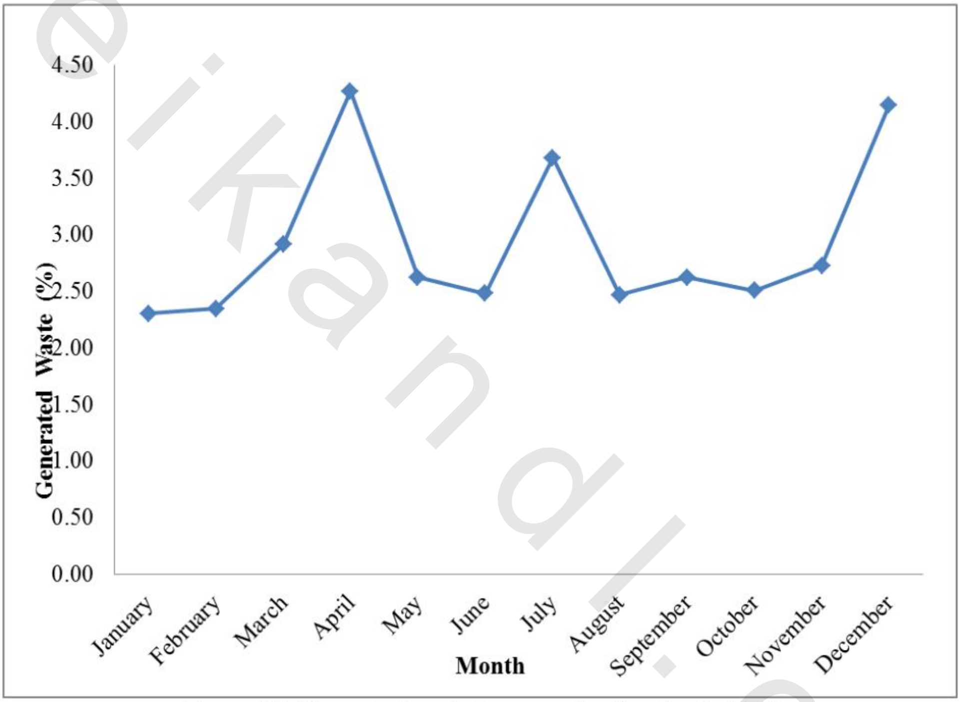


Figure 20: Generated waste from production line in 2012

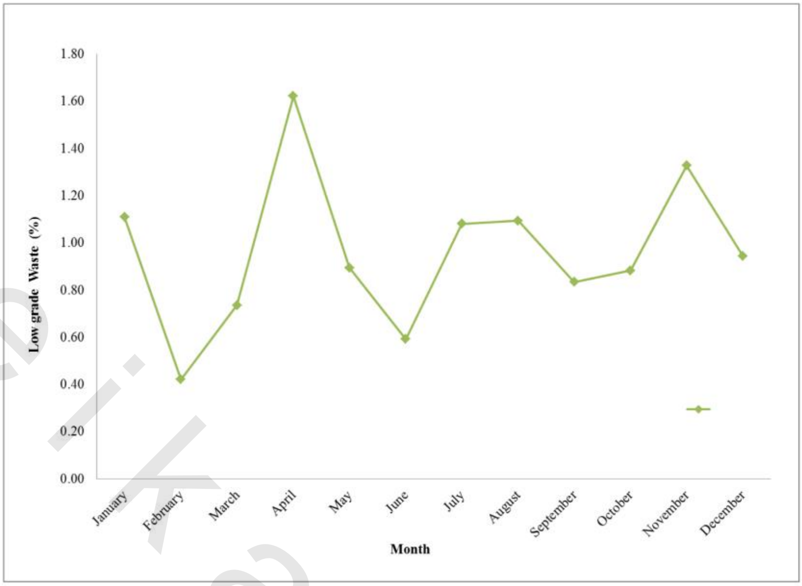


Figure 21: Low grade waste in 2012

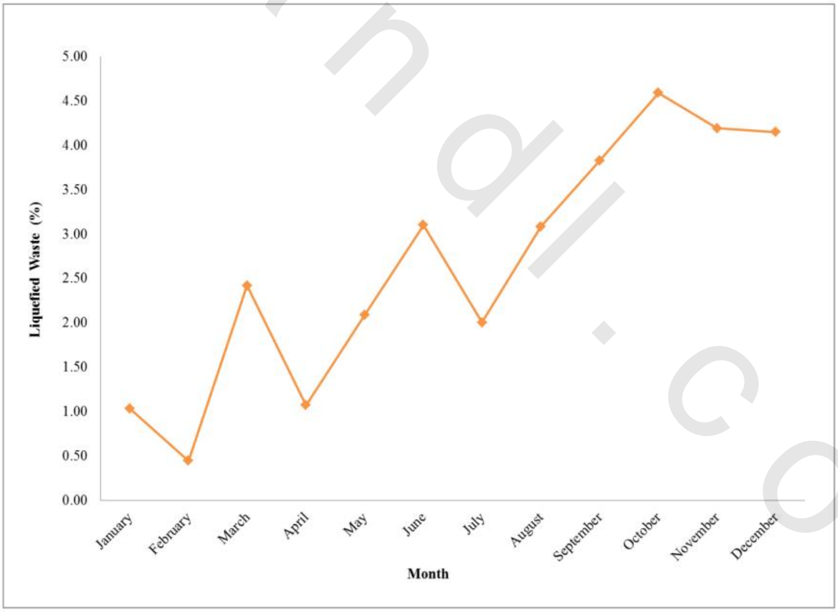


Figure 22: Liquefied waste in 2012

V.3.2. Implementation of action plan

According to ISO 50001:2011 and ISO 14001:2004 an action plan for the energy and waste management system was established. Covered points by the energy management team and external auditors mentioned in the energy audit report included: 1) Power factor improvement, 2) Recovery of steam condensate, 3) Change type of lighting, 4) Raw material and water leak survey and 5) Addition of liquefaction unit. Details of the mentioned points are illustrated next.

V.3.2.1. Power factor improvement

Power factor is a simple way to describe how much of the current contributes to real power in the load (Rashid, 2010).

It was found that the present power factor at the system start of the monitoring system was 0.94 for the whole factory. There is an incentive of 0.5% of electricity bill for every increase of 0.01 in power factor from 0.92 onwards. In agreement with Gustavo *et al.*, (2003) capacitor banks were used to improve the quality of the electrical supply and the efficient operation of the power system. It is important to have a power factor as close as possible to unity. Reflected power is undesirable because the transmission lines or power cord will generate heat according to the total current it carries, the real part plus the reflected part. This causes problems for the electric utilities. Also the reflected power that isn't wasted in the resistance of the power cord may generate unnecessary heat in the source (Rashid, 2010).

Table (14) shows location of installed capacitor banks and power factor improvement before and after the installation of each capacitor. The incentive of the electrical bill for power factor increase from 0.94 to 0.98 will have an estimated potential saving of 0.14 million EGP/year, details of calculation are present below and in Table (15).

Cost of average power consumption
= Average monthly power consumption (kWh) x Cost of power consumption (EGP/kWh) …. (2)
= 86,000 x 0.3 = 619,200 EGP

Gained incentive
= Cost of power consumption (EGP/kWh) x Incentive (0.5% per 0.01 increase) x months per year . (3)
= 619,200 x $\frac{0.5}{100}$ x 4 x 12 = 148,608 EGP/Year

Table 14: Data of capacitor banks

Location	Rated Voltage	Power Factor	
		Before	After
Material Preparation area	440	0.78	0.95
Material Preparation area	440	0.78	0.99
Material Preparation area	400	0.82	0.91
Material Preparation area	400	0.82	0.91
Production area	400	0.82	0.91
Production area	400	0.82	0.91
Production area	400	0.82	0.91
Production area	440	0.81	0.99
Utilities area	440	0.82	0.98

Table 15: Savings from power factor improvement

Parameter	Unit	Value
Old Power Factor		0.94
New Power Factor		0.98
Incentive		0.5% per 0.01 increase
Tariff*	EGP/kWh	0.3
Avg. Monthly Power Consumption	kWh	86000
Cost of Avg. Power Consumption	EGP/Month	619,200
Gained incentive	EGP/Month EGP/Year	12,384 148,608

* Electrical Tariff 0.3 EGP/kWh, Egyptian Electrical Utility and Consumer Protection agency, 2014.

V.3.2.2. Modifying lighting system

The lighting system provides many opportunities for cost-effective energy savings with little or no inconvenience. Lighting energy use represents only 5-25% of the total energy in industrial facilities, but it is usually cost-effective to address because lighting improvements are often easier to make than many process upgrades (William *et al.*, 2003).

Results of plant survey are shown in Table (16), three types of lamps are used in the facility: Fluorescent, High Pressure Mercury Vapour (HPMV) and Compact Fluorescent lamps (CFL). Fluorescent lamps are used in most of the areas, they represent 76.9% of the total lighting used in the plant areas. HPMV are mainly used in material preparation, production and utilities areas, they represent 21.5% of the total lighting used in the facility. CFL represent 1.5% of the total lighting used in the facility, they are used in the offices and switch gear rooms.

According to General Electric Company (TP-105, 2010) the 40W fluorescent lamps can be replaced with 40W Energy Efficient fluorescent light (EEL), monitory saving for replacement of all lamps was 3,390 EGP/Year. Table (17) presents related saving calculation data. The replacement of 250W HPMV lamps with a 150W High Pressure Metal Halide (HID) had a potential saving of 87,869 EGP/Year when replacing all lamps. In the same way, the replacement of 400W HPMV lamps with a 200W High Pressure Sodium lamp (HPS) had monitory saving of 47,174 EGP/Year (McKinney, 1987 and Vikram *et al.,* 2012).

Table 16: Lighting data

Location	Type of Fittings							
	Fluorescent				CFL	HPMV		
	1*11 W	1*28 W	2*28 W	2*40 W	1*18 W	1*125 W	1*250 W	1*400 W
	No. of Fittings							
Material Preparation area	5	27	126	21			28	8
Production area	33	54	550				311	60
Utility units	1		42	21				
Cooling Tower				4				
Effluent Treatment Plant				43				16
Water Treatment Plant				44				7
Storage Area	3	33	25					
Workshop	2		62					
Office Building	5	4	81		20			
Switch gear rooms	17	154	134	85	12	10		
Total	**66**	**272**	**1020**	**218**	**32**	**10**	**339**	**91**

Table 17: Saving calculation data for lighting change

Present Lamp	Substitute lamp	Energy Saving per lamp		Fittings	Total Saving*	
		W	%	No.	W	EGP/Year
Fluorescent, 40 W	EEL, 40 W	7	15	218	1526	3,955
HPMV, 250 W	HID, 150 W	100	26	339	33900	87,869
HPMV, 400 W	HPS, 200 W	200	50	91	18200	47,174
Total Saving		307			53626	138,999

* Electrical Tariff 0.3 EGP/kWh (off pick time, power factor 0.9), Egyptian Electrical Utility and Consumer Protection agency, 2014.

Total saving of lighting change

= Energy saving per lamp (kW) x Number of fittings x Cost of power consumption (EGP/kWh) x Lighting duration within the year (8 hr per day x 365 days per year) .. (4)

V.3.2.3. Addressing compressed air leaks

Compressed air is a very expensive energy source. From the total costs of compressed air production 75% are spent on energy (Radgen and Blaustein, 2001). Leaks are the most visible and most significant contributors to compressed air losses. Air leakage rate varies between 20% and 40% of the total air usage (Šešlija, *et al.,* 2011).

According to Dudić *et al.,* (2012) eliminating air leaks is the simplest and cheapest way to minimize and improve energy efficiency of compressed air. In order to do so it is necessary to detect leaks and eliminate the causes of leaks. Active leak detection and adequate repair can reduce leaks to less than 10% of the total compressed air production.

Several audits were conducted for compressed air leakages inspection: internal audits were conducted every week by members of the energy management committee, each week in a specific area. Another audit was conducted by external auditors in the month of April, using Ultrasonic leakage detector (William *et al.*, 2003). Total 65 compressed air leaks were identified in the circuit. Table (18) presents the air leakages identified during the inspection, their location, pressure, leak rate and cost savings. The digital reading of the ultrasonic detector is converted into leak rate using detector's system chart "Guess -Timator chart" Table (19) (Vikram *et al.*, 2012 and Wolstencroft, 2008).

Monitory saving from elimination of compressed air leakages was approximately 97,500 EGP/Year. Cost saving calculations were done using the below equation (5). Cost saving was calculated for each leak separately, operating hours were assumed to be 8000 hours per year and compressed air generation requirement 18 kW/100 cfm (Lightner, 2000).

Cost saving = Leakage rate (cfm) x Compressed air generation requirement (kW/cfm) x Operating hours (hr/year) x power consumption cost (EGP/kWh) ….. (5)

Table 18: Major compressed air leakages in the steam circuit

S.	Location	Pressure(kg/cm^2)	Pressure (psig)*	Extent of leakage (dB)**	Leak rate (cfm)***	Cost saving (EGP/Year)
1	Tow Baler 11	4.5	66.1	75.0	6.6	2851.2
2	Panel of breaker -4	4.5	66.1	75.0	6.6	2851.2
3	Panel of breaker -5	4.5	66.1	75.0	6.6	2851.2
4	Tow Dryer platter-T joint	5.0	73.5	75.0	6.7	2894.4
5	Tow Dryer platter-A piston	5.0	73.5	75.0	6.7	2894.4
6	Tow Washing Machine, main roller inlet	5.0	73.5	72.0	6.6	2851.2
7	Spinning Machine - air control valve 3	5.0	73.5	70.0	5.0	2160.0
8	Steamer back side - control valve inlet	5.0	73.5	70.0	5.0	2160.0
9	Streamer - first door piston	5.0	73.5	70.0	5.0	2160.0
10	Breaker-3 bump	4.5	66.1	68.0	4.2	1814.4
11	Breaker -2, Panel	4.5	66.1	68.0	4.2	1814.4
12	Second Hot Stretch – Squeeze roller piston	5.0	73.5	68.0	4.8	2073.6
13	Second Hot Stretch – Squeeze roller 2 ,piston	5.0	73.5	67.0	4.7	2030.4
14	Breaker -2 main panel	4.5	66.1	66.0	4.3	1857.6
15	Top bailer-1 tubing	4.5	66.1	66.0	4.3	1857.6
16	Top bailer-2 tubing	4.5	66.1	66.0	4.3	1857.6
17	Shaping machine-1	4.5	66.1	66.0	4.3	1857.6
18	Second Hot Stretch – Squeeze roller-3 piston	5.0	73.5	66.0	4.5	1944.0
19	Streamer - control valve, panel inlet	5.0	73.5	66.0	4.5	1944.0
20	Main receiver bottom	6.7	98.5	65.0	5.2	2246.4
21	Spinning Machine 4 - clutch 3	5.0	73.5	65.0	5.0	2160.0
22	Hose pipe leak Tow Baler	4.5	66.1	64.0	3.0	1296.0
23	Crimper air inlet	5.0	73.5	64.0	3.2	1382.4
24	Crimper main line to pump	4.5	66.1	63.0	3.2	1382.4
25	End of steamer	4.5	66.1	63.0	3.2	1382.4
26	Breaker 6 panel	4.5	66.1	63.0	3.2	1382.4
27	Shaping machine-2	4.5	66.1	63.0	3.2	1382.4
28	Primary hot stretch roller inlet	5.0	73.5	63.0	3.1	1339.2
29	Primary hot stretch roller inlet	5.0	73.5	62.0	3.1	1339.2
30	Acid preparation area control valve 3	5.0	73.5	62.0	3.1	1339.2
31	Second Hot Stretch – Squeeze roller piston 2	5.0	73.5	62.0	3.1	1339.2
32	emergency stop holding-1	4.5	66.1	61.0	3.0	1296.0
33	emergency stop holding-2	5.0	73.5	61.0	3.1	1339.2
34	Spinning Machine air control valve 1	5.0	73.5	60.0	3.0	1296.0
35	Spinning Machine air control valve 2	5.0	73.5	60.0	3.0	1296.0
36	steamer under control panel	5.0	73.5	60.0	3.0	1296.0
37	Primary hot stretch inlet hose	5.0	73.5	59.0	3.0	1296.0
38	breaker-2 packing roller	4.5	66.1	58.0	3.0	1296.0
39	breaker-3 packing roller	5.0	73.5	57.0	3.0	1296.0
40	Spinning Machine air control valve 3	5.0	73.5	56.0	2.9	1252.8
41	Spinning Machine 1 clutch 4	5.0	73.5	56.0	2.9	1252.8
42	Primary hot stretch open air control	5.0	73.5	55.0	2.9	1252.8

	valve					
43	Spinning Machine 4 clutch 4	5.0	73.5	55.0	2.9	1252.8
44	Pipe leak bailing press	4.5	66.1	54.0	2.8	1209.6
45	Half inch valve Tow breaker 12	4.5	66.1	54.0	2.8	1209.6
46	Acid preparation area control valve 2	5	73.5	54.0	2.9	1252.8
47	Breaker -4 head	4.5	66.1	53.0	2.8	1209.6
48	Acid preparation area control valve 4	5.0	73.5	53.0	2.9	1252.8
49	streamer ring door last piston	5.0	73.5	52.0	2.9	1252.8
50	Spinning Machine 3 clutch 5	5.0	73.5	52.0	2.9	1252.8
51	Bailing press tow to dye	4.5	66.1	51.0	2.8	1209.6
52	Balling press -Cylinder joint leak	4.5	66.1	50.0	2.8	1209.6
53	Spinning Machine 1 clutch 3	5.0	73.5	50.0	2.8	1209.6
54	Steamer back side Switch valve	5.0	73.5	50.0	2.8	1209.6
55	Spinning Machine 6 clutch 4	5.0	73.5	50.0	2.8	1209.6
56	Spinning Machine 3 clutch 6	5.0	73.5	46.0	2.8	1209.6
57	Crimper - clutch 2	5.0	73.5	43.0	1.6	691.2
58	control air under the main panel	5.0	73.5	42.0	1.5	648.0
59	joint leak in bailing press	4.5	66.1	41.0	1.5	648.0
60	Spinning machine globe valve leak	4.5	66.1	41.0	1.5	648.0
61	Primary hot stretch- control panel	5.0	5.0	5.0	5.0	5.0
62	Spinning Machine- control panel	5.0	5.0	5.0	5.0	5.0
63	Spinning Machine 1 clutch 1	5.0	5.0	5.0	5.0	5.0
64	Spinning Machine 1 control valve 3	5.0	5.0	5.0	5.0	5.0
65	Air hose Vertical washing machine	5.0	5.0	5.0	5.0	5.0
Total						**97,545.6**

* psig: pound per square inch (1 atm. = 14.7 cfm)
** dB : Decibel Reading
*** cfm: Cubic Feet per Minute

Table 19: Guess -Timator Chart for dB verses cfm

Digital Reading*	100 psig**	75 psig**	50 psig**	25 psig**	10 psig**
10dB	0.5	0.3	0.2	0.1	0.05
20dB	0.8	0.9	0.5	0.3	0.15
30dB	1.4	1.1	0.8	0.5	0.4
40dB	1.7	1.4	1.1	0.8	0.5
50dB	2.0	2.8	2.2	2.0	1.9
60dB	3.6	3.0	2.8	2.6	2.3
70dB	5.2	4.9	3.9	3.4	3.0
80dB	7.7	6.8	5.6	5.1	3.6
90dB	8.4	7.7	7.1	6.3	5.3
100dB	10.6	10.0	9.6	7.3	6.0

* dB : Decibel Reading
**psig: pound per square inch

V.3.2.4. Recycling of waste in the liquefaction unit

Chemical use may be reduced through recovery and reuse (Barclay & Buckley, 2000). In order to recover a portion of the waste generated fiber a special unit is used to dissolve that waste fiber and convert it into liquid dope using sodium thiocyanate and use it once again in the production line. In ideal conditions around 1 ton of waste fiber was recovered per day. The monthly liquefied amount is independent of the generated waste from the production line, it depends on the operation stability of the liquefying unit.

One unit was already in operation, it consisted of two tanks for liquefaction. However, it did not meet the liquefaction requirements due to the high percentage of waste fiber from production. Installation of a new liquefaction unit was set as a goal in the action plan of waste reduction. The new unit was manufactured on site using a 30 m^3 tank, proper agitator and a motor for the agitator were provided. The tank was installed in the material preparation area close to the existing liquefying unit. Two sets of pipes were installed: Inlet pipes for sodium thiocyanate addition and out let pipes for liquid dope transfer. Operation tests were done during September 2012 and actual operation of the unit started in October 2012. Table (20) shows the amount of liquefied fiber by the new unit. It can be noticed that the liquefied fiber by the new unit is almost double the liquefied amount by the existing unit. That was due to the high capacity of the new unit and frequent break downs in the existing unit.

Table 20: Liquefied fiber by new unit

Month	Unit	September 2012	October 2012	November 2012	December 2012
Production	Ton	1307.0	1433.0	1431.0	1326.0
Liquefied in Tank 1 (Existing)	Ton	12.0	15.0	14.5	16.5
Liquefied in Tank 2 (Existing)	Ton	6.2	10.0	7.1	6.4
Liquefied in Tank 3 (New)	Ton	31.8	40.8	38.4	32.1
Total Liquefied waste	Ton	50.0	65.8	60.0	55.0

V.3.2.5. Recovery of steam condensate

Condensate returned from process heat exchangers typically has an elevated temperature and a significant energy value. Energy savings result from the elevated temperature of the returned condensate. Condensate recovery systems collect condensate from the steam system and feed it back into the boiler feed tank (Vandana *et al.,* 2012).

It was observed that steam headers condensate was sent to drain. It was planned to collect that condensate and send it to DW tank in boiler house to preheat water. For the same a separate condensate collection header was provided at the pipe rack. It was connected with all steam trap discharges. Collected condensate was transferred to boiler house by using pressure power pump.
In agreement with Vikram *et al.,* (2012) this action saves heat content as well as DW, the estimated cost saving was almost 441,637 EGY/Year. Table (21) presents the collected data for condensate recovery and cost saving. According to Vandana *et al.,* (2012) the potential savings for steam recovery were calculated as follows:

Quantity of flash steam generation

$$= \frac{(\text{Sensible heat of condensate at high pressure} - \text{Sensible heat of condensate at low pressure})}{\text{Latent heat of steam at low pressure}} \times 100 \ldots(6)$$

$$= \frac{(144.4 - 99.7)}{539.3} = 8.29\ \%$$

Generated flash steam per hour
= Quantity of flash steam generation x Steam consumption of plant (kg/hr) ……….(7)
= 0.08 x 33,300 = 2,760 kg/hr

Annual steam saving
= Generated flash steam per hour (Ton/hr) x Annual Operating hours (hr/year) x Steam Cost (EGP/Ton) ……(8)
= 2,760 /1000 x 8000 x 20 = 441,637 EGP/Year

Table 21: Saving calculation data for usage of steam condensate in boiler house

Sr.	Parameter	Unit	Value
1	Total enthalpy of steam at 4 bars*	kcal/kg	654
2	Total enthalpy of steam at 1 bars*	kcal/kg	640
3	Condensate quantity	kg/hr	8000
4	Condensate pressure	bar	1
5	Cost of steam	EGP/Ton	20
6	Annual Operating hours	hr	8000
7	Sensible heat of condensate at 1 bar*	kcal/kg	99.7
8	Sensible heat of condensate at 4 bar*	kcal/kg	144.4
9	Latent heat of condensate at 1 bar*	kcal/kg	539.3
10	Flash steam generation	%	8.29
11	Steam consumption of plant	kg/hr	33300
12	Generated flash steam per hour	kg/hr	2,760
13	**Cost saving**	**EGP/Year**	**441,637**

* Steam tables (Keenan *et al.,* 1969)

V.3.2.6. Improving intake well water pumps

There were four intake well pumps, two in operation and two used as stand-by. The intake well pumps were situated at a 2 km distance from the plant. Pumping system efficiency is calculated according to "U.S. Department of Energy" (2005) and Vikram *et al.,* (2012) by the below equations (9) and (10). Table (22) present comparison between design and actual operating data measured on site for intake well pumps with both pumps in both parallel operation and with both pumps in single operation.Both discharge and suction pressures were measured by on-site pressure gauges and assuming motor efficiency 0.9.

Total differential pressure (m) = Discharge pressure head (m) - Suction pressure head (m) …(9)
Pumping system efficiency (%)

$$= \frac{Flow\ rate\ \left(\frac{m3}{hr}\right) x\ Total\ differential\ pressure\ (m)\ x\ 9.81}{Power\ \ (kW) x\ Motor\ Efficiency} \text{ x } 100 \ldots\ldots\ldots\ldots(10)$$

With both pumps in parallel operation pump 1 and pump 2 operate at 62% and 70% efficiency respectively, which was lower than standard design efficiency of 84%. This was mainly due to improper selection of capacities when new pumps were purchased.

Flow requirement was 400 m^3/h, one pump designed for 400 m^3/h did not deliver as per the design due to piping pressure drop. It was found out that the pressure drop in piping was high due to pitting corrosion inside and pipes leak. Proactive steps were taken into consideration for chlorination of water to avoid corrosion due to sulfate reducing bacteria. It was planned to replace both pumps with 400 m^3/h flow by a new energy efficient intake well pump of 500 m^3/h with high efficiency motor to save pumping power.Table (23) presents comparison of performance between old and new status. The usage of one new pump 500 m^3/hr instead of two parallel pumps (400 m^3/hr) will increase pumping system efficiency by 18%.

Table 22: Comparison between design and actual operating data of intake well pumps (pumps in parallel and single operation)

Particulars	Unit	Design data	Operating data				
			Single		Parallel		
			Pump 1	Pump 2	Pump 1	Pump 2	Combined
Power	kW	110	72.4	89.1	71.9	74.9	146.8
Flow rate	m^3/hr	400	340	362	187	220	407
Speed	rpm	1490	1490	1490	1490	1490	1490
Suction pressure*	bar	-0.3	-0.3	-0.3	-0.3	-0.3	-0.3
	meter	-3	-3	-3	-3	-3	-3
Discharge pressure*	bar	7.3	5.8	5.4	7.3	7.3	7.3
	meter	74	58.7	55.5	74	74	74
Total differential pressure	meter	77	61.7	58.5	77	77	77
Pumping System Efficiency	%	84	89.7	73.6	62	70	66.1

*Converting pressure in bar to head in meter = $\frac{\text{Pressure (bar)} \times 10.197}{\text{Specific gravity of water}}$

Table 23: Performance of old and new operation of intake well pumps.

Parameter	Unit	Old (Two pumps in parallel)	New (one pump only)
Flow	m^3/hr	407	500
Head	m	77	80
Motor Efficiency	%	88	93
Power Input	kW	146.8	139.5
Pump Efficiency	%	66.1	84.00
Motor Rated Power	kW	75	75
Motor Speed	rpm	1475	1450

Table 24: Cost saving data for old and new of intake well pumps.

Parameter	Unit	Old (Two pumps in parallel)	New (One pump only)
Flow	m^3/hr	407	500
Operating time	hr/day	22.1	18
Power Consumption	kW	146.8	139.5
Power consumption per day	kW/day	3246.2	2511
Operating days per year	day/year	360	360
Electrical Tariff*	EGP/kWh	0.3	0.3
Annual cost	EGP/Year	350,589	271,188
Cost saving	**EGP/Year**	**79,400.7**	

* Electrical Tariff 0.3 EGP/kWh (off pick time, power factor 0.9), Egyptian Electrical Utility and Consumer Protection agency, 2014.

Furthermore, the monetary cost saving of using one new pump 500 m^3/hr based on daily water requirements of plant 9000 m^3/day (AFCO-EIA, 2007), was estimated to be 79,400 EGP/Year. Cost savings were calculated using the below equations (11 – 14). Summary of cost savings is shown in Table (24).

Operating time (hr/day)

$$= \frac{\text{Daily water requirement of plant (m3/day)}}{\text{Pump Flow rate } (\frac{m3}{hr})} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots(11)$$

Power consumption per day (kW/day)

= Operating time (hr/day) x Power Consumption (kW) …………(12)

Annual Cost of pumps operation (EGP/Year)

=Power consumption per day (kW/day) x Operating days per year (day/year) x Electrical Tariff (EGP/kWh) ….(13)

Annual Cost saving (EGP/Year)

= Annual Cost of present two parallel pumps (EGP/Year) - Annual Cost of one new pump (EGP/Year) ……….(14)

V.3.3. Establishing working groups

In accordance to Caffal, (1996), Stapleton *et al.,* (2001), William *et al,.* (2003), Manoloudis (2007) and McKane *et al.,* (2011) top management and employees involvement are crucial elements in the success of any energy or waste management system. According to ISO 50001:2011 and ISO 14001:2004 management representatives with appropriate skills and competence were appointed for the implementation of both systems. The roles of all persons involved in the energy and waste management committees were determined and clarified.

Two committees were formed: one for monitoring and reporting energy consumption in the plant, identify potential savings and improvement projects. The second committee for waste monitoring, reporting, identifying and implement improvement actions as well.Each committee consisted of a manager, coordinator and a cross functional technical team from different departments such as electrical, instrumentation, material preparation, production, utility, and mechanical. Details of the energy and waste management committees and role of each member are shown in Table (25). The selected members for the committees were assigned to the programs and the committees started their work on January 2012.

In agreement with ISO 19011:2002 and ISO 50001:2011 top management should demonstrate its commitment to support the energy and waste management systems and to continually improve its effectiveness by conducting management reviews. Top management should ensure that the audit program objectives are consistent with management system policy, established to direct the planning and the audit program is implemented effectively. Accordingly a monthly review meeting was held by the energy management committee to identify abnormalities, suggest improvement areas, set targets and review taken actions. Moments of meetings were being documented and circulated to all concerned and top management. The recommendations of these meetings were being discussed with top management and the agreed goals set in the action plan. Inputs to the management review included:

a) Follow-up actions from previous management reviews.
b) Review of the energy/waste policy.
c) Review of energy performance/waste generation and related actions.
d) The extent to which the energy/waste objectives and targets have been met.

Table 25: Details of the management committee and role of each member

Role	Responsibility
Committee Manager	- Responsible of program implementation. - Reports the progress to top management - Provides direction to the program - Facilitates any obstacles
Coordinator	-Coordinates different activities of the program. - Follow-ups the implementation of agreed points in the action plan. - Monitors energy consumption or waste generation and checks reasons of abnormalities - Frequently updates information and documents related to the program
Technical team (3-5 Cross functional members)	-Provides technical backup in the necessary engineering disciplines. -Implements goals of the action plan

V.3.4. Development of Awareness Raising

To be successful an energy management program must have the backing of the people involved Caffal, (1996), Stapleton *et al.*, (2001), William *et al,*. (2003), Manoloudis (2007), Worrell *et al.,* (2010) and McKane *et al.,* (2011) agreed on the same. Moreover, according to ISO50001:2011 the organization should ensure that any persons working on its behalf related to significant energy uses are competent on the basis of appropriate education, training, skills or experience.

Consequently, two awareness campaigns were launched in the company. One to introduce the importance of energy management to all levels of employees.The other to introduce waste management. The campaigns consisted of the following:

- Training to shop floor employees about energy conservation and waste reduction.
- Started the practice of closing steam valves during shut downs.
- Started the practice of shutting down running equipment during ideal time.
- Started the practice of closing lights, PCs, ACs and printers while not being used.
- Started the practice of recycling and reusing some non-hazardous waste materials such as papers and plastics.
- Editing articles about energy conservation and publishing them in the monthly newspaper of the company. The newspaper was circulated to all the employees and displayed as well.
- Energy saving posters were displayed in each office near the power switch key to remind the employees to switch off the lights, PCs and printers when not being used.
- A function called "Environmental Day" was organized. The function targeted all employee levels, it aimed to spread awareness about different environmental issues such as going green, energy conservation and waste reduction.

Part II. Life Cycle Assessment for the Acrylic Fiber Industry

V.4.Environmental impact of manufacturing

LCA for the acrylic fiber industrywas based on the International Organization for Standardizations: Environmental management - Life Cycle Assessment- Principals and Frameworks (ISO14040:2006) and International Organization for Standardizations: Environmental Management -Life Cycle Assessment- Requirements and Guidelines (ISO14044:2006).

V.4.1. Goal and Scope Definition

The present LCA analyzed the impact of acrylic fiber manufacturing on the environment starting from obtaining the raw material till the end of the production process (Cradle to Gate). In agreement with Tobler (2000) LCA of textile process depended on water and energy management of the company, therefore focus was given to water consumption, energy utilization in acrylic fiber production and generated waste from the industry.

Since the goal of the present study was to obtain information for decision makers and environmental protection, the output of the calculations is presented in the form of separated single indicators to pinpoint the most influential factors. This approach was used by Hassanain (2013) in analyzing different technologies of using oil and recently by Van der Velden *et al.,* (2014) in finding bench marks of the textileindustry.In order to perform the LCA several indicators should be set. A single indicator in LCI analysis is one score that expresses the result of the cumulative inventory list in one indicator. Additionally, the effects of the resources used and the emissions generated would be grouped into a number of impact categories which are weighted for importance.System boundaries of the study are presented in Figure (23). The study modeled the environmental effects of producing 1 ton acrylic fiber on the environment as to be multiplied by the actual production in any manufacturing facility to identify the overall impact.

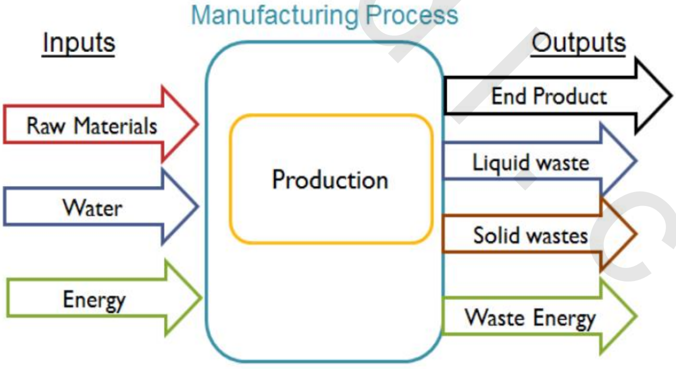


Figure 23: LCA system boundaries of the acrylic fiber industry

V.4.2. Inventory Analysis

LCA of the acrylic fiber industry started with a systematic inventory of all resource consumption and emissions during the product's entire life cycle. All input/output data used in this study are presented in Table (26). The results of this inventory are presented in a list of consumed resources, emissions and impacts on both human health and ecosystem following the system of Goedkoop & Spriensma (2000). For this purpose SimaPro software was used to model the inputs/outputs mentioned.

The inputs taken into account were a) chemicals that are used as raw materials in the production process,b) treated water used, and c)the energy sources (steam and electrical power). The outputs were: a) the end product of acrylic fiber, b) liquid waste, c) solid wastes and d) energy losses (Figure 23). The foreground data in the inventory was obtained from Alexandria Fiber Company from process production manuals, utility manuals, data sheets and environmental impact assessment study of the facility. Background data was created by the model utilizing "Eco-profiles" from the Eco-Invent database (Swiss Center for Life Cycle Inventories, 2008).

In compliance with ISO14044:2006Section 4.2.3.3., a cut-off criteria of 0.1% was chosen. As suggested by Goedkoop *et al.,* (2008) a cut-off criteria of 0.1%shows only process that has more than 0.1% of the environmental load. They reported that in most cases very few processes turn out to have a contribution that is above this threshold.

Eco-indicator 99 methodology of the Sima Pro software was used for LCA single score and weighting, to aggregate the LCA results into numbers and units as recommended by Goedkoop & Spriensma, (2000) and Frischkneckt *et al.*, (2007). The eleven impact categories taken into consideration as compiled by the Eco-indicator 99 methodology were: Global Warming Potential (GWP) represented by climate change, Acidification Potential (AP), Eutrophication Potential (EP), Carcinogens Potential (CP), Ecotoxicity Potential (ETP), Respiratory Inorganic Formation Potential (RIFP), Respiratory Organic Formation Potential (ROFP), Radiation Potential (RP), Ozone Layer Depletion (OLD), Minerals Depletion (MD), Land Use (LU), and Fossil Fuels Depletion (FFD) (Figure 11). Also, Cumulative Energy Demand (CED) indicator was used as a single-issue indicator for energy consumption. It was found that calculated results of fossil fuel depletion by Eco-indicator 99 methodology were multiple indicators; consequently, as suggested by Van der Velden *et al.,* (2014) CED methodology was used as a single-issue indicator to energy consumption as it is simple to understand and to extrapolate impacts.

V.4.3. Life Cycle Impact Analysis

V.4.3.1. Overall Impact

According to ISO 14040:2006and 14044:2006 life cycle impact analysis is essentially meant to scrutinize in the results of the inventory of the production phase in order to be able to take any necessary mitigations on measures (Goedkoop & Spriensma, 2000). By applying the LCA model to identify the overall impact assessment of acrylic fiber production on the environment the share of each category was calculated as shown in Table (27).

Table 26: Input/output data for acrylic fiber production (1 Ton production)

Inputs			
Inputs from Materials			
Name	**Amount**	**Unit**	**Remarks**
Acrylonitrile	910.0	kg	
Vinyl Acetate	92.5	kg	
Sodium Chlorate	6.0	kg	
Sodium Metabisulphite	18.0	kg	
Sulphuric Acid	0.3	kg	
Sodium Hydroxide (50%)	19.0	kg	
Titanium Dioxide	4.2	kg	
Sodium Sulphate	0.7	kg	
Nitric Acid	2.4	kg	
Demineralized water	144.0	m^3	Treated water for production process
Inputs from Electricity/Heat			
Electricity	1320.0	kWh	
Steam	9.8	Ton	Used mainly in dryers and material preparation area

Outputs			
Product			
Acrylic Fiber	1.0	Ton	Main product
Waste and emissions			
Waste Effluent	69.2	m^3	Collected from all areas
Hazardous waste from process	1.0	kg	Pigment waste, chemical bags and cans
Chemical sludge	1.2	kg	From water treatment plant
Reused mixed plastics containers	1.0	kg	Non-hazardous solids (containers)
Recycled textiles	4.0	kg	Filter cloth and waste fiber

- ❖ Excess solvents (Sulphuric Acid and Sodium Hydroxide) are recovered and recycled.

Table 27: Overall impact of acrylic fiber manufacturing

Category	**Weighting**
Human health	15.9 (%)
Ecosystem quality	2.1 (%)
Resources	82.0 (%)

It can be noticed that the highest impact was on the resources which represent 82.0% of the overall impact. The reason is that production of acrylonitrile substance is a high consumer of fossil fuels. Second highest impact was on human health (15.9% of the overall impact) major effect was on the respiratory system of human body, carcinogens and on climate change. This impact is due to the inorganic chemicals used during the manufacturing process of the product. The lowest impact was on ecosystem quality (2.1% of the overall impact) represented in the overall acidification impacts on the environment due to the usage of acrylonitrile substance, acids and other chemical compound as raw materials. These categories were further assessed to set better analysis for the decision makers.

LCA results in Figure (24) show the impacts of acrylic fiber manufacturing on the different environmental categories. Fossil fuels depletion is the highest category affected by the manufacturing process, followed by human respiratory system due to inorganic substances used in the industry. Potential impact was also noticed on climate change, acidification/eutrophication potential, ecotoxicity and smallest impacts were on carcinogens potential. No impacts were detected on radiation, ozone layer depletion, land use, minerals depletion or human respiratory system due to organic substances. The reason for not detecting any impacts on the previous categories is that the process of acrylic fiber manufacturing does not use any radiation elements, nor generate any substances that may affect the ozone layer, nor uses large land areas in the production. Furthermore, no organic substances are used in the manufacturing process and the raw materials used in the process are chemical compounds from petrochemicals, no minerals are used.

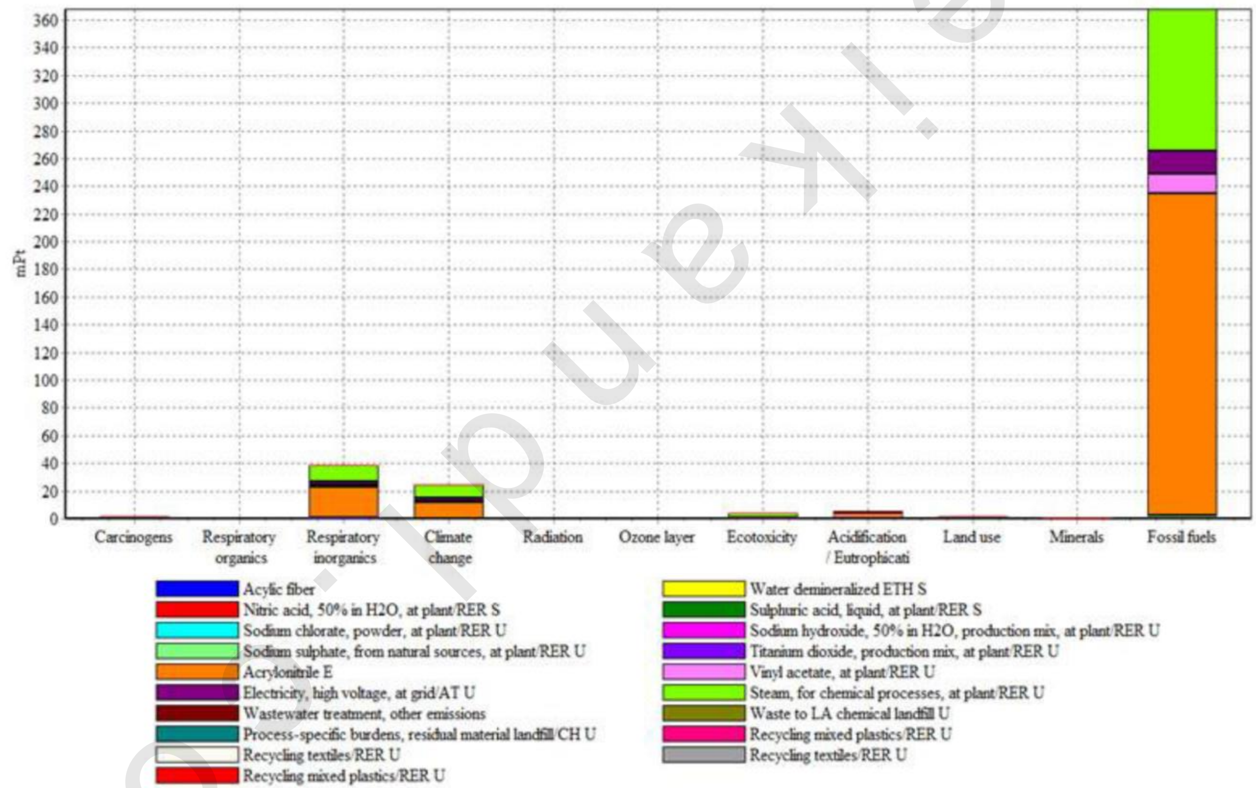


Figure 24: Impact assessment of acrylic fiber production on the environment (Weighting)

V.4.3.2. Global Warming Potential (GWP)

The global warming potential was taken into consideration as an indicator of greenhouse effect. It is expressed in ton CO_2 equivalent as shown in Table (28) and Figures (24 - 25). The calculated potential indicates that the manufacturing of 1 ton acrylic fiber releases to the environment approximately 5.4 tons CO_2equivalent. Close results were reported by Van der Velden *et al.,* (2014), the range for their cradle to gate analysis for synthetic textiles were 2.69 – 8.6 ton CO_2 equivalent/TF.

In agreement with BSR (2009) synthetic fibers have high greenhouse emissions in comparison to other textile materials as a result of energy use required for raw material production. Carbon dioxide is mainly released during the usage of fossil fuels in steam and electricity generation.

V.4.3.3. Acidification Potential (AP)

Acidification potential as an indicator of acid rain phenomenon, is calculated and expressed in SO_2 equivalent, as shown in Table (28). About 13.46 kg SO_2equivalent is released from 1 ton production of acrylic fiber. Barclay & Buckley (2000) identified that air pollutantsemitted from various textile processes and from energy production is the second greatest pollution source for the textile industry. Process emissions include volatile organic substances and particulate matter from printing, dyeing, and chemicals handling. At the same time, boilers are one of the major point sources for air emissions, producing nitrogen and sulphur oxides.

In the current case study, air emissions from acrylic fiber process are scrubbed in a monomer gas absorber and recycled back to the process. Also, in agreement with Barclay& Buckley (2000) emissions to air can be minimized by using design products that do not require the use of volatile chemicals, optimizing boiler operations and reducing the use of solvents.

V.4.3.4. Eutrophication Potential (EP)

Eutrophication is generally associated with the environmental impact of excessively high level of nutrients that lead to shifts in microbial and algal species and increase biological productivity. Nitrogen and phosphorous levels released to waterways are the major contributors to eutrophication potential (Bengtsson & Howard, 2010).

It has been cited by Alonso & Camargo (2006) and US.EPA (1993) that also NO_2 could lead to the eutrophication phenomenon. Table (28) presents results of the eutrophication potential. For each one ton production of acrylic fiber, 6.86 kg NO_2 is released. As indicated in the previous section process emissions and boilers are one of the major point sources for air emissions, especially nitrogen (Barclay & Buckley, 2000).

V.4.3.5. Carcinogens Potential (CP)

The results of life cycle analysis are presented in Table (28) and Figures (24 - 25).The carcinogens potential effect from the manufacturing of acrylic fiber is due to the release of arsenic, cadmium, zinc and chromium to both air and effluent.

According to "U.S. National Research Council" (1980), Laing (1991), Barclay & Buckley (2000), Brito *et al.,* (2008) and Lo *et al.,* (2012) the dying process in textile industry could produce huge amount of toxic emission, the loss of dyes to effluent can be estimated to range from 2% to 10% of the overall used dyes in the dying process. Knackmuss, (1996), Slokar & Le Marechal, (1998) and Kolekar, (2010) reported that the following dyes are applied to

Table 28: Life cycle inventory of acrylic fiber manufacturing

	Unit	Amount		Impact Indicator
		(TF)	(50 TF/Day)[a]	
Emissions to Air				
Major Elements				
CO_2	Ton	5.4	270.0	GWP[1] , RIFP[6]
CO [*]	g	13.0	650.0	GWP[1]
CH_4 [*]	kg	25.7	1285.0	GWP[1]
SO_2	kg	13.4	671.5	AP[2], RIFP[6]
NH_3 [**]	kg	0.03	1.5	AP[2] , RIFP[6]
NO_2	kg	6.8	343.0	EP[3]
Cd	g	0.2	10.0	CP[4], ETP[5]
Ni	g	4.0	200.0	CP[4], ETP[5]
N_2O	kg	0.06	3.0	GWP[1], RIFP[6]
Particulates, < 10 um	kg	0.8	40.5	RIFP[6]
Minor Elements				
Particulates, < 2.5 um	kg	0.39	19.5	RIFP[6]
As	mg	1.4	70.0	CP[4], ETP[5]
Benzo(a)pyrene	mg	0.65	32.5	CP[4]
Phenol	mg	0.28	14.0	CP[4]
Zn	g	0.8	40.0	ETP[5]
Pb	g	0.6	30.0	ETP[5]
Cr	g	0.5	25.0	ETP[5]
Cu	g	0.5	25.0	ETP[5]
Hg	mg	0.53	26.5	ETP[5]
Cr VI	mg	0.11	5.5	ETP[5]
Liquid Effluent				
Major Elements				
As	g	0.5	25.0	CP[4]
Cd	g	0.04	2.0	ETP[5]
Cr	µg	0.01	0.5	ETP[5]
Zn	mg	12.8	640.0	ETP[5]
Cu	g	2	100.0	ETP[5]
Ni	g	4	200.0	ETP[5]
Minor Elements				
PAHs	mg	0.79	39.5	CP[4]
Solid Wastes				
Major Elements				
Cd	mg	0.6	30.0	CP[4]
Cr	mg	0.6	30.0	ETP[5]

Cr VI	mg	0.1	5.0	ETP[5]
Zn	g	0.3	15.0	ETP[5]
Minor Elements				
As	mg	4.52	226.0	CP[4]
Cu	mg	0.77	38.5	ETP[5]
Resources consumption				
Energy	GJ	133.0	6650.0	FFD[7]

a Actual production of the studied case (Alexandria Fiber Co.)

1. GWP: Global Warming Potential, 2. AP: Acidification Potential, 3.EP: Eutrophication Potential, 4.CP:Carcinogens Potential

5. ETP: Eco-toxicity Potential, 6. RIFP: Respiratory Inorganic Formation Potential, 7.FFD:Fossil Fuels Depletion.

* CO_2 equivalent, ** SO_2 equivalent

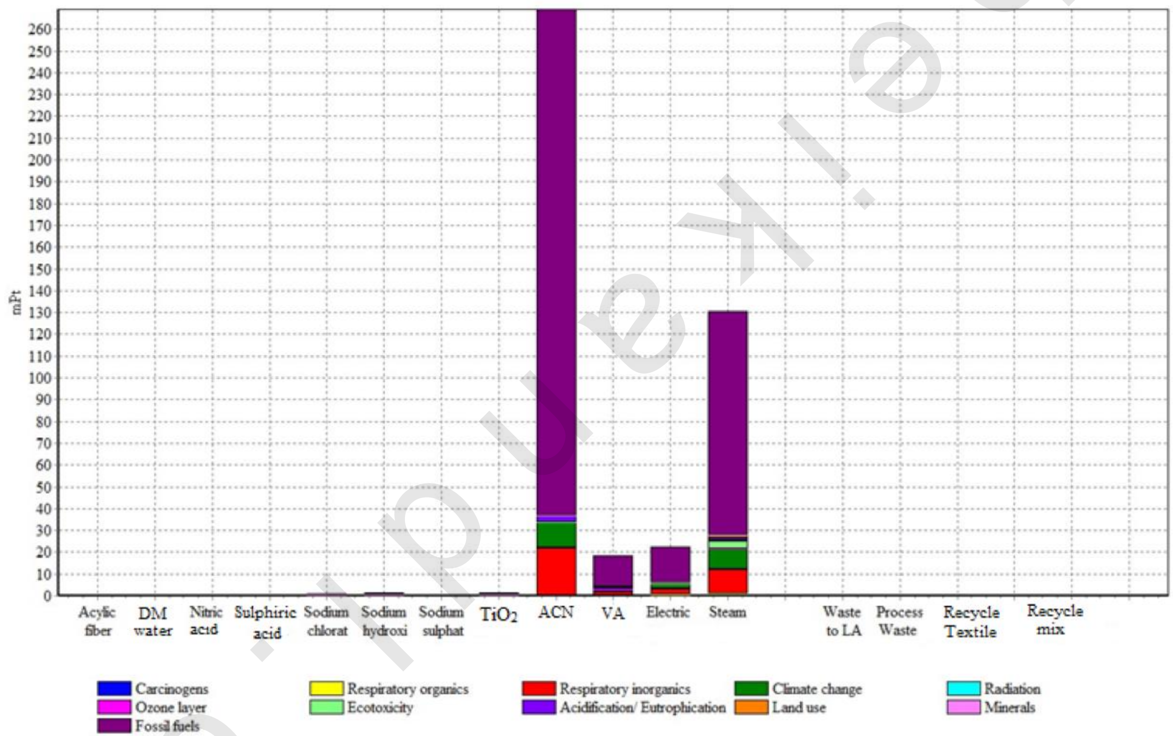


Figure 25: Impact assessment of acrylic fiber production on the environment (Single score)

acrylic fibers: a) acid dyes , b) basic dyes which require preparation as a double salt of zinc, dichromates to oxidize and c) disperse dyes. Further carcinogenic potential may happen due to carriers with phenol compounds used with disperse dyes (Shenai, 2001).

Moreover, Ning *et al.,* (2014) declared that as components of synthetic dyes, polycyclic aromatic hydrocarbons (PAHs) are present as contaminants in textile dyeing sludge, which may pose a threat to environment in the process of sludge disposal. As for, Benzo(a)pyrene emissions to air are produced as a byproduct of incomplete combustion during steam and electricity generation (US EPA, 2013).

V.4.3.6. Ecotoxicity Potential (ETP)

The ecotoxicity potential included three sub-categories as reported by Bengtsson & Howard (2010): fresh water aquatic ecotoxicity, marine aquatic ecotoxicity and terrestrial ecotoxicity. Results of the ecotoxicity potential of the life cycle analysis are shown in Table (28) and Figures (24 - 25). Results indicated that there is apotential for ecotoxicity in all three sub-categorieswhich is mainly attributed to the release of nickel and zinc from dyes.

In agreement with Robertson & Kirsten (1993) and Gomes *et al.,* (2012) textile industries consume a large amount of water and employs toxic products in their industrial processes such as metals, solvents and dyes. As indicated previously some dyes contain chromium, cobalt, copper, nickel, zinc, lead and trace concentrations of mercury, cadmium and arsenic can be present as well (Laing, 1991 and Barclay & Buckley, 2000).

V.4.3.7. Respiratory Inorganic Formation Potential (RIFP)

The primary emissions that affect the respiratory potential are NO_x, NH_3, CO and SO_x (Bengtsson& Howard, 2010). Analysis results in Table (28) and Figures (24 - 25) show that the respiratory inorganic formation potential generated by the manufacturing of acrylic fiber is due to the release of SO_2, N_2O and NO_2 to air, both are generated from fuel used during the production of the raw material i.e. acrylonitrile, vinyl acetate and titanium dioxide. Also, the generation of steam used in the chemical area of the manufacturing plant causes the release of particulates > 2.5 μm and < 10 μm which increases the respiratory inorganic formation potential as well.

According to US EPA (2011) air pollutant emissions from the production of acrylic include emissions of acrylonitrile (volatilized residual monomer), solvents, additives, and other organics used in fiber processing. The most cost-effective method for reducing solvent VOCs emissions from spinning process is a solvent recovery system. In wet spinning processes, distillation is used to recover and recycle solvent from the solvent stream that circulates through the spinning, washing, and drawing operations. This explains the negligible effect of solvents used in the acrylic fiber industry.

V.4.3.8. Fossil Fuels Depletion (FFD)

In accordance with Udo de Haes & Heijuns (2007) energy is involved in all life cycles. Table (28) and Figures (24 - 25) show that fossil fuels is the highest indicator affected by the manufacturing of acrylic fiber, LCA results were consequences of the fact that the manufacturing of acrylic fiber is energy consuming (Barclay & Buckley, 2000 and BSR, 2009). LCA cradle to gate analysis indicates that the total consumed energy during the manufacturing of acrylic fiber was 133 GJ/TF. Close results were reported by Van der Velden *et al.,* (2014), the range of their CED calculations for synthetic textileswere 78.4 to 129.7 GJ/TF. Another figure was given by BSR (2009) who indicated that 157 GJ of energy is used per ton of fabric. The production of profiles from the Eco-Invent database (Swiss center for life cycle inventories, 2008) for all the necessary input materials and processes.

All input/output data used in the study are presented in Table (27). In compliance with ISO14044:2006 Section 4.2.3.3., a cut-off criteria of 0.1% was chosen, as suggested by Goedkoop *et al.,* (2008) a cut-off criteria of 0.1% shows only process that has more than 0.1% of the environmental load.Eco-indicator 99 methodology was used for LCA single score and weighting of the eleven impact categories taken into consideration (Goedkoop & Spriensma, 2000 and Frischkneckt *et al.*, 2007).

It was found that calculated results of fossil fuel depletion by Eco-indicator 99 methodology were multiple indicators, consequently, as suggested by Van der Velden *et al.,* (2014) Cumulative Energy Demand (CED) methodology was used as a single-issue indicator to energy consumption. The used LCA simulation model considered the following as well: a) for detecting the impacts of waste streaming it was envisaged to use "worse - case scenario" in both landfilling and incineration. b) regarding landfill: short term leaching to surface waters from waste water treatment plant and air emissions, long term leaching to ground water in case of base lining failure and c) regarding incineration: short term emissions to rivers and long term emissions to ground water from slag bottom.

V.5.3. Life Cycle Impact Analysis

V.5.3.1. Overall Impact

Results in Tables (29-31) and Figures (26-27) present the overall environmental impactsofthe waste streaming approaches: landfill and incineration.

In worse - case scenario a sanitary landfill and leachate takes place as assessed by the model, a high ecotoxicity and carcinogenic potential have been detecteddue to the release of cadmium and arsenic as shown in Figures (26-27), Woodard (2001) reported that such scenario may take place.In order to avoid/minimize the environmental impacts, a landfill needs to be constantly monitored (Cherubini *et al.,* 2009). As for incineration, if the incinerator does not control the emissions properly as assumed, various impacts could be detected as presented in Figures (26-27)

In accordance with previous results reported by Arena *et al.,* (2003), Mendes *et al.,* (2004), Finnveden *et al.,* (2005), Cherubini *et al.,* (2009), Assamoi & Lawryshyn (2012) and Lettieri *et al.,* (2014), Figure (27) indicates that incineration is more environmentally friendly.

Table (29) shows that the highest impact of both approaches is on ecosystem quality due to their ecotoxicity potential from copper, zink and nickel emissions. Overall impact of incineration on ecosystem quality is higher than overall impact of landfill, reaching 68.4% and 51.3%, respectively. On the other hand due to the high potential of cadmium release into the effluent, the human health indicator is the second highest impact. Landfill has an overall impact of 46.8% on human health as compared to 28 % overall impact by incineration.

acrylonitrilethe main raw material used in the acrylic fiber manufacturing process, made from ammonia and propelyne requires large amounts of energy.

In conclusion by analyzing the life cycle impact of acrylic fiber manufacturing on the environment from raw material stage till the end of production phase,taking into consideration: water consumption, energy resources and generated wastes, significant impacts were detected on seven environmental categories: global warming, acidification, eutrophication, carcinogens, ecotoxicity, human respiratory system due to inorganic substances and fossil fuels depletion. Highest impact was on fossil fuels depletion due tothe high energy requirement for acrylonitrile production. At the same time, no impacts were detected on radiation potential, ozone layer depletion, land use, minerals depletion or human respiratory system due to organic substances. The study modeled theenvironmentaleffect of producing 1 ton acrylic fiber on the environment, these results can be multiplied by the actual production in any manufacturing facility to identify the overall impact and accordingly use it as an indicator for better decision making.

V.5.Waste Streaming Approaches

The inventory of waste generation from acrylic fiber process was described previously in section V.1.3.of this chapter. The results indicated that air emissions are adsorbed and recycled back in the process, liquid effluents are treated in effluent treatment plant before final disposal to the environment, non-hazardous solids are reused, such as plastic containers, or recycled back in the process, like liquefied waste fiber. As hazardous solid wastes contain mainly pigment waste, chemical bags and chemical sludge, proper handling should be done for disposal. In this investigation, LCA methodology was used to compare the environmental impacts of two waste streaming approaches for handling hazardous solid wastes of the acrylic fiber manufacturing: landfill or incineration, the investigation aimed to identify which approach is more environmental friendly.

V.5.1. Goal and Scope Definition

The investigation compared the environmental impacts of two wastestreaming approaches: landfill and incineration of the generated hazardous waste from 1 ton production of acrylic fiber. The aim of the investigation was to analyze and evaluate their environmental impacts based on the current case study "Alexandria Fiber Company"and find out which approach has less negative impacts on the environment.

The study consisted ofthe eleven impact categories as compiled by the Eco-indicator 99 methodology, presented in the previous section as well as in the Materials and Methods chapter (Figure 11). These categories have been chosen given their environmental significance and also because they are internationally accepted in accordance with the requirements of ISO14044:2006.

V.5.2. Inventory Analysis

LCA was applied for two waste streaming scenarios: the first scenario was based on 100% incineration of hazardous solid waste and the second scenario was 100% landfill of the hazardous solid waste. All wastes were done for 1 ton production of acrylic fiber.

The foreground data in the inventory was gotten from Alexandria Fiber Company from process production manuals, utility manuals, data sheets and environmental impact assessment study of the facility. Background data was created using Sima Pro software by utilizing eco-

Table 29: Impact assessment of waste streaming approaches

Category	Landfill	Incineration
Human health	46.8 (%)	28.0 (%)
Ecosystem quality	51.3 (%)	68.4 (%)
Resources	2.0 (%)	3.5 (%)

Table 30: Life cycle inventory of landfill approach of waste

	Unit	Amount (TF)	Amount (50 TF/Day)	Impact Indicator
		Emission to Air		
Major Elements				
CO_2	g	14.3	714.0	GWP[1], RIFP[6]
CH_4 *	g	15.5	773.0	GWP[1]
NO_2	mg	88.0	4401.0	EP[3], RIFP[6]
N_2O *	mg	3.2	158.5	GWP[1]
Minor Elements				
Particulates, < 2.5 um	mg	7.9	398.0	RIFP[6]
SO_2	mg	35.1	1756.0	AP[2], RIFP[6]
NH_3 **	mg	1.3	63.5	AP[2], RIFP[6]
		Leachate		
Major Elements				
Cd	mg	8.7	437.5	CP[4], ETP[5]
Cu	g	0.9	45.5	ETP[5]
Ni	mg	80.5	4025.5	ETP[5]
Zn	mg	810.7	40535.0	CP[4]
Minor Elements				
As	µg	472.1	23605.5	CP[4]
Pb	mg	376.5	18826.5	ETP[5]
		Resources Consumption		
Energy	MJ	235.0	11750.0	FFD[7]

1. GWP: Global Warming Potential, 2. AP: Acidification Potential, 3.EP: Eutrophication Potential, 4.CP:Carcinogens Potential

5. ETP: Eco-toxicity Potential, 6. RIFP: Respiratory Inorganic Formation Potential, 7.FFD:Fossil Fuels Depletion.

* CO_2 equivalent, ** SO_2 equivalent

Table 31: Life cycle inventory of incineration approach of waste

	Unit	Amount		Impact Indicator
		(TF)	(50 TF/Day)	
Emission to Air				
Major Elements				
CO_2	kg	0.5	24.5	GWP[1]
NO_2	g	0.5	24.5	EP[3], RIFP[6]
N_2O^{*}	mg	13.6	680.0	GWP[1]
Minor Elements				
Particulates, < 2.5 um	g	0.1	6.0	RIFP[6]
Particulates, > 2.5 um, and < 10um	mg	6.8	343.5	RIFP[6]
SO_2	mg	46.6	2329.0	AP[2], RIFP[6]
NH_3^{**}	mg	10.9	546.5	AP[2], RIFP[6]
Leachate				
Major Elements				
As	mg	0.7	35.0	CP[4]
Cu	g	1.1	54.5	ETP[5]
Ni	mg	104.5	5225.5	ETP[5]
Zn	mg	344.7	17238.5	ETP[5]
Minor Elements				
Cr VI	mg	9.7	484.0	ETP[5]
Cd	mg	0.3	15.0	CP[4]
Pb	g	0.2	11.0	ETP[5]
Resources Consumption				
Energy	MJ	356.0	17800.0	FFD[7]

1. GWP: Global Warming Potential, 2. AP: Acidification Potential, 3.EP: Eutrophication Potential, 4.CP:Carcinogens Potential
5. ETP: Eco-toxicity Potential, 6. RIFP: Respiratory Inorganic Formation Potential, 7.FFD:Fossil Fuels Depletion.

* CO_2 equivalent, ** SO_2 equivalent

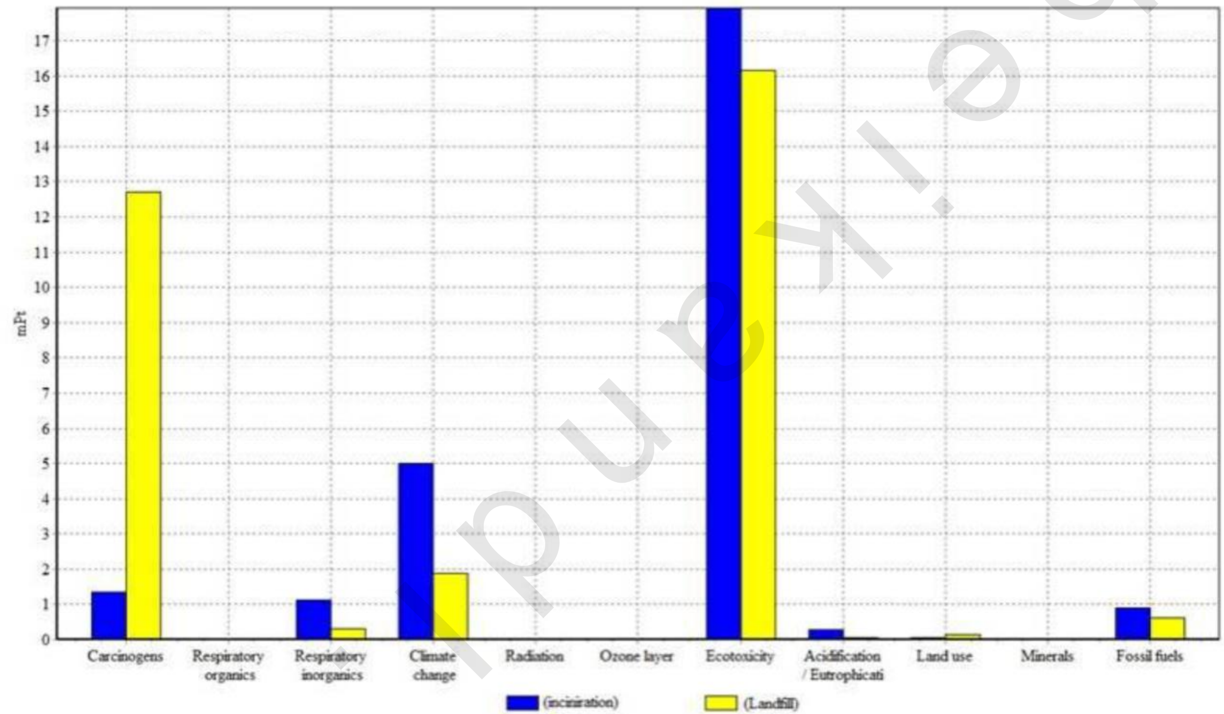


Figure 26: Comparison of impact assessment of two waste streaming approaches (weighting)

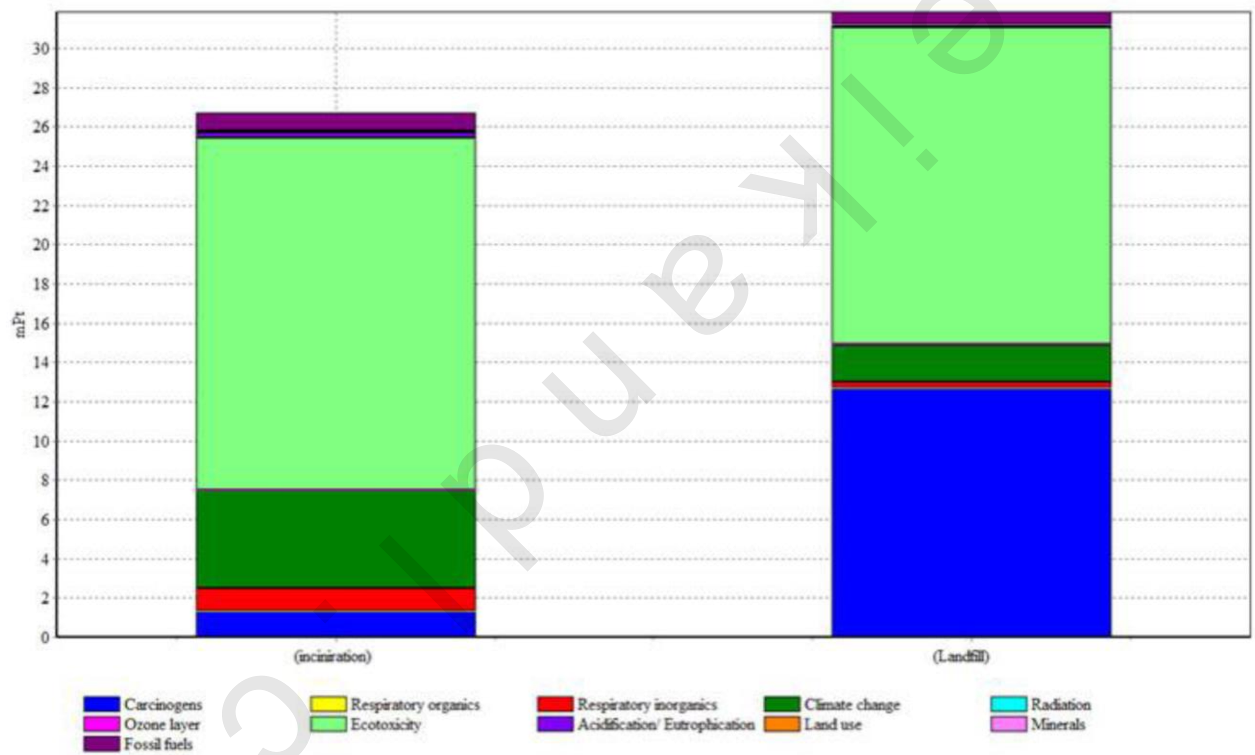


Figure 27: comparison of impact assessment of two waste streaming approaches (Single score)

As for resources it is evident that the impact of incineration approach is higher than the impact of landfill with, 3.5 % and 2.0%, respectively. The amount of fossil fuels (coal and natural gas) used by incineration is higher than the used in a landfill. Fossil fuels are mainly consumed during incineration through the combustion process and during landfill by transportation and handling processes.

Furthermore, LCA results in Figures (26-27) show the impact assessment of the two waste streaming approaches on the different environmental categories. Ecotoxicity is the highest category affected by both waste streams, followed by carcinogens potential, climate change, human respiratory system, due to inorganic substances.Fossil fuels depletion and acidification/eutrophication potential came next. Smallest impact of both waste streams was on land use which could beattributed to the occupation of road network during transfer of the hazardous solid wastes from the plant area to the landfill or incineration area and occupation of the dump site itself. It can be noticed in Figure (26) that land use potential in case of landfill is higher than incineration due to the large dump site area required for the landfilling.

Impact indicators matrix for the two waste streaming approaches is attached in Appendix (A3). No impact was detected on radiation, ozone layer depletion, minerals depletion or human respiratory system due to organic substances. The reason for not detecting any impact on the previous categories is that both waste streams do not generate any substances that may affect the ozone layer nor cause radiation. Neither organic substances nor minerals are used in both waste handling approaches.

V.5.3.2. Global Warming Potential (GWP)

In accordance with Cherubini *et al.,* (2009) the calculated GWP through the life cycle analysis indicates that landfill is more preferable in terms of climate change impact. The GWP is expressed in CO_2 equivalent as shown in Tables (30-31) and Figures (26 - 27). The usage of landfill for the treatment of hazardous wastes generated from 1 ton acrylic fiber releases 32.9 gm CO_2 equivalent. The footprint is mainly constituted by landfill methane. As for incineration, it releases 513.1 gm CO_2 equivalent. The combustion step strongly affects final results: CO_2 from fossil carbon and NO_x emissions. Similar results were reported by Cherubini *et al.,* (2009).

V.5.3.3. Acidification Potential (AP)

Life cycle analysis indicates that landfill is also more preferable in terms of acidification potential, Assamoi & Lawryshyn (2012) and Lettieri *et al.,* (2014) reported the same. Gases responsible of rain acidification are SO_2, NO_x, HCl, H_2S and NH_3.AP isexpressed in SO_2 equivalent as shown in Tables (30-31).

As a result to the combustion process in incineration approach, it can be contemplated that the released SO_2 from incineration is higher than the released from landfill: 46.85 mg against 35.12 mgSO_2 equivalent/TF.

V.5.3.4. Eutrophication Potential (EP)

Nitrogen and phosphorous levels released to waterways contribute to eutrophication potential. Tables (30-31) present the eutrophication potential due to the treatment of hazardous solid wastes generated from 1 ton production of acrylic fiber.

NO_2 emissions from incineration arealmost five times higher than NO_2 emissions from landfill i.e.488.54 and 88.02 mg NO_2 equivalent/TF, respectively. NO_2 emissions from incineration are generated from the combustion process of acrylic fiber hazardous wastes and from the used fossil fuels through the incineration process.

Assamoi & Lawryshyn (2012) reported in their environmental comparison between landfilling and incineration that the landfilling option has a noticeably smaller eutrophication impact on the environment

V.5.3.5. Carcinogens Potential (CP)

The carcinogens potential of acrylic fiber hazardous solid waste treatment is presented in Tables (30-31) and Figures (26-27).It can be noticed that the CP of landfill approach is almost ten times higher than the CP of incineration. The effects of polluted surface run-off and leachate on surface water and ground water are the most serious pollution in the mid and long term perspective brought by landfills (Law-wai, 2001 and Doka, 2003).

Life cycle analysis results indicate that CP by landfill of hazardous solid wastes generated from acrylic fiber industry is a result of arsenic, zink and cadmium reaching the effluent.As indicated previously some pigments and dyes contain zinc, trace concentrations of cadmium and arsenic (Laing, 1991 and Barclay & Buckley, 2000).

V.5.3.6. Ecotoxicity Potential (ETP)

Effect of the ecotoxicity potential by landfill and incineration in Tables (30-31) and Figures (26-27), indicated that ecotoxicity has the highest impact of both approaches on environment, moreover, landfill has a higher ecotoxicity potential than incineration.

As indicated in the previous section, in worse - case approach landfill leachate takes place, high ecotoxicity potential are expected due to the surface run-off and leachate reaching surface water and ground water containing copper, zink, nickel, cadmium, lead and mercury released from the pigment wastes.As for incineration, cadmium and arsenic could be released from pigment wasteswhich would cause the ecotoxicity potential

V.5.3.7. Respiratory Inorganic Formation Potential (RIFP)

Analysis results in Tables (30-31) and Figures (26-27) show that the respiratory inorganic formation potential generated by incineration approach is almost two and half times the RIFP generated by landfill, due to the emissions of NO_x, SO_2, NH_3, CO, Particulates < 2.5 µm and Particulates > 2.5 and < 10 µm released to air.

In agreement with Buonanno *et al.,* (2008) the most significant negative outcome of incineration is the emissions that result from combustion. This air pollution has both a harmful effect on the local area and on the climate in general.

As indicated before in the GWP section, the combustion step during incineration, which releases NO_x emissions, strongly affects the final results. Similar results were reported by Cherubini *et al.,* (2009).

V.5.3.8. Fossil Fuels Depletion

As shown in Tables (30-31) and Figures (26-27) incineration consumption of fossil fuels is higher than landfill consumption. The life cycle analysis indicates that 95% of the fossil fuels used in the incineration approach are consumed within the combustion process. On the other hand, 94% of the used fossil fuels by landfill are consumed during landfill operations: transportation, waste spreading and landfill shaping.

In agreement with Mendes *et al.,*(2004), Finnveden *et al.,* (2005), Assamoi & Lawryshyn (2012) and Lettieri *et al.,* (2014) waste treatment is recommended byincineration, shifting waste treatment from landfillingto incineration would decrease the overall environmental impact andwill allow energyrecovery.

Finnveden *et al.,* (2005) stated that debates are currently ongoing regarding how to reduce the use of fossil fuels and increase the use of renewable fuels, waste is sometimes regarded as a renewable fuel. Waste-to-energy technologies hold the potential to create sustainable renewable energy.

In the current study a proper waste management system for acrylic fiber industry was investigated and applied. The study started by investigating the generated wastes from the manufacturing process either as air emissions or as liquid discharge or solid wastes. Two sources of air emissions were found: water vapors from production line which are sucked and vented to the atmosphere and vapors from polymerization area which are scrubbed in a monomer gas absorber and recycled back to the process. Regarding liquid discharges: two major streams are generated from process plant areas and utilities; both steams are treated through an E.T.P. It was found that pollution levels for treated effluent from this unit were within environmental regulations. As for generated solid wastes from the process, an inventory was made and presented earlier in this chapter.

Next, a waste policy was set to reduce waste generation in the plant to be less than 1% of the production. A waste management committee was established to monitor the generated waste, identify means of waste minimization and implement an action plan for waste reduction. The action plan included: a) minimization and reduction actions by developing awareness raising among employees through introducing waste management and training operators of different waste reduction practices, b) reuse non-hazardous solid wastes, c) recycle of waste fiber by liquefying then re-inject it in the process and d) recovery of steam condensate and reuse it in boiler house. The implementation of the waste management system achieved a 2.9% reduction in waste generation (Table 8).

Finally, two waste streaming approaches for hazardous solid waste treatment (landfill and incineration) were investigated to identify which approach was more environmentally friendly. Results revealed that incineration was better. If landfill is not properly designed as a sanitary landfill or ifa long term leachate to ground water occur due to base lining failure, high ecotoxicity and carcinogenic potential would be expected due to the release of metals from pigment wastes to surface and ground waters. Those impacts could be mitigated if state of the art incinerator or landfill were used.

VI. ENGLISH SUMMARY

Acrylic fiber textile industry has developed substantially in manufacturing processes as well as in usage, but it should be mentioned that the industry is both energy intensive and highly polluting. The most important point addressing the global industry nowadays is to develop an eco-friendly technology. The current study aimed to identify proper energy and waste management systems for the acrylic fiber industry by implementing programs in a local plant (Alexandria Fiber Company). At the same time investigate the impact of the manufacturing process on the environment by establishing an effective system for energy utilization and conservation.Also the studyaimed to identify waste streaming approaches using life cycle analysis technique.

❖ Results can be summarized as following:

1. According to ISO 50001:2011 and ISO 14001:2004 standards, an energy and a waste management programs were used based on the Plan - Do - Check – Act/Review (PDCA) continual improvement framework. Policies wereset to achieve at least 15% reduction in energy consumption and reduce solid waste generation to reach less than 1% of the produced fiber.
2. An implementation plan was done as summarized in the following steps:

a. Collection of previous data regarding energy utilization indicated that the total power is about 26.3 GWh per year, and the average power consumption ratio (kW/TF) ranged between 1,311 – 1,592 in the years 2009 -2012. The average steam consumption ratio (T/TF) ranged between 13,4 - 13,7 in the years 2011 -2012. The monthly waste generation (% of production) ranged between 2.3 – 4.3 within 2012.

b. Monthly average of power consumption in 2012 was 73.9 MWh, utility area was the highest power consumer in the plant (68.1 % from the total consumption) followed by production section (19.7 %) then material preparation (11.4 %), accordingly the utility area was considered the focus area for further improvements.

c. Further analysis was done for each subarea as follows:

i) Material preparation area: highest consumption was in polymerization (45.2%) of the total consumption in the area followed by solvent recovery (44.3%) and then dope preparation (10.5%).

ii) Production area: highest consumption was in spinning machine section (72.9%), followed by dryers (13- 14%) and then baler (4.5%).

iii) Utility area: highest power consumption was by brine chillers (42.7%), then cooling towers & water chillers (39.9%), and air compressors (17.3%), then at a lower levelcameRO & DW plant (7.8%), pumping station (7.7%) and E.T.P.(5.4%).

d. Total steam consumption in 2012 was 222,473 ton, consumed for the production of 16,556 ton fiber. However, steam consumption data was limited due to non-availability of steam flow meters.According to design, steam is distributed to areas of: polymerization (1.1 T/TF), dope preparation (1.0 T/TF), solvent recovery (3.0 T/TF) and production (4.7 T/TF). Data analysis showed that highest steam consumption ratio was in January and the lowest consumption was in August, as additional steam was required for heating during cold conditions. Steam consumption related to production was two times higher in April and September due to frequent shut downs.

3. The energy management program started in January 2012, conducted audits and reviews was done till April 2012, implementation of targeted goals in the plan was done during the rest of 2012. Implementation of energy management in 2013 indicated that monthly reduction in power consumption was 3.9% which was estimated as a direct saving of 919,500 EGP/Year, this reduction was achieved by:
   a) Addition of capacitor banks increasedthe power factor from 0.94 to 0.98 achieving an estimated saving of 148,608 EGP/Year.
   b) Applying efficient lighting systemachieved a monitory saving of 138,999 EGP/Year.
   c) Identifying and arresting compressed air leaks saved approximately 97,500 EGP/Year of lost energy.
   d) Recovery of steam condensate saves 441,637 EGP/Year.
   e) Replacement of well pumps improved the operating efficiency by 20%, reducing power consumption by 18% and saved up to 79,400 EGP/Year.
   f) Rest of the cost savings were achieved as a result of employee's involvement by applying energy saving practices such as shutting down unnecessary machinery.
4. A waste management study for liquid discharge,solid wastesand air emissions started by making an inventory of the generated wastes from the manufacturing process.The study indicated the following:
   a) The generated effluent (3600 m^3/day) is treated in the effluent treatment plant (E.T.P) before discharged to west Nubariya drain. The inflows to the E.T.P are generated from the process plant areas (43.3%) and utilities (56.7%). It was found wastewater quality of the treated effluent from E.T.P were within regulations (Law 48/82).
   b) An inventory was made for the generated solid wastes from the process. Daily waste generation consists of waste fiber (% of the production), waste pigment (60 kg), chemicals waste slurry from production line (150 kg), chemical sludge from utility (50 kg) and others.
   c) Air emissions included water vapours from production line which are sucked and vented, or vapours from polymerization area which are scrubbed in a monomer gas absorber and recycled back to the process.
5. Data analysis showed thatthe monthly generated waste was 5.4% of production, highest percentage was in April and July.
6. Waste management action plan aimed to reduce the generated waste to reach less that 1% of production by: a) minimization and reduction actions by raising awareness among employees through training on different waste reduction practices. b) reuse non-hazardous solid wastes and c) recycle of waste fiber by liquefying then re-injecting in the process
7. The implementation of waste management program reducedwaste generation to about2.9%during the first year of implementation, which means a direct saving of 854,700 EGP/Year.
8. LCA was revealed the environmental impacts of acrylic fiber manufacturing from raw material stage till the end of production phase: water consumption, energy resources and generated wastes were taken into consideration as well.
9. Results showed significant impacts on seven environmental categories: Global Warming Potential, Acidification Potential, Eutrophication Potential, Carcinogens Potential, Ecotoxicity Potential, Respiratory Inorganic Formation Potential and Fossil Fuels Depletion. The following are the major:

a) Highest impact (82%) was on environmental resources due to the consumption of fossil fuels within the production process of acrylonitrile.Second highest impact was on human health (15.9%) due to the inorganic chemicals and dyes used during the manufacturing process. Lowest impact was on ecosystem quality (2.1%) represented in acidification impacts on the environment due to the usage of acrylonitrile, acids and other chemical compound as raw materials.No impacts were detected on radiation potential, ozone layer depletion, land use, minerals depletion or human respiratory system due to organic substances.
b) The calculated potential for GWP indicated that the manufacturing of 1 ton acrylic fiber releases to the environment 5.4 ton CO_2 equivalent. Carbon dioxide emissions are released during the usage of fossil fuels in steam and electricity generation for usage in the different processes.
c) Acidification, eutrophication and respiratory potentials were affected due to the release of 13.46 kg SO_2 equivalent and 6.86 kg NO_2 from printing, dyeing, chemicals handling and boilers emissions.
d) Both carcinogens and ecotoxicity potentials were affected due to the release of arsenic, cadmium, chromium, nickel and zinc released from dyes and pigments. Both potentials have a small impact in comparison to the impact of fossil fuels depletion.
e) Fossil fuels are the highest category affected by the manufacturing of acrylic fiber. About 133 GJ are consumed during the production of one ton of acrylic fiber, mainly due to the production of acrylonitrile.

10. LCA was used to compare two waste streaming approaches for hazardous solid waste treatment (i.e. landfill and incineration). Incineration was more environmentally friendly. In case of "Worse-case scenario" as high ecotoxicity and carcinogenic potential would be expected due to the release of metals from pigment wastes to surface and ground waters.
11. Highest impact of both approaches is on ecosystem quality due to their ecotoxicity potential from metals releases. Overall impact of incineration on ecosystem quality is higher than overall impact of landfill, 68.4% and 51.3%, respectively.
12. Human health indicator is the second highest impact. Landfill has an impact of 46.8% on human health compared to 28% by incineration due to the high potential of metals inleachate.
13. As for resources, the impact of incineration approach is higher than the impact of landfill, 3.5% and 2.0%, respectively. The amount of fossil fuels used by incineration is higher than the used by landfill, 95% of the fossil fuels used in the incineration are consumed within the combustion process and 94% of the used fossil fuels by landfill are consumed during transportation and waste spreading.
14. Global warning potential was affected due to the release of 32.9 gm CO_2 equivalent during the usage of landfill for the treatment of hazardous wastes generated from 1 ton acrylic fiber. The footprint is mainly constituted by landfill methane. Incineration releases 513.1 CO_2equivalent, while combustion step strongly affects final results.
15. Acidification, eutrophication and respiratory potentials were affected by the combustion process in incineration approach. The released SO_2 from incineration is higher than the released from landfill (46.85 mg against 35.12 mg SO_2 equivalent/TF). NO_2 emissions from incineration are almost five times higher than NO_2 emissions from landfill: 488.54 and 88.02 mg NO_2 equivalent/TF, respectively.

16. Regarding carcinogens potential, CP of landfill is almost ten times higher than the CP of incineration, this could happen in case of long term leachate to ground water.

In conclusion, the current study proved that the implementation of energy and waste management systems assists in environmental protection and achieved a number of direct cost savings, the most important environment impacts can be determined and quantified.The established systems in this study can be implemented in different industries.