

Waste management through life cycle assessment of products

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Abstract. The rapid growth of a population in a country can contribute to high production of waste. Municipal waste and industrial waste can bring unhealthy and unpleasant environment or even diseases to human beings if the wastes are not managed properly. With increasing concerns over waste and the need for 'greener' products, it is necessary to carry out Life Cycle Assessments of products and this will help manufacturers take the first steps towards greener designs by assessing their product's carbon output. Life Cycle Assessment (LCA) is a process to evaluate the environmental burdens associated with a product, process or activity by identifying and quantifying energy and materials used and wastes released to the environment, and to assess the impact of those energy and material used and released to the environment. The aim of the study was to use a life cycle assessment approach to determine which waste disposal options that will substantially reduce the environmental burdens posed by the Polyethylene Terephthalate (PET) bottle. Several important observations can be made.

1) Recycling of the PET bottle waste can significantly reduce the energy required across the life cycle because the high energy inputs needed to process the requisite virgin materials greatly exceeds the energy needs of the recycling process steps.

2) Greenhouse gases can be reduced by opting for recycling instead of landfilling and incineration.

3) Quantity of waste emissions released from different disposal options was identified.

4) Recycling is the environmentally preferable disposal method for the PET bottle.

Industry can use the tools and data in this study to evaluate the health, environmental, and energy implications of the PET bottle. LCA intends to aid decision-makers in this respect, provided that the scientific underpinning is available. Strategic incentives for product development and life cycle management can then be developed.

1. Life Cycle of the Polyethylene Terephthalate

An analysis of the flow of energy involved in the production of a product is one aspect of a life cycle assessment, an objective process of analysis that attempts to evaluate the environmental burdens associated with a product, process, or activity by [1]:

- Quantifying the quantities of energies and materials used and the quantities of waste emissions released into the environment.

- Assessing the impact of energy and emissions releases on the environment.

- Evaluating opportunities to effect improvements in the final disposal of the product.

The assessment, if at all possible, should consider all the activities related to the manufacture of a product or operation of a process; this includes activities such as processing of raw materials, manufacturing, transportation and distribution, use/reuse, recycling, and final disposal [2]. Figure 1 shows the simplified processing and manufacturing of PET.



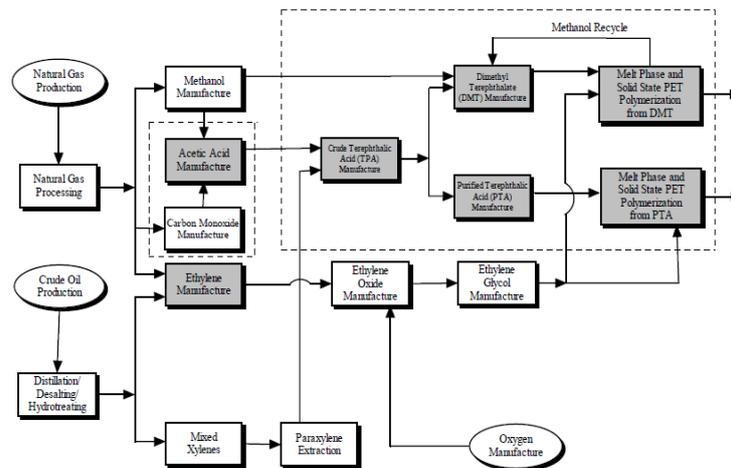


Figure 1. The simplified processing and manufacturing of PET.

2. Life Cycle Inventory

Plastic Production. This section gives an overview of the complex and varied processes involved in making the PET bottle plastic. We also look at ‘additives’, which enhance the performance of plastic bottle or aid its processing. These chemicals often have a greater potential impact on the environment than the polymer itself. Finally, we consider information on the impact of making plastics on the environment and human health [3].

Production Stage – Emissions and Energy Requirements for producing a 1L PET bottle.

The production of different kinds of polymers has totally different energy requirements and the amount of emissions released. In this section, PET plastic bottle will be discussed in order to provide a clear result during the production stage (table 1).

Table 1. Environmental Profile for PET – PET Production Stage

Raw material	Oil & natural gas	Main Product	1kg PET is produced
Energy	83.8 MJ/kg	Solid waste	0.045130 kg/kg
Transport	0.2 MJ/kg	Emissions	CO ₂ 2330 g/kg SO _x 25 g/kg NO _x 20.2 g/kg CO 18 g/kg HCs 40 g/kg

Use of PET bottle. This section looks at the main sector that uses PET plastic bottle: packaging. During this stage, there are no energy and emissions released involved. Therefore, no data can be used to indicate the effect of PET plastic bottle during the use stage to the entire life cycle of plastic bottle.

Transport of PET bottle. In this section, the produced PET bottle will be transported to consumers and eventually to recycling centers and disposal sites once it reaches the end of life of its services. Meaning to say, consumers dump the bottles into their dustbins after the plastic product becomes useless. We assumed the maximum of transport distance to consumers, recycling centers and disposal sites to be 200 km. The energy required for transportation was 0.01 MJ/kg/km according to. We assumed no emissions released during transportation stage because the emissions released are most like to be insignificant.

Transportation Stage – Emissions and Energy Requirements for a 1Kg PET bottle

Environmental Profile – Transportation Stage of PET

Transport = $0.01 \times 200 = 2 \text{ MJ/Kg}$

Disposal of PET plastic bottle Waste. Plastic waste can be disposed-off using different kinds of methods. Recycling was also one of the improvement methods to be considered in this study. The idea being that recycling activities will reduce the waste generated to the earth and eventually lessens the risks of environmental burdens caused by the PET bottle.

PET Waste Recycle – Emissions and Energy Requirements. Where reuse is not the most environmentally sound way of extracting value from plastic bottle wastes, an alternative is to recycle them into feedstock or into energy recovery so that their intrinsic value is not lost. These two technological methods of plastic waste recovery have been developed in the industrialized countries on a large scale, mechanical recycling and incineration with energy recovery. Once the recyclates have been cleaned and shredded, the process is much the same as for the production of the PET plastic bottles from feedstock. Most plastics are recycled mechanically, but chemical recycling is at a developmental stage. Plastic bottles are the main type of plastics collected and recycled from household waste. During the process of recycling, energy is required and emissions are released to environment.

Waste Recycled – Emissions and Energy Requirements for a 1 Kg PET bottle (table 2)

Table 2. Environmental Profile for PET – Waste Recycled

Raw material	-	Main Product	1 kg new PET bottle is produced
Energy	27.07 MJ/kg	Solid waste	-
Transport	0.2 MJ/kg	Emissions	CO ₂ 163 g/kg SO _x 0 g/kg NO _x 0.081 g/kg CO 0.205 g/kg HCs 0.016 g/kg VOCs 6.95 g/kg

Waste to Landfill – Emissions and Energy Requirements for a 1Kg PET bottle (table 3)

Table 3. Environmental Profile for PET – Waste to Landfill

Energy	60.007 MJ/kg	Solid waste	-
Transport	0.2 MJ/kg	Emissions	CO ₂ 94.597 g/kg SO _x 0.848 g/kg NO _x 1.728 g/kg HCs 2080.609 g/kg

Waste Incinerated – Emissions and Energy Requirements for a 1Kg PET bottle (table 4)

Table 4. Environmental Profile for PET – Waste Incinerated

Energy	32.5MJ/kg	Solid waste	-
Transport	0.2 MJ/kg	Emissions	CO ₂ 2016 g/kg SO _x 0.609 g/kg NO _x 2.436 g/kg CO 0.609 g/kg

Summary – Emissions and Energy Requirements for a 1Kg PET bottle. In this section, we summed up and summarized the emissions released and energy requirements during the entire life cycle of a PET bottle. Table 4 summarizes the total energy required in MJ and total emissions released for the entire life cycle of 1 kg of the PET bottle for the different methods of waste disposal.

3. Life Cycle Impact Assessment

In this section we used the results from the life cycle inventory to assess the potential impacts of PET bottle treated with different disposal methods. The best way of making a comparison of the PET bottle waste disposal method from an environmental point of view was to compare and analyze the energy involved and waste emissions released in the entire life cycle of the PET bottle. Next step was to assign the air emissions to the impact of global warming [4].

Energy Use. Results for the total energy used are shown in Table 5 for PET with different treatment methods of disposal. The energy required to recycle 1Kg PET bottle is relatively lower than the energy consumed by the other two options. This is because it takes less energy to make recycled products due to its greatest environmental benefit provided that the recycled product is used to substitute virgin polymers. Besides, recycling is advantageous because every time that the material is reused, it is not produced again and, therefore, only half the waste remains in the soil than if virgin resin is used. The more times a material is recycled, the less the amount that remains in the soil and this will subsequently reduce the environmental load in the waste stream. According to Table 5, landfilling option required much more energy for the whole cycle of a kg PET bottle maybe due to vehicle fuel consumption on transportation, maintenance and the continuous monitoring on the landfill area. On the other hand, incineration is also one of the options to manage the PET bottle waste. Incinerator will burn all waste in ovens and the energy recovered is equivalent in amount to the heat of combustion of the different components.

Table 5.Energy consumed and emissions released for entire life cycle of 1kg PET bottle

	Waste Recycled	Waste to Landfill	Waste Incinerated
Total Energy (MJ)	113.27	144.2	118.7
Total Emissions (g)	2603.45	4610.98	4452.85

Global Warming. Table 6 presents the environmental impact for a 1kg PET bottle treated with different waste disposal methods. Global warming is the rising of the global temperature due to emissions of greenhouse gases. The only greenhouse gas emissions of any significance in the manufacture and disposal stages of the PET bottle are carbon dioxide and methane. Based on the results in table 6, the order of preference is that recycling is better than incineration and landfilling in terms of energy and emissions. The emissions contributing to global warming for incineration of PET bottle is rather similar to the emission for landfilling. This is because all the fossil carbon is released during incineration, as well as during landfilling.

PET can also be co-incinerated with other combustible products from the waste stream which will give even greater contributions to the reduction of greenhouse gases by the prevention of the emission of methane gas from landfills. Methane has a global warming potential of 30 times that of CO₂ [5]. This is why the prevention of waste going to landfill is a key measure to reduce the greenhouse gas emissions.

Table 6.Environmental impact for different treatment methods of the PET bottle

Environmental Impact	Waste Recycled	Waste to Landfill	Waste Incinerated
Global Warming (kg CO ₂ -eq)	3.33	47	4.3

Example of Calculation for Global Warming Value

Process X releases 2.495 kg CO₂ and 0.040016 kg CH₄

The equivalency factors are the 100-year Global Warming Potentials (GWPs):

Q global warming-CO₂ = GWPCO₂ = 1 g CO₂

Q global warming-CH₄ = GWPCH₄ = 21 g CO₂/ g CH₄. The potential contribution to global warming of methane is:

$$Q \text{ global warming-CH}_4 \times g\text{CH}_4 = 21 \text{ g CO}_2/\text{g CH}_4 \times 40 \text{ g} = 840 \text{ g CO}_2\text{-Eq.}$$

The total contribution of Process X to global warming is:

$$\text{Total global warming} = (2.495 + 840) \text{ kg CO}_2 = \mathbf{3.33 \text{ kg CO}_2\text{-Eq.}}$$

4. Summary

PET bottle plastics make a valuable contribution to the way we live, but as a society we need to find ways of using these plastics more wisely. The way we make, use and dispose of PET plastic bottles should have a minimal impact on the environment. Some of the methods to reduce the impacts on the environment are:

1) *A greener plastics industry*

The manufacture of plastic materials is one of the major industries with potential for serious pollution to the surrounding environment. Different types of plastics manufacturing processes and disposal methods will contribute to different effects on the environment. Therefore, government agency must ensure that industry operates in a way that minimises adverse effects on people and the environment, and contributes to the achievement of sustainable development.

2) *The potential impact of chemicals leaching from PET plastic bottles on human health and the environment*

The use of PET plastic bottles in beverages and packaging increases the risk of exposure. Risk assessments have been carried out for some, but not all chemicals used in plastics. Where information exists, it suggests that the quantities released during the manufacture and disposal stages of the life cycle of plastics are much greater than those lost during the use phase, when humans are likely to be most exposed. This information gap needs to be addressed.

3) *Reducing the waste generation*

As a society, we are generating an increasing amount of waste. As with other materials, more must be done to reduce the amount of PET plastic bottle waste we produce. There has been a shift towards a 'disposable' culture, and the lower cost of plastics may have contributed to this and the associated growth in waste.

4) *Practicing recycling habit*

The attitude of the public in recycling practices should be improved. The public should be well informed of the importance to recycle. Environmental influences appear particularly effective among members of the public who have a "strong belief in personal responsibility and influence, as well as the power of self-determination". The public would recycle more if they had a greater understanding of the environmental benefits of recycling.

5) *Charging for waste*

Although this practice is still not common in most countries, but several recycling centers in Russia are already implementing this concept, as a way to encourage more people to recycle. This concept is mainly targeting specifically at those who don't recycle, and in turn supports those who do. By charging for the waste sent to the recycling centers, this can help to encourage more recycling practices among the public.

6) *Introducing more recyclable products*

By replacing the PET plastic bottles for packaging beverages, with recyclable and biodegradable ones; this can initially encourage more people to recycle. By displaying the international standard 'Recycling Logo' on recyclable products, the consumer will be fully informed whether the items can be recycled or not. When the consumer is aware that the items can be recycled, they will automatically categorize the items as recyclable products and will not dump them together with non-recyclable wastes. With such measures, it is hoped that the public will be more aware of the recyclable items available in the market.

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