POLICY APPLICATION: USE OF LIFE CYCLE ASSESSMENT IN THE PET PLASTIC MARKET TO DETERMINE OPTIMAL DEGREES OF SOLID WASTE RECYCLING.

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A policy application in product and process analysis from a sustainability point of view is presented in this paper. The work is part of a project sponsored by a consortium of industries who participate in the Polyethylene Terephtalate (PET) market as resin producers, bottle manufacturers, soft drinks producers, distributors and plastic recyclers in Mexico.

There has been a substantial increase in the PET bottle's market since a decade due to its high resistance, light weight and adaptability to many bottle designs which constantly improve. In contrast, there is some concern about the environmental implications of PET use and the lack of analytical tools to describe the market and environmental effects of PET as a material for new product designs.

As such, this paper provides a robust framework to analyse a raw material along the supply chain, considering the main production and operation steps that need to be managed. As part of this work, a robust Simulation Model and a Life Cycle Assessment (LCA) of PET were performed, including all stages from raw material extraction to recycling and landfill. In order to perform the LCA under Mexican conditions, an inventory of emissions for Mexican electricity generation was prepared. Results show that PET will continue increase its market participation in the bottle sector.

Among major insights in this work is the use of LCA tools to determine an optimal degree of solid waste recycling. This work demonstrates that higher degrees of bottle recycling does not necessarily imply lower environmental impact. In fact, in all cases studied in this work and under various sensitivity scenarios, it was possible to identify a point at which total environmental impact is minimized. As such, this framework and the results will be used by industry and legislators as a basis for decision making in environmental policy.

1. INTRODUCTION

Some decades ago soft drinks and water were bottled in glass. This has been a significant market for glass industries considering that more than 6,000 million gallons of drinks are sold every year (only in Mexico). In the last decade the Mexican market has experienced some transformations including the significant growth of bottled water and soft drink retailing. As a consequence of this growth, a new bottling material has been introduced: polyethylene terephtalate (PET). The main advantages of this material are its price, low weigh (thus, low transport costs), easiness to be blowed into almost any mold and neatness. This product has been successfully introduced in many markets around the world and in some cases it has experienced growth rates of two digits.

The environmental and market impacts of this rapid growth has brought attention to industries and government. Landfill space and materials consumption derived from bottle production and use are among the main drawbacks. However, PET is a recyclable material, which may represent a significant advantage in terms of environmental impact. Currently, there are no analytical tools to describe the effect of operations in the market structure and the environmental impact.

The aim of this project is to provide a joint analysis of the PET market's future situation and its environmental impact. The tools to be used are a simulation model for the market forecasting (including several possible future scenarios) and a Life Cycle Assessment (LCA) that allows us to understand the environmental effect of several operations related to this market. The framework presented in this work has been developed for the Mexican context but can easily be adapted into any other market.

2. PET PLASTIC MARKET MODEL

2.1 Model Description

PET goes through several stages during its life cycle as presented in Figure 1. PET resin can either be imported or produced in Mexico. There are three types of resin which is designed for there main segments: bottling, textile and films. Bottling PET is employed by carbonates, bottled water and oil producers mainly. Once the beverage is consumed, bottles are disposed into landfill while some may be collected by recyclers. Collected PET follows two mainstreams: recycling and exporting as raw material. There are three different recycling processes, these are chemical recycling, mechanical recycling and thermal recycling. The recycled material is then reintroduced to the production system.

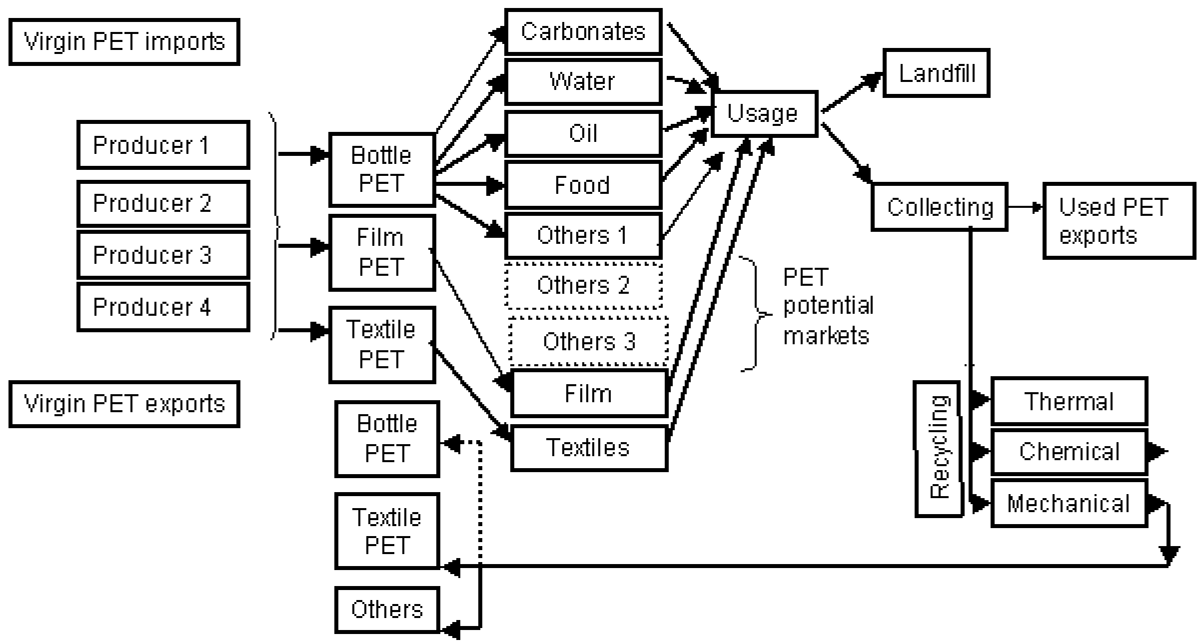


Figure 1. Schematic approach of PET market in Mexico

Market distribution has not been constant in the previous years. Therefore, part of this work aimed to understand the behavior of each market segment in order to eventually develop a model demand forecasting. As such, historical and forecasted information on the growth of these sectors has been used for demand considerations. In addition the market model considers not only market growth but also the growth of PET usage inside each particular industry (some are still converting from aluminum or glass into PET).

2.2 Simulation Model

The objective of this PET simulation model is to provide users with a probabilistic approach to demand forecasts. This simulation model recreates PET market behavior. The main advantage of this simulation (as opposed to a regression analysis) is that companies can predict under a probabilistic risk assessment scheme, which scenarios are more probable to occur during the next years. In other words, knowing which scenario is more likely to occur, companies can develop strategies in order to compete with more information about their markets and operations.

This model parts from data gathered from several PET sub markets. Three types of data were collected regarding each market. First, the historical demand of PET for each of these markets; second, the growth rate of every market during the last years and the forecasted growth rates for future years; and finally the PET's share growth within each market. Probability distributions were estimated with this data for each market with respect to its PET demand growth rate. These growth rate probability distributions allow to establish which growth rate is more likely to happen for future years. The next step in this simulation is to forecast a probability distribution of PET demand for a certain year. With the probability distributions of every PET market growth rate and from the historical data of every PET market demand for a baseline year from which to start, a probability distribution can be generated in order to predict which demand scenarios are more likely to occur during a certain year. The probability distribution of each sector was adjusted into a statistical beta function. This function can be adapted into a wide range a data profiles and also can be adjusted into a specific range. Once the beta distributions were derived, it was incorporated into a scheme similar to the one showed in figure 2 in order to provide the outcome of PET demand for each year. In other words, demand for each market is first calculated by simulation, and finally these demands are added up in order to generate the probability distribution for the PET market in Mexico for the next year (Figure 2).

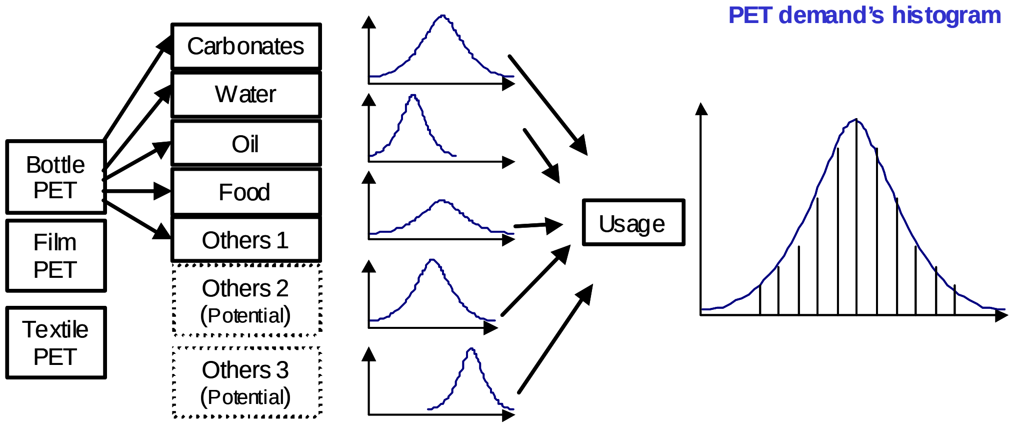


Fig 2. Schematic overview of the PET demand forecasting model.

The previous model was applied to generate various scenarios for PET demand in the following five years. Figure 3 shows the results obtained from the simulation for the first year (2003) and the period 2003-2007, respectively.

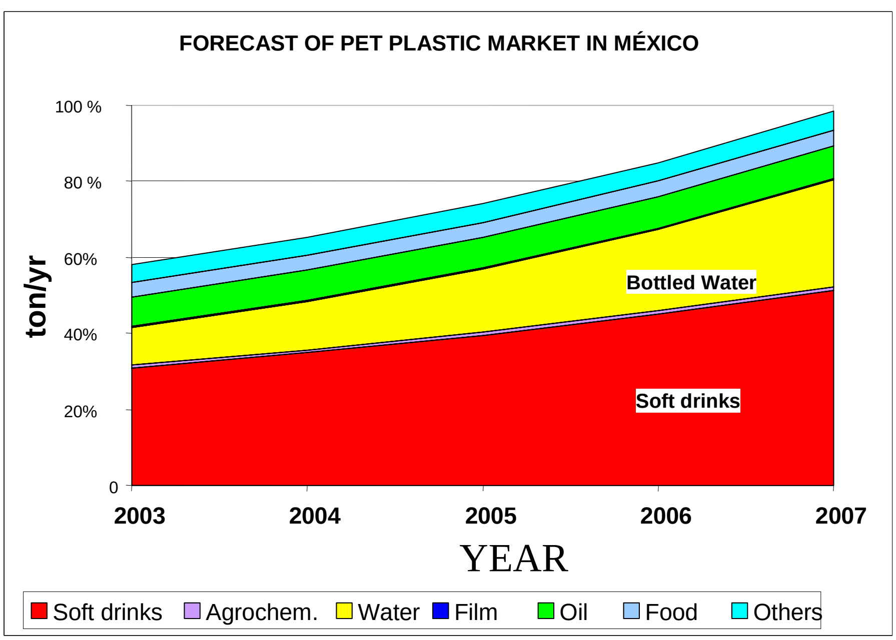


Fig 3. Forecast of PET plastic market in Mexico (2003-2007)

3. ENVIRONMENTAL PROCESS PERFORMANCE

The model presented in Figure 1 is also the basis to evaluate the environmental impact produced along the life cycle of PET (from Raw Materials Extraction to Recycling and final disposal). The methodology used to evaluate the environmental performance of the various processes related to PET is defined as Life Cycle Assessment.

3.1 Forecast for PET recycling quantity and rate

The simulation model was combined with visits to landfills and interviews with the managers of the main collecting and recycling companies. As a result it was possible to develop a forecast of the quantity of PET bottles that our sustainability model predicts. Furthermore, a new insight appeared: even though the total quantity of PET collected is increasing every year, the recycling rate (PET collected/ PET produced) of PET is decreasing (see Figures 4 and 5). This is due to the fact that market demand for PET grows faster than collecting infrastructure.

Fig 4. Forecast of PET collected in Mexico (2003-2007)

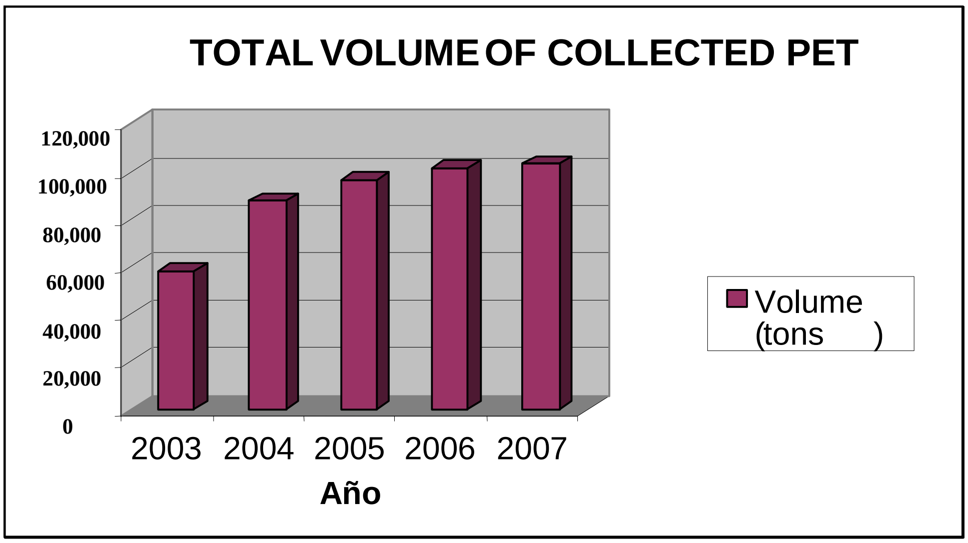
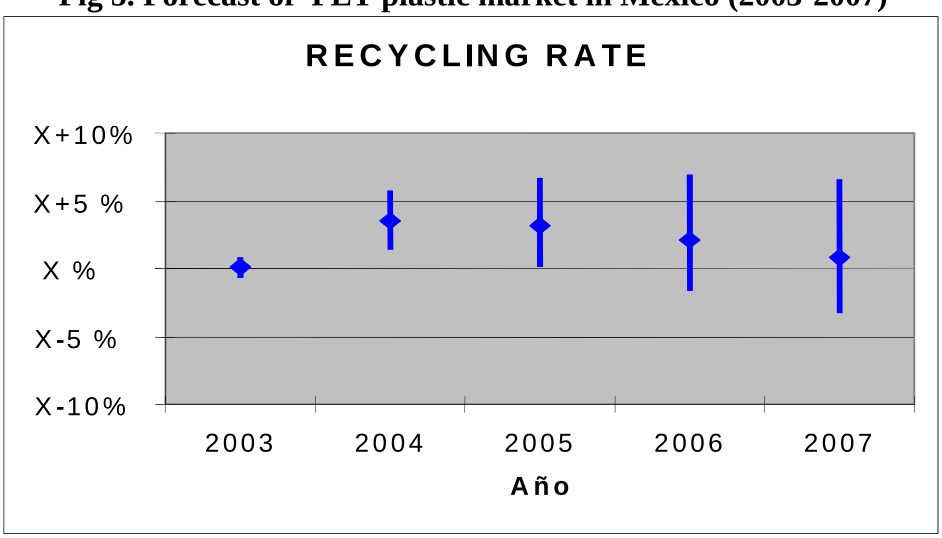


Fig 5. Forecast of PET plastic market in Mexico (2003-2007)



3.2 Life Cycle Assessment

Life Cycle Assessment (LCA) is a tool used to determine environmental impacts of processes (Romero, 1998) or products. LCA allows to determine the amount of energy required for producing or operating and also to identify an inventory of pollutants emitted or generated.

This tools includes the emissions inventory phase where the amount pollutants discharges are quantified. The tools goes beyond production and use of a product to include further stages such as landfill, recycling, incineration, etc. It is a holistic examination of the damages it may cause to the environment ´from cradle to grave´.

3.3 Inventory of emissions for electricity generation in México

The following table presents the final results obtained for an inventory of emissions developed for Mexican electricity generation. This inventory was prepared from several literature resources in the Energy Secretariat and the Environment and Natural Resources Secretariat, interviews with government servants and emissions reported by generation plants. More details, such as energy mix, fuel mix, min and max from more than 100 electricity generation plants in Mexico are available upon request. Results are on the same order of magnitude as those found in SimaPro and GaBi for other countries.

Emissions/Gross Generation (Ton/GW-h)	Ton/GW-h	Kg/MJ
SO_2	10.9	0.00302778
NO_x	1.95	0.00054167
TSP (Total Suspended Particles)	0.7	0.00019444
VOC	0.021	5.8333E-06
CH_4	0.016	4.4444E-06
N_2O	0.0082	2.2778E-06
CO	0.21	5.8333E-05
Total	13.8052	0.00383478
CO_2 (GEI)	688	0.19111111

3.4 Environmental impacts

The environmental impact, measured in terms of Global Warming Potential (GWP), of the PET life cycle is presented in Figure 6. The PET life cycle has two main parts: *beverage production* and post-use *waste scenario* process and the part where the two main negative sources of GW are included. In Figure 6, the line thickness is set to express the environmental load of each process flow. Red lines indicates adverse environmental impact while green lines represent a favorable environmental impact.

The main source of adverse GWP impact (measured in terms of CO2 equivalent emissions) of the Mexico's PET life cycle is the PET box, which represents the production of **PET** granulate. The second most significant source of adverse GWP effects is the **Blowing** process. This is due to the amount of electricity required to convert each perform into a bottle by means of blowing hot air.

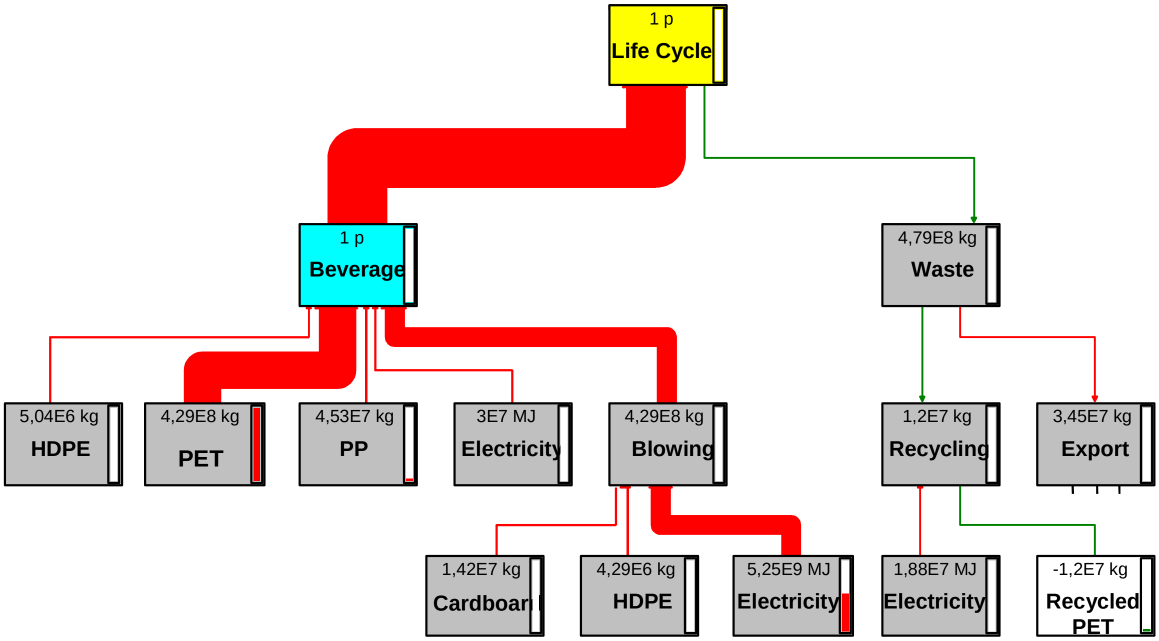


Figure 6. Environmental impact (Global Warming) of various stages in the supply chain

The waste scenario presented on the left side of the LCA presents different results. This issue is presented in more detail in Figure 7.

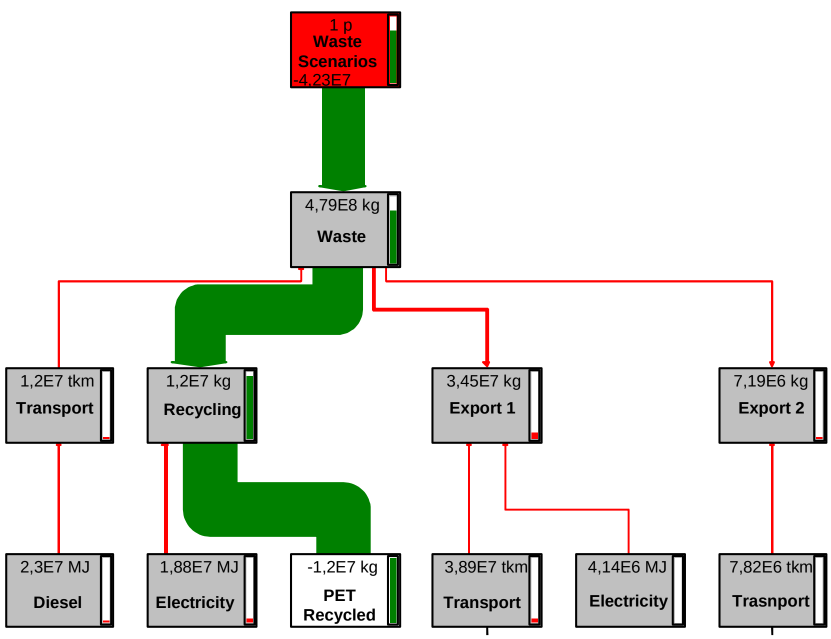


Figure 7. Environmental impact (Global Warming) of the waste scenario

The **Waste Scenario** process (described in figure 7) has an overall favorable GWP impact that reduces the total amount of equivalent CO_2 produced in Mexico. There is a favorable GWP impact related to PET **Recycling**. This thick green line indicates that recycling reduces the total amount of equivalent CO_2 emitted in Mexico as a consequence of PET production. However, the waste scenario also a adverse impact related to post-used PET transport (negative). The PET **Transport** includes **Exporting** and the general collecting of PET from the consumers to the collection centers.

4. SUSTAINABILITY ANALYSIS

The sustainability analysis aims to understand the effect of some processes into the whole environmental impact. Specifically, for this paper, two variables has been chosen: collecting distance and recycling rate. Due to space limitations in this paper, we present the combined effect of this variables.

4.1 Optimal degree of solid waste (PET Bottles) collected/recycled

The previous results of both simulation and LCA were integrated in order to explore the effect of distance in both collecting and recycling. These calculations delivered the most important insight of this work: the existence (at relatively low values) of optimal degrees of solid waste collection/recycling at which total environmental impact is minimized.

Results presented in Figure 8 show that increasing recycling rates from 0 to ca. 35% generate lower environmental impacts (measured in terms of Global Warming Potential). However, after this point, the total GWP impact increases constantly. In terms of environmental policy, this means that after 35%, collecting PET represents higher cost and higher environmental impact.

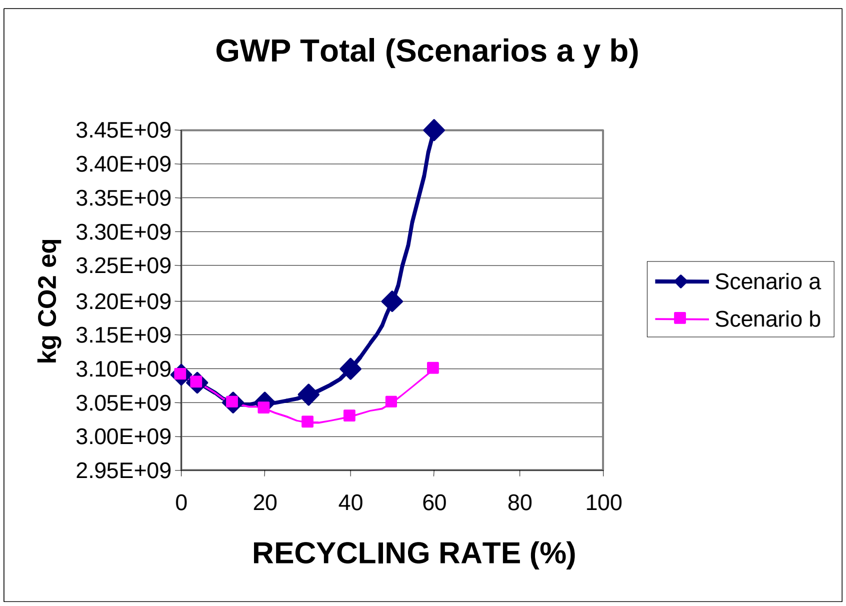


Figure 8. Effect of recycling rate on Global Warming Potential (GWP). Two distance scenarios (a and b)

5. CONCLUSIONS

This work has presented a general framework which aims to analyze the economic and environmental effects related to the introduction of a new product / process / material. In this paper, one of the most successfully introduced plastics material, PET, has been analyzed along its supply chain and life cycle.

Simulation models developed in this work for various processes and operations related to PET proved to be a significant source for understanding the main effects of market variations into the quantity of product demanded and consequently, production levels. Specifically, this model allowed to understand the impact of each sub-market (soft-drinks, bottled water, food, etc) into the overall demand. Results illustrate also the flow of materials along the supply chain.

Environmental performance was also an issue of concern. In this respect, the model was robust enough to describe the interactions and environmental effects related to each process in the supply chain: raw material extraction, raw material transformation, plastic production, perform bottles, beverage production, transport, use, disposal, collection, recycling and landfill. One of the main advantages of the analysis framework presented in this paper is that it supports the understanding of complex systems. Moreover, once characterized, the system can be continuously modified in order to understand the effect of various variables into the whole economic or environmental impact.

Results presented in this work show that increasing recycling rates from 0 to ca. 35% generate lower environmental impacts (measured in terms of Global Warming Potential). However, after this point, the total GWP impact increases constantly. In terms of environmental policy, this means that after 35%, collecting PET represents higher cost and higher environmental impact.

The insight behind this research can easily be adapted into almost any process or material. As such, this work can be a basis for comparing different design alternatives and also to identify competitive advantages in the selection of products, process and materials.

6. ACKNOWLEDGMENTS

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