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THE USE OF STREAMLINED LCA FOR THE ENVIRONMENTAL ASSESSMENT OF PLASTICS RECYCLING: THE CASE OF A PVC CONTAINER

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Abstract

The problem of disposal of plastic wastes due to declining landfill capacity, together with the polluting emissions when thermal treatment is involved, has encouraged plastics recycling. Recycle strategies for plastic-based products can be yield significant environmental benefits. However, these strategies have also been criticized because of their possible links to other types of resource and environmental impacts. The purpose of the present paper is to identify and quantify the environmental effect of recycling of a PVC container. For this evaluation, the methodology of Life Cycle Assessment (LCA) is used, and especially its version of Streamlined LCA. According to the results of this analysis, recycling can substantially reduce the environmental burden of the container in question (JEL Classification: Q20, L60).

Key Words: Streamlined LCA, Life Cycle Assessment, Plastics Recycling, PVC, Integrated Waste Management.

1. Introduction

Every product introduced into the market has some impact on our environment: each is made from raw materials, uses energy, or creates waste. While the focus of the early environmental movement was to mitigate pollution from point sources, the recent, more holistic trend is to minimize their environmental impact. Industry now recognizes that it is often profitable and even less expensive to make ecologically sound products (Borland and Wallace, 2000). This increasing awareness of the environment has contributed to concerns regarding the disposal of solid wastes (Subramanian, 2000). In these circumstances, plastic waste has become an important issue since a significant component of the waste stream is plastics. This is rather expectable as industry and householders generate more and more plastics wastes. Statistics show that plastic waste in municipal solid waste (MSW) in Western Europe reached 17,5 million tons in 1994 (European Environment Agency, 1998). In fact plastics waste has become one of the larger categories of MSW, particularly in industrialized countries (Scent et al., 1999). Among plastics, polyvinyl chloride (PVC) gives an important contribution. PVC, due to its chemical and mechanical characteristics, is widely used in building, transport, packaging, electrical, electronic and healthcare applications and, with an annual world output of 19 million tons, is second only to polyethylene for the volumes of thermoplastic materials produced (Borgianni et al., 2002).

The growth of plastics waste has a great impact on management of MSW by landfilling or incineration, because available capacity for landfill of MSW is declining and plastics incineration may cause emission and toxic fly ash and bottom ash which contains lead and cadmium (Scent et al., 1999). Moreover, the presence of PVC in the waste stream can result in a very serious incineration problem. PVC, due to its high chlorine content, causes pollution problems, mainly hydrochloric acid, chlorine gas and dioxins, when thermal treatment is involved (Borgianni et al., 2002). One alternative way to plastics waste disposal is recycling. Plastics waste recycling is a method of reducing the quantity of net discards of MSW. Although the benefits have not been quantified, plastics recycling also offers the potential to generate demonstrable savings in fossil fuel consumption, both because the recycled plastics can supplement and even compete the virgin resins produced from refined fossil fuel and because the energy required to yield recycled plastics may be less than that consumed in the production of the same resins from virgin feedstock. Therefore, plastics waste recycling conserves both material and energy and provides a comparatively simple way to make a substantial reduction in the overall volume of MSW (Scent et al., 1999; Patel et al., 2000). However, recycling strategies, in general, have also been criticized because of their possible links to other types of resource and environmental impacts that are less obvious but no less important. For example, the environmental benefits of recycling paper have been questioned in light of studies that have shown increased fossil fuel consumption and greater emissions of greenhouse gases and acidifying gases (Ross and Evans, in press).

In this context, the aim of the present paper is to identify and to quantify the major environmental benefits of plastics recycling. For this purpose, the methodology of Life Cycle Assessment (LCA) and especially its version of Streamlined LCA has been used. LCA is a tool used to evaluate the environmental impacts associated with a product over its entire life cycle, from the manufacturing processes to the final waste disposal stages. Individual LCA studies are modified to fit the specific objectives of individual analyses. Generally, a producer should use LCA to compare alternatives involving environmental externalities at any stage of production, use and disposal of intermediate and final goods. The classic product LCA is based on a vertical summation of all environmental inputs and outputs associated with a product, "from cradle to grave" (Ayalona et al., 2000). Inventory Analysis is the phase of an LCA in which the material and energy flows are compiled and quantified (Ekvall, 2000). If no limitations to time, expense, data availability, and analytical approach existed, a comprehensive LCA could provide the ideal advice for improving environmental performance. In practice, however, these limitations are always present. As a consequence, although very extensive LCAs have been performed, a complete, quantitative LCA has never been accomplished, nor is it ever likely to be. There are many compromises of necessity, among which have often been the use of averages rather than specific local values for energy cost, landfill rates, and the like, the omission of analysis of catalysts, additives, and other small (but potentially significant) amounts of materials, neglect of capital equipment such as chemical processing hardware, and the failure to include material flows and impacts related to supplier operations. As consequence, detailed LCAs cannot be regarded as providing rigorous quantitative results, but rather as providing a framework upon which more efficient and useful methods of assessments can be developed. In this context, techniques that purposely adopt some sort of simplified approach to life-cycle assessments, *streamlined life-cycle assessments,* form part of a continuum of assessment effort, with the degree of detail and expense generally decreasing as one moves from *fully comprehensive LCA* to *Eco-screening.* The assessment is complete and rigorous enough to be a definite guide to industry and an aid to the environment, yet no so detailed as to be difficult or impossible to perform (Graedel, 1998). As it is mentioned above, the philosophy of Streamlined LCA is used here. More precisely, an application of this methodology, which concerns the evaluation of the environmental performance of a PVC container for various levels of recycling, is presented in the paper. This is realized by calculating and comparing for selected recycling rates the main environmental effects of the container (energy consumption, solid waste and the major atmospheric and waterborne emissions) throughout its entire life cycle.

2. Plastics Recycling

The treatment and disposal of waste is one of the central themes of sustainable development. Waste disposal methods depend largely on the potential resource utility of the material. This varies by a large degree as materials move through a product life cycle. Waste generated in the early stages of production is generally high in volume and low in resource utility, for example mining and other raw material extraction processes. As material moves through the production cycle it increasingly becomes a repository of added value that is generally an aggregate of raw material, energy, labor, and other resources. This cycle ends with the disposal of the product itself with potentially high resource utility for specific materials or components. Disposal costs have a similar slope that increases through the production cycle and becomes most significant with hazardous materials. Both effects progressively increase the benefit of waste minimization in progression with the stages of the product life cycle (Billatos and Basaly, 1997). The approach of the European Union and its member states for the management of waste has developed via a series of Directives and Programmes into a strategy concerning the treatment of waste, which has the key objectives of minimizing the amount that is produced, and minimizing any risk of pollution. Recycling is included in this strategy (Williams, 1998).

Recycling of non-renewable resources serves both to reduce the draft of virgin supplies and to reduce the discharge of associated residuals back into the natural environment. Many resources change their chemical and physical nature so much during utilization that they cannot be recovered in useful form. This includes, for example, fossil energy resources, fertilizer minerals and food resources. Other resources, however, finish their useful lives in forms that can be recycled as raw materials back into the production process. This includes many metals, wood and paper, and chemicals derived from petroleum. The sequence of steps linking the initial removal of the material from the waste stream and its final re-incorporation back into the final product can be complex both physically and economically. It starts with the end-users of the material in question; either they or some other entity must extract from the waste stream those materials destined for recycling. These materials then will often move through a sequence consisting of various combinations of steps: transporting, sorting, re-concentrating, re-processing, and finally re-use. Sometimes these functions are accomplished by a single firm, but in most cases the activities of many different firms are coordinated by markets and by the forces of supply and demand that they affect them (Field, 2000).

The potential to recycle material from waste is high, but it may not be appropriate in all cases, for example, where the abundance of the raw material, energy consumption during collection and re-processing, or the emission of pollutants has a greater impact on the environment or is not cost effective. Materials' recycling also implies that there is a market for the recycled materials. The collection of materials from waste where there is no end market for them merely results in large surpluses of unwanted materials and also wastes additional energy with no overall environmental gain (Williams, 1998). Among recyclable materials, plastics practically present the biggest challenge for effective recycling efforts. This is particularly true for thermoplastics, which can be ground, melted, and reformulated with relative efficiency. Polyethylene teraphthalate, polyvinyl chloride, polystyrene and the polyolefins (such as high-density polyethylene, low-density polyethylene and polypropylene) are among the thermoplastics for which recycling facilities now exist (Graedel and Allenby, 1995). One of the key issues in producing recycling plastics is the resin content. Currently, there appear to be sizable and lucrative markets for products made from single resins but not for commodities produced from mixed plastic, which command a lower market value. The problem is, even though many products are made of only a single resin, all of these end up together in the waste stream. To achieve a homogeneous collection of a particular resin, different kinds of plastics have to be identified and separated after collection - a costly step in the recycling process (Callan and Thomas, 2000). Moreover, the utility of plastics recycling is a function of their purity, which implies that the use of paint, flame-retardants, and other additives should be minimized or avoided if at all possible. Having plastics of many different colors in a product limits recyclability option as well (Graedel and Allenby, 1995).

One of the most common types of plastics in use today is PVC. The monomer, from which this thermoplastic is made, is a chlorinated organic compound. This monomer can be polymerized into a useful synthetic. Polyvinyl chloride is more commonly used than any other plastic with the exception of polyethylene. The major products pf PVC include upholstery materials and waterproof fabrics such as shower curtains. Pipe fittings, chemical storage tanks, floor covering, packaging films and bottles, garden hoses, and plumbing materials are just a few applications of it (Billatos and Basaly, 1997). PVC recyclability is, more or less, similar to the recyclability of most products made out of plastics: primary recycling (involves converting plastic waste into products with characteristics similar to the original product), is difficult to be achieved (but not impossible), while secondary recycling (involves producing products with less demanding physical and chemical characteristics) has been the usual method of recycling mixed plastic waste (Ambrose et al., 2002).

3. Methodology Overview

Life Cycle Assessment is probably the most commonly accepted method for assessing the environmental impact of products. LCA is a method for systematically assessing the environmental impact of a product through all of its life-cycle stages: from extraction and processing of raw materials, to manufacturing, transportation and distribution, and finally reuse, maintenance, recycling, and final disposal (Borland and Wallace, 2000). Moreover, LCA seems to be also useful in waste management. More specifically, as it is already mentioned, there is increasing pressure on waste managers, planners and waste regulators to deliver a sustainable approach to waste management and to integrate strategies that will produce the best practicable option for the environment. Unfortunately, as most practitioners will readily testify, establishing the environmental impact associated with waste management systems is no easy task. Currently, there is no universally accepted measure of performance that has the confidence of industry, the regulators and the public. LCA has the potential to meet this need (Barton et al., 1996). A recent relevant example concerns Integrated Waste Management (IWM), an approach that can be used to develop more sustainable waste management systems. IWM takes an overall approach to waste management; it combines a range of collection and treatment methods to handle all materials in an environmentally effective, economically affordable and socially acceptable way. IWM systems can be optimized using the tool of Inventory Analysis. The Inventory Analysis of solid waste starts the moment a material becomes waste (i.e. loses value) and ends when it ceases to be waste by becoming a useful product, residual landfill material or an emission to either air or water. The inputs for an IWM system are solid waste, energy and other raw materials. The outputs from the system are both useful products in the form of reclaimed materials, energy and compost, and emissions to air and water and residual landfill material. The usefulness of Inventory Analysis in waste management is in assessing environmental efficiency (Mc Dougall, 2001).

Apart from Inventory Analysis, a standard LCA has three more major stages. The four stages of a complete LCA are: Goal Definition and Scoping, Inventory Analysis, Impact Assessment and Interpretation (Borland and Wallace, 2000). The Goal and Scope Definition establishes the purpose and scope of the study, the functional unit (as a central measure of the service delivered), the main delineation of the product system boundaries, the level of detail required by the aim of the study and a procedure for ensuring the quality of the study. Definition of the boundaries of the product system with its environment is of critical importance. It influences the quantitative outcomes of the analysis and the selection of categories, which are to be regarded as loadings to the environment (Georgakellos, 2001). The goal of the Inventory Analysis is to map out the environmental interventions (a general term for emissions and all other inputs and outputs from and to the environment) per part of the life cycle (Nieuwlaar et al., 1996). In other words, Inventory Analysis best serves as a means to highlight areas where there might be big opportunities for environmental quality improvements through resource conservation and emissions reductions. The true value of Inventory Analysis is the realization that a change in one portion of a product's life cycle will have some effect (either positive or negative) in other areas of the product's life cycle. By applying this "life cycle thinking" to the product design process, true improvement opportunities can be identified (Kuta et al., 1995).

Impact Assessment characterizes and assesses the effects on the environment of the loadings identified in the previous LCA phase, the Inventory Analysis. Impact Assessment comprises three consecutive elements: (1) classification, (2) characterization, (3) valuation. Classification is the step in which the relevant impact categories, i.e. environmental problem areas, are identified and where the loadings are assigned to each problem area they contribute to (Udo de Haes et al., 1997; Dante et al., 2001). The characterization element tries to assess the contribution of all input/output data from the inventory to the respective category to finally result in an impact profile for assessed product. This can be achieved by using models, which combine the input/output data from the inventory and a so-called indicator expressing the environmental effects or damages (Herrchen et al., 1997). The last stage of Impact Assessment is valuation, which attempts to compare and rank the differing impact categories in order to simplify them down to a common base (Barton et al., 1996). In this element, the different impact categories are weighed against each other. The aim is to obtain an overall environmental comparison of the available alternatives. Weighting, normalisation, grouping and ranking are the most common optional steps in Impact Assessment (Goedkoop and Oele, 2001). The last LCA stage concerns Interpretation. Here the results of the proceeding LCA stages are compared with the goal of the study set in the goal and scope definition. One crucial element of this phase is validation. Another element may be the improvement assessment in which options for reducing the environmental impacts of the system under study are identified and evaluated. This is performed on the basis of results from the previous LCA stages (Udo de Haes et al, 1997).

The foundation of a product LCA study is the Inventory component, where energy, raw materials and environmental releases are measured. In order to calculate these environmental consequences is necessary a clear definition of system boundaries. In LCA studies, the term "system" refers to a collection of operations that together perform some defined function (Vigon et al., 1993). After system boundaries are determined, the system should be divided to subsystems. According to the goal and the specificity of the analysis, each subsystem should be subdivided to others etc. The level of the required detail is influenced by data availability. Each one of the subsystems requires input of materials and energy and has outputs of products, atmospheric and waterborne emissions and solid waste. An LCA system begins with raw materials acquisition and continues with manufacturing and packaging, use, re-use and maintenance through final disposition (recycling and solid waste management). Once the system has been determined, a detailed system flow diagram is developed which depicts every operation contribution to the system function. This is important in constructing the mathematical model because it numerically defines the relationships of the individual subsystems to each other in the production of the final product. Except system determination, any other parameter and assumption that affects the analysis, such as the basis of comparison, the energy production and distribution system, the solid waste management practices, the allocation basis, the level of technology etc, should also be defined and clearly explained (Henn and Fava, 1994; Georgakellos, 2001).

4. The Case Study

The task of this case study is to calculate and to compare the environmental performance of a PVC container for different recycling levels. The container under examination is a 1,5 lt table water bottle from polyvinyl chloride.

Product system contributions to environmental effects can occur at every point of the life-cycle of the packaging, right through from the extraction of the original materials and energy resources, the transformation of these into useable manufacturing inputs, the manufacturing process itself, the transport and distribution of intermediate and end products, and the use and final disposal. Thus, we chose to include all stages in the life-cycle from "cradle to grave". More precisely, the LCA system consists of twelve subsystems that together cover the entire life cycle of the containers. These twelve subsystems or stages of the system are the following: (1) Raw Materials Acquisition and Materials Manufacture (all the activities required to gather or obtain a raw material or energy source from the earth and to process them into a form that can be used to fabricate a container); (2) Materials Transportation (includes transportation of the materials to the point of containers fabrication); (3) Containers Fabrication (the process step that uses raw or manufactured materials to fabricate a container ready to be filled); (4) Containers Transportation (transport of empty containers to the point of filling); (5) Filling - Final Product Production (processes that fill the containers and prepare them for shipment); (6) Final Product Transportation (transport of filled containers to retail outlets); (7) Final Product Use (includes activities such as storage of the containers for later use, preparation for use, consumption etc.); (8) Solid Wastes Collection and Transportation for Landfilling or Incineration (begins after the containers have served their intended purpose and enter the environment through the waste management system); (9) Solid Wastes Landfilling (includes all necessary activities for the land disposal of waste); (10) Solid Wastes Incineration (includes all necessary activities for the thermal treatment of wastes); (11) Used Containers Collection and Refilling (all the activities required to off-site re-use such as the return of the containers to the bottler to be re-filled for their original purpose); (12) Recycling (this stage encompasses all activities necessary to take the used containers out of the waste management system and deliver them to the container fabrication stage).

Other special conditions, parameters and assumptions that influence and limit the system are the following

- Basis of Comparison: 1000 lt of table water.
- Level of Technology: the mix of the current technology.
- Basis of Allocation: weight proportioned (per kg).
- Energy System: the national basic energy sources and the national average fuel mix and grid for electricity.
- Capital Equipment: the energy and emissions involved with capital equipment are excluded.

The next step is the construction of the mathematical model. This model is necessary to calculate the total energy and resource use as well as the total environmental releases from the overall system. This step consists of summing the energy, raw materials and various emission values that result from the energy and material flows, for each stage of the product's life cycle. This model, which defines numerically the relationships of the individual subsystems to each other in the production of the final product, has been developed and analyzed in detail elsewhere (Georgakellos, 2001a). However, for better understanding the present case study, a brief overview of the model follows

The mathematical model is constructed according to the system, by summing the energy, raw materials and various emission values that result from the energy and material flows, for each stage of the product's life cycle, as follows

The total energy consumption of the system (E_{tot}) can be calculated by the equation (1)

$$E_{tot}=(e_1 + e_2). (1 - f).(1 - k). m + (e_3 + e_4). (1 - f). m + (e_5 + e_6 + e_7). m+$$

$$+ e_8 . (1 - f). [1 - a . (1 - b)]. m + e_9 . (1 - f). [1 - a . (1 - b)]. c . m +$$

$$+ e_{10} . (1 - f). [1 - a . (1 - b)]. (1 - c) . m + e_{n} . f. m + e_{12} . (1 - f) . a . m$$

(equation 1)

where

"a" is the recycling rate of the product that examined $(0 \leq a \leq 1)$. This rate refers to systematic and well-organized recycling programs.

"b" is the fraction of the products collected for recycling that rejected for any reason, such as losses during transportation $(0 \leq b \leq 1)$.

"c" is the percentage of municipal solid wastes that landfilled $(0 \leq c \leq 1)$. According to the above-defined system, we assume that only two waste management alternatives exist: landfilling and incineration (with or without energy recovery).

"k" is the recycled content level of the product $(0 \leq k \leq 1)$.

"m" is the mass of the product.

"f' is the reuse - refilling rate of the product $(0 \leq f \leq 1)$.

"e_j" is the specific energy consumption of the subsystem j (where j = 1,2... 12).

Respectively, the total consumption of any raw material or the total release of any waste of the system (X_{tot}) can be calculated by the equation (2):

$$X_{tot}=(x_1 + x_2) . (1 - f). (1 - k). m+(x_3 + x_4). (1 - f). m+(x_5 + x_6 + x_7). m+$$

$$+ x_8 . (1 - f) . [1 - a . (1 - b)] . m + x_9 . (1 - f) . [1 - a . (1 - b)] . c . m +$$

$$+ x_{10} . (1 - f). [1 - a . (1 - b)]. (1 - c) . m + x_n . f. m + x_{12} . (1 - f) . a . m$$

(equation 2)

where

"X_j" is the specific consumption of any raw material or the specific release of any waste of the subsystem j (j = 1,2...12).

According to the existence or not of energy recovery during the municipal solid waste incineration, this stage of the system is divided to two others. Therefore, the above mentioned mathematical model includes also the following equations (3) and (4)

$$e_{10} = e_{10without} . (1 - c_R) + e_{10with} . c_R \qquad \text{(equation 3)}$$

$$X_{10} = X_{10without} \cdot (1 - c_R) + X_{10with} \cdot c_R \qquad \text{(equation 4)}$$

In these equations

"c_R" is the percentage of incineration with energy recovery $(0 \leq c_R \leq 1)$.

"e_{10with}" is the specific energy consumption of the subsystem 10 (case with energy recovery).

"$e_{10without}$" is the specific energy consumption of the subsystem 10 (case without energy recovery).

"x_{10with}" is the specific consumption of any raw material or the specific release of any waste of the subsystem 10 (case with energy recovery).

"$x_{10without}$" is the specific consumption of any raw material or the specific release of any waste of the subsystem 10 (case without energy recovery).

The results of the present Streamlined LCA application are presented in table 1. These results are calculated according to the above mathematical model (equation 1 to 4), for various recycling levels (we assume that "a" and "k" are the same) and using the collected data. Wherever possible, actual or specific data from the manufacturing industry for production processes, from the energy industry for the electricity and fuels production and distribution, as well as from the municipalities and the trade associations for solid waste management and recycling, are used. However, because of certain difficulties in data gathering (data gaps, absent or incomplete data, differences in the way data were collected, data confidentiality etc.), the major source of data is the open literature (books, reports, country specific databases, conference papers and technical articles). A quite significant part of the collected and used in this application data has been previously presented elsewhere. More precisely, the data concerning the energy consumption and the environmental impacts as a result of the raw materials acquisition and the processes used in the production of polyvinyl chloride are based mainly on available European studies. This data is accessible in a related work of the author (Georgakellos, 2002). Likewise, the similar data associated with the transportation stages of the examined life cycle (e.g. delivery of raw materials etc.) was obtained from various sources from Greece, Europe and the USA and can be found in a relevant review of the author as well (Georgakellos, 1998). As it is already mentioned, the energy and emissions involved with the construction of the transportation equipment are excluded. In road transport, however, the maintenance energy requirements (lubrication, tyres, garaging and spares) are included. This data is based on a study from the UK, making the assumption that it is also valid in our case. This may be rather crude, but it is certainly better to make a reasonable assumption for this energy than to entirely ignore it, as it is custom in most life cycle assessments. Furthermore, the data relating to the energy system (fuels and fuel production, feedstock energies, energy delivery efficiencies etc.) is taken from surveys on the Greek energy sector as well as from specialized studies. This data is included in another essay of the author (Georgakellos, 2001b). At last, the complete set of the used here data, i.e. all the above-mentioned data and the remaining ones (e.g. data concerning the product distribution and use, the waste collection, recycling and final disposal etc.), is given in full detail in the thesis of the author (Georgakellos, 1997).

According to table 1, it is obvious that the environmental performance of the PVC container examined in this study is being improved as the level of recycling is being increased. More specifically, comparing the environmental impacts of concern here when from zero recycling it is achieved recycling level of 50 %, the following observations can be made:

- Energy: The life-cycle energy consumption is about 10 % less. Recycling 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.

- Atmospheric Emissions: The emissions of hydrocarbons are more than one third less (about 36 *%)* while the emissions of carbon monoxide are also remarkably reduced (about 14 %). A reduction of the emissions of particles, nitrogen oxides and sulphur dioxide is also noted which, however, doesn't seem to be significant enough (it is 3,26 %, 2,19 % and 2,22 % respectively). Likewise, the reduction of the volatile organic compounds emissions is negligible (it is only 0,41 %).

- Waterborne Waste: Recycling can significantly reduce the waterborne waste of suspended materials and dissolved materials, which is, for both of them, about 50 %. On the contrary, there is no reduction of BOD. This is because, according to the model that is used, responsible for this waste indicator is the life-cycle subsystem of *containers fabrication,* which is obviously not affected by the origin of the raw materials (virgin or recycled). However, the reduction of COD is very important (about 30 %).

- Solid Waste: As it is expectable, recycling can significantly reduce the amount of the generated solid waste. More precisely, the total amount of this kind of waste is about 50 % less.

5. Concluding Remarks

This study has demonstrated very clearly that recycling strategies can significantly reduce the environmental burden of the PVC container that is examined. This reduction is very important mainly in solid waste, in waterborne waste of suspended and dissolved materials and in hydrocarbons emissions. The reduction was also remarkable in energy consumption and atmospheric emissions of carbon monoxide. However, although recycling has a significant role in reducing energy consumption and carbon monoxide emissions it has less effect on the emission of particles, nitrogen oxides, sulphur dioxide and volatile organic compounds.

The extent to which these results could be generalized to other materials and products will depend on many factors. However, if a product requires a large input of energy derived from fossil fuels during primary production, as is the case for plastic-based products derived from virgin materials, then recycling is likely to reduce a product system's environmental burden.

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APPENDIX

TABLE 1

Inventory Analysis of a 1,5 It PVC container for different recycling levels

Recycling Level (%)	**0**	10	20	30	40	50
Energy Consumption (MJ /1000 It)						
Energy	8265,072	8098,675	7932,278	7765,880	7599,438	7433,086
Atmospheric Emissions far/1000 It)						
Particles	311,9176	309,8935	307,8693	305,8452	303,8211	301,7970
Carbon Monoxide	129,2659	125,6853	122,1046	118,5240	114,9433	111,3627
Hydro-carbons	478,6637	444,2796	409,8956	375,5115	341,1275	306,7434
Nitrogen Oxides	2195,643	2186,033	2176,422	2166,811	2157,201	2147,590
Sulphur Dioxide	4171,675	4153,187	4134,698	4116,210	4097,721	4079,233
Vol. Org. Compounds	35,49720	35,46777	35,43834	35,40891	35,37948	35,35005
Waterborne Waste far/1000 It)						
Suspended Materials	2,035902	1,833162	1,630422	1,427682	1,224942	1,022202
Dissolved Materials	1041,443	938,8203	836,1979	733,5755	630,9530	528,3306
BOD (*)	0,008502	0,008502	0,008502	0,008502	0,008502	0,008502
COD (*)	0,05559	0,05232	0,04905	0,04578	0,04251	0,03924
Solid Waste (cm3/100(lt)						
Municipal Waste etc.	35311,42	32042,73	28774,04	25505,35	22236,65	18367,96

(*) waste indicators