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Life Cycle Assessment of Packaging Materials for Milk and Dairy Products

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Abstract

This paper introduces the methods and tools that will guide in the design analysis of the role of materials and processes selection in terms of embodied energy, carbon foot print, recycle fraction, and sustainability criteria. The goal of this study is to evaluate the environmental impacts of packaging systems for milk and dairy products through their entire life cycle. The energy consumption and emissions produced during the material primary production, manufacturing, transportation, and the use of the milk and dairy packaging are determined. The analysis was performed on one liter glass, plastic, and carton milk bottles and fifty liters aluminum can. The results show the phase of the life cycle of the milk packaging that makes the largest impact on the environment and the material selection strategies to minimize eco-impact.

Keywords: *Milk, Food Packaging, Life Cycle Analysis, Energy, Carbon Foot print*

1. Introduction

Cows, goats, sheep, camels, and buffalos are used in different parts of the world for the production of milk for human consumption. Milk is liquid and requires containers at every stage of movement: production, storage, transport, distribution and marketing. The most appropriate containers and components are used during the packaging process for safe delivery of the milk and milk derived products from the manufacturer to the consumer. Innovative packaging technologies for milk and milk derived products are very important in the distribution process, development of extended life of the product, storage and the value added to the food and food products. Packaging is defined as tool that protects and contains goods with also the aims of minimizing the environmental impact during the consumption of this product. The design of packaging for milk and milk derived products is determined by the demand of the product, the environmental awareness, the consumer market and the new technology development. The selection of the best materials to satisfy the design criteria (prevent the interaction of the food products with external environment from the time it is packages till the product is consumed) and at the same time reduce the energy use and the environmental impacts during the life of this product is very important during the design process. Packaging Materials for milk and dairy products include paper and paper based products (coated or lined), glass, tin plate, aluminum foil, timber (wood), plastics and laminates. The materials and the energy needed to make and shape the food packaging systems are drawn from natural resources. The demand of natural resources throughout the 20th century appeared infinitesimal. There is also a link between the population growth and resource depletion. The global resource depletion scales with the population and with per-capita consumption [1-2]. Per capita consumption is growing more quickly.

The first concern is the resource consumption [1-2]. Speaking globally, we consume roughly 10 billion tones of engineering materials per year. Figure 1 shows the annual world materials production (tones/year) for ceramics and glass; hybrids: composites, foams, natural materials; metals and alloys; and polymers and elastomers. For ceramics/glass and hybrids, the really big ones are the materials for constructions (concrete, cement, plaster, and bricks for ceramics/glass and wood and cardboard for hybrids). For metals, it appears that the consumption of steel is the number one (~ 0.8 billion tones per year) followed by aluminum (10 millions tones per year). The consumption of steel exceeds, by a factor of ten all other metals combined. Polymers come next: today the combined consumption of commodity polymers polyethylene (PE), polyvinyl chloride (PVC), polypropylene (PP) and polyethylene-terephthalate, (PET) begins to approach that of steel (see figure 1).

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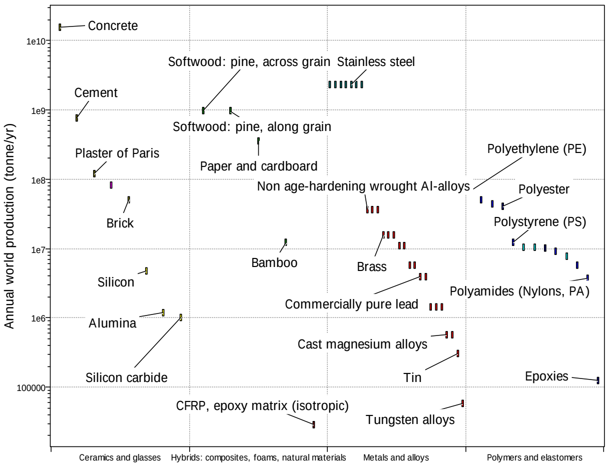


Fig. 1. **Annual world production for principal materials**

The second concern is the energy [3] and carbon release to atmosphere caused by the production of these materials as shown in Figure 2. This is calculated by multiplying the annual production by the embodied energy of the material (MJ/Kg – energy consumed to make 1 Kg of material). During the primary production of some materials such as metals, polymers, composites, and foams the embodied energy is more than 100 MJ/Kg and the CO2 foot print exceeds 10 Kg of CO2 per Kg of materials.

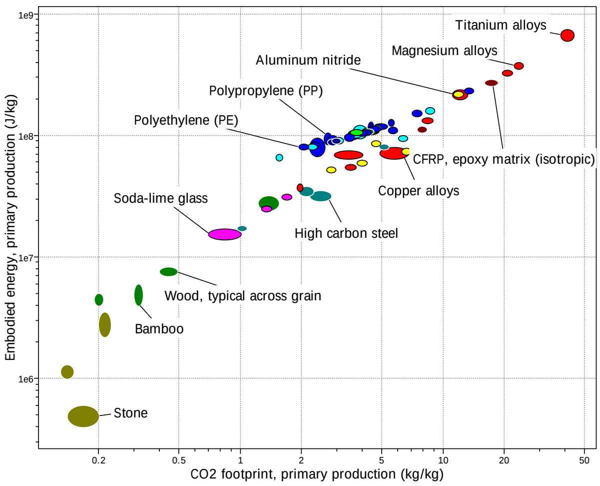


Fig. 2. **Embodied Energy and CO2 footprint for the primary production of materials**

New tools are needed to analyze these problems (high resource consumption, energy use and CO2 emissions) and respond to them. To select an eco friendly and sustainable material, one needs to examine first the materials life cycle and consider how to apply life cycle analysis [4-7]. The materials life cycle is sketched in Figure 3. Ore and feedstock are mined and processed to yield materials. These materials are manufactured into products that are used and at the end of life, discarded, recycled or (less commonly) refurbished and reused. Energy and materials are consumed in each phase (material, manufacturing, use, transportation and disposal) of life, generating waste heat and solid, liquid, and gaseous emissions [4-5]. The results of the life cycle analysis will reveal the dominant phase that is consuming more energy or producing high CO2 emissions. For selection to minimize eco-impact one needs to ask first this question: which phase of the life cycle of the product under consideration makes the largest impact on the environment? The second step is to develop strategies for guiding eco design. If the material production is the phase that is consuming more energy, then choosing a material with low embodied energy is the way forward. If the problem is with the manufacturing process, one needs to minimise the process energy. If the problem is with the product phase use, then choosing a material to make use less energy-intensive is the right approach – even if it has a higher embodied energy.

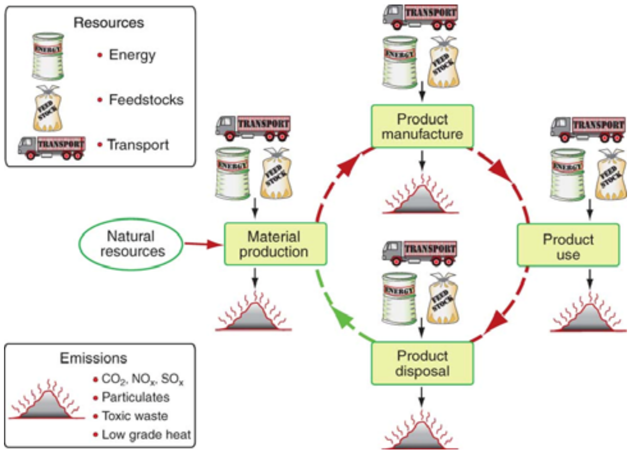


Fig. 3. **Material Life Cycle [5]**

This paper introduces the methods and tools that will guide in the design analysis of the role of materials and processes selection in terms of embodied energy, carbon foot print, recycle fraction, and sustainability criteria. A particular skills need to be used by engineer or designer to guide design decisions that minimize or eliminate adverse eco impacts. The Cambridge Engineering Selector software [8] is used in this study for better understanding of these issues, create material charts, perform materials and processes selection, and eco audit or life cycle analysis allowing alternative design choices to meet the engineering requirements and reduce the environmental burden. The principal objective of this study is to evaluate the environmental impacts of packaging systems for milk and dairy products through their entire life cycle. The energy consumption and emissions produced during the material primary production, manufacturing, transportation, and the use of the milk and dairy packaging are determined.

2. Life Cycle Analysis and Selection Strategies

The material life cycle is shown in Figure 3. Ore and feedstock, drawn from the earth's resources, are processed to give materials. These materials are manufactured into products that are used, and, at the end of their lives, discarded, a fraction perhaps entering a recycling loop, the rest committed to incineration or land-fill [7-10]. Energy and materials are consumed at each point in this cycle (phases), with an associated penalty of CO2, SOx, NOx and other emissions, heat, and gaseous, liquid and solid waste. These are assessed by the technique of life-cycle analysis (LCA) [7-10].

2.1. Steps for life cycle analysis:

(1) Define the goal and scope of the assessment: Why do the assessment?

(2) Compile an inventory of relevant inputs and outputs: What resources are consumed? (bill of materials) What are the emissions generated?

(3) Evaluate the potential impacts associated with those inputs and outputs
(4) Interpretation of the results of the inventory analysis and impact assessment phases in relation of the objectives of the study: What the result means? What is to be done about them?
The life cycle analysis study examines energy and material flows in raw material acquisition; processing and manufacturing; distribution and storage (transport, refrigeration…); use; maintenance and repair; and recycling options.

2.2. Strategies for guiding the design:

The first step is to develop a tool that is approximate but retains sufficient discrimination to differentiate between alternative choices. A spectrum of levels of analysis exist, ranging from a simple eco-screening against a list of banned or undesirable materials and processes to a full LCA, with overheads of time and cost. The second step is to select a single measure of eco-stress. On one point there is some international agreement: the Kyoto Protocol [11] committed the developed nations that signed it to progressively reduce carbon emissions, meaning CO2. At the national level the focus is more on reducing energy consumption, but since the energy consumption and CO2 production are closely related, they are nearly equivalent. Thus there is certain logic in basing design decisions on energy consumption or CO2 generation; they carry more conviction than the use of a more obscure indicator. The third step is to separate the contributions of the phases of life because subsequent action depends on which is the dominant one (see Figure 4). If it is that a material production, then choosing a material with low "embodied energy" is the way forward. But if it is the use phase, then choosing a material to make use less energy-intensive is the right approach, even if it has a higher embodied energy. For selection to minimize eco-impact we must first ask: which phase of the life cycle of the product under consideration makes the largest impact on the environment? The answer guides material selection. To carry out an eco-audit, the bill of material, shaping or manufacturing process, transportation used of the parts of the final product, the duty cycle during the use of the product, and also the eco data for the energy and CO2 footprints of materials (see Figure 2) and manufacturing process are needed.

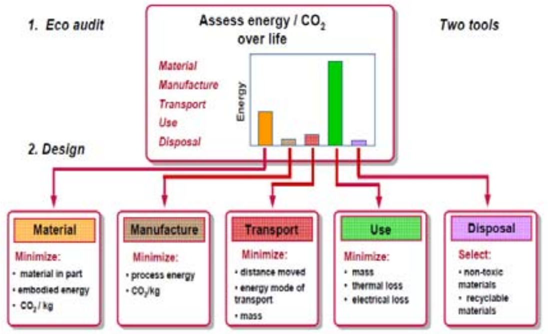


Fig. 4. Eco Audits and Strategies for Guiding the design [5]

3. Results

An eco audit was performed in this study for milk packaging to quickly evaluate the environmental impact of the milk packaging and to provide guidance on how to reduce it. The eco audit study will focus on the (1) the two environmental stressors: energy usage and CO_2 footprint, and (2) identification of the main product life phases (material, manufacture, transport, use, and end-of-life) that is most demanding of both these stressors (energy and CO2 footprint). An eco audit identifies the phases of the product life that carry the highest demand for energy or create the greatest burden of emissions. This will help to identify the main phase where the greatest gains (energy saving and CO2 reduction) might be made. The second step is to focus on this dominant phase where the potential of innovative material choice to reduce energy and carbon are greatest. The milk packaging systems selected for this eco audit or life cycle analysis are summarized in Table 1. Four types of materials were selected for this study: plastic bottle (materials: high density polyethylene, volume = 946 milliliters, masse = 51 g), glass bottle (material: soda lime, volume = 1000 milliliters and masse = 410 g), cartons bottle (material: polypropylene, volume = 942 milliliters and masse = 57 g) and aluminum can (material: aluminum, volume = 50 liters and masse = 8100 g).

Table 1. Materials and end of life options for milk bottles and can

	Plastic Bottle	**Glass Bottle**	**Cartons Bottle**	**Aluminum Can**
Milk Volume (l)	0.946	1	0.942	50
Mass (Kg)	0.051	0.410	0.057	8.1
Material	High Density Polyethylene HDPE	Soda Lime - 0070	Cardboard Pine (softwood) and Polypropylene PP (coating)	Aluminum, Wrought - T87
Density (Kg/m^3)	939 – 960	2440 – 2490	400 – 490 - Pine 896 – 906 - PP	2840 - 2870
Embodied Energy Primary Production [J/Kg]	$8.9\ 10^7 – 9.8\ 10^7$	$1.76\ 10^7 – 1.94\ 10^7$	$7.2 – 7.9\ 10^6$ (Pine) $9.0\ 10^7 – 9.9\ 10^7$ (PP)	$1.97\ 10^8 – 2.18\ 10^8$
CO2 foot print Primary production [Kg/Kg]	3.04 – 3.36	1.04 – 1.15	0.43 – 0.47 (Pine) 3.11 - 3.44 (PP)	11.4 – 12.6
Water Usage Primary production [m^3/Kg]	0.198 – 0.218	0.0068 – 0.0375	0.5 – 1.5 (Pine) 0.203 – 0.225 (PP)	0.49 – 1.49
End of life options	recycle down cycle combustion landfill	recycle down cycle landfill reuse	Recycle, down cycle, combustion, landfill (Pine) Recycle, down cycle, combustion, landfill (PP)	recycle down cycle remanufacture reuse Landfill reuse
Recycle fraction %	8.02 – 8.86	23 – 25	8.55 – 9.45 (Pine) 5.26 – 5.81 (PP)	40.5 – 44.7

The analysis of the product life cycle is split into three main sections in the eco audit tool: (1) materials, manufacturing and end of life, (2) Transport, and (3) use.

(1) Materials, manufacturing, and end of life: The material name, type, quantity or number, mass of single component, and the recycle content (0% virgin material ad 100% fully recycled materials) should be entered. After that the primary process should be selected. This will dependent on the material used to make the final product. The end of life option (landfill, recycle, reuse, down cycle, combustion for energy recovery) is then selected. The eco audit performed in this study is based on 5000 liters of milk. For the plastic bottles, high density polyethylene material was used for the milk bottle and low density polyethylene material was used for the bottle cap. Polymer molding is the manufacturing process used for the plastic milk bottle and cap. For the aluminum can: the aluminum 2219, wrought T87 was selected for material and the rolling, forging for manufacturing. For the glass milk bottle, the soda lime was selected for the milk nbottle and aluminum for the cap. Glass molding was used for the manufacturing process for milk bottle. For the cartons bottle, cardboard (pine or softwood) was selected as the raw material. The cardboard is coated with polyethylene (PE-HD). The carton milk is made of 90% cardboard and 10% polyethylene (coating). The energy used for the manufacturing process of the card board is already included in the material value. For polyethylene (coating), the manufacturing process is polymer modeling. The eco audit study can be performed with virgin material or with recycled material (0% - 100% recycled content). The material is classified as virgin if the material has no recycled content (feedstock is produced from raw materials). A recycled content of 100% represents the other extreme, where the material is manufactured entirely from recycled materials. The recycled fraction depends on the material used as shown in Table 1. For example, lead alloys generally contain 50–60% recycled material. For the product end of life, several options (landfill, recycle, reuse, combustion for energy recovery) were tested in thus study. The effect of recycle fraction and end life options on the energy consumption and CO2 emission are presented in this paper

(2) Transportation: The second part of the product definition is the transportation phase. This relates to the transport of the finished product from the source of manufacture to the customer. For each stage, three parameters are defined: stage name, transport type and efficiency, and distance. The transport type should be specified: sea fright, river/canal fright, rail fright, 32 tones truck, 14 tones truck, light goods vehicle, air fright (short or long haul), and helicopter. For this study, a 14 tones truck and a distance of 500 Kilometers were selected for the transportation phase for all the milk bottles.

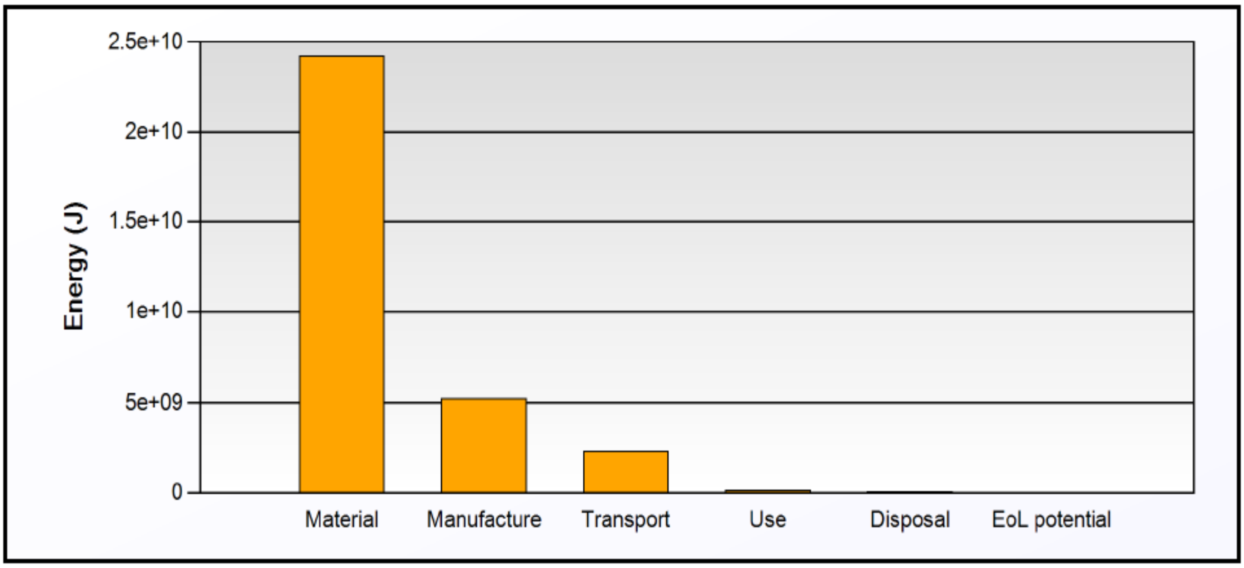
(3) Use phase: During the use phase, the number for the product life, in years, the country electricity mix and the modes (static and Mobile) should be selected. The static product is one that stays on one place (chair, washing machine, and refrigerator). A mobile product is one that moves e.g. a car, a refrigerated truck. The static mode was used for this eco audit study to take into account the energy used to refrigerate the bottles of milk. The country electricity mix was set to USA. The energy input and output was set to electrical to mechanical (electric motors). The power rating for the refrigerator was 12 kW. The duty cycle or the usage of the power to refrigerate the milk was set to 5 days per year 24 hours/day.

The energy and CO2 foot print summary of the life cycle analysis (LCA) of plastic milk bottles is shown in the Figure 5. It is noted that virgin material and landfill end of life option were selected. The results show that the material phase is the dominant phase with 75.8% of the total energy and 59.2 % for the total CO2 emissions. The manufacturing process and transportation account respectively for 16.4% and 7.2% of the total energy and 28.3% and 11.7% of total CO2 emissions. The energy and CO2 emissions during the use phase are negligible (0.4% for the energy and 0.6% for the CO2). The bottles of milk will stay in the refrigerator only few days before they are consumed. It is also noted that some energy is needed for processing the plastic bottles of milk after the milk is consumed at the end of life of the product. If the bottles of milk will be send to landfill, 0.2% of the total energy is needed to processes them and 0.3% of total CO2 is produced because some of the equipments or machines will be used to process these bottles. The results of the life cycle analysis of the plastic milk bottles with respectively recycling and combustion for energy recovery (waste to energy) end of life options are shown in Figures 6 and 7. The aim is to determine the end of life energy recovery and CO2 emission reductions when the landfill option is replaced with recycling or combustion. The results (see Table 2) show clearly that some energy can be recovered when the plastic bottles of milk are recycled or burned. If the bottles are recycled 33% of the total energy can be recovered but only 9.1% of the energy can be recovered when the bottles are burned. For the CO2 emissions the results show a reduction of 418 Kg of CO2 (30% reduction) when the bottles are recycled but a net increase of CO2 emission (611 Kg of CO2 or 44% of the total) when the plastic bottles are burned.

Table 2. End of life potential - Plastic Milk Bottle

	Energy (J)	**CO2 (Kg)**
Landfill	**0**	**0**
Recycle	$-1.06\ 10^{10}$	-418
Combustion	$-2.93\ 10^{9}$	+611

Energy and CO2 Footprint Summary:



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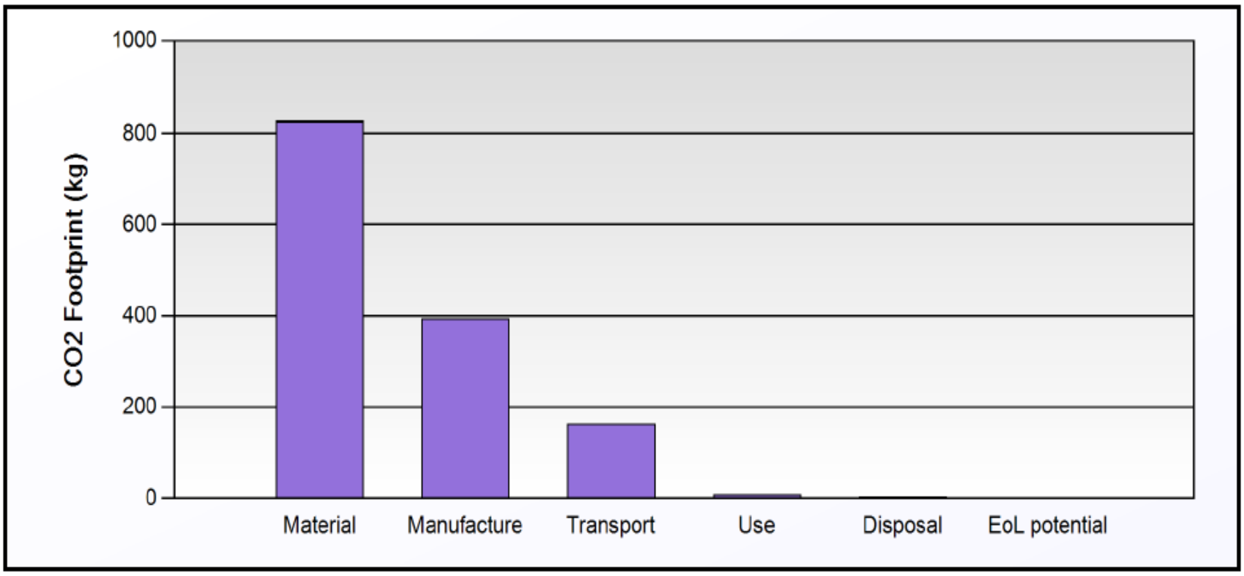
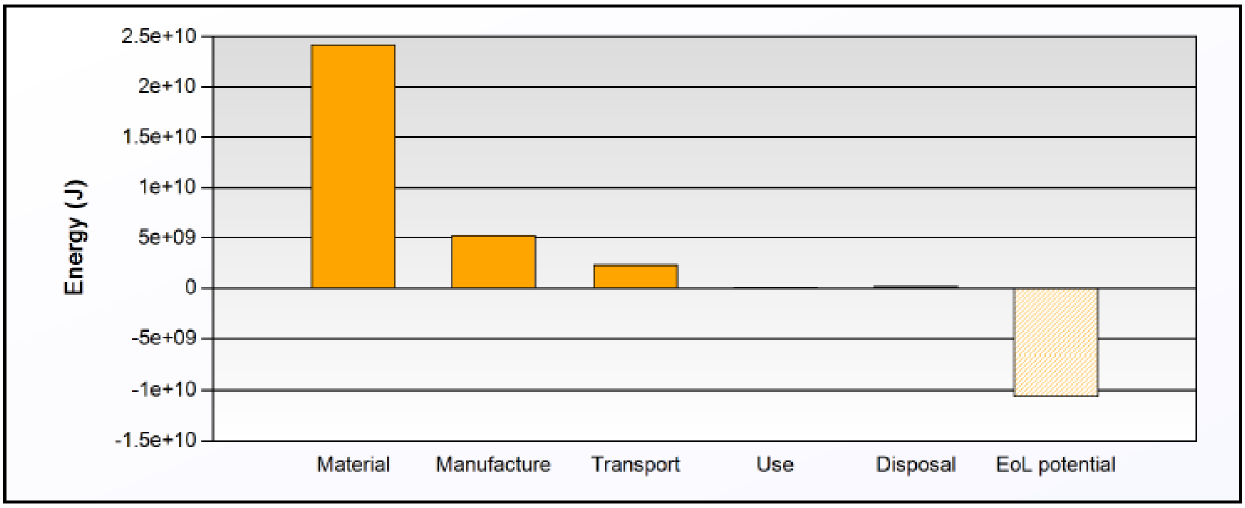


CO2 Details...

Phase	Energy (J)	Energy (%)	CO2 (kg)	CO2 (%)
Material	2.42e+10	75.8	825	59.2
Manufacture	5.25e+09	16.4	394	28.3
Transport	2.3e+09	7.2	164	11.7
Use	1.32e+08	0.4	8.15	0.6
Disposal	5.2e+07	0.2	3.64	0.3
Total (for first life)	**3.2e+10**	**100**	**1.39e+03**	**100**
End of life potential	0		0	

Fig. 5. Life Cycle Analysis of Plastic Milk Bottle: Virgin material and landfill for end of life option

Energy and CO2 Footprint Summary:



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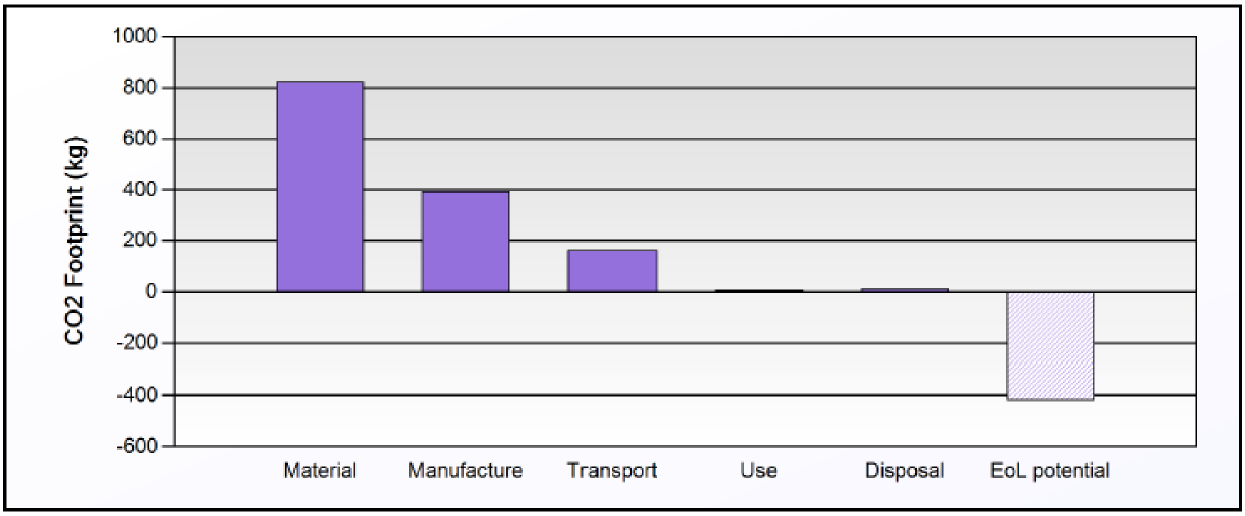
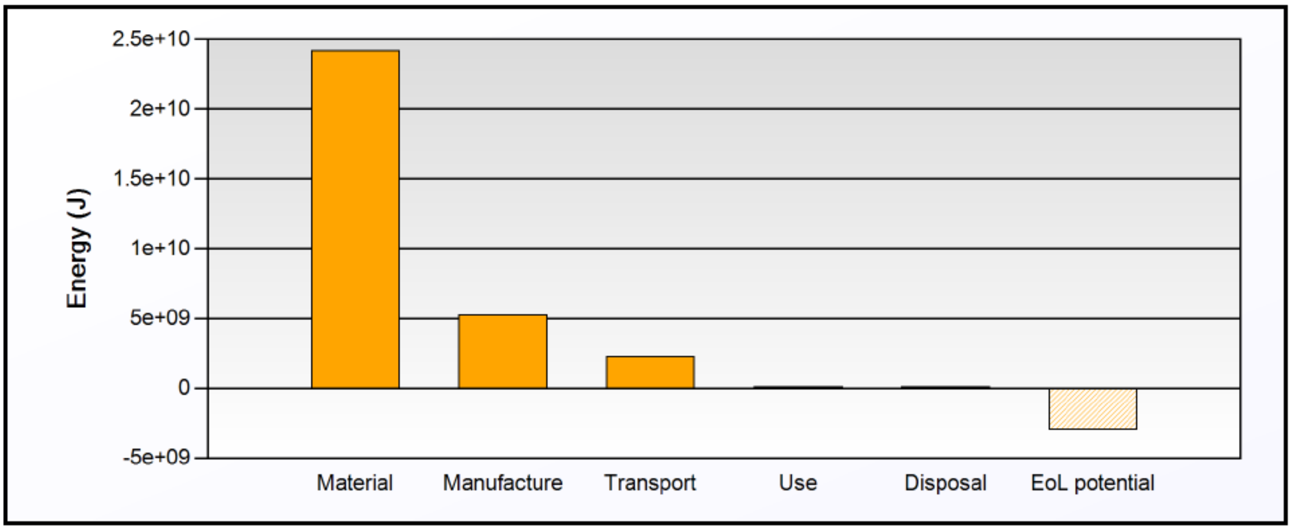


CO2 Details...

Phase	Energy (J)	Energy (%)	CO2 (kg)	CO2 (%)
Material	2.42e+10	75.5	825	58.8
Manufacture	5.25e+09	16.4	394	28.1
Transport	2.3e+09	7.2	164	11.7
Use	1.32e+08	0.4	8.15	0.6
Disposal	1.82e+08	0.6	12.7	0.9
Total (for first life)	**3.21e+10**	**100**	**1.4e+03**	**100**
End of life potential	-1.06e+10		-418	

Fig. 6. Life Cycle Analysis of Plastic Milk Bottle: Virgin material and Recycle for end of life option

Energy and CO2 Footprint Summary:



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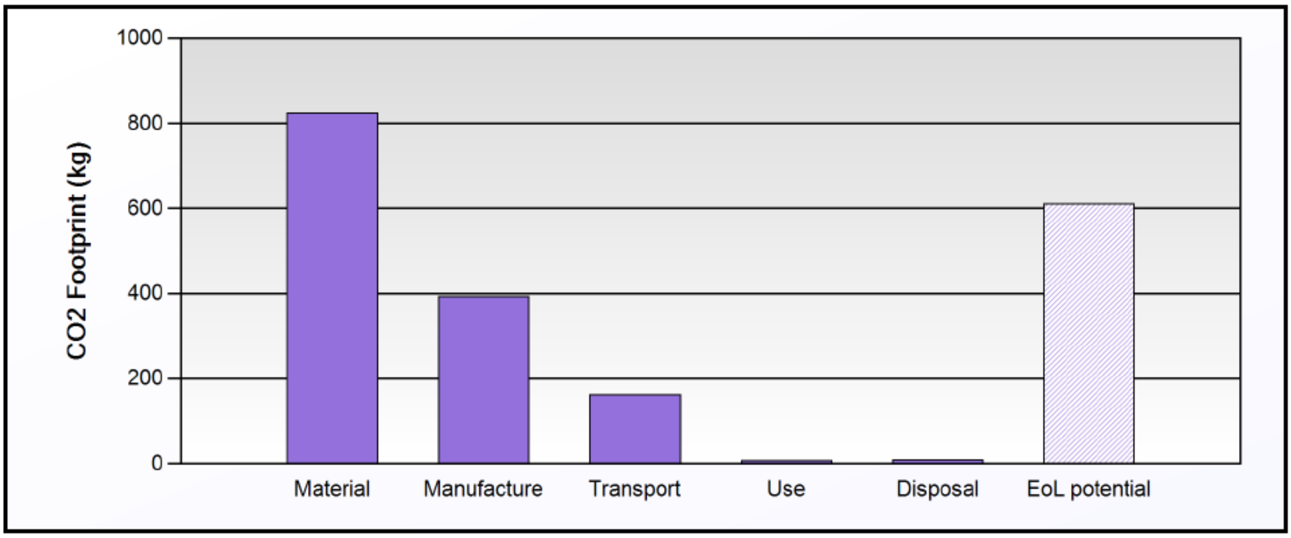


CO2 Details...

Phase	Energy (J)	Energy (%)	CO2 (kg)	CO2 (%)
Material	2.42e+10	75.6	825	58.9
Manufacture	5.25e+09	16.4	394	28.1
Transport	2.3e+09	7.2	164	11.7
Use	1.32e+08	0.4	8.15	0.6
Disposal	1.3e+08	0.4	9.1	0.7
Total (for first life)	**3.2e+10**	**100**	**1.4e+03**	**100**
End of life potential	-2.93e+09		611	

Fig. 7. Life Cycle Analysis of Plastic Milk Bottle: Virgin material and Combustion for the end of life option

The results of the life cycle analysis of the milk packaging system for different materials are shown in Tables 3 and 4. It is noted that these results are obtained with virgin materials. Table 3 summarizes the energy used during the material production, manufacturing and transport phases. For all the materials, the material production is the dominant phase (phase that is consuming more energy and producing high CO2 emissions). The highest energy and CO2 emissions during the material production are obtained for the Aluminum can. The aluminum cans have a high embodied energy (MJ/Kg) and the highest mass (see Table 1). The lowest energy and CO2 emissions during the material production are obtained for the carton bottle. The carton bottle has a low embodied energy (MJ/Kg) and the mass is lower compared to the aluminum can and glass bottle a shown in Table 1. During the manufacturing process, the glass bottle is showing the highest energy consumption (see Table 3) and the highest CO2 emissions (See Table 4) compared to the other milk bottles. The carton bottle has the lowest value for energy and CO2 emissions during the manufacturing process.

Table 3. Energy (J) for materials, manufacturing and transport phases

	Material Production	Manufacturing	Transport
Plastic	$2.42\ 10^{10}$	$5.25\ 10^{9}$	$2.3\ 10^{9}$
Glass	$4.01\ 10^{10}$	$1.82\ 10^{10}$	$3.07\ 10^{9}$
Carton	$5.53\ 10^{9}$	$9.85\ 10^{8}$	$1.25\ 10^{8}$
Aluminum	$1.68\ 10^{11}$	$7.24\ 10^{9}$	$2.54\ 10^{9}$

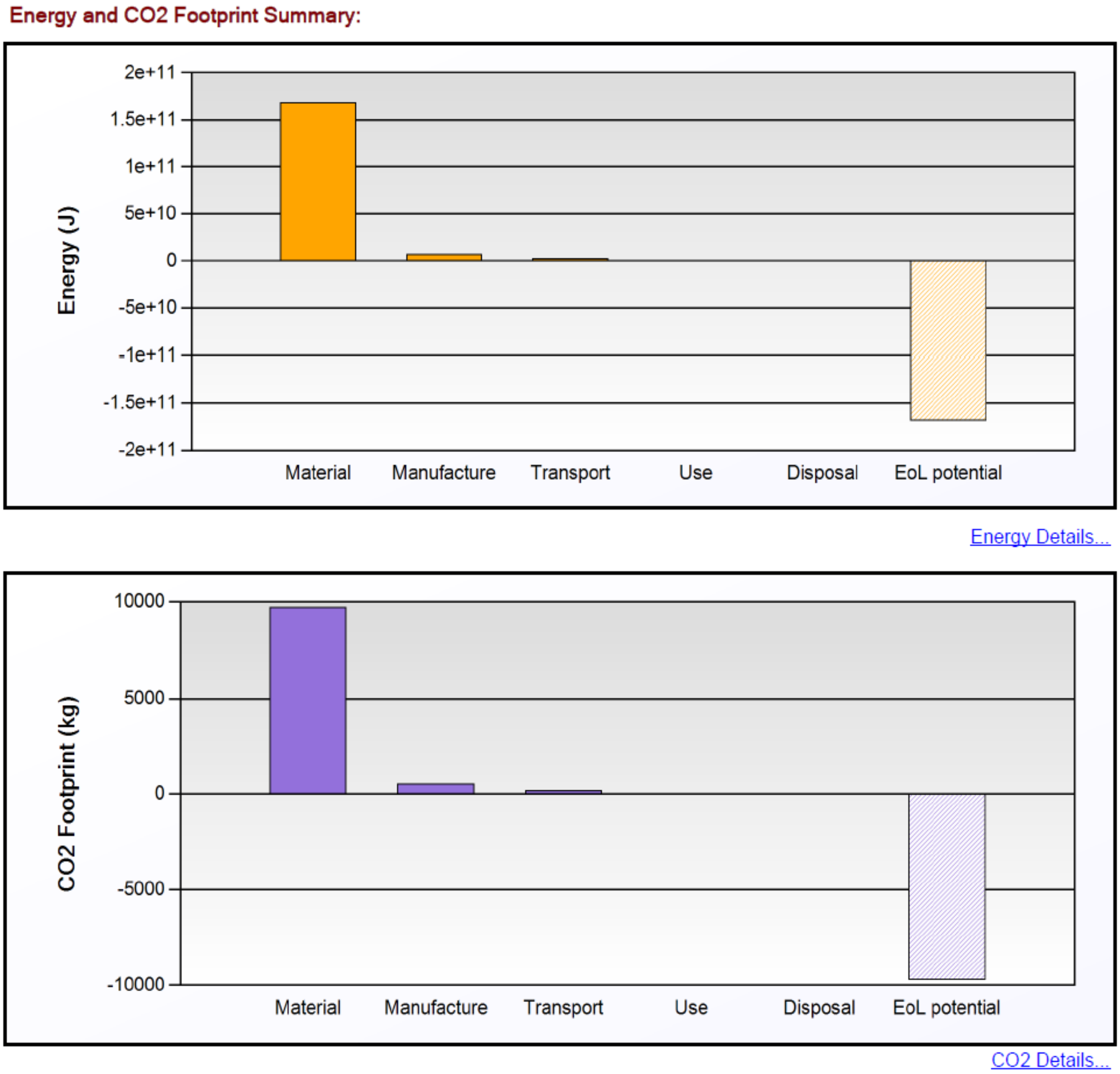
Table 4. Carbon foot print CO2 (Kg) the for materials, manufacturing and transport phases

	Material Production	Manufacturing	Transport
Plastic	825	394	164
Glass	2370	1450	218
Carton	204	74	9
Aluminum	9720	543	180

The results show clearly that the aluminum cans and glass bottles are consuming more energy and producing high CO2 emissions during the material production, manufacturing and transport phases. In the other hand, the glass bottle and aluminum can be reused. A life cycle analysis was performed for the aluminum can and glass bottle to determine the energy recovery and CO2 reduction potential when the milk bottles or cans are reused. The results of the life cycle analysis for the aluminum can and glass bottle with the reuse end of life option are shown in Figures 8 and 9. The energy recovery for the aluminum cans is $1.68\ 10^{11}$ Joules compared to the total energy of $1.78\ 10^{11}$ Joules consumed during the primary material production, manufacturing, transport, use and disposal. For the glass bottle the energy recovery is $3.99\ 10^{10}$ Joules compared to the total energy of $6.19\ 10^{10}$ Joules used during the primary material production, manufacturing, transport, use and disposal. For the reuse end of life option, 94% and 64% of the total energy is recovered respectively for the aluminum cans and glass bottles. Most of the energy can be recovered if the milk packaging systems can be reused after the first life cycle. The end of life potential for CO2 emissions reductions is also shown in Figures 8 and 9. If the milk packaging system can be reused again, a net reduction of CO2 emissions of 9720 Kg is obtained for the aluminum cans (see Fig. 8). This represent 93% of the total CO2 emissions produced during primary material production, manufacturing, transport, use and disposal. For the glass bottles the CO2 emissions reduction is 2360 Kg. This represent 58% of the total CO2 emissions produced during primary material production, manufacturing, transport, use and disposal. The reuse is one of the best end of life option for both energy recovery and CO2 emissions reductions. The best material should be selected for the milk packaging system based on the design requirements but also with the possibility of reuse after the first life cycle of the product.

All the results of the life cycle analysis presented in Fig. 5 to Fig. 9 are obtained with different materials (plastic, glass, carton, aluminum), different end of life options (landfill, recycle, combustion, and reuse) but with virgin materials. A life cycle analysis was performed in this study to investigate the effect of the recycled fractions content on the energy consumption and CO2 emissions during primary material production. The life cycle analysis was performed with the aluminum cans since it has the highest maximum recycled fraction (40.5% – 47.5%) as shown in Table 1. The life cycle analysis was performed with recycled fraction of aluminum and reuse as the end of life option. The results of the life cycle analysis are summarized in Table 5 to Table 9.

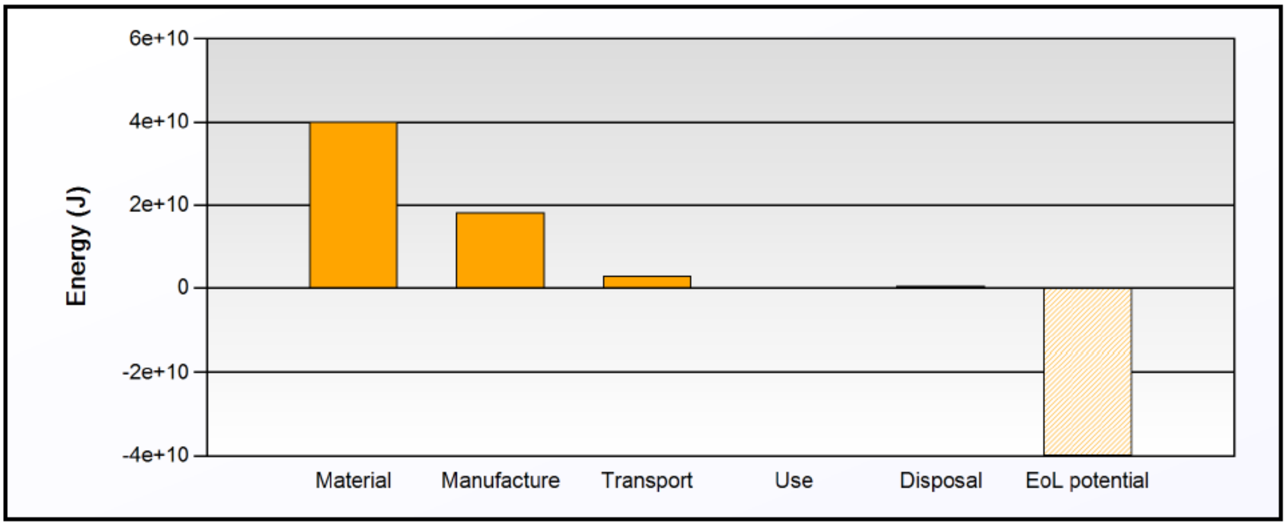
The results show a 36% reduction for the energy and CO2 emissions during the primary materials production when virgin material is replaced with aluminum material with recycled fraction of 40%. The energy consumption and CO2 emissions during the material production decrease by increasing the recycled fraction. It is also noted that the total energy and CO2 emissions for the first life (material, manufacturing, transport, use and disposal) decreases by increasing the recycled fraction. The total energy for the first life of milk packaging system decreases from $1.78\ 10^{11}$ Joules for virgin material to $1.11\ 10^{11}$ Joules for material with recycled fraction of 40%. The Total CO2 emissions decreases from 10500 Kg for virgin material to 6920 Kg for aluminum material with 40% recycled fraction.



Phase	Energy (J)	Energy (%)	CO2 (kg)	CO2 (%)
Material	1.68e+11	94.3	9.72e+03	92.9
Manufacture	7.24e+09	4.1	543	5.2
Transport	2.54e+09	1.4	180	1.7
Use	1.32e+08	0.1	8.15	0.1
Disposal	1.62e+08	0.1	11.4	0.1
Total (for first life)	**1.78e+11**	**100**	**1.05e+04**	**100**
End of life potential	-1.68e+11		-9.72e+03	

Fig. 8. **Life Cycle Analysis of Aluminum Can: virgin material and reuse for the end of life option**

Energy and CO2 Footprint Summary:



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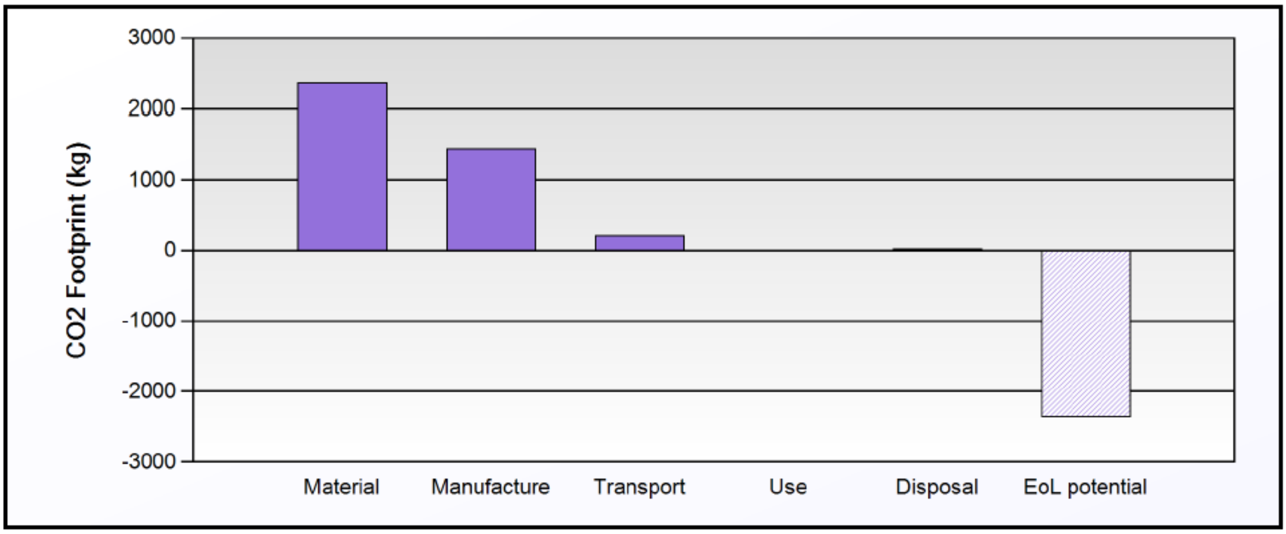

CO2 Details...

Phase	Energy (J)	Energy (%)	CO2 (kg)	CO2 (%)
Material	4.01e+10	64.8	2.37e+03	58.1
Manufacture	1.82e+10	29.4	1.45e+03	35.7
Transport	3.07e+09	5.0	218	5.3
Use	1.32e+08	0.2	8.15	0.2
Disposal	4.17e+08	0.7	29.2	0.7
Total (for first life)	**6.19e+10**	**100**	**4.08e+03**	**100**
End of life potential	-3.99e+10		-2.36e+03	

Fig. 9. Life Cycle Analysis of Glass Bottle: virgin material and reuse for the end of life option

Table 5. Aluminum Cans: 0% Recycled fraction

Phase	Energy (J)	Energy (%)	CO2 (kg)	CO2 (%)
Material	1.68e+11	94.3	9.72e+03	92.9
Manufacture	7.24e+09	4.1	543	5.2
Transport	2.54e+09	1.4	180	1.7
Use	1.32e+08	0.1	8.15	0.1
Disposal	1.62e+08	0.1	11.4	0.1
Total (for first life)	**1.78e+11**	**100**	**1.05e+04**	**100**
End of life potential	-1.68e+11		-9.72e+03	

Table 6. Aluminum Cans: 10% Recycled fraction

Phase	Energy (J)	Energy (%)	CO2 (kg)	CO2 (%)
Material	1.53e+11	93.8	8.84e+03	92.2
Manufacture	7.24e+09	4.4	543	5.7
Transport	2.54e+09	1.6	180	1.9
Use	1.32e+08	0.1	8.15	0.1
Disposal	1.62e+08	0.1	11.4	0.1
Total (for first life)	**1.63e+11**	**100**	**9.58e+03**	**100**
End of life potential	-1.53e+11		-8.84e+03	

Table 7. Aluminum Cans: 20% Recycled fraction

Phase	Energy (J)	Energy (%)	CO2 (kg)	CO2 (%)
Material	1.37e+11	93.2	7.95e+03	91.5
Manufacture	7.24e+09	4.9	543	6.2
Transport	2.54e+09	1.7	180	2.1
Use	1.32e+08	0.1	8.15	0.1
Disposal	1.62e+08	0.1	11.4	0.1
Total (for first life)	**1.48e+11**	**100**	**8.69e+03**	**100**
End of life potential	-1.37e+11		-7.95e+03	

Table 8. Aluminum Cans: 30% Recycled fraction

Phase	Energy (J)	Energy (%)	CO2 (kg)	CO2 (%)
Material	1.22e+11	92.4	7.07e+03	90.5
Manufacture	7.24e+09	5.5	543	7.0
Transport	2.54e+09	1.9	180	2.3
Use	1.32e+08	0.1	8.15	0.1
Disposal	1.62e+08	0.1	11.4	0.1
Total (for first life)	**1.32e+11**	**100**	**7.81e+03**	**100**
End of life potential	-1.22e+11		-7.07e+03	

Table 9. Aluminum Cans: 40% Recycled fraction

Phase	Energy (J)	Energy (%)	CO2 (kg)	CO2 (%)
Material	1.07e+11	91.4	6.18e+03	89.3
Manufacture	7.24e+09	6.2	543	7.8
Transport	2.54e+09	2.2	180	2.6
Use	1.32e+08	0.1	8.15	0.1
Disposal	1.62e+08	0.1	11.4	0.2
Total (for first life)	**1.17e+11**	**100**	**6.92e+03**	**100**
End of life potential	-1.07e+11		-6.18e+03	

4. Conclusion

Life cycle analysis of milk packaging system was performed in this study. The life cycle analysis will guide in the design process of the role of materials and processes selection in terms of embodied energy, carbon foot print, recycle fraction, and sustainability criteria. A particular skills need to be used during the design process of packaging system not only to satisfy the design requirements but also to minimize or eliminate adverse eco impacts. The environmental impacts of milk packaging systems through their entire life cycle were analyzed. The energy consumption and emissions produced during the material primary production, manufacturing, transportation, and the use of the milk packaging were determined. This assessment was used to identify the phase of the product life that carry the highest demand for energy or create the greatest burden of emissions. The life cycle analysis was performed using different packaging materials (plastic, glass, carton, and aluminum), recycled fraction content, and end of life options (landfill, recycle, combustion for energy recovery, and reuse). The results of the life cycle analysis show:

1. The primary material production is the dominant phase. The Material phase is consuming more energy and producing high CO2 emissions compared to manufacturing, transport, use and disposal phases.

2. The aluminum can is consuming the highest energy and producing the highest CO2 emissions during material production, followed by the glass, plastic and carton bottles.

3. Even the aluminum cans and glass bottles are consuming more energy and producing more CO2 for the primary material production, they can be reused at the first end of life of the packaging system. They represent the best end of life potential for both energy recovery and CO2 emissions reductions. With a reuse end of life option, 94% and 64% of the total energy is recovered respectively for the aluminum cans and glass bottles.

4. The energy consumption and CO2 emissions during the material production decrease by increasing the recycled fraction. The results for the aluminum cans show a 36% reduction for the energy and CO2 emissions during the primary materials production when virgin material is replaced with aluminum material with recycled fraction of 40%. The total (material, manufacturing, transport, use and disposal) energy and CO2 emissions for the first life of the packaging system also decreases by increasing the recycled fraction.

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