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Sensitivity Analysis of the Environmental Impact of Polymer Injection Molding Process

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Abstract:

During the last decades the environmental concern of society has experienced an increase. Specific tools like the Life Cycle Assessment (LCA), and software and databases to apply this method have been developed to calculate the environmental burden of products or processes very diverse. Global plastics production rose to 288 million tonnes in 2012. Among the different ways of plastics processing, the injection molding process is one of the most used in the industry worldwide. In this paper an analysis of the influence of the polymer in the environmental impact of the injection molding process has been carried out. In order to perform this study, the EcoInvent database inventory considered and the data from which this database is obtained for this process have been studied. In general, when a LCA of a product is carried out, databases such EcoInvent, where materials, processes and transports are characterized providing average values, are used. This approach can be good enough for some cases but in order to assess a specific process, like the injection molding process, a further level of detail is needed. This study shows how the final results of environmental impact differ significantly when modifying the generic dataset's values, using the PVC's, PP's or PET's original report data or more updated values. This aspect suggest the necessity of studying, in a more precise way, this process to evaluate its environmental burden correctly so the priority areas can be properly identified and thereby actions to develop a more sustainable way of manufacturing can be determined.

Keywords: Environmental impact; injection molding process; LCA

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1. Introduction

Over the last decades the environmental concern of society has increased and changes in legislation of this matter have occurred [1]. These circumstances have stimulated the development of specific tools, like the Life Cycle Assessment (LCA), that allows us to determine the environmental impact of different products or processes [2-3]. In order to apply this tool, a Life Cycle Inventory (LCI) has to be carried out. In this inventory all the aspects to consider in a LCA calculation will be collected [4-5]. To make this task easier, environmental impact databases have been created. They characterize datasets and its environmental burden. Among the different existent databases, EcoInvent is the most recognized worldwide, achieving more than four thousand users and including more than ten thousand materials and processes [6]. Also it is integrated in the software SimaPro which is the world's leading LCA software [7].

The main goal of applying the LCA to a product or a process is to identify the elements that cause the greater effects to our environment. This way it would be known where to put effort to reduce this impact [8]. In order to evaluate the environmental impact of a product or a process, it has to be analyzed profoundly. Its materials, the manufacturing processes to obtain its form, its distribution, use phase and end-of-life will have to be taken into account. Normally a commercial database would be used in order to perform this task. Among the characterized processes by EcoInvent is the injection molding process. This manufacturing process is one of the more used around the world, having an important relevance in the economy, for instance global plastics production rose to 288 million tonnes in 2012 [9]. In this paper this process is studied, analyzing how EcoInvent's database characterizes it. A sensitivity analysis of the environmental impact results it is going to be displayed, modifying the generic dataset's values, using the PVC's, PP's or PET's original report data or more updated values, and obtaining the final results with the ReCiPe Endpoint (H/A) methodology [10], that measures in only one endpoint value the harm caused to the environment, which make the final results easier to understand for engineers and designers than with other midpoint indicators. For these calculations the software SimaPro 8.0.2 [7] and EcoInvent v3 has been used.

2. Methods

The first step that has been made in this analysis is to figure out how the EcoInvent dataset for this process has been configured, analyzing the documentation provided by EcoInvent and comparing it with the final dataset to identify its connection. In this report, [11] , it is specified the original data used for the final dataset (Injection moulding {RER}| processing | Alloc Def, U). This phase is essential because it is not possible to perform this study if it is not known how the data has been treated.

The following table (Table 1), which is summarized, shows some elements of the original inventory and how EcoInvent has adapted these values. In this table, necessary input and obtained output has been collected for the processing of three different types of plastic: PVC, PP and PET that were studied in some reports [12-13].From these values the arithmetic mean is obtained and it is relevant to notice that when there was no data, it was considered as zero.

Lubricants, Lubricating oil and grease are considered as lubricating oil. It is important to know that they are valued in different units, kg and MJ. It has been determined that EcoInvent has used a value of 42 MJ/kg in order to make this unit conversion. It is also remarkable the elements such solvents, stabilizers, pigments, fillers or the hazardous waste generated that are exclusive for the PVC processing. In particular pigments are divided as 44% Kaolin, 6% of Malusil (talc) and 50% Lime [14].

This inventory also included, for example, the water used during the process for cooling and packaging materials needed for prepare the product for delivery. Ecoinvent has adapted the assigned value for pallets and wood pallets as 1,46E-03 pallets.

The energy section collects all the input registered in the factory. Fuels like butane, propane and gasoline are related to internal transport in the plant and they are omitted in the EcoInvent v3 dataset. On the other hand, the natural gas and fuel oil appear to be related with the plant heating. In addition, EcoInvent adds to its dataset the infrastructure of the factory as 1,43E-09 units of a packaging box factory per kilogram of processed plastic.

Table 1: Injection molding process's inventory (Summarized)

Per kg output		APME report		BUWAL report		
	Unit	PVC	PP	PET	Arithmetic mean	EcoInvent v3.0.1.
INPUT						
Materials						
Lubricants	Kg	0,0068			0,0023	Lubricating oil {GLO}| market for | Alloc Def, U
Lubricating oil	MJ	0,0948			0,0316	
Grease	MJ		0,0007		0,0002	
Solvents	Kg	0,1349			0,0450	Solvent, organic {GLO}| market for | Alloc Def, U
Filler	Kg	0,0227			0,0076	Kaolin {GLO}| market for | Alloc Def, U Malusil {GLO}| market for | Alloc Def, U Lime {GLO}| market for | Alloc Def, U
Packaging materials						
Wooden Pallets	Kg	0,0461	0,05		0,0320	EUR-flat pallet {GLO}| market for | Alloc Def, U
Pallets	Kg	0,0005			0,0002	
Energy						
Electricity	kWh	1,3746	2,096	1	1,4902	Electricity, medium voltage market for | Alloc Def, U
Natural gas	MJ		12,6982		4,2327	Heat, district or industrial, natural gas | market for heat, district or industrial, natural gas | Alloc Def,
OUTPUT						
Waste						
Regulated Waste	kg	1,00E-04			3,3333E-05	Hazardous waste, for underground deposit {GLO}| market for | Alloc Def, U

Considering the above, results modifying the dataset values are going to be obtained for the next scenarios and compared with the generic EcoInvent case:

- Generic EcoInvent, omitting specific aspects of PVC processing: EcoI3M
- PVC
- PP
- PET
- PP (2010 Electricity): PP '10

Next table (Table 2) indicates the used values for calculation, they are showed grouped in different sections so the space occupied by the table in this text is not excessive.

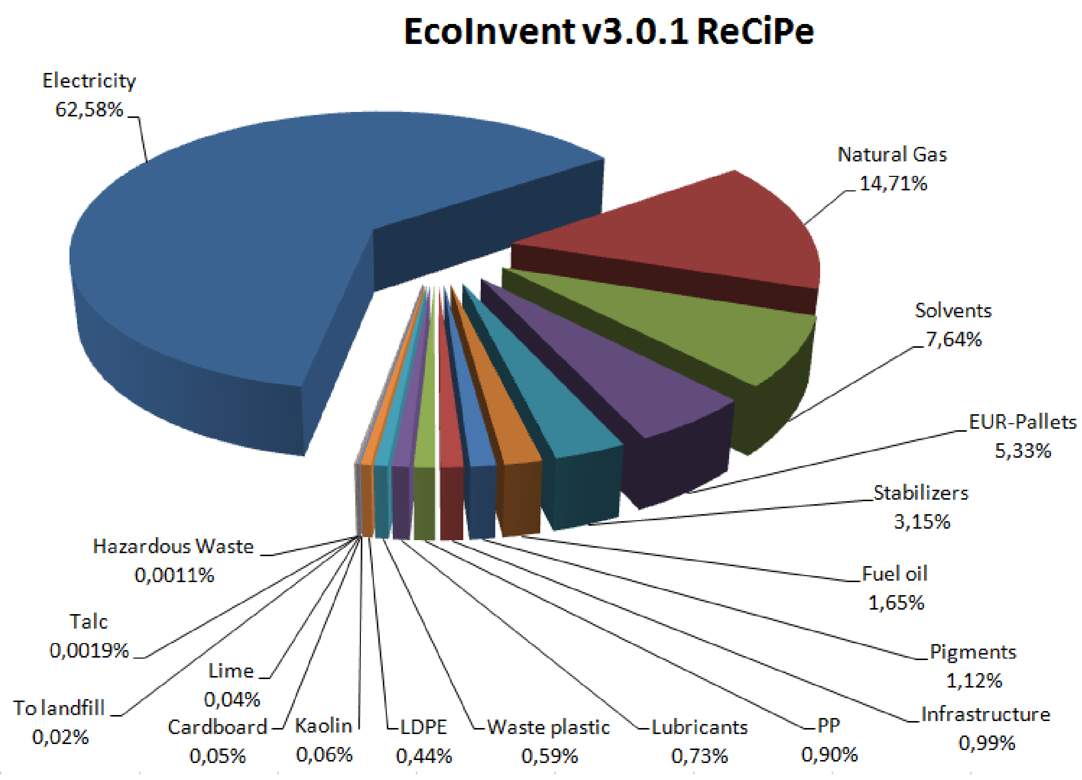
Table 2: Values used for calculation

	Units	EcoInvent v3	EcoI3M	PVC	PP	PET	PP '10
Electricity	kWh	1,480	1,480	1,375	2,096	1	0,799
Heating	MJ	4,439	4,439	0,347	13,043	---	13,043
Lubricant oil	Kg	3,03E-03	5,56E-06	9,06E-03	1,67E-05	---	1,67E-05
PVC Additives	Kg	0,059	---	0,174	---	---	---
Packaging materials	Kg	0,037	0,037	0,056	0,056	---	0,056
Waste	kg	-0,007	-0,006	-0,010	-0,005	-0,005	-0,005

3. Results and Discussion

For the EcoInvent v3 original dataset, the results are showed in the diagram below (Figure 1).

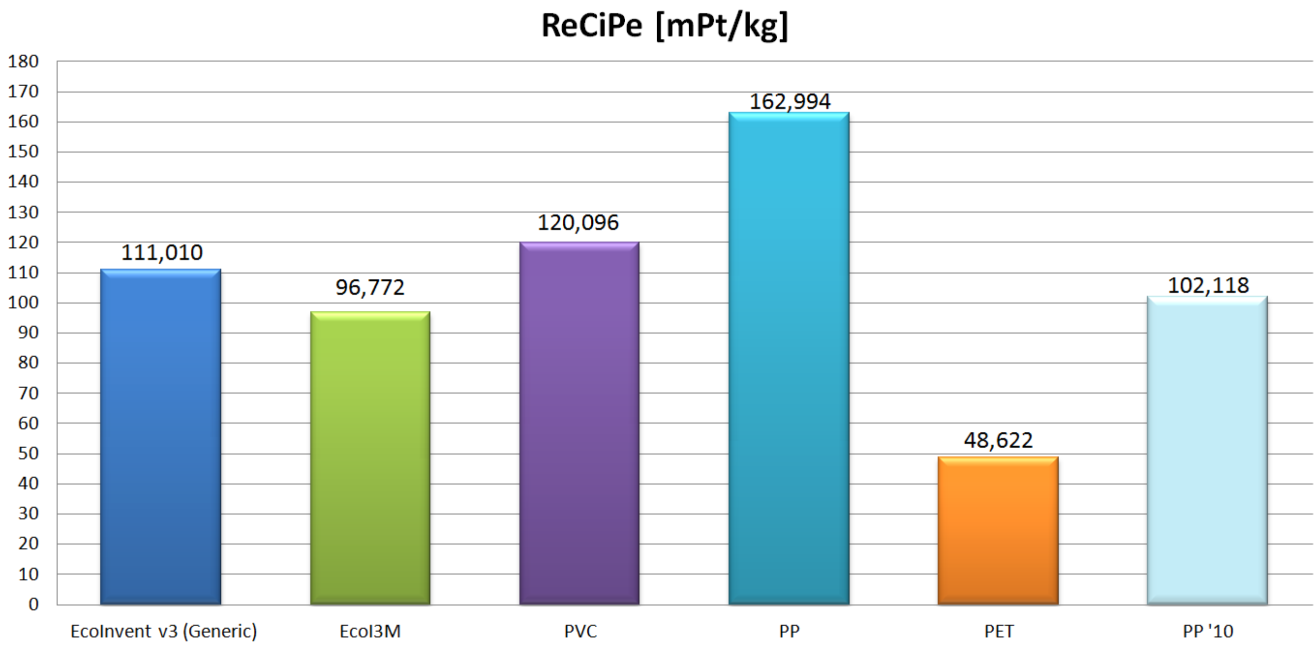
Figure 1: EcoInvent v3 results, ReCiPe methodology



Power consumption is positioned as the element that means more impact for the environment (+60%). The heating (natural gas and other fuels) constitute around 16% of the final result, the packaging materials added all together are about 7% of the impact. Different types of additives, in which are included lubricants, solvents, stabilizers, pigments and fillers such as kaolin, lime and malusil, represents almost the 13 % of the result.

Figure 2 represents the total results for every proposed case. The generic case, omitting specific aspects of the PVC inventory (EcoI3M) shows a reduction of 12,83%. However the environmental impact of the PVC processing suppose an increase of about an 8%. The PP case is the one that has the greater impact due to a high value of energy with a final result 46,83% bigger than the generic case (EcoInvent v3). When modifying the electricity consumption for a more updated value, such as the one registered in [15], 0,7922 kWh/kg, the environmental impact of the process is reduced by 62 mPt/kg, a 8% smaller (PP '10). The most relevant variation (-56,2%), is the one achieved by the PET processing which inventory was shorter than in others polymers considered.

Figure 2: Environmental impact results for the injection molding process, ReCiPe EndPoint (H/A)



With Table 3 we can see how each block contributes to the total environmental impact of the process. The electricity consumption is by far the most influent factor. In the PET processing it achieves a 96,55% due to a lack of registered data.

The heating contribution represents a relevant percentage in the generic case (16,36%). However we can see that is because of the PP data, neither the PVC nor the PET inventory have that element assigned to its inventory. In addition the used additives that are about the 12% of the final result, don't appear in any more cases. Finally the contribution of waste and packaging materials are more or less quite similar. The considered infrastructure is exactly the same value for all of the scenarios so the variations are only due to the differences in other sections.

Table 3: Results's percentage, divided into different groups

	EcoInvent v3	EcoI3M	PVC	PP	PET	PP '10
Electricity	62,58%	71,79%	53,73%	60,37%	96,55%	36,74%
Heating	16,36%	18,76%	2,31%	31,90%	---	50,92%
Lubricant oil	0,73%	0,002%	2,02%	0,003%	---	0,004%
PVC additives	12,01%	---	30,79%	---	---	---
Packaging materials	6,71%	7,63%	9,48%	6,70%	---	10,69%
Waste	0,62%	0,68%	0,75%	0,36%	1,20%	0,57%
Infrastructure	0,99%	1,13%	0,91%	0,67%	2,26%	1,07%

4. Conclusions

This study has showed how hugely the environmental impact results for the injection molding process vary when modifying some of the inventory values, obtaining a great difference between polymers. Results have revealed how the special PVC additives contribute to increase the final results in +15mPt/kg. Analyzing the three plastic studied in the report, the polypropylene has the higher impact due to a high value of energy consumption (2,096 kWh/kg), because electricity it is the most relevant factor in the final results. On the other hand, the fewer data considered for the PET processing contribute to reduce the obtained results in the generic case.

All these considerations imply that a deeper study is needed to assess correctly the environmental performance of a specific process, in order to propose actions that will achieve a more sustainable development in the industry, and avoid double counting in LCA analysis.

Conflict of Interest

The authors declare no conflict of interest.

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