Assessing the Economic and Ecological Impact of Plastic Products

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Summary: The framework of the International Standard Organization's (ISO) 14040 series provides the practitioner with rules to deal with different aspects of analysis and assessment of the life cycle of products. The standard emphasizes the importance of accurate data to perform a valid analysis. This premise lets LCA (life cycle assessment) studies become time-consuming and expensive. But, sound decision-making by management in enterprises can be done even in cases where data are incomplete or vary, when the eco-efficiency analysis methodology is used that has been developed and applied by BASF in more than 150 projects during the last five years.

Keywords: calculations, eco-efficiency, life cycle assessment, plastics, Ultramid®

Introduction

Among worldwide operating chemical companies the environmental activities of BASF have again focused attention during the last years. With the dawn of the new century the company has anchored Sustainable Development even more firmly in its management system. In 1992, representatives of 172 governments adopted Agenda 21 in Rio de Janeiro. At that time, very few of the signatories envisaged the enormous power that the idea of Sustainable Development would attain within only a few years. With the creation of a Sustainability Council at the top corporate level, BASF is one of the first large concerns in the world to anchor this principle in its organization. In addition, the company established a Competence Center for Responsible Care to advance environment, safety and health worldwide throughout the BASF Group. And Fortune Magazine ranks BASF number one among world chemical companies and among German businesses in its annual listing of Global Most Admired Companies. Sustainability is not just window dressing as far as BASF is concerned. Instead, *sustainable success* has become a precondition for all activities. How closely economic success and ecological progress are related, is impressively highlighted by the *BASF type eco-efficiency analysis*.

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At the heart of this analysis lies the question "What must BASF's products of the future look like?" The goal is to offer competitive, environmentally friendlier products with optimum benefits for the customers. Eco-efficient products like these also give the company a competitive advantage. BASF's analysis already includes financial and environmental criteria and the specialists are working to incorporate social indicators, too. BASF intends to then have a unique strategic instrument to optimize its product portfolio according to sustainability criteria.

Indeed, different concepts already exist to evaluate the environmental performance of products and services. But, from the viewpoint of BASF these concepts are not sufficient to help the management makes sound decisions on how to optimize the company's portfolio by selection of prosperous products.

BASF's Methodology

The principal concept of the eco-efficiency analysis method of BASF has been developed in 1996 by teaming up with management consultants Roland Berger + Partner. Since then the methodology has been refined continuously based on BASF's own growing expertise. The method is combining ecological and economic thinking. The ecological part is based on lifecycle thinking according to the International Standard Organization's (ISO) 14040 series. The functional unit in particular is defined from the viewpoint of the final customer, who is the driving force in industrial societies to manufacture goods and provide services. The economical part of the methodology assumes that the final customer has to pay for all activities directly in the form of prices for products and services or indirectly by taxes, charges, fees etc. whether he is aware of or not. At first glance the methodology looks simple, but it is also capable to perform detailed cost analysis, which is beyond the scope of this paper.

Thus, the BASF type of eco-efficiency analysis is a two-dimensional analysis that requires two or more products to be compared. Something like a "score figure" for a single product cannot be calculated. In addition, it is not allowed to calculate single figures like the "ratio of environmental and economical impact" to compare the performance of products and services. Therefore, the result must be presented graphically as so-called "eco-efficiency chart", which is similar to portfolio charting used in economics.

The lifecycle analysis is done by using the following set of selected categories.

Material: water, coal, oil, gas, lignite, limestone, bauxite, sulfur, sodium chloride, potassium chloride, feldspar and sand. This listing can be amended according to the necessities of a specific analysis.

Energy (Fuel): coal, oil, gas, hydro power, nuclear power, lignite, biomass and others.

Air emissions: carbon dioxide, sulfur oxides, nitrogen oxides, methane, non-methane organic volatile substances, halogen compounds, ammonia, laughing gas and hydrogen chloride.

Water emissions: BOD (biological oxygen demand), COD (chemical oxygen demand), nitrogen compounds, ammonia ions, phosphate ions, AOX (absorbable organic halogenated compounds), heavy metals, hydrocarbons, sulfate ions and chloride ions.

Waste: domestic waste, special waste and overburden (including building rubble).

The selection of these emission categories has been done from the viewpoint of existing "limit values" like scarcity factors, maximum allowable release concentrations, effects that harm the environment etc. These limits are fixed by laws and ordinances, which often differ country by country and region by region.

Furthermore the two categories "toxicity potential" and "risk potential" have been introduced, which are especially important for judgment in chemical companies.

The toxicity potential of products and services is determined by using figures from the German MAK (Maximale Arbeitsplatzkonzentration) list and/or R-phrases that are common in the EU (European Union) for characterization of chemicals. The calculation is done according to a special procedure[1] that has been developed by BASF and takes hazard and/or chemical risk considerations into account.

The concept of "risk potential" covers the idea of risk of accidents and injuries, which are based for example on statistics published by professional and trade associations. The calculation is done semi-quantitatively.

Figure 1 shows an example of the so-called "ecological fingerprint", which is a radar chart with five axes representing the main categories "material consumption", "energy consumption", "emissions" (air, water, solid waste), "toxicity potential" and "risk potential". The environmental impact caused by waste and emissions into air and water are treated as one total "emissions" category. In case renewable resources have to be investigated an additional axis is introduced that represents the use of land.

In the first step potential effects like GWP (global warming potential), ODP (ozone depletion potential), POCP (photochemical ozone creation potential) and AP (acidification potential) as well as water pollution and waste are quantified similar to a known procedure.[2] The aggregation is then done by using the "societal perception" scheme of Figure 2 to get one final figure representing the environmental load of a product's life cycle.

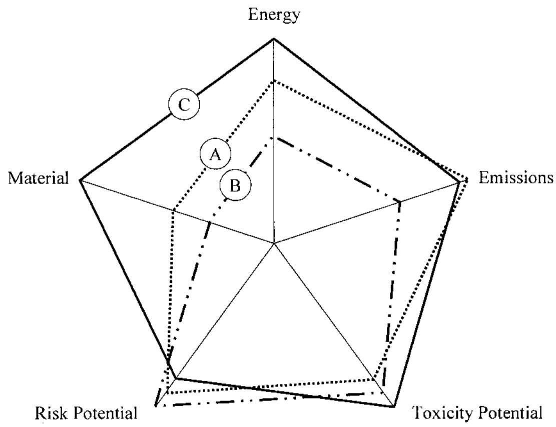

Fig. 1. Example of an ecological fingerprint for a representative scenario analyzing three products.

In addition a second weighting scheme is applied that is based on specific environmental categories occurring in the life cycle of a product. The absolute value of these individual resource and emission categories like carbon dioxide, nitrogen oxides etc. is related to the respective total value of these categories observed for example in Germany during one year. This weighting leads to so-called "relevance factors" which are then amalgamated on equal basis with the mentioned weighting scheme of societal perception to give one ultimate figure representing the environmental impact of a product based on "social and relevance weighting". It is important to recognize that the indicated percentage figures for social perception must not be regarded as fixed. The initial values are only used to calculate the so-called basic scenario, which then serves as starting point to perform variation calculations.

In parallel the total monetary burden imposed on the final customer is determined by taking into account the annual turnover this product (group) contributes to the GNP (gross national product).

Based on the respective figures for environmental load and monetary burden of two or more products to be compared the relative positions of these products are calculated to construct the so-called eco-efficiency chart. According to the labeling concept, which is different to Cartesian xy-plotting, products in the upper right quadrant are eco-efficient, because they have low environmental load and cause less monetary burden. The contrary is true for those products located in the opposite lower left quadrant. In addition the diagonal running from the upper left to the lower right corner is a boundary to separate less eco-efficient products located on its left side from more eco-efficient ones on its right side.

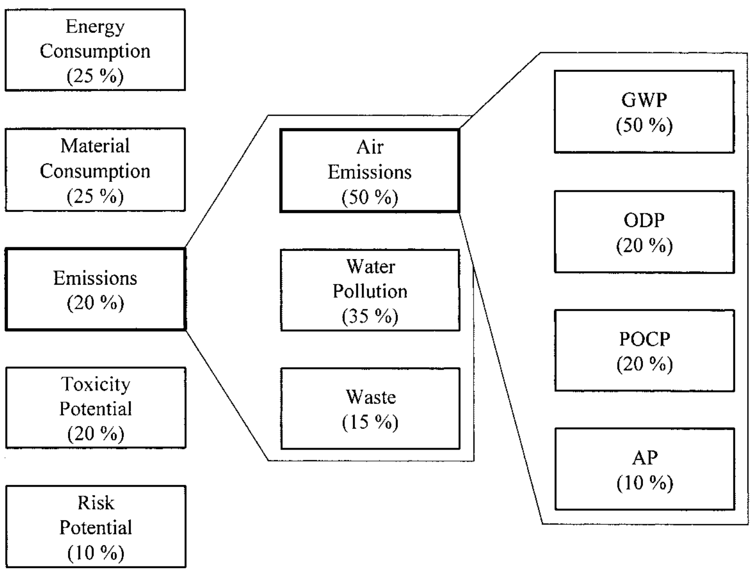

Fig. 2. Aggregation scheme based on "societal perception" for creating the ecological fingerprint and eco-efficiency chart.

There is always much debate that the selection of the weighting factors of Figure 2 will remarkably influence the result of a study. Indeed, this can be true in cases where the selection is over-emphasizing one or two categories like toxicity and risk potential.

As an example the initial values of the five weighting factors on the left side of Figure 2 are permutated. It becomes obvious that the product positions will shift as expected, but there is no dramatic change. Therefore, the principal decision based on the initial factors will not be affected as long as the monetary burden keeps constant as Figure 3 shows. For reference, the (x) marks show the result when all environmental categories are weighted equally. Even in this case the principal decision is not affected.

Case Study[3]

In vehicle construction, plastics have successfully replaced many conventional materials. Initially, most of the replacement occurred with interior parts. Use in the engine compartment represents a particular challenge for design and material properties. Intake manifolds made of Ultramid®, a BASF polyamide, are a classic example.

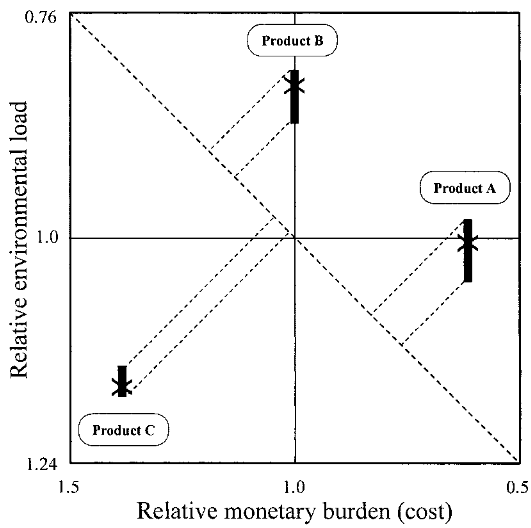

Fig. 3. Eco-efficiency chart that shows the effect when the weighting factors of Figure 2 are permutated.

These intake systems are geometrically complex components that in the past were sand cast from cast iron or aluminum. In the early 1980s, BASF began initial attempts to use plastics to manufacture these components. Even then, at a time when eco-efficiency or life cycle analyses were not widely known concepts, BASF engineers had set ambitious economic and environmental goals: The purpose of replacing metallic materials by polymers was to reduce costs and weight.

In order to be able to achieve these goals, it was first necessary to perfect the so-called lost core technology. In this process, a tin/bismuth core generally corresponding to the inner cavity of the intake system is first cast. This core is placed in a mold and plastic is injected around it. Then, the core is melted again, leaving behind the plastic intake system, which requires no further processing. The tin/bismuth alloy can be reused.

BASF has made key contributions to advancing this process to the large-scale production level and thereby helping plastic intake systems achieve a break-through. BMW was the first automobile manufacturer to use a system of this type in standard production: Beginning in early 1990, all of its 6-cylinder 4-valve engines were equipped with this manifold. Porsche followed in the same year with two intake manifolds for its 3.6-liter boxer engine used on the "911".

However, the lost core technology is not the only way to make intake manifolds from Ultramid®. In the meantime a half-shell technology has been developed, in particular for applications in which the shape of the components is not extremely complex. In this technology, two injection-molded parts are manufactured separately and then vibration-welded together. The advantages over the lost core technology are substantially lower capital spending and manufacturing costs.

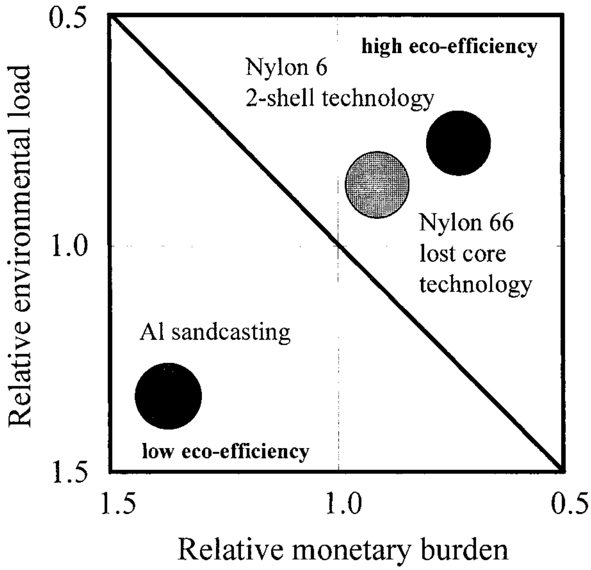

Fig. 4. Eco-efficiency chart showing the base case result when intake manifolds made of nylon 6, 66 and aluminum are compared.

Both processes have proven their effectiveness, and plastic intake systems are now the state of the art. About 70% of all passenger vehicles manufactured in Europe are equipped with such units. About 40% of these units are made of the BASF plastic Ultramid®. But, this development is not limited to Europe. Plastic intake systems have also gained a substantial market share in Asia and the USA.

There are economical and ecological reasons for this. First, in terms of economy: even though the lost core technology seems to be very complex and expensive at first glance, intake systems made of plastic are up to 50% less expensive than the equivalent metal design.
The life-cycle analysis is equally convincing. As Figure 4 shows, three different intake system designs were studied: one, manufactured from aluminum using the sand casting process, another manufactured from polyamide 6.6 using the lost core technology, and finally, a nylon 6 version fabricated from two individual shells. The analysis began by looking at the full life cycle of these components, from manufacturing, to use, to disposal.
Most important result: Compared to the metal version, both plastic versions have obvious environmental advantages. For one, less energy is used to manufacture them. For another, they are lighter and therefore reduce fuel consumption when the vehicle is being driven. However, there are differences between the plastic types. The complex lost core technology is somewhat more energy intensive than the two-shell technology. Added to this is the fact that nylon 6 has a somewhat better LCI (life-cycle inventory) sheet when manufactured than does nylon 66. Therefore, the intake system produced by joining two shells together comes out on top.
As for disposal of old parts, in the current case it has been assumed that the aluminum would be recycled while the plastic would end up in a landfill.

Conclusion

More than 150 eco-efficiency projects performed by BASF have proven that sound decision-making based on eco-efficiency charts can be done without meticulously create overmuch detailed LCI data, a procedure that is cost and time consuming. Existing data or wisely created data sets that are based on reasonable expertise are sufficient for decision-making in enterprises when a set of basic principles is observed consistently.

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