# Economic and environmental analysis of the wine bottle production in Spain by means of life cycle assessment

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# ECONOMIC AND ENVIRONMENTAL ANALYSIS OF THE WINE BOTTLE PRODUCTION IN SPAIN BY MEANS OF LIFE CYCLE ASSESSMENT


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**ABSTRACT**

The article's objective is to analyse the improvements obtained by the implementation of eco-efficiency in the wine production. The principal aim is to achieve the rational energy and materials consumption in the whole wine production process implementing the Life Cycle Analysis (LCA) methodology. The production processes and the products are analysed taking into account their LCA from the raw materials and the intermediate process products, to the final product, the wastes and the emissions generated. Their possible re-utilization and the processes integration are analysed as well in order to minimise the load pollutant. Through the LCA, energy, material requirements and wastes are identified and described quantitatively for each process. Moreover the associated impacts are evaluated and explained identifying the processes with the higher improvement potential. Finally the innovative solutions implemented for the eco-efficient wine production are described and analysed.



**KEYWORDS**

Eco-efficiency, life cycle assessment, wine production, minimisation of emissions, rational energy use, dematerialization, energy management, environmental impact, waste reuse.

## BIOGRAPHICAL NOTES

Alfonso Aranda Usón is Industrial Engineer and Economist from the University of Zaragoza and Master in Industrial Management and New Technologies. From 1998 he works in CIRCE Foundation as Project Manager. He has participated and directed more than 11 R&D projects focused in energy efficiency, renewable energies, life cycle assessment and ecoefficiency. He belongs to the CIRCE Research Group “Life Cycle Assessment and Ecoefficiency”. He teaches in several post-degree courses and coordinates the Specialization Diploma in Renewable Energies "Core Section” of the EUREC Master in Renewable Energies organised with the collaboration of 8 European Universities.

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Law. Sabina Scarpellini is Deputy Director of CIRCE – founded in 1993 (Spain). She gained her professional experiences in the energy sector at CIRCE where she is responsible of several R&D Projects since 1996 as well as University Professor at the Mechanical Engineer Department of the University of Zaragoza. She is a lawyer expert on the liberalisation of electricity sector in Spain and in Europe. She is Author and/or co-author of 12 papers on energy efficiency, she has participated in several international congresses on energy field and she is member of the Power-Gen Europe Committee.

## INTRODUCTION

The European wine sector constitutes a very diversified and dynamic sector in continuous evolution. It represents the first world position with the 45% of the vineyard crops, the 60% of the production and almost the 60% of the wine consumption. Inside the EU, this sector comprises 3.4 million hectares and involves to 1.7 million of wine producers, manufacturing the 6% of the net agricultural production. Traditionally the wine has been elaborated in a sustainable way guaranteeing the minimum environmental impact. However, the current globalisation tendencies have gradually modified the wine production process, increasing the energy and environmental costs.

In order to minimise these costs it is necessary to change the approach to the wine production, as well as to its consumption and the related services. An ecoefficient production implies necessary the optimal materials and energy resources exploitation as well as the minimisation of wastes and emissions. This innovative approach allows us to obtain a more ecological and sustainable production increasing the companies' competitiveness and reducing their production and operation costs as well [1,2]. Therefore the target is to maximise the products and services added value with the minimum resources consumption.

## METHODOLOGY

### SYSTEM BOUNDARY

In order to achieve the minimization of the environmental impacts, the companies' management have to consider a global vision of the whole process, "from the cradle to the grave", so that the resources consumed and the wastes per unit of product were known. This approach involves the use of the Life Cycle Assessment as a new tool for the environmental management in order to achieve a higher degree of ecoefficiency.

The wine function is the final disposition of a bottle of wine in the consumer hands. The environmental aspects are taken into account, excluding the ecology or commercial aspects. The functional unit selected is a bottle of wine. The data used is: 1 kilo of grape after the complete process corresponds to 0.75 litre of wine.

In all processes the electricity production and transport limits are not considered (power plants, thermal plants,...). The wastes generated during the processes are not considered as well: in the majority part of them are implied as raw materials of other processes or as organic fuel. The wine shoot, for instance, are used as biomass for energy production. The stalk resulting form the de-stalker is used as fuel as well or as livestock feed. The pomace and the lees (the tank waste) are used as raw material for vinic alcohol plants.

The follow rules and limits are considered in the analysis:

- Components with weight are more than 1% of the product final weight is considered.
- Components that represent less than 1% of total economical value are not taken into account.
- Phases that contribute less than 1% to the inventory analysis or to the environmental relevance analysis are not considered.

The system limits (processes, manufacture, transport and waste treatment, inputs-outputs to be considered) can be:

- Second order limits: the production phase, the energy flows and the raw materials production are considered for each component.
- Third order limits: Capital goods and the materials production necessary for their elaboration are included.

In the studied system the inventory data used proceeded from the Software “Pré Consultants SimaPro” v. 5. Different data bases have been used, particularly the BUWAL 250, ETH-ESU

96, IDEMAT 2001, Industry data y Methods. The impact assessment method selected is the Eco-indicator´99 H/A.

The above-mentioned indicator gathers the different assessment categories in three categories of damage [4]:

- Harmful damages, according to the lost years and the number of years lived as disabled. These are devised as DALYs (Disability Adjusted Life Years).
- Quality Ecosystem damages, according to the species loose in an area during a time period.
- Resources damages, according to the necessary energy for the future minerals mining and fuels extractions.

INVENTORY DATA

Electricity represents the majority part of the spent energy in these processes. For its assessment, the data base figures of electricity in Spain have been used. It included the energy sources production, inventory and transport, considering an average output of 30% and a 1.8% of looses in the net. Transport and production infrastructures are not included.

The system has been divided in four big sub-systems according to the chronological processes of the wine production [5]. These steps are:

- Planting, growing and the grape harvest.
- Winery processes.
- Transport and distribution to the consumers.
- Final disposition. Bottle recycling.

VINE GROWING

Basic operations in the vine growing are: land preparation, planting, wiring vine in spaliers, cultivation and maintenance of land, irrigation, fertilisation, prune, phytosanitary product application, grape harvest and transport. The three first operations are done once each 50 years for vine growing. The other activities are done in the vineyard yearly for the good growing of the vine. The production for 1 hectare is calculated in 2,760 kilos of grape for crop that grows on irrigated or dry lands.

In the Table 1 are presented the global inputs considered for growing the vine.

PRODUCTION IN WINERY

In order to obtain data that represent faithfully the standard product elaborated in wineries, the average data of wine production have been chosen taking into account the quality and the variety of wine as well. Processes carried out are: samples taking, stalk pressing, sulphuration, alcoholic fermentation, pressing, malolactic fermentation, clarification, stabilisation, filtering and vintage. Materials involved in these processes are shown in Table 2.

As it can be observed in the above table, all elements are process inputs except for fermentation $CO_2$, that is an output. It is originate because, for each mol of sugar, 25 kcal are given off in the chemical reaction. Heats detached in the must fermentation can danger the yeast live. The yeasts develop in the right way only in a little temperature range. The fermentation start is practically impossible under the 13º or 14º Centigrade. It does not evolve correctly up 35º Centigrade and when this temperature is achieved the yeasts activity stop and they can dead.

It is necessary to take into account strictly the temperature at the beginning of the fermentation process if a determinate alcoholic grade has to be obtained. In this case an adequate process conditioning is needed. Table 3 presents the materials involved in the bottling process.

TRANSPORT

In the studied zones, the wine distributed for national consume or for export represents the 68% and the 32% respectively.

For what concerns exports, the final product target Countries basically are: EU Countries (Germany, France, Belgium, Holland, Finland, Sweden, Denmark, United Kingdom, Suisse, Austria….) where are sent by road transport (by 16 and 40 ton truck) and American Countries (United States and different Latin-American Countries) where are sent by sea.
In the by sea exports, the transport of product in containers has been considered, but the port loading and unloading operations are not included. The turn trip and the production and consumption of fuel are considered. Table 4 displays the materials and fuels required for the transportation of a bottle of wine.

## DISPOSAL SCENARIO OF THE BOTTLE

Actually, the 33% of the glass packages used are recycled. The input involves the necessary transport of the bottles to the waste treatment plant and the following transport to the packages production plant, where they will be incorporated as raw material for the production of new packages. There are two possible outputs: the transport of the no recycled packages (67% of the total) to the municipal garbage dump and the recycling of the packages as raw material (33% of the total).
The treatment of waste materials in the municipal garbage dump is considered like an average of the standard practices in several European countries like Denmark, France, Germany, Greece, Ireland, Italy, Luxembourg, Spain, Holland and United Kingdom. These practices are described in different sources, such as Eurostat. [6,7,8]

# RESULTS

## CHARACTERISATION

In the Characterisation, the results of the Inventory table are multiplied by the characterisation factors of the substances included in any of the impact categories. The impact categories are expressed in the same unit of the indicator and are aggregated in damage categories:

- *Human Health*: Cancerigenic, Organic and Inorganic particles breathed, Climatic change, Radiation and Ozone Layer.
- *Ecosystem Quality:* Ecotoxicity, Acidification/Eutrophication and Land Use.
- *Resources*: Minerals and Fossil Fuels.

Figure 1 presents the contribution of the different stages to the total impact: 41% for transport, 32% for growing and 27% for the winery processes, which is the stage with lower relative impact.

Unexpectedly, the stage of winery processes causes the smallest environmental impact and the stage of transport and distribution to the consumer is the most critical stage. If we had prioritised to improve the winery processes we would have not optimised the resources. This is one of the results of the Life Cycle Assessment of a product. Next, the phases of greater environmental impact within each stage are described.

In the vine growing stage, the greater impact is caused by the use of fertilizers and pesticides. The irrigation water has a contribution of 20% in this impact. This percentage could be increased depending on the water pumping height for each area. Hydric needs of 1,000 $m^3$ per hectare, with a yield of 2,750 kg per hectare have been considered. The Figure 2 presents the contribution of each phase to the impact in the vine growing stage.

In the winery processes, the bottling phase, mainly due to the glass use, causes the greatest environmental impact. A composition of the bottle from 78% of green glass and 28% of white glass, as well as the necessary packing to transport the bottles, have been considered to evaluate the impact. The Figure 3 shows the contribution of each phase to the impact in the winery processes stage.

In the distribution and transport stage, although only 32% of the total wine production in the regions studied is exported, the environmental impact supposes the 77% of the total impact, since the distance transport is much greater. Transport by highway within the European continent, and by ship in extra continental transports have been considered. The relative impact of the transport and distribution stages according to the destiny of the product is presented in the Figure 4.

Figure 5 shows the results of the Characterisation.

NORMALISATION

In the Normalisation, the relative contribution of several impact categories is obtained. The results of the characterisation are multiplied by the normalisation factors. The normalisation factors of Eco-Indicator ‘99 are calculated for European countries. Most of them are based on data of 1993, but the most important emissions are updated. The results of the Normalization are described in Figure 6.

VALUATION

In the valuation the total score obtained in the global process is calculated. The valuation factors according to the damage categories are presented in Figure 7.

The transport stage involves the 40.3% of the impacts, mainly in the Fossil Fuels and Inorganic Particles Breathed Categories, because of the diesel oil consumption as fuel for transport. The growing stage represents the 32.3% of the total impact, and the production the 27.6% of the total, mostly due to the energy consumption.

The most significant damage categories are the Human Health and the Resources. The Figure 8 presents the total score according to the impact categories and shows clearly the importance of the transport and production stages in the life cycle of the process. The Figure 9 displays the relative impact of the different subsystems of the process.

The stage of bottles recycling does not have any score, since it does not involve damaging effects to the environment, just the opposite. This happened in the characterisation as it has been presented.

## DISCUSSION. ALTERNATIVE SCENARIOS

As it was exposed in the previous section, the critical stages of the process are the growing and the grape harvest, the bottling, and the transport to the consumer. The economic and environmental improvements in these stages are significant.

### ECOLOGICAL VINE GROWING

Ecological vine growing are the growing techniques that do not use an extraordinary water contribution for irrigation, fertilizers or pesticides unless they were from organic matter. This type of vine growing, without water contribution for irrigation and using natural fertilizers, often from the productive process of the wine in the wineries, was typical in Spain until 80's.

The previous calculations of the environmental impact associated to the irrigation water consider a maximum pumping height of 50 meters. This is an optimistic pumping height, since sometimes it is necessary a pumping height up to 250 meters.

The Figure 10 displays the environmental impact of the alternative scenarios in the growing vine stage. The ordinates axis represents the environmental valuation (in eco-points) according to the Eco-Indicator '99. The column A represents the ecological vine growing, the column B the actual growing techniques, that suppose an economic cost of 0.04€ per bottle, considering a water pumping height of 50 m. Finally, the column C represents some irrigated land that need a water pumping height of 150 m. In this case, the economic cost is increased about 200%.

### TO TRANSPORT THE BULK WINE AND TO BOTTLE IT IN DESTINY

A solution for the transport problem and the intensive use of glass for the bottles is to employ lighter bottles, with less material but the same mechanical resistance. In the brewing sector the weight of the bottles has been reduced progressively to less than half. The Figure 11 shows the environmental impact of the alternative scenarios in the transport and distribution stage. The column A represents the actual way to transport, that supposes an average cost (including exports) of 0.13€ per bottle. The column B presents the results using bottles specially designed in order to use the half of glass. The economic cost is decreased about 23%. The column C presents the impact of transporting the bulk wine (for exports) and bottling in destiny. In this case the economic cost decreases in 38%.

REUSE OF BOTTLES

In Spain, only the 33% of the glass used for packages in the food sector is recycled to be used as raw material for new packages. Although this percentage is increasing, it is still small. The environmental impact would decrease if we were able to reach 70% of recycled glass or the total reuse of the bottles, by means of a population awareness campaign. The Figure 12 displays the environmental impact of the alternative scenarios in the winery processes. The column A presents the results using a 30% of recycled glass as raw material for the new packages; the column B, using a 70% of recycled glass as raw material for the new packages; and the column C, reusing the bottles, considering a 10% of broken bottles during the transport.

## CONCLUSIONS

The final scenario valuated can be used as an example in order to demonstrate that it is possible to reduce the global environmental impact of the wine bottle production in a practical way, reaching a reduction of 52% in this case. The scenarios presented are not the only existing alternatives but they are used as examples. They demonstrate that all reductions of energy or materials consumption can reduce the damaging effects caused in the environment by human activity. In the Figure 13 the proposed alternative scenarios are compared and the assessments using the method “Eco-Indicator ‘99” [10] are evaluated.

In the graph are displayed the environmental impacts produced by the different options analysed in this study. The different options are compared with the initial situation that represents the activity at present and the final increased situation as the result of the selection of the two best and easily implementing alternatives chosen among the different studied options.

The increment of water and phytosanitary products use in the vineyards, the sales increase of wine bottled to the detriment of the bulk wine, the minority use of recycled bottles, the widespread use of industrial cooling equipment in the wineries and the impact associated to the transport due to the bigger commercialisation of wine towards distant countries have increased considerably the energy and raw materials requirements for the whole process.

For these reasons it is necessary to focus the companies' strategies in order to differentiate the high-quality and competitive products in the national and international markets. If we achieved that our wine was a ecoefficient product, considering the plantation of the grapevine, the reuse of the packages or their substitution for lighter ones, the wine commercialisation using new packages, it would be possible to create an eco-label for these products, increasing the competitiveness between the wineries.

As we have explained, the main tool to evaluate the ecoefficiency in the productive processes must be the Life Cycle Assessment of the product. The companie's management have to consider not only the maximum efficiency for a particular process, but rather if this process is absolutely necessary or it can be substituted for a more ecoefficient process.

At present, the market considers the environmental protection as a value more and more. As soon as the wine sector of a Region start to produce using ecoefficiency criteria it will distinguish its competence. Consumers are going to consider the ecoefficiency production and they will appreciate the difference.

## ACKNOWLEDGEMENTS

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**TABLES**

Table 1. Global inputs for growing the vine

| **Element** | **Quantity (kg)** | **Type** |
|---|---|---|
| Fuel | 0.086 | LHV = 42.8 MJ/kg |
| Wire and metallic clips | 0.014 | GX12Cr14(CA15)I |
| Oak stakes | 0.015 | Density = 650 kg/m$^3$ |
| Fertilisations | 0.145 | |
| Phytosanitaries | 0.01 | Pesticides |
| Sulphur | 0.036 | For grape vine blight |
| Irrigation water | 362 | Pumping of 50 metres |

Table 2. Global inputs and outputs for wine production processes

| **Element** | **Quantity (kg)** | **Process** |
|---|---|---|
| $SO_2$ | 0.013 | Sulphuration |
| Water process | 3 | Various |
| Phenol | 0.014 | Clarification |
| Electricity (kWh) | 0.1507 | Various |
| Fuel | 0.0141 | Air conditioning |
| $CO_2$ | 0.097 | Output fermentation |

Table 3. Global inputs for bottling

| **Element** | **Quantity (kg)** | **Type** |
|---|---|---|
| Green glass | 0.43 | Red wine |
| White glass | 0.12 | White or rosé wine |
| Pellet wood | 0.015 | Pine wood |
| Wrapping paper | 0.0125 | Corrugated cardboard |
| Water | 0.6 | Drinkable |
| Electricity (kWh) | 0.011 | |

Table 4. Transport means used and necessary fuel quantities. Source: BUWAL 250
(*) tkm: tons transported per kilometre covered.

| Transport | Unit (tkm)* | Load (%) | Diesel (kg) | Heavy Fuel-oil (kg) |
|---|---|---|---|---|
| **Truck 16 ton** | 0.7 | 50 | 0.0635 | 0 |
| **Truck 40 ton** | 2.7 | 50 | 0.0259 | 0 |
| **Ship** | 18.02 | 100 | 0.00055 | 0.0337 |

**FIGURE CAPTIONS**

Figure 1. Contribution of the different stages to the total impact.

Figure 2. Contribution of each phase to the impact in the growing vine stage.

Figure 3. Contribution of each phase to the impact in the winery processes stage.

Figure 4. Relative impact of the transport and distribution stage according to the destiny of the product.

Figure 5. Results of the Characterisation.

Figure 6. Results of the Normalisation.

Figure 7. Results of the Evaluation (I): Valuation factors according to the damage categories.

Figure 8. Results of the Evaluation (II): Total score according to the impact categories.

Figure 9. Relative impact of the different subsystems of the process.

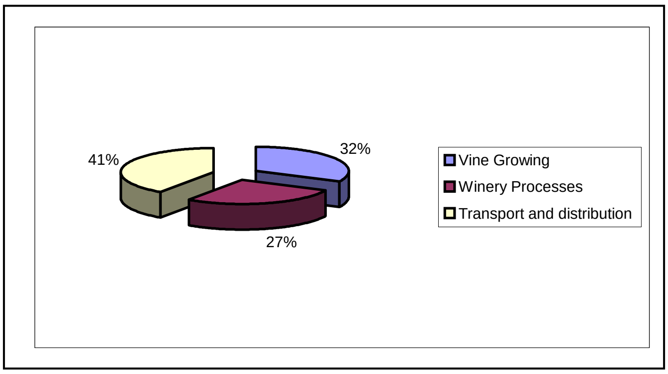
Figure 10. Environmental impact (in mPt) of the alternative scenarios in the growing vine stage.

Figure 11. Environmental impact (in mPt) of the alternative scenarios in the transport and distribution stage.

Figure 12. Environmental impact (in mPt) of the alternative scenarios in the winery processes.

Figure 13. Comparation (in mPt) between proposed alternative scenarios.

# FIGURES

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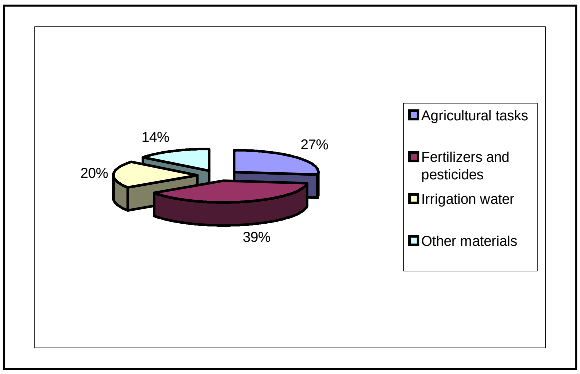


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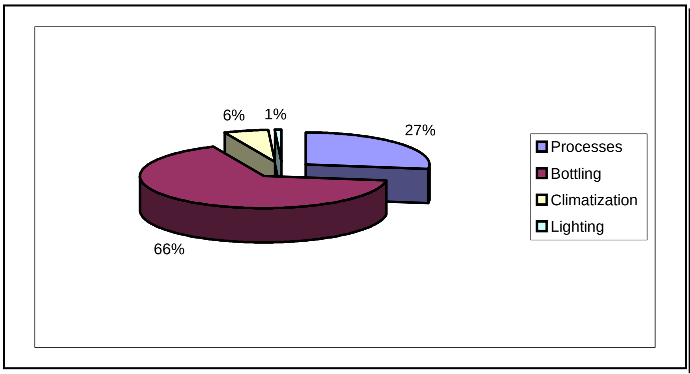


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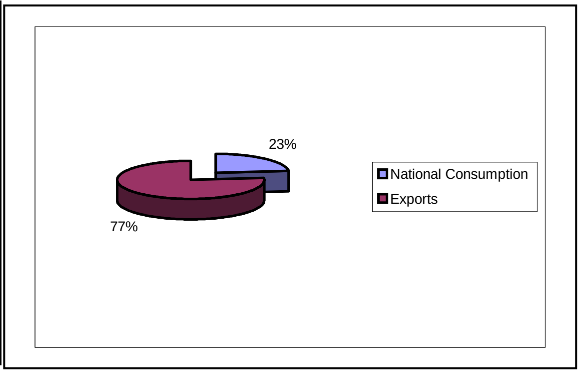


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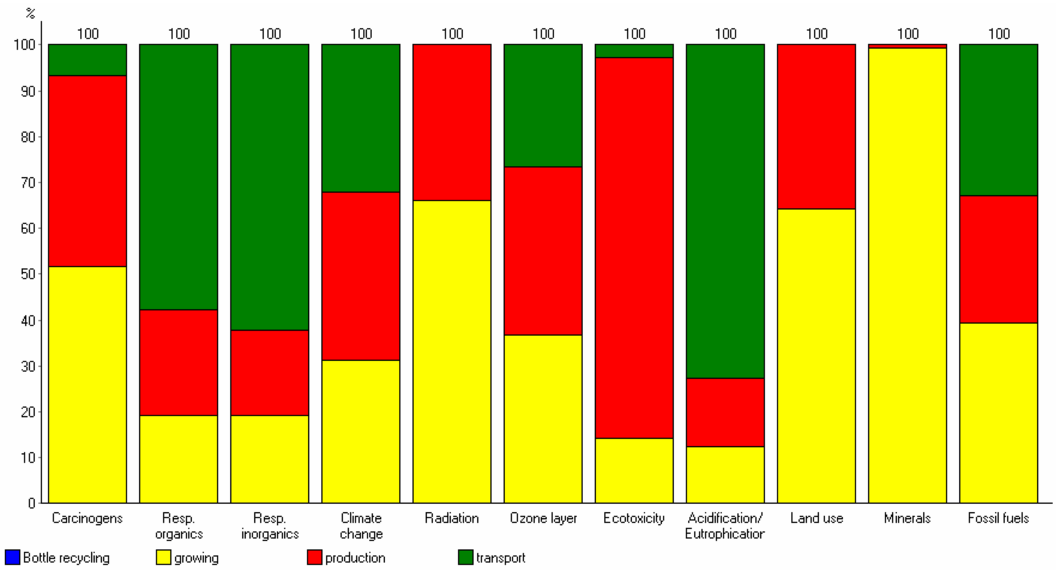


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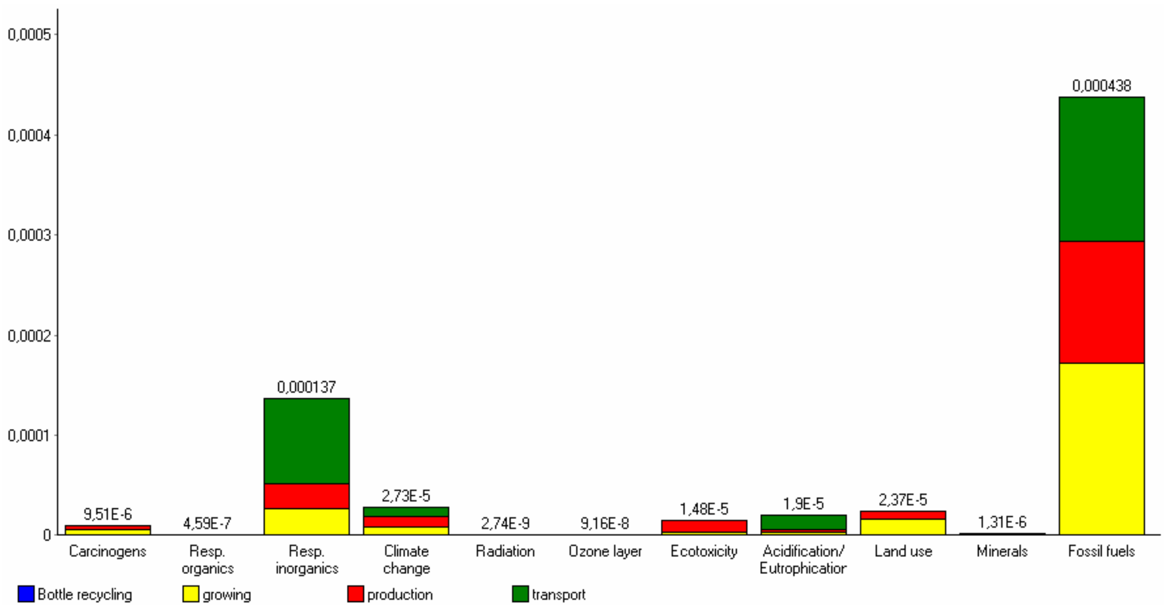


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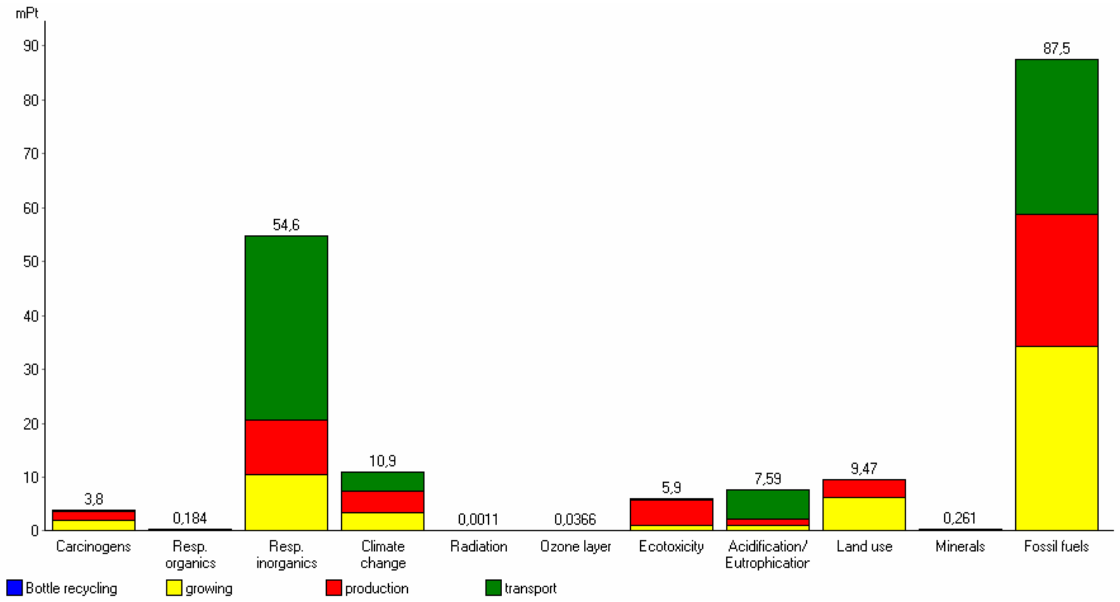


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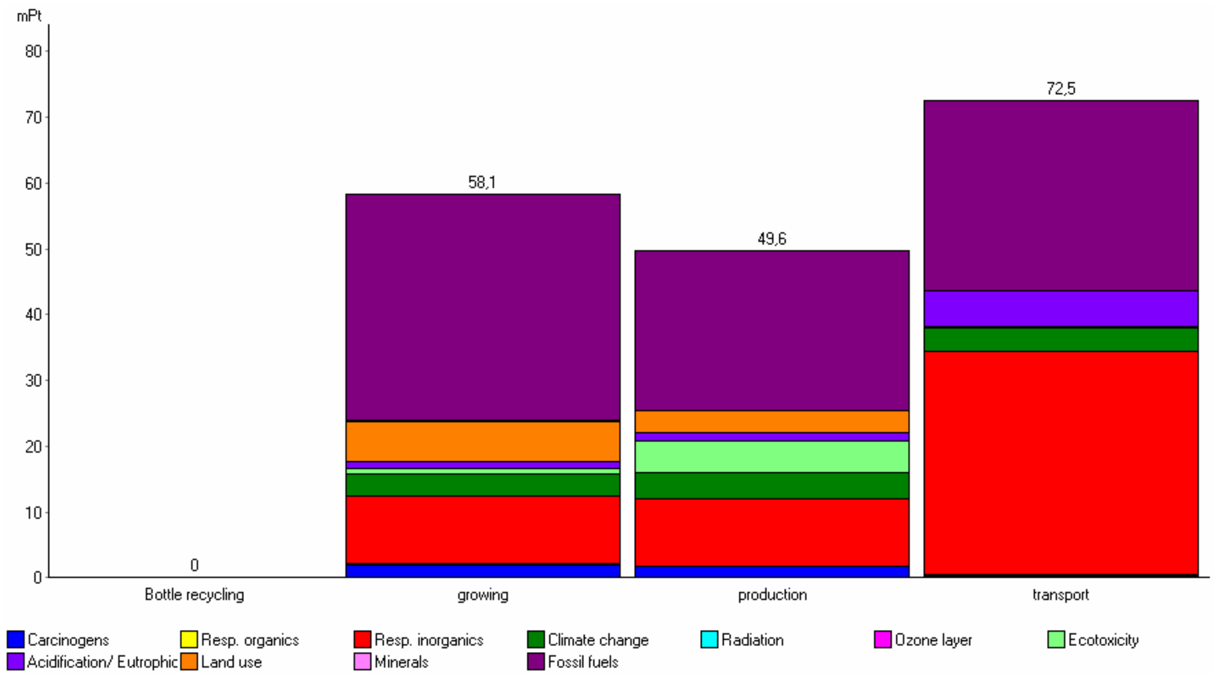


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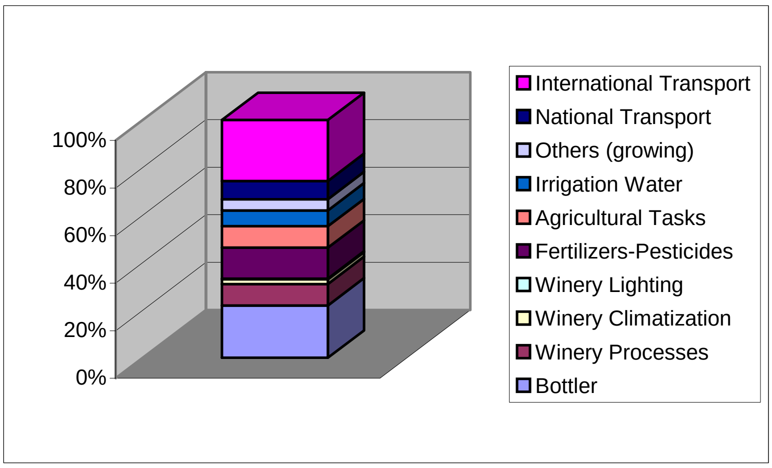


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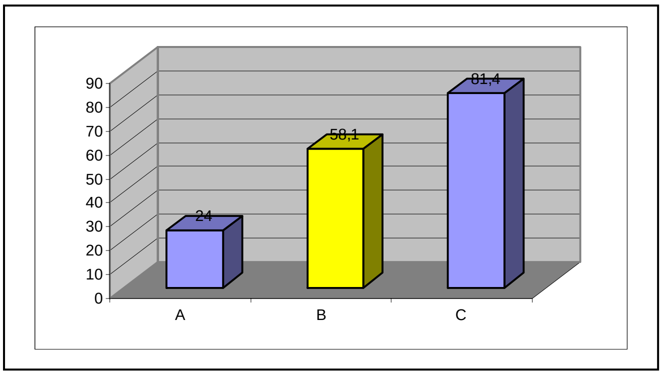


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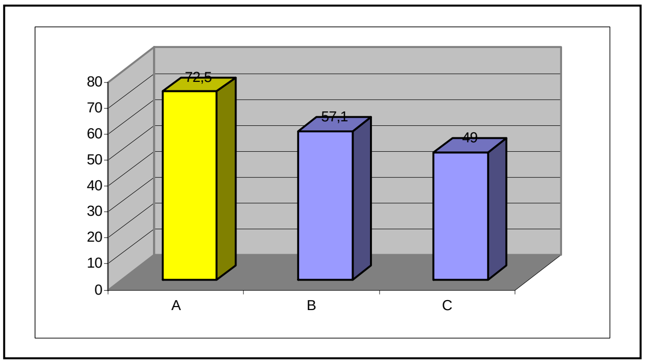


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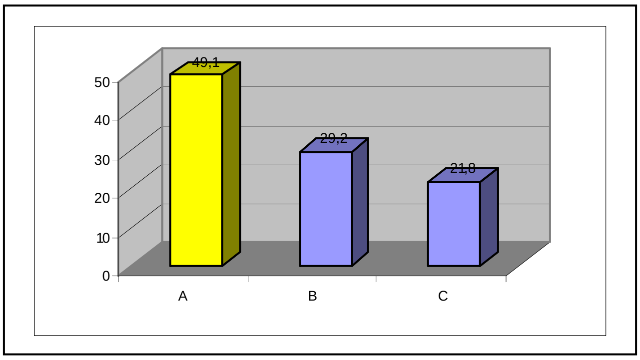


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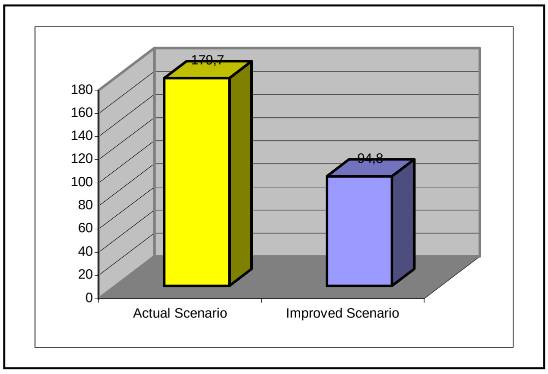


Figure 13.