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A sustainable innovation in the Italian glass production: LCA and Eco-Care matrix evaluation

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ABSTRACT

The world glass containers production in 2015 reached 50.63 million of tonnes (MT), and is estimated to grow by 2022, achieving 65.42 MT. In Italy in 2016 the production was 4.6 MT, by registering an increment of 3.2% compared with 2015. The glass transformation process occurs in high temperature ovens, where the fusion stage takes place. The life cycle of this commodity is correlated to the exploitation of natural resources, as well as to the emissions of different greenhouse gases (GHG), that have negative effects on natural environment system. In order to decrease the negative environmental impact of the glass industry we analyse the combination of recycling methods and process innovation applications in an Italian company. We reported an environmental and cost analysis of a process innovation implemented by a company operating in the hollow glass sector in Italy: we scientifically demonstrated that important results in energy savings could be reached by the implementation of the aspiration system and the re-use of the hot air produced by the furnace. In this research study we demonstrate that energy savings can be achieved: The results have been reported according the Life Cycle Assessment (LCA) methodology, by using the software Simapro 7.1 and the database ReCiPe 1.07 (2012). The relationship between cost efficiency, environmental and social benefits have been displayed in the Eco-Care matrix (ECM), in order to graphically quantify the benefits of a low cost process innovation. The study wants to demonstrate that the innovation is efficient in economics, social and environmental perspective, and it could represent a benefit for the companies operating in the glass industry.

1. Introduction

Since 1970 the consumption of materials and the extraction per capita increased from 7 to 10 tonnes (t) in the last 40 years (EU, 2016). This rate indicates a growing demand of natural resources and the necessity to adopt specific measures that support the reuse of materials, improve the quality and the environmental and safety standards, and increase the lifespan of the final products. The possibility to repair, remanufacture or recycle a product and its components and materials depends in large part on the initial design of products. It is therefore crucial that these aspects are taken into account when investigating possible eco-design implementing measures. The eco-design focuses on actions aimed at environmental empowerment of products during the initial design phase through functional enhancements: selection of materials with lower impact, application of alternative processes and technology, improvement of transportation ad use, and minimisation of impact during the end-treatment stage.

Another important mechanism that can be compared to the eco-design in terms of importance and relevance is the possibility to recycle materials with the aim of mitigating the loss of natural resources giving to the sustainability another significance (Fernandez-García et al., 2015). In this way we can abandone the logic of linear production systems, and facilitate the transition from a linear production system to a circular production system. The circular production system generates the circular economy paradigm (Mathews and Tan, 2011), defined as an open production system in which waste are reuse as resources (Preston, 2012), emphasizing the focus on the entire life cycle of a product. A change in the economy vision, could bring to the mitigation of negative economic effects through the creation of new businesses and new jobs, stimulating the transformation process of the old linear production systems, generating environmental benefits. This more responsible approach can be integrated in the processes of

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"decision making" business through Life Cycle Assessment (LCA) methodology (Johnson et al., 2013). LCA is a procedure for evaluating the environmental effects/impacts of each stage of a product or a service over the entire productive cycle (from raw material extraction through materials processing, manufacture, distribution, use, repair and maintenance, and disposal or recycling). The LCA methodology accounts different indexes such as economic, environmental and social variables in order to define an accurate analysis of the system analysed in relation with specific impact categories. The mechanism purposes to improve recycling process and integrate the phases in the life cycle of a product, from production and consumption to waste management and secondary raw materials market, such as plastics, food waste, critical raw materials, construction and demolition, biomass and bio-based products. LCA is based on the analysis and determination of quantitative variables associated with products, systems and services processed by mathematical equations, composed by data that describe the life cycle. This methodology permits to quantify the energy and materials used (input) and the wastes released in the environment (output), in order to evaluate tangible opportunities to reduce the environmental negative output (Koci and Trecakova, 2011). The study through the LCA method, allows to compare the production of goods by analysing the amount of first raw materials requests or the amount of CO_2 emissions (Hertwich, 2005). Currently, requests from market have changed, consumers no longer ask for products or services, but also evaluate the environmental impacts. One of the areas in which this greater sensitivity to environmental impacts is most emphasized is in the packaging sector, where the waste produced are closely related to the growing food demand in perspective of world population increase.

By considering the food chain, glass packaging accounts for the 40% of total world packaging production, but its environmental impact is equal to 45%, varying on the type of food and beverage packed and the type of packaging used (Schenck and Huizenga, 2014). Glass is one of the most used materials for packaging foods and beverages, and offers advantages as the perfect preservation of foods and the ability to be recycled many times that allows the reintegration into the production cycle as secondary raw material.

In this study, we used the quantitative method for assessing the LCA of a company that produces glass-packaging bottles by analysing the process innovation and the optimization of production cycle (Auer et al., 2017). In the paper, we have used Simapro software 7.1 for the calculation of specified environmental, economic and social indexes, by mathematical processing of data describing the life cycle.

2. Glass industry in Italy

The Italian glass industry presented in 2015 a production equal to 5,243,733 t, by registering a reduction of 1% compared to the previous year 2014, where the production accounted 5,296,134 t. In 2016 the Italian glass industry achieved a yearly income equal to € 6.3 billion, with 4130 national companies operating in the sector and including 40,000 employees. As shown in Table 1, the industry can be subdivided into different categories, according to the final products allocation on the market.

Specifically, concerning the hollow glass category, object of our sector study, the total national production for the year 2015 was equal to 3.79 megatonnes (Mt). Because the industry is relevant as transformation and production process on the Italian scenario (AlQdah, 2013), we want to deeply investigate on this sector in order to demonstrate how a simple innovation can improve the quality of the final product as well as the quality of our environment in terms of energy demand reduction and total emissions released in the atmosphere (Jorgelina Pasqualino et al., 2011). To better understand the most relevant elements that can be included in our research we distinguish three sub-categories of glass products: bottles (3,070,637 t), flacons (141,042 t) and food tanks (233,623 t). The Italian legislation supports the recycling process of this material by different law procedures that contribute to the implementation of the circular economy system, promoted also by the European Union. According to the Italian legislation decree (D.Lgs. 152/06) the minimum amount of recycled glass is 60%, but in 2015 the recycling rate was equal to 70.9% and previsions show that in 2018 the total amount of recycle rate would achieve 75.1%. Moreover, in the Italian system, we can distinguish two different modalities of glass recycling: *consortium management* and *independent management*.

The *consortium management* system deals with the national consortium (CO.RE.VE., 2016) operating through the D.Lgs. 22/97 for the glass packaging waste collection, recycling and recovery produced on national territory. The consortium can operate in three different modalities: signing conventions and agreements directly with the municipality or with a delegate managing authority (awarded conventions); signing conventions and agreements between a glassmaker and a municipality (assigned conventions); signing conventions and agreement between the glassmaker and the treatment agent, and between the treatment agent and the municipality (GTM).

Differently, the *independent management* system consists in different agents on the market that independently from the national consortium purchase packaging glass waste (Sleeswijk et al., 2008).

The Italian glass chain in 2015 contributed to the recycle of 84% of glass packaging, accounting an increase of 5%, compared to the results of 2014. In Fig. 1 is represented the national glass recycling rate per origin, and the glass from packaging is the most important category, underlying the importance of recycling processes in Italy (Papong et al., 2014).

We focus our attention on this important industry because scientific evidence demonstrate that glass production is characterized by high energy consumption, related namely to the fusion process

Table 1
Glass industry sub-categories. (Source: Join Research Centre, Best Available Techniques (BAT) Reference Document for the Manufacture of Glass, Industrial Emissions Directive 2010/75/EU).

Glass industry sub-categories	Products
Hollow glass	bottles and containers for beverages and food
Float glass	materials for construction and car industry
Continuous filament glass	fiber reinforcement for composite materials (textile, plastics, electronics)
Glass for domestic usage	articles for tables and furniture
Special glass	borosilicate glass for pharmaceutical usage, lighting, television screens, lead crystal
Glass and stone wool	heat and acoustic isolation fibres
Ceramic fibres	heat and high temperature isolation materials
Glass powder	upholstery material for ceramics, tiles and for decoration on glass

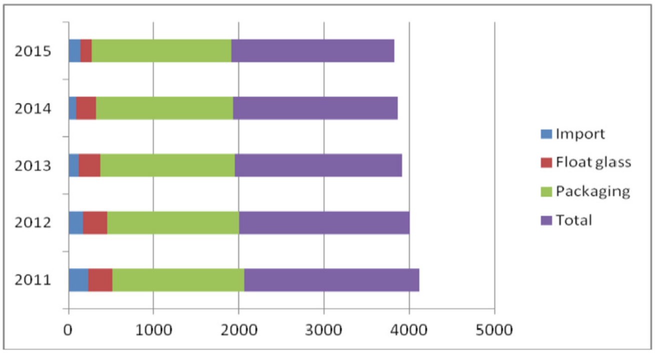


Fig. 1. Quantity of recycle glass (kt) in the Italian industry per origin (2011–2015). Source: Assovetro, 2015

that absorb between 50% and 80% of energy total demand. Glass is obtained by the homogeneous minerals blend of namely three components, calcium carbonate ($CaCO_3$), silicon dioxide (SiO_2) and sodium carbonate (Na_2CO_3). Consequently, the most relevant emissions during the production process are related to the CO_2 component, accounting between 500 and 1400 kg CO_2/t, depending on the glass final product. The emissions in the atmosphere represent the main source of pollution connected to the sector. According to the Joint Research Centre and reported also into the Industrial Emissions Directive 2010/75/EU, excluding the CO_2 amount of emissions, the atmospheric composition related to the glass production are represented by:

- NO_X: 50–80%;
- SO_X: 24–40%;
- Total ashes: 4–6%;
- Gaseous chlorides: 1%;
- Gaseous fluorides: 0.2%.

The usage of glass scraps as secondary raw material (SRM) permits to obtain considerable savings, in terms of raw materials, energy and emissions. In fact, the relation between scrap glass and glass per kg of product is 1:1, while the rate becomes 1:1.2 per kg for the reuse of raw materials such as sodium carbonate, sand, limestone, calcium and magnesium carbonate (dolomite), feldspar. The reduction in the usage of raw materials such as $CaCO_3$, Na_2CO_3 and dolomite can be expressed also in quantity of CO_2 emission saved from the decomposition of carbonates contained in the traditional vitrified blend. This quantity has been calculated equal to 452,567t in 2015. In Table 2 is represented the raw materials savings derived by the recycling process, national and from the import.

The total energy savings for the year 2015 were equal to 2061 Gigawatt/hour (GWh) corresponding to 176,481t of oil equivalent (TOE). By considering that the energy consumption for the extraction and the process production depends on the specific site of extraction and production, the direct energy savings related to the employment of glass scraps for the year 2015 were equal to 1300 GWh, equivalent to 111,300 TOE. In fact, according to our calculation, the energy savings is equal to 2.5% each 10% of glass scraps added to the blend. The total energy savings (direct and indirect) amount to 6693.3 GWh per year, equal to 287,781 TOE (Table 3).

3. Methods and tools

3.1. Study design

This research wants to evaluate quantitatively the benefits connected to the introduction of an innovation process in an Italian company operating in the hollow glass industry that recycle the air for producing more efficient products in terms of sustainability of process. The study is based on the comparison between two different system scenarios, the first one is the traditional production process system (System A), where the production system does not recycle the heated air from the end-port furnace; and the second one is the innovative production system (System B), where the heated air is recycled and used in the furnace. In order to evaluate the differences of the two systems in terms of economic, environmental and social costs we applied the LCA methodology (Falkenstein et al., 2010), comparing the performances and impacts of the two systems concerning the aspiration of heated air and its re-use after the rejection from the end-port furnace (Fig. 2). The performance data, cost saving and greenhouse gas emission, were calculated directly from the industry in the period 2013–2016.

The results have been identified, demonstrated and processed in a matrix (ECM), in order to show and compare the environmental, social and economic benefits of the two Systems. The study has been conducted through the standards of environmental management ISO 14040/14044 (International Organization for Standardization, 2015) and LCA (Woodward, 1997); data refer to the period 2013–2016.

3.2. Manufacturing system

Fig. 3 shows the production system of glass containers before the process innovation (Trifonova and Ishun'kina, 2007), while Fig. 4 represents the process innovation in the company. For the hollow glass production, it is necessary an end-port furnace. In an end-port furnace, the air from the outside is preheated through the passage in a chamber filled with refractory elements (vessels, cruciform, etc.), arranged in a honeycomb. This type of furnace owns two chambers: the first one in which the air is channelled and preheated; the second one, where the hot air expelled from the furnace is reused for heating the reticulated honeycomb brick. In order to implement System B, a new aspirator from the furnace's ceiling has been built, with the aim of canalizing the heated air to the heating rooms at the start of the furnace. This innovation is simple and innovative especially because melting glass process necessitates oxygen and all toxic substances from combustion would remain trapped in the oven. The oven is heated through a series of nozzles from which protrude flame fuelled by methane and fuel. The calorific value can be increased also through the use of

Table 2
Raw materials savings tons per year (t/y) (Source: data organized by the authors of the documents according the association *Assovetro* www.assovetro.it).

Category	Sand	Soda	Marble	Dolomite	Feldspar	Other	Total
no packaging national collection	130,644	20,804	18,921	9209	3031	2846	**185,455**
packaging national collection	1.220,12	350,859	222,736	108,412	35,677	33,509	**1.971,32**
import	103,028	29,627	18,808	9154	3013	2,83	**166,46**
companies internal recycle	459,694	132,19	83,918	40,845	13,442	12,625	**742,714**
Total	**1.913,49**	**533,48**	**344,383**	**167,62**	**55,163**	**51,81**	**3065,945**

Table 3
Direct and indirect energy savings (GWh, TOE) in 2015 (Source: data organized by the authors of the documents according the association *Assovetro* www.assovetro.it).

Category	Indirect energy savings (GWh)	Direct energy savings (GWh)	Indirect energy savings (TOE)	Direct energy savings (TOE)
no-packaging national collection	139.8	71.1	12,021	6115
packaging national collection	1153.6	837.1	99,195	71,985
import	138.9	70.6	11,949	6078
companies internal recycle	620.0	315.4	53,316	27,121
Total glass recycled	2052.4	1294.4	176,481	111,300
Total energy savings	**6693.3**		**575,561**	

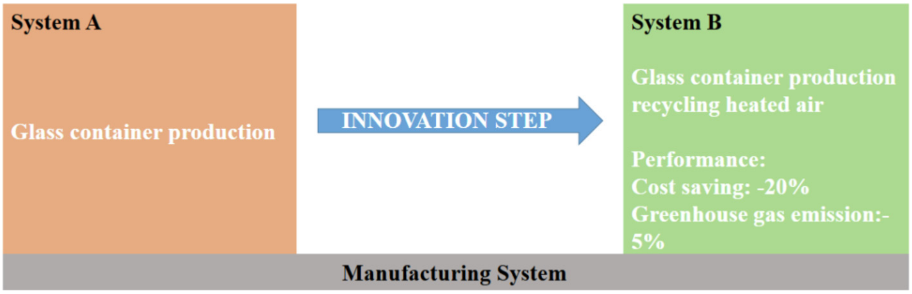


Fig. 2. Benefits deriving by process innovation.

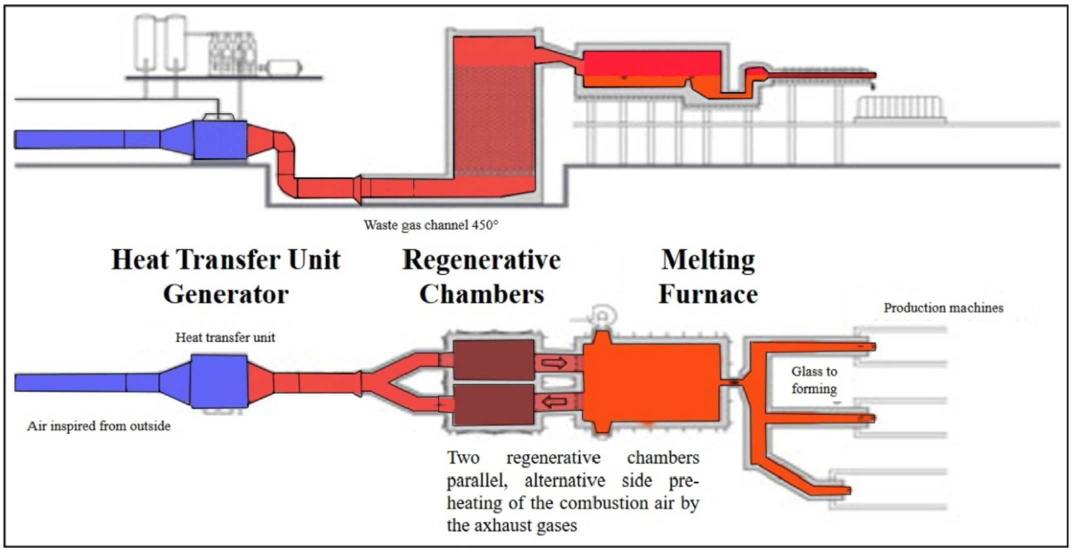


Fig. 3. Representation of the production cycle of glass container manufacturing. The batch is melted in the melting furnace. The glass gobs are distributed in the molds through the compressed air flows to shape the container.

electrical equipment, called electrodes, which allow greater thermal uniformity of the glass.

The innovation of the system we analysed is the processing of the hot air the company extract for the reuse: the hot air to be sucked out comes from the melting process inside the oven (Fig. 4). Air intake is through the construction of a steel pipe. The aspirator's mouth is placed on the ceiling of the oven, so as not to disperse the heat generated by the combustion. The aspirator conveys hot air directly into the pre-heating chambers of the air aspirated from the outside. Recycled hot air extracted from the oven saves the gas to heat the air to be fed into the oven (Lòpez-Gamero et al., 2010).

The oven temperature is around 1500 °C; at this temperature it is possible to merge all raw materials. Burners flames across the combustion and melting area until the end of the furnace, combustion gases come out of the oven through the drainage ports located on the oven walls. The gases and fumes coming out of the furnace combustion area are aspirated inside the electro-filter in which the SOx and dust reduction is achieved below the permissible limits. In addition to the flames released by the burners, the output heat can also be increased by the use of electrical equipment, called electrodes that allow greater thermal uniformity of the glass. By utilizing the convective motion generated by the boosting system, better homogenization of the glass is achieved and the melted glass bath refinement helps to improve the quality of the glass (Manfredi and Vignali, 2014).

The molten material cannot be transported and worked at the melting temperature because it would be too liquid, so, once it comes out of the combustion chamber it passes through the oven's throat and then for the conditioning channel. The passage in the conditioning channel is crucial cause it allows to the liquid glass

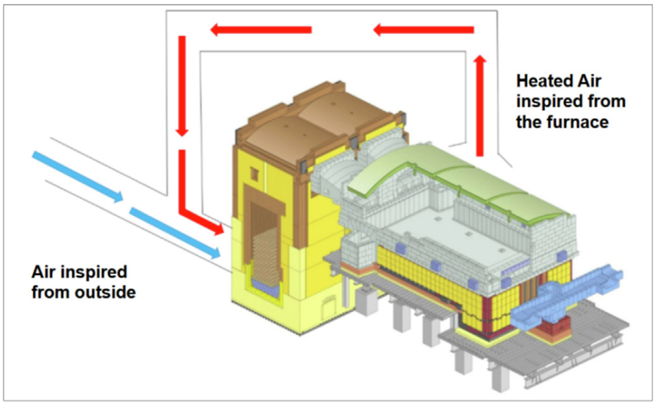


Fig. 4. Depiction of hot air exchange process - cold air into the furnace.

temperature to drop to 1300 °C.

For this purpose, burner ramps for heating are installed on the sides of the air conditioning channels, and there are adjustable openings for cooling on the turn of the burners.

The incandescent glass drop (approx. 1200 °C) reaches the mold of the forming machine by vertical drop. At the output of the air conditioning channels specific equipment, called feeders, produce molten glass drops that are delivered to the machines (Vellini and Savioli, 2009).

These drops are transferred to cast iron molds by means of special drop guides, and for the combined effect of vacuum and compressed air, the container is created.

The glass containers then undergo a surface treatment to improve mechanical strength: it is necessary to proceed with annealing which consists of a heating up to 550 °C and a slow cooling to room temperature (Pulselli et al., 2009).

Containers are transported to the annealing galleries. The tunnels are equipped with methane burners controlled by a series of electronic regulators that allow the creation of a recoil curve of the containers.

After the annealing treatment, the containers pass to the defect control systems; all discarded containers are reintroduced into the oven as internally recycled glass scrap.

After automatic checks, it is passed to palletising and shrinkage machines; finally, packed containers are transported to the finished product warehouse. For this purpose, we want to demonstrate how this innovation technology related to the reuse of hot hair can improve many variables related to economic, social and environmental aspects (Simon et al., 2016).

3.3. *Life Cycle Assessment (LCA)*

3.3.1. *Goal and scope definition*

The case study leads the purpose to identify the following factors:

a) Life cycle steps in which there are effects on the environment and the economy.
b) Environmental impact derived by components of the entire system.
c) Production differences between “System A″ and “System B″

Results deriving by the comparison between System A and System B have been quantitatively evaluated trough the LCA methodology (Del Borghi et al., 2014).

For the case study, the manufactured numbers of glass containers in a certain time frame has been defined as the functional unit to analyse the environmental impacts. The numbers of glass container manufactured is 70,000 tonnes (t) per year. Method of performance assessment are listed in Table 4.

3.3.2. *Life cycle inventory (LCI) analysis*

The Life Cycle Inventory (LCI) is the first stage of the LCA, regarding the collection of data and information, analysis and validation of data, by defining and studying the exact amount of input and output derived from the system studied. In this section is represented the data collected of our case study in a standard situation, without the innovative installation in use. The results are based on the historical records obtained from the company object of our research study. In Table 5 are represented the detailed input and the output of the company production system (scenario A). Starting from scenario A, it was possible to assess effects by process innovation application of scenario B. We derived the estimation of the CO_2 emissions on the base of the database we used for our application (Simapro 7.1).

3.3.3. *Life cycle costing (LCC)*

The LCC is a valuation method that determines the overall cost of products and services, considering its entire life cycle (International Standard Organization, 2006a,b). The analysis permits to determine the cost drivers and understand the potential cost savings that can be applied in a system thanks to innovations of materials, processes or products, especially if different alternatives are compared and the cost-effective option can be derived (Lindahl et al., 2014).

In the LCC definition methodology, the overall cost is considered with the aim of assisting the decision makers in the choices regarding modification of some variables in the Life Cycle of specific products or services, for determining the most cost-efficiency and competitive solutions for the production process.

3.3.4. *Life cycle impact assessment (LCIA)*

The life cycle impact assessment phase (LCIA) provided us the information to interpret the environmental significance of the comparison between our different situations analysed (Goedkoop and Spriensma, 2000). In this phase, the environmental effects are quantified as consequences of physical interaction between the production system studied and the environment. We choose our indexes according to the model we implemented in the programme *Simapro 7.1.* We choose the following impact categories that we analyse in section 4.2.:

- Climate change ecosystem;
- Climate change human health;
- Fossil depletion;
- Fresh water eutrophication;
- Human toxicity;
- Ionising radiation;
- Metal depletion;
- Natural land transformation;
- Ozone depletion;
- Particulate matter formation;
- Photochemical oxidant formation;
- Terrestrial acidification;
- Terrestrial ecotoxicity;
- Urban land occupation.

The categories have been chosen for the strong relationship between electricity demand and environmental outputs linked to the systems.

Table 4
Summarization of the performance assessment method.

Scope of LCA	System A	System B
Manufacturing/construction stage	End-port furnace production system data	End-port furnace production system data with the new component
Use stage	Measurement: performance data from Simapro 7.1	Measurement: performance data from Simapro 7.1
End of life stage	Approximated, based on assessment of key components	Approximated, based on assessment of key components

Table 5
LCI analysis, input and output estimation for glass bottles annual production.

Input of production (unit)	System A	System B
Water consumed (m^3)	498,960	498,960
Energy consumed (Gj)	496,586	381,337
- Methane	484,586	372,122
- Electricity	12,000	9215
Waste (Kg)	98,000	98,000
- disposed	80,000	80,000
- recycled	18,000	18,000
Atmospheric CO_2 emissions released (Kg)	466,620	358,325

3.4. *Eco-Care-matrix*

The Eco-Care-Matrix (ECM) is a tool that is applied in Portfolio Management Process (PMP) to support product portfolio decisions, as well as in research and development process (R&D) to help with product design selection. In 2005 has been described by Ehrenfeld and associated with Eco-efficiency; in 2007 has been applied by Huppes and Ishikawa. Only in recent years the ECM has been applied in the environmental portfolio for product lifecycle management, in order to graphically visualize the eco-efficiency of models in a system of *x* and *y axis*, where are represented the economic benefits and the environmental benefits respectively. In fact, the matrix is composed by variables derived from LCC and LCA calculations; in this model, the zero point is represented by the traditional system using traditional technology, while the innovative system is located in the matrix according to the environmental benefits in terms of output reduction and economics benefit for consumers in terms of health performances. In Fig. 5 are represented different combinations of environmental benefits and consumer benefit, in order to understand the graphical construction. The application of ECM is useful for understanding the convenience of products and services development that contribute in a reduction of environmental and economic costs. The position assumed by the point in the graphic can be considered as "*greener solution*" if the environmental performance is better performed at the same level of consumer satisfaction in the comparison. Furthermore, the application as well as the interpretation of the results is consistent only if the definitions of limits, data sources and assumption is the same used for the LCC and the LCA study (Jolliet et al., 2003).

4. Results and discussion

Life cycle interpretation is the final phase of the LCA procedure, in which the results of LCI and LCIA are summarized and discussed as starting point for conclusions, recommendations and decision-making, in accordance with the goal and scope definition.

4.1. *Life cycle costing (LCC)*

In this phase, costs were derived using a cost breakdown structure summarized in Fig. 6. Our data were calculated according to specific and direct investigations and observations before and after the technology installation in the company. We want to demonstrate the evidence that in terms of costs the system where the innovation is installed demonstrate effective reduction of economic and environmental costs. System B results more efficient in terms of energy expenditures and in one year the total savings of this system compared to System A are equal to 1,692,942.21. In Fig. 6 is represented the comparison of LCC of the two systems, by showing the corresponding cash value over the lifespan considered as one year.

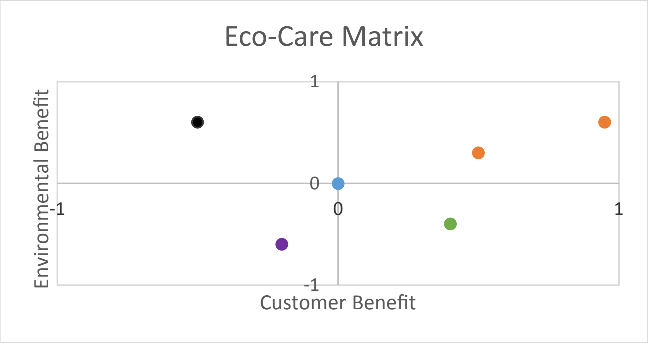
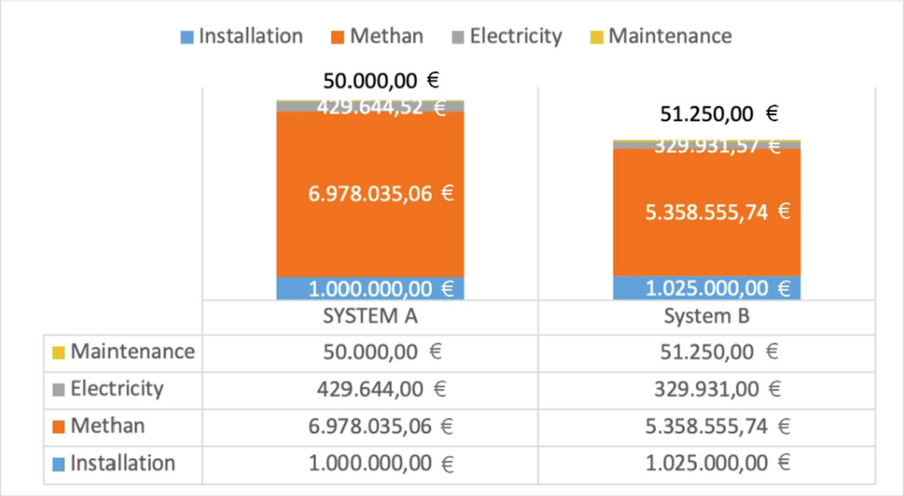


Fig. 5. Eco-care matrix sample.

4.2. *LCIA and Eco-Care matrix*

4.2.1. *Impact category: classification, characterization, normalization and weighting*

For the calculation of the environmental and social impact of production, impact categories have been defined and chosen. The environmental variables were calculated by using *Simapro 7.1* software for both System A and System B, in order to compare the results before and after the process innovation installation. The most significant variables for studying the environmental profile of each category have been selected and the percentage of variation for each impact category have been calculated with the aim of ordering and estimating the variables that impact largely on the systems considered (Guinee, 2002). Only the impact categories with a variation higher that 2% have been considered, for both the environmental and the economic group. In Table 6 are shown the results obtained from the conversion of relevant characterization factors of each impact category with the LCIA results. The normalization phase allows to understand the order of magnitude of each indicator, giving information on the significance of indicators. Usually in LCI and LCIA the functional units are expressed as fractions of a well-defined contribution of a given community over a given period time, then the normalization is an optional step (ISO, 2000; Grant et al., 2001). In this study, the number of glass bottles produced in one year was not increased and consequently, the indicators are not being normalized. The impact categories chosen were expressed in three different units (DALY, species/year and €), and the indicators with the same unit are considered in the same category. Moreover, to reflect the relative importance of the chosen categories, each indicator was weighted. According to the literature, there are many methods for weighting the indicators (Ahmadi and Barna, 2015; Komly et al., 2012). In this research, is



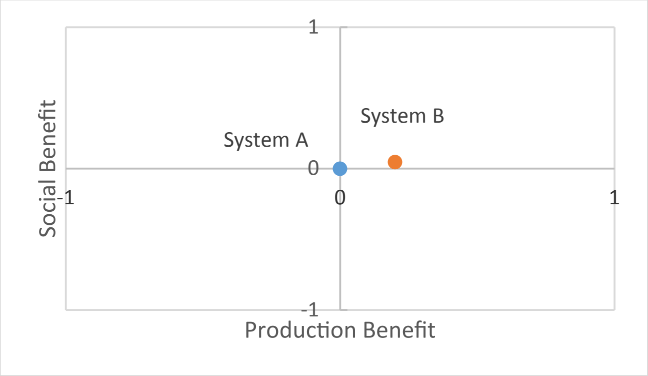


Fig. 6. LCC cash value comparison between the two systems.

apply the following methodology for the calculation (1), where each indicator was weighted by multiplying its value for its percentage variation. The coefficient was calculated as follows:

$$W_i = \frac{CV_i}{\sum_i^n CV_i} \tag{1}$$

In the formula, W_i is the weight coefficient and CV_i is the percentage of variation of each impact categories.

Only the impact categories up to 2% of variation were considered in this study. For environment aspects were climate change, terrestrial acidification and natural and transformation; for social aspects were climate change, ozone depletion and photochemical oxidant formation; for economic ones were investment, electricity, methane and maintenance. In these categories System B appear to have minor impact, compared to System A, in all the sustainability

Table 6
Impact factor categories differences and variation (* *impact categories considered for the calculation*).

Impact categories	System A	System B	Δ%
ENVIRONMENT			
Agricultural land occupation (species/yr)	0.2116	0.2115	0.05
Climate change ecosystem * (species/yr)	0.7484	0.7126	4.78
Urban land occupation (species/yr)	0.0133	0.0133	0
Terrestrial acidficiation * (species/yr)	0.003	0.0029	3.33
Natural and transformation * (species/yr)	0.0453	0.0441	2.65
Human toxicity (species/yr)	73.358	73.227	0.18
Terrestrial ecotoxicity (species/yr)	0.003	0.003	0
SOCIAL			
Particulate matter formation (DALY)	414.216	409.406	1.16
Climate change human health * (DALY)	1,321,323	1,258,221	4.78
Ozone depletion * (DALY)	0.0304	0.0288	5.26
Fresh water eutrophication (DALY)	0.0001	0.0001	0
Photochemical oxidant formation * (DALY)	0.0122	0.0119	2.46
Ionising radiation (DALY)	0.1807	0.1804	0.17
ECONOMIC			
Metal depletion (€)	8.377	8.353	0.29
Fossil depletion (€)	5.963	5.933	0,5
Investment * (€)	1,000,000	1,025,000	2.5
Electricity * (€)	429,644	329,931	23.21
Methane * (€)	6,978,035	5,358,555	23.21
Maintenance * (€)	50,000	51,250	2.5

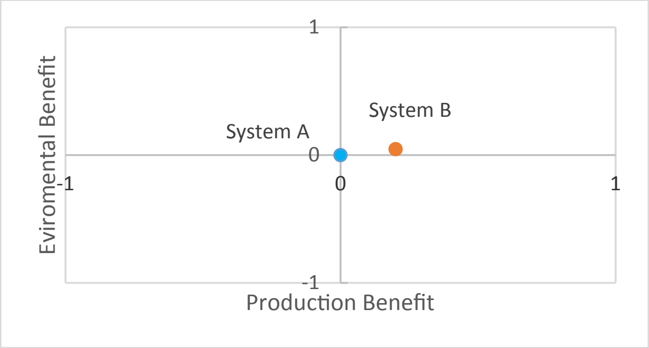


Fig. 7. ECM Social and Economic dimension.

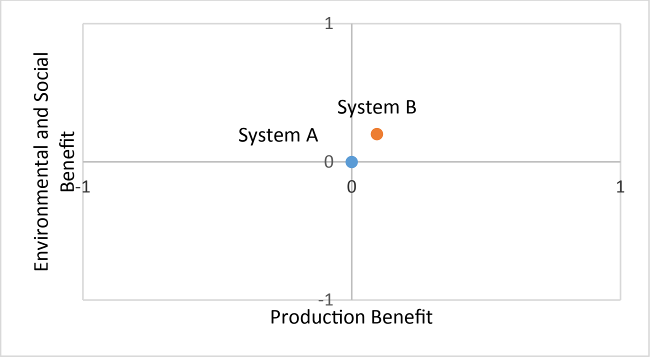


Fig. 8. ECM Environmental and Economic dimension.

aspects.

4.3. Eco-care matrix

The ECM has been graphically constructed by using the values obtained with (1), and adding a total score from each unit. In this stage of the study we identified:

- on the *x* axis the economic benefit the company registered in the two different systems (A and B, Figs. 7 and 8);
- on the *y* axis the social benefit (Fig. 7) and the environmental benefit (Fig. 8) calculated from the impact categories.

The limits of our system for the ECM representation are fixed to (−1; 1).

Fig. 6 shows the social benefit achieved with the system implementation. As highlighted in the ECM, System B has a minor impact on human health compared to System A.

The introduction of the innovation lead to an improvement of health performance and economic savings, as shown in Fig. 7, where is graphically represented the relationship between the Environmental benefits and the production benefits compared between the two Systems (Hertwich, 2005).

In Fig. 9 is represented the combination of social and environmental benefits derived from the innovation, in relation to the economic benefit for the company according to the different production systems, the traditional (System A), and the innovative (System B).

The combination of environmental, social and economic benefits derived from the innovation installation are well understood, having System B a higher score compared to System A, as shown in the graphs.

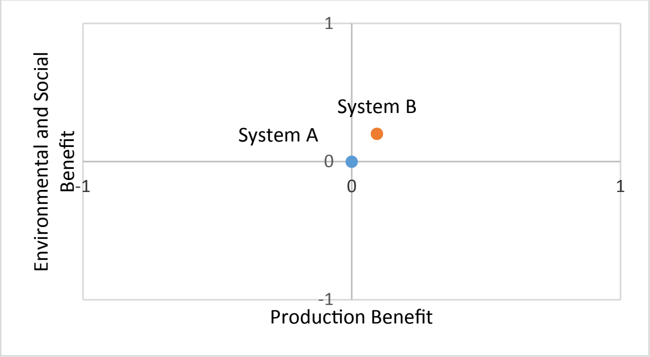


Fig. 9. ECM Social and Environmental benefits and economic dimension.

This demonstrate that the applied innovation led to a more sustainable production process for glass industry in Italy (Zeng et al., 2010).

5. Conclusions

The long recession started in 2008 and the scarce growth of the EU GDP in 2015 (World Economic Situation and Prospects, 2015) underlines the importance of fostering growth and competitiveness to sustain and strength materials recovery with the aim of achieving the economic expected expansion growth rate. Specifically, an active role is played by the European manufacturing industry that accounts for over the 80% of the export and 80% of private sector innovation. The main challenge for the European market is the creation of added value for enterprises and production, to revitalise the internal economy through the reduction of input costs, the efficiency in business processes and the promotion of a more sustainable growth approach. The regulatory framework should ensure the integration of the economic sectors to redefine the value chains, enhance the resource efficiency and the resource management and reshape the division of labour in accordance with the vision of a new life cycle of products. In this case study the firm process innovation is fully in line with the sustainability policy, which will produce economic, social and environmental effects. The project involves saving energy and raw materials through the reuse of hot air coming out of the melting furnace. By the recycling of heated air, it is possible to have a more efficient production system that requires less resources. Moreover, the innovation added into the manufacturing system, permits the achievement of energy efficiency results in the throughput for the company, objective that will pay off in terms of cost savings and the reduction of environmental impact. Focusing on the cost benefit evaluation we can affirm that even a small refurbishment of an existing system can be helpful for improving performance. This case study highlighted as LCA is a suitable tool to demonstrate a sustainable production innovation. In particular, for the glass production the hot-air recycling is a key-step to improve the eco-efficiency and reduce costs and emissions. A new improvement could be the use of waste crushed glass as raw material. For companies which use the LCA methodology to support eco-design of the profits and to support the campaigns for sustainability, the apportion is to adapt the methodology to the system perspective and be able to map possible applications in the context.

The evolution and development of the method used should aim at linking technical, economic and environmental aspects with the targeted goal of further optimizing the offer, identifying and evaluating additional portfolio elements or further integration. The use and application of LCC and LCA methods for environmental costs and impacts could identify an additional portfolio element, trough the definition of the ECM support method as improvement of LCC and LCA results.

The ECM could be useful as a tool to display the options in a comparative view with the initial solution as reference point. This tool could be even more interesting if two or more options could be compared. For the assessment of environmental performance regarding process innovation, it is necessary to deepen the knowledge to be able to define standardization and weighting schemes in order to allow a solid decision based on different impact indicators.

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