

# Foamy polystyrene trays for fresh-meat packaging: A life-cycle inventory data collection and environmental impact assessment

Carlo Ingrao <sup>a,e\*</sup>, Agata Lo Giudice <sup>b</sup>, Jacopo Bacenetti <sup>c</sup>, Amin Mousavi Khaneghah <sup>d</sup>, Anderson de Souza Sant'Ana <sup>d</sup>, Roberto Rana <sup>a</sup>, Valentina Siracusa <sup>e</sup>

<sup>a</sup> Department of Economics, University of Foggia, Largo Papa Giovanni Paolo II, 1, 71121 Foggia, Italy

<sup>b</sup> Department of Quality and Operations Management, Faculty of Engineering and the Built Environment, University of Johannesburg. APB Campus, P. O. Box 524, Auckland Park 2006, Johannesburg, South Africa

<sup>c</sup> Department of Agricultural and Environmental Sciences, Production, Landscape, Agroenergy, University of Milan, Via G. Celoria 2 - 20133 Milan, Italy

<sup>d</sup> University of Campinas, Faculty of Food Engineering, Department of Food Science, Campinas, São Paulo, Brazil

<sup>e</sup> Department of Industrial Engineering, University of Catania, Viale A. Doria 6, 95125 Catania, Italy

\* Corresponding author: [ing.carloingrao@gmail.com](mailto:ing.carloingrao@gmail.com); [carlo.ingrao@unifg.it](mailto:carlo.ingrao@unifg.it)

## Abstract

Food packaging systems are designed to perform series of functions mainly aimed at containing and protecting foods during their shelf-lives. However, to perform those functions a package causes environmental impacts that affect food supply chains and that come from its life-cycle phases. Therefore, package design should be done based upon not only the issues of cost, food shelf-life and safety, as well as practicality, but also of environmental sustainability. For this purpose, Life Cycle Assessment (LCA) can be applied in the packaging field with the aim of highlighting environmental hotspots and improvement potentials, thus enabling more eco-friendly products. In this context, an LCA of foamy polystyrene (PS) trays used for fresh meat packaging was performed here. The study highlighted that the highest environmental impacts come from PS-granule production and electricity consumption. In this regard, the authors underscored that there are no margins for improvement in the production of the granules and in the transport of the material inputs involved as well as of the trays to users. On the contrary, changing the energy source into a renewable one (by installing, for instance, a wind power plant) would enable a 14% damage reduction. In this way, the authors documented that alternative ways can be found for global environmental improvement of the system analysed and so for enhanced environmental sustainability of food packaging systems.

**Keywords:** *Packaging system; Tray; Foam polystyrene; Life Cycle Assessment; Environmental hotspots; Wind power*

## 37 **1. Introduction**

38 During last decades, sustainable development has been one of the most popular and universal  
39 concerns; in another hand, the issue that future generation will be able to experience the same  
40 standards of living and opportunities for growth attracted lots of attentions (Accorsi et al., 2014a).  
41 In order to obtain goods with environmentally sustainable properties, application of Life-cycle  
42 Thinking (LCT) to design of them is essential. Thereby, consideration to their environmental impact  
43 along the whole life-cycle (from extraction of raw materials to product disposal at the end of use),  
44 in terms of human health, climate change, resources and ecosystem quality, is important. As Bauer  
45 et al. (2008) reported according to ISO 14040:2006 and 14044:2006 (International Organisation for  
46 Standardization (ISO), 2006a; International Organisation for Standardization (ISO), 2006b), Life-  
47 cycle Assessment (LCA) is a tool which substantiates LCT by a clear and structured methodology  
48 to estimate and assess the potential environmental impacts due to a product's life-cycle. In the ISO  
49 14040:2006, "LCA is in fact defined as the compilation and evaluation of the inputs, outputs and of  
50 the potential environmental impacts due to a product-system throughout its life-cycle". As  
51 consequence of the LCT approach, the design of product should be adopted to possible evaluation  
52 of effects of product during using and also end-of-life. In another hand, LCA can be applied as a  
53 support tool for design and also to finding and assessing some technical solutions which can be  
54 used in the production process of product to minimise the impacts originated not only from the  
55 production itself but also from the phases of use and end-of-life.

56 As a systematic tool for identification and quantification of the environmental impacts associated  
57 with products' life-cycle, LCA has evolved significantly during the past three decades (Jeswani et  
58 al., 2010; Ingrao et al., 2015). Huge number of sectors such as automotive, buildings and  
59 construction, electronics, textile, agriculture, food production and packaging and so many others  
60 have used this methodology over the years (Madival et al., 2009). **In particular, the role of**  
61 **packaging systems is highly** important in the protection of food quality and shelf life, especially in  
62 the supply chain, since they are designed to allow consumers to obtain foods that correspond to  
63 their food quality and safety expectations (Accorsi et al., 2014b; Bertoluci et al., 2014). Packaging  
64 should provide the following objects: 1) food quality and freshness conservation; 2) correct  
65 identification of product; 3) convenience during storage and distribution (Meneses et al., 2012;  
66 Williams and Wikström, 2011). Other main functions are to display the brand image and to give  
67 information on the composition, preparation and traceability mode of stocking and end-of-life  
68 management (Bertoluci et al., 2014). In order to perform such functions, packaging causes  
69 environmental impacts that affect food supply chains (SCs) and, as a result, its life-cycle phases,  
70 namely production, transportation until consumption and disposal. Design of package usually is

71 done based upon not only of the issues of cost, food shelf-life and safety, as well as practicality, but  
72 also of environmental sustainability (Leceta et al., 2013; Zampori and Dotelli, 2014). For this  
73 purpose, LCA can be applied with the aim of highlighting environmental hotspots in order to enable  
74 and promote more eco-friendly packaging systems, so positively affecting the life-cycle of foods. In  
75 particular, in the field of plastic trays and clamshells for both fresh and cooked food, several studies  
76 have been conducted over the years. By way of example, Madival et al. (2009) performed a cradle-  
77 to-cradle LCA of polylactic acid (PLA) in comparison with PET and PS thermoformed clamshell  
78 containers (for strawberry packaging) with emphasis upon different end-of-life strategies.  
79 Moreover, Díaz et al. (2010) did an evaluation of the effects of two packaging systems, such as  
80 vacuum pouch and plastic tray, on spoilage in a cook-chill pork-based dish kept under refrigeration.  
81 In addition, Kaisangsri et al. (2012) developed biodegradable foam trays from cassava starch  
82 blended through appropriately dosage and mixture of natural polymers of kraft fibre and chitosan.  
83 Results showed that foam produced from cassava starch by 30% kraft fibre and 4% chitosan  
84 revealed mechanical properties similar to PS foam.

85 The comparison performed by that team of authors could be extended also to the environmental  
86 perspective so as to highlight the less impacting system, thus enabling marketing of eco-friendly  
87 packaging products. For this purpose, LCA could be used as a comparative assessment tool, as  
88 already done by Roes and Patel (2011) to compare a sugar cane-bagasse food tray to food trays  
89 made from PET, PLA, and moulded pulp. Similarly, Suwanmanee et al. (2013) benchmarked the  
90 environmental impact of bio-based against petroleum-based plastics for single use boxes focussing  
91 attention upon PS, PLA, and PLA/starch.

92 As regards cooked food, the suitability of shallow aluminium trays for heating of different  
93 casseroles in microwave ovens in comparison with Crystalline Polyethylene Terephthalate (CPET)  
94 trays was studied by Ahvenainen and Heiniö (2006).

95 Therefore, it can be concluded that the field of plastic trays has been widely investigated, especially  
96 from a technological point of view, with the aim of evaluating their basic functions towards food  
97 content. Indeed, not so many studies dealt with plastic trays' life-cycle environmental assessment,  
98 in particular, for what concerns to foamy PS trays. From this point of view, a gap in the literature  
99 was observed, thus emphasising upon the need for more LCAs on this area to be performed.

100 In this regard, the present study discusses application of LCA to the life-cycle of foamy PS trays  
101 and so the authors believe that it could contribute to enhanced knowledge in the field by delivering  
102 reliable insights on data inventoried and results obtained. In particular the latter, as for similar  
103 studies, could be used for development of environmental assessments of packed-meat SCs, thus  
104 highlighting the importance of the study conducted.

## 105 **2. Materials and methods**

### 106 *2.1 Methodological approach*

107 To the ends of the study development, LCA was applied with the aim of assessing both  
108 environmental impacts and improvement potentials in the life-cycle of foamy PS trays for fresh  
109 meat packaging. This methodology was used because it enables addressing the environmental  
110 aspects of a product and their potential environmental impacts throughout its life-cycle (Guinée et  
111 al., 2011). The study was developed following the ISO standards 14040:2006 and 14044:2006 and,  
112 therefore, was divided into the phases of: 1) Goal and scope definition; 2) Life-cycle Inventory  
113 (LCI); 3) Life-cycle Impact Assessment (LCIA); 4) Life-cycle Interpretation (LCI). All data  
114 collected were loaded into the SimaPro v.7.3.3 (SimaPro, 2006), accessing the Ecoinvent databases  
115 (Ecoinvent, 2011) and then elaborated using the Impact 2002+ method (Jolliet et al., 2003) for  
116 LCIA development. As stated by Siracusa et al. (2014) referring to the ILCD-handbook (2010),  
117 Impact 2002+ allows for a feasible implementation of a combined midpoint/endpoint approach  
118 since it links LCI results via midpoint (impact) categories to endpoint (damage) categories. In this  
119 regard, Table 1 shows the distinction, provided by this method, between impact and damage  
120 categories. In particular, according to Joillet et al. (2003), the former represent the negative effects  
121 to the environment through which the damage (due to substances emitted and resources used)  
122 occurs, whilst the latter are obtained by grouping the impact categories into major ones and  
123 represent the environmental compartments suffering the damage. Furthermore, the method  
124 calculates non-renewable energy consumption and recognises carbon dioxide as the emitted  
125 substance with the greatest responsibility for the greenhouse effect and then for climate change. In  
126 this regard, it is underscored that, as clarified by Jolliet et al. (2003), Impact 2002+ is based upon  
127 the latest IPCC Global Warming Potentials (IPCC, 2001) with a 500-year time horizon, thus  
128 accounting for long term effects. In this regard, this author team believe that these aspects are  
129 fundamental to be considered, especially in the case of industrial processes such as the one object of  
130 the present environmental study. Finally, thanks to its set-up, the method appears to be more  
131 comprehensible for insiders and also more accessible compared to other methods.

132

#### 133 **Table 1**

134 Damage and Impact categories (Impact 2002+)<sup>1</sup>

135

136 As regards the LCIA, this was carried out using both a mid-point and an end-point approach, and so  
137 the phases of normalisation and weighing were included in the assessment. The midpoint approach

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<sup>1</sup> Source: extrapolated from Jolliet et al. (2003)

138 was used in order to express impacts by means of appropriate equivalent-indicators such as, for  
139 instance, kgCO<sub>2</sub> for Global Warming, kgPM<sub>2.5</sub> for Respiratory Inorganics and kgC<sub>2</sub>H<sub>3</sub>Cl for  
140 Carcinogens. Whilst, the endpoint approach was adopted because, in agreement with Ingraio et al.  
141 (2014), it allows researchers to present results with equivalent numerical parameters (points) and, in  
142 turn, to have environmental impacts quantitatively represented. Hence, according to Siracusa et al.  
143 (2014) damage and impact categories, processes and both substances emitted and resources used,  
144 could be easily compared to each other based upon the damage unit-point. The end-point approach  
145 enabled this author team to highlight the most impacting processes that so represent the system's  
146 hotspots and require priority attention when environmental improvements are planned.  
147 Finally, to enable greater understanding of the study conducted, it is clarified that "total damage"  
148 stands for the damage associated to the life-cycle of 1 kg foamy PS trays. It can be calculated by  
149 summing up the contributions of the processes and materials included in the system boundaries or  
150 of the damage categories and of the impact categories or even of all substances emitted and  
151 resources used (Ingraio et al., 2014).

152

## 153 *2.2 Goal and scope definition*

154 This paper discusses application of attributional LCA in order to analyse inventory flows and  
155 environmental impacts associated with the life-cycle of trays made from foamy PS **and generally**  
156 **utilised as the base of packaging for fresh meat. For the assessment development, the authors could**  
157 **benefit from the collaboration of a firm located in the North of Italy that was positively involved in**  
158 **allowing them to visit the production plant and in providing them all the needed primary data and**  
159 **technical information. In this way, the authors managed to create a model as-close-as-possible to**  
160 **reality and to perform a study of scientific value and reliability.**

161 The study will make it possible to identify the most inventory processes and materials and to both  
162 qualify and quantify the environmental impacts due to the trays' life-cycle. For contrast, they could  
163 be divided to: 1) the most impacting phases; 2) the most impacted damage categories; 3) the most  
164 impacting substances emitted and resources used; 4) the processes causing the emission and  
165 consumption of the above-mentioned substances and resources; 5) the most significant impact  
166 categories; 6) the environmental improvement potentials.

167 Finally, this team of authors believe that producers, technicians, LCA practitioners, researchers and  
168 policy makers will learn about both inventory data collected and results gathered. In this way, the  
169 study will support them in making decisions oriented to contributing to enhanced environmental  
170 sustainability of food supply chains. From this point of view, in agreement with Bare et al. (2000),  
171 the study could be of direct relevance for the producer to better understand both the environmental

172 effects due to the manufacturing process and the improvement interventions needed. Therefore, the  
173 study carried out could support the producer to re-examine the merits not only of the tray  
174 production system but of the whole environmental company policy, in order to find ways for global  
175 improvement.

176

### 177 2.2.1 Functional unit and system boundaries

178 As established by the ISO 14044:2006, the “Goal and scope definition” phase includes definition of  
179 both Functional Unit (FU) and system boundaries. **The FU was chosen in order to represent the**  
180 **reference for the link of inventory flows to environmental impacts and for comparability of results,**  
181 **whilst the system boundaries were defined so as to include all the most significant and pertaining**  
182 **processes related to the system analysed.** In particular, the FU was identified with 1 kg of packed-  
183 trays delivered to food production and packaging firms, **thus facilitating data collection and**  
184 **elaboration. However, according to the authors, doing so does not compromise usage of the created**  
185 **model for implementation of packed-food related assessments.** In fact, the life-cycle of the trays  
186 **investigated can be easily input to that of the food package based upon weight of the single tray**  
187 **utilised. In particular, the latter is equal to 8.98 g, whilst the maximum capacity amounts to almost**  
188 **800 cm<sup>3</sup>: in this regard, main dimensions of the single tray were provided by the producer and**  
189 **depicted in Fig. 1.** This size of tray was chosen as the object of the present study because it is the  
190 most commercialised one amongst the other different types produced by the firm and so represents  
191 its core-business.

192

193 **Fig. 1.** Main dimensional characteristics of the analysed tray based upon information provided by the firm<sup>2</sup>

194

195 As per the system boundaries, these were defined so as to include the following subsystems (SS):

- 196 - SS1: preparation of the raw materials for the tray production;
- 197 - SS2: tray production;
- 198 - SS3: transportation to mass retailers (delivering phase);
- 199 - SS4: tray end-of-life.

200 It should be observed that transports to the tray manufacturing plant of the input materials  
201 concerning to SS1 were accounted for and modelled as part of SS2. In contrast, the use of the tray  
202 for fresh meat packaging was excluded from the system boundaries because it was considered by  
203 the authors as free from significant environmental impacts. This consideration was made because,

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<sup>2</sup> Source: personal elaboration from the tray’s image provided by the firm

204 as stated by Siracusa et al. (2014), once transported to users (mass retailers), such a package enters  
205 into the packed-food production as an input material at all effects: it is used as such, thereby  
206 accounting for the environmental impact associated with its life-cycle. Additionally, production of  
207 the food content was not taken into account, since it was considered by this author-team as outside  
208 of the aim and scope of the study: the study was, indeed, focussed upon the environmental  
209 assessment of an industrial process for production of food packaging trays. Furthermore, in  
210 agreement with Siracusa et al. (2014), the food production phase is outside of the system  
211 boundaries, because the analysed package can be for any type of fresh meat (cattle, pork and fowl),  
212 so making the model difficult to be implemented. In the light of this, considerations upon the waste  
213 generated by the expiry of the food product contained were not made, because they were considered  
214 by the authors as to be pertaining not to similar studies but to packed-food related assessments.

215 As regards the end-of-life phase (SS4), the latter occurs when the food contained is unpacked by the  
216 consumer and then the tray is thrown away into the domestic container of un-separated wastes. So,  
217 SS4 was modelled by the authors assuming that such post-use trays are disposed of in sanitary  
218 landfills, as generally established by local waste management systems. This is because the tray  
219 behaves like a sponge in the sense that one of its main functions is to absorb blood released from  
220 the fresh meat, thereby enabling reduced visual impact and, in turn, enhanced marketability. As a  
221 result, the tray is being contaminated with variety of microorganisms and so recycling is  
222 impracticable. Moreover, it should be observed that transport of the post-consumer trays (municipal  
223 waste collection phase) to the treatment plants involved in the development and management of  
224 their end-of-life scenario, namely those of municipal sorting and landfilling, were not included in  
225 the assessment. The reason for this stands in the fact that such trays are delivered to mass retailers  
226 located all over the Italian territory and so lots of those plants come to be part of their end-of-life  
227 phase. For this reason, high rates of variability were found by the authors to be associated with  
228 locations of the aforementioned plants. As a consequence, the transport system associated with SS4  
229 was not modelled and the related transportation flows, expressed as kg\*km, were not estimated.

230 In addition to the above, it is underscored that the end-of-life stage of the plastic bags used as  
231 packages for the trays to be delivered was not taken into account, too. The authors did so due to the  
232 difficulty of data collection and modelling, and also because, in the light of the almost negligible  
233 amounts implied for trays packaging, very low environmental impacts were expected compared to  
234 the other phases such as, for instance, tray production.

235 The system boundaries were depicted in Fig. 2 in which all the main activities and both materials  
236 and energy flows were indicated in qualitative terms. There is evidence that the scrap material  
237 produced during thermoforming is regenerated and re-input to the extrusion process.

238 **Fig. 2.** Boundaries of the system under investigation<sup>3</sup>

239 *2.3 Life Cycle Inventory*

240 This stage of study was developed in order to quantify the usage of resources and materials and the  
241 consumption of energy, as well as the involved transports associated with the life-cycle of the  
242 analysed FU. For this purpose, production process of the trays were studied **with consideration** to  
243 details in order to obtain required information about merits of processes and both materials and  
244 energy used (Fig. 1 and 2). For LCI to be carried out, since a particular specialised production  
245 system was assessed, using primary data attracted great importance. In particular, the latter were  
246 supplied by the firm involved and mainly concerned consumption of input resources, materials and  
247 energy. The processes used for representing the extraction of resources, the production of both  
248 materials and energy, as well as the life-cycle of the transport means involved, were extrapolated  
249 from the Ecoinvent database system, because the latter is acknowledged worldwide to be a reliable  
250 background data source. Indeed, it accommodates most of the background materials and processes  
251 often required in LCA case studies (Frischknecht and Rebitzer, 2005). Data collection was carried  
252 out continuously accessing the aforementioned database system in order to verify which kind of  
253 processes and raw materials were needed to be specifically created. From this point of view, it was  
254 observed that all the required supportive data were already inserted to Ecoinvent.

255 **In particular, as regards the trays' end-of-life, due to the difficulty of collecting primary data for the**  
256 **reasons previously explained,** this phase was implemented using the model **of sanitary landfill for**  
257 **MSW** already contained in Ecoinvent.

258 All the data required for implementation of the phases of tray production and delivering was listed  
259 in Table 2, thereby enabling greater understanding of the study conducted. **All the materials and**  
260 **processes indicated in Table 2 were extrapolated from Ecoinvent, based upon primary data provided**  
261 **by the firm.**

262 **Table 2**

263 Input data for implementation of tray production and delivering phases<sup>4</sup>

264  
265  
266 The values of transports shown in Table 2 were detailed in Fig. 3 in which transported amounts,  
267 travelled distances, diesel consumption as well as type of means used were indicated. In particular,  
268 as regards transport of 1 kg packed trays to users, it was done as was at study of Siracusa et al.  
269 (2014). As a matter of fact, the transportation flow amount reported in Table 2 (580 kg\*km) was

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<sup>3</sup> Source: personal elaboration

<sup>4</sup> Source: personal elaboration based upon data provided by the firm involved



270 calculated as weighted average, based upon distances between tray manufacturing plant and users.  
271 For this purpose, the authors took into account not only the travelled kilometres but also the supply  
272 frequency.

273 **Fig. 3.** Input material transports<sup>5</sup>

274

### 275 2.3.1 Input data and damage allocation

276 All data demanded for the study development were collected on site and then allocated to the  
277 system for required investigations, using appropriately defined procedures and tools. In particular,  
278 interviews were made with the firm technicians during visits at the production site and then all data  
279 and information gathered were recorded in appropriately designed check-lists, thus facilitating  
280 revision and subsequent elaboration. Moreover, in-depth meetings with the aforementioned  
281 technicians as well as with the managers of the production and the environmental quality divisions  
282 were made in order to assure common understanding of the questions posed and their consistency  
283 with the objective of the study.

284 Finally, as regards the environmental impacts associated with the tray's life-cycle, because no co-  
285 products were considered, no allocation was done in accordance with the ISO standards: 100% of  
286 the environmental impacts corresponded, indeed, to the system's FU.

287

## 288 **3. Results and discussion**

### 289 *3.1. Life Cycle Impact Assessment*

290 The LCIA highlighted that the total damage associated with the analysed system is equal to 0.00156  
291 pt and is mainly due to production of 1 kg of PS granule: indeed, this phase contributes to that  
292 damage for 69.3%, corresponding to 0.00108 pt. In addition, consumption of the electricity required  
293 for the whole process (1.417 kWh) covers 14.5% of the total damage. The other materials and  
294 processes comprised by the system boundaries, including all transports involved and the end-of-life  
295 phase, represent the remaining 16.2% of the total damage. For greater understanding, Fig. 4 was  
296 reported in order to show single-score results per damage categories. Hence, the total damage  
297 mentioned above can be easily calculated by summing up, for instance, the total amounts  
298 corresponding to the inputs depicted in the figure. Moreover, in Fig.4 for each single input-item  
299 considered, each damage category was allocated a weighing point. Doing so enabled documenting  
300 that *Resources* is the one to be mostly affected by the system due to the high contribution coming

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<sup>5</sup> Source: personal elaboration using data provided by the firm. Images of the mean and of the manufacturing plant were downloaded from [dreamstime.com](https://www.dreamstime.com)

301 from production of 1 kg PS-granule. Reduced impacts occur to *Climate Change* and *Human Health*,  
302 in a more evident manner for PS-granule production; whilst, the damage affecting *Ecosystem*  
303 *Quality* can be considered as almost negligible for all inputs taken into account.

304  
305 **Fig. 4.** Single-score evaluation per damage category<sup>6</sup>  
306

307 Finally, from Fig. 4 the damage values (per single damage category) associated with process inputs  
308 considered were summed up: the resulting totals were listed in Table 3 together with the damage  
309 assessment values.

310  
311 **Table 3**

312 Weighing points and damage assessment (values per damage category)

313  
314 The system output flows (resources used and substances emitted) most affecting the aforementioned  
315 damage categories were listed in Table 4 and were associated to the related inventory amounts and  
316 damages caused per kg of packed trays. The processes mostly contributing to both consumption of  
317 those resources and emission of those substances were also indicated.

318  
319 **Table 4**

320 Substances emission and resources consumption (values per kg of packed trays)

321  
322 For better understanding, it is underscored that all resources and substances listed in Table 4 could  
323 be considered as the most significant impact-indicators to be taken into account in order to find  
324 ways for improved environmental sustainability of tray-production system design, implementation  
325 and management. Finally, as regards the impact categories, from Fig. 5 there is evidence that those  
326 with the highest contributions to total damage are: *Non-Renewable Energy*; *Global Warming*; and,  
327 *Respiratory Inorganics*. **These impact categories were reported in Table 5 in association with both**  
328 **damage points and characterisation values (mid- and end-point approach results).**

329  
330 **Fig. 5.** Weighing per impact category<sup>7</sup>

331 **Table 5**

332 Weighing points and the characterisation values for each of the impact categories causing the greatest damage

### 333 334 335 *3.2. Interpretation and improvement*

336 The study developed attained the objective defined and, indeed, enabled understanding that the  
337 most impacting phase is 1 kg PS-granule production followed by electricity consumption and

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<sup>6</sup> Source: personal elaboration based upon LCIA-results from Impact 2002+

<sup>7</sup> Source: Source: personal elaboration based upon LCIA-results from Impact 2002+

338 transport of both input materials and 1 kg trays. Moreover, thanks to the study here discussed it was  
339 possible to observe that:

- 340 - the most affected damage category is *Resources* due to the consumption of crude oil and  
341 natural gas in the amounts equal to 1.247 kg and 1.252 m<sup>3</sup>, respectively;
- 342 - the most significant impact categories are *Non-Renewable Energy*, *Global Warming* and,  
343 *Respiratory Inorganics*.

344 For what concerns to the emitted substances, the most impacting one is carbon dioxide with a  
345 damage value levelling out at 4.18E-4 pt due to the high contributions coming from granule  
346 production and electricity consumption. In addition, Nitrogen oxides (NO<sub>x</sub>), as emitted (to air) in  
347 the amount of 8.25 g, affect both *Human Health* and *Ecosystem Quality* and, in particular, more the  
348 former than the latter. This was considered by the authors as to be attributed to the classification  
349 scheme characterising the Impact 2002+ setting and, more specifically, to the characterisation and  
350 weighing factors which this method is based upon. However, for both damage categories, as evident  
351 from Table 4, NO<sub>x</sub>-emissions are mainly due to granule production. The latter is the most  
352 contributing process for all the resources and substances considered but for zinc and aluminium  
353 where the greatest contributions mainly come from all the transports involved and from butane-1,4-  
354 diol production.

355 In this context, a flow chart of the damages being originated from the materials and processes  
356 encompassed by the system is shown in Fig. 6, where “Pt” stands for “weighing points” or “damage  
357 points” or simply “points”.

358

359

360

**Fig. 6.** 1 kg trays' life-cycle: damage flows<sup>8</sup>

361 For greater understanding, it should be observed that those reported Fig. 5 and 6 represent the exact  
362 names (in the Ecoinvent database) of the inventories (materials, energy and processes), already  
363 reported in Table 2 and used for the assessment.

364 In the light of the obtained results, suitable solutions for damage reduction were addressed at the  
365 most impacting activities that characterise the production of the examined packaging product. In  
366 this regard, it should be observed that from meetings with the firm technicians it was emerged that:

- 367 - nothing can be done as per reduction of the amount of PS-granule used or as per usage of  
368 recycled granules because in both cases tray's functionality would be compromised;

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<sup>8</sup> Source: personal elaboration of results from LCIA development as performed by Impact 2002+

369 - regarding road-transports, all the means used are euro 5 lorries, thus contributing to reduced  
370 GHG-emissions, and the distances travelled are strictly dependent on locations of both input  
371 material suppliers and tray users. In this sense, any change-decision should be made  
372 considering the internal policy and so should be operated by the competency management  
373 bodies of the firm.

374 For this reason, it was opted for the installation of a wind power plant (WPP) in order to supply, at  
375 least, the internal electricity requirements: in agreement with the technicians interviewed, a 150 kW  
376 nominal power was considered as feasible for the case. Therefore, the author team environmentally  
377 tested the aforementioned solution, as agreed with the technicians, in order to evaluate if it is  
378 effectively an improvement. For this purpose, no primary data were used and the model already  
379 existing in Ecoinvent v.2.2 was accessed. In particular, the latter provides accounting for the life-  
380 cycle of both moving and fixed parts as composing the WPP considered. In particular, besides  
381 production and disposal of those parts the dataset includes: the energy required for the assembly  
382 phase; the transports of the input materials to the manufacturing industries and of the manufactured  
383 WPP-parts to the tray production firm; the connection activities to the grid; and, the gear oil change  
384 needed for the correct working of the plant. For greater understanding, it should be observed that  
385 the module accounts for the share of WPP's life-cycle corresponding to production of 1 kWh  
386 electricity considering for the plant a 40-year lifetime and a 125 MWh average annual production.  
387 Therefore, it was used to model the tray production process by associating it with the related energy  
388 requirement (1.417 kWh/kg<sub>tray</sub>).

389 From such an improvement proposal application, the authors could be proven right because the  
390 comparative assessment performed documented a damage reduction of almost 14%, from 1.56E-4  
391 to 1.35E-4 pt (Fig. 7). In particular, carbon dioxide is reduced from 4.146 to 3.39 kg, whilst crude  
392 oil and natural gas are reduced from 1.247 to 1.19 kg and from 1.252 to 1.09 m<sup>3</sup>, respectively.

393  
394 **Fig. 7.** Environmental assessment of 1 kg tray's life-cycle with application of the proposed electricity-sourcing by wind  
395 power: a comparison with the initial study<sup>9</sup>  
396

397 In the light of the results gained, there is evidence about the environmental sustainability of such  
398 renewable energy sources. However, more studies are needed to enable greater understanding of the  
399 technical feasibility and of the economic convenience associated with the solution proposed. Those  
400 issues were not addressed in the present study because the authors considered them as of strict  
401 competency of the firm technicians and so outside of the aim and scope of the study itself.

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<sup>9</sup> Source: histogram extrapolated from Impact 2002+ (mPt: points E-3)

#### 402 4. Conclusions

403 The study here presented was designed to investigate the food packaging field from an  
404 environmental point of view: its objective was, in fact, to perform LCA of the life-cycle of 1 kg  
405 trays for fresh meat packaging and preservation. The excellent cooperation of the producer allowed  
406 the team of researchers to effectively gather high-quality data, thereby making it possible to develop  
407 reliable results, thus forming a solid foundation for decision making at the firm level.

408 **Development of the study enable the authors to document** that most of the environmental impact  
409 associated with the system analysed comes from production of expandable PS granulates and from  
410 consumption of electricity as both required for tray manufacturing. This has to be attributed mainly  
411 to the exploitation of primary energy resources, such as crude oil and natural gas, and also to the  
412 emission (in air) of carbon dioxide, thereby contributing to affecting both non-renewable energy  
413 resource stock and climate change.

414 In the light of the findings of the study, the environmental improvement issue was addressed in  
415 order to enable reduction of the environmental impact associated with the system investigated and  
416 so to contribute to enhanced rates of sustainability. In this regard, in the occasion of meetings with  
417 the firm technicians it emerged that no improvements are possible to be made in the granule  
418 production and, more specifically, in terms of both amount and type used. This is because reduction  
419 of the PS-granule amounts to be implied or use of recycled granules would cause reduction of the  
420 functionality of the tray and so of its marketability. Furthermore, during those meetings the  
421 technicians clarified that no margins for improvement are possible as per all transports involved. In  
422 particular, all the means used are euro 5, so being characterised by GHG-emission rates largely  
423 compatible with the recent limits imposed by the European Commission, and the distances travelled  
424 are strictly dependent upon the locations of both input material suppliers and tray users. In this  
425 sense, any change-decision should be based upon the internal policy and so should be operated by  
426 the competency management bodies of the firm. In the light of the above, there is evidence of the  
427 existence of limiting conditions that cannot be neglected and so must be taken into due account for  
428 a more correct and pertinent planning of improvement interventions. In this context, the use of a  
429 wind power plant for sourcing the electricity demand for tray manufacturing was tested in  
430 agreement with the technicians, thus revealing a 14% environmental impact decrease.

431 Doing so made it possible for the authors to show that the use of renewable energy is a good mean  
432 for contribution to reduction of the environmental impacts associated with any industrial system, as  
433 the one investigated. **Therefore, such energy production plants can help to enable production of**  
434 **more eco-friendly food packaging systems contributing, in turn, to enhanced environmental**  
435 **sustainability in the food SC.**

436 In this context, it should be observed that the conclusions of the study are specific to the examined  
437 case, the obtained results, as well as the tray production technologies and the input data.  
438 Nevertheless, the study was designed to be as detailed as necessary to provide a useful contribution  
439 to the LCA approach in the food production and packaging sector. Based upon this research, all the  
440 targeted stakeholders may, indeed, be informed about the input/output flows involved in the system  
441 analysed, the related environmental impacts and the evaluable improvement potentials. In this way,  
442 the research-study developed will contribute to enriching the international knowledge on the  
443 environmental performance of 1 kg trays' life-cycle by providing reliable information on data  
444 inventoried and results obtained. Moreover, the authors believe that the study will enable  
445 understanding of how significantly the food packaging industry contributes to global climate change  
446 and environmental pollution, especially considering the huge amounts of packages produced.  
447 Therefore, solutions must be found to reduce such a contribution allowing, in turn, for  
448 implementation and development of cleaner production systems. **In this regard, thanks to its  
449 findings, the present study could be used by the firm as the starting point for the development of  
450 more innovative and efficient packaging technologies in order to evaluate the alternative use of  
451 recycled and biodegradable polymers.**

452

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459

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