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Comparison of the Environmental Effects of Coating Technologies for Interior Wood Furniture

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Abstract:

The environmental performance of the coating process in the European furniture industry has become a critical issue after the publication of the "Solvent emission directive" by the European Community in 1999. Consequently, several technologies and materials have been introduced in order to improve the sustainability of this key process. With this respect, life cycle assessment (LCA) can play a decisive role in the selection of the most appropriate coating system. The article presents the main features and the results of an LCA study which was undertaken in an actual plant in order to compare eight different coating systems. The results show that three aspects (namely energy consumption, volatile organic compound emissions and coat application technique) are mainly responsible for the overall impact of

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the process and that the most promising technologies are those which have small impacts with respect to those aspects.

Key words: furniture; wood; wooden products; coating; life cycle assessment; LCA; Best Available Technologies; BAT; product finishing; cleaner technology; solvent

1 Introduction

The wood furniture industry accounts for 6% of the annual production volume of Italian manufacturing (source: Italian Ministry of Economic Development) and has maintained for several decades a strong reputation in national and international markets because of the design and quality of its products. Small and medium-sized enterprises (SMEs), which constitute the main part of the sector, had some competitive advantages in the past, such as the high service flexibility and the ability to provide highly customized products. Nevertheless, they have shown a limited capability to introduce frequent innovations in processes. Regarding environmental innovation, wood furniture SMEs rarely have been pro-active, conversely they have searched and applied cleaner technologies or practices mainly in response to external pressure (Borga et al., 2009). In this respect, the environmental regulations and standards adopted by the European Union have played a decisive role to push manufacturers into adopting an environmental policy (European Commission, 2009).

The study presented in the paper refers, in particular, to coating of wood furniture, a process which has been especially affected by the European Union's regulations concerning the prevention and control of pollution and the production and use of hazardous substances, in particular volatile organic compounds (VOCs) contained in solvent-based paints (Roux, 2004). In the first place, manufacturers reacted to the directive by installing systems for abating gaseous pollutants while preserving solvent technology. Nonetheless, a tendency to innovate products and processes, by limiting pollutants at the source, has been growing in recent years due to the availability of coatings with less organic solvent. Therefore, furniture manufacturers need to select the technology which may assure results in line with their environmental policy and meet the set economic and quality requirements.

The eight coating systems considered in the study are technically and economically feasible for SMEs as they usually require only minor revisions to the existing plants. The focus of the comparison was the environmental performance of the technologies and, in this regard, a life cycle assessment (LCA) of each solution was performed. The study aimed to identify the solutions with the least overall environmental impact and to individuate the factors which mainly contribute to the impact. In section 2, the main environmental issues of the wooden furniture sector are outlined and the main coating technologies are introduced. The “Materials and methods” section describes the coating technologies which were investigated and the principal assumptions and features of the LCA study. Finally, in section 4, the results of the assessment are summarized and discussed, and some conclusions are drawn.

2 Background

2.1 Environmental issues and regulation in the furniture industry

Over the last ten years, Italian wood furniture manufacturers have devoted increasing attention to the environmental performance of their products and processes. This fact may be related to the influence played by different factors: national and international regulation, customers’ requirements and initiatives of the specific industry sector (Arena et al., 2009). Such factors are not specific of the furniture industry, but their relative importance can differ from that found in other business sectors. In Italy small and medium-sized enterprises make up the largest part of the furniture industry; therefore, some aspects which are typical of industries of this size, such as the unification of ownership and management, the scarcity of resources, productivity as the main driver of technological innovation (Hall et al., 2009), play an important role in defining their environmental awareness and their readiness and capability to innovate (Ciliberti et al., 2008; Coppa and Sriramesh, 2013). The environmental design and management of products can facilitate the promotion of the product lifecycle management (PLM) approach and its methods in SMEs (Bras, 2009), even if there is a need to adopt appropriate guidelines so as to transform the PLM's concept into a competitive factor in such organisations (Batemburg et al., 2006).

As far as wood furniture is concerned, Italian manufacturers have traditionally focused their attention on design, usability and aesthetics of the finished product as these have been considered as distinctive features of Italian furniture style in the target markets (mainly Italy and Europe). Still, the consumers' demand for products with a reduced environmental impact, which has been growing during the last decade, and the environmental regulation adopted by European countries have put pressure on the sector to introduce product and process innovation. Some SMEs have started to redesign their processes and products according to the principles of Design for Manufacturing and Green Manufacturing to deal with the competition of producers from other countries (González-García et al., 2011; Parikka-Alhola, 2008), in particular in the market segments where customers' willingness to pay is higher (Bovea and Wang, 2007), or because they have been fostered by partners which promote green supply chains (Srivastava, 2007). Nevertheless, the main reactions of SMEs have been to search and apply affordable technological solutions to pre-existing processes, whereas they seem to have underrated the economic and competitive advantages of ecodesign and cleaner innovation, which are confirmed by several studies (see e.g. Finster et al., 2001; Frondel et al., 2008).

The main efforts of Italian manufacturers have been focused on the improvement of materials and processes related to wood based panels and their finishes so as to reduce the overall environmental burden of products throughout their life cycle; in effect, these solutions have been applied effectively in other countries (Bovea and Vidal, 2004). In particular, the finishing of visible furniture components (e.g. fronts or cabinet doors) contributes to the aesthetic value and durability of wood furniture products and, in this respect, coating still has a prominent role. Processing and use of coating materials may have significant health and environmental effects throughout their life cycle (Scruggs, 2013), but application techniques and technologies contribute as well to the overall environmental impact that can be ascribed to this finishing process (Gustafsson and Börjesson, 2007): a careful assessment is therefore needed in order to support the selection of the techniques which are able to meet the quality requirements and to achieve the financial and environmental policy goals set by a company (Bovea and Pérez-Belis, 2012; Geldermann and Rentz, 2005).

Life cycle assessment is a mature methodology which is employed to analyse and assess the overall environmental impact of products and processes (see e.g. Curran, 1996; Guinée et al., 2011). LCA has been adopted by the European Union as a standard and is considered as an essential tool to enable the diffusion of life cycle thinking and environmental innovation among industries (Ansems et al., 2005; European Commission, 2011). As far as coating products are concerned, LCA studies have been focused on the impacts on human health attributable to the production, manipulation and use of hazardous substances (Askham et al., 2012; Meijer et al., 2005; Olsen et al., 2001).

Indeed, the evaluation of the environmental performance of coating products and processes has become critical after the European Council Directive 1999/13/EC or "Solvent Emissions Directive" (European Council, 1999) which sets strict limits to the emission of Volatile Organic Compounds (VOCs) as they are a source of risks to human health. The directive is aimed at assuring safety and protection for health both in the workplace and the areas surrounding industrial facilities. It regulates limit values, improvement criteria of processes and structures, and methods of analysis and assessment of emissions produced by industrial plants. Since the adoption of the directive, customers have requested coating products with low VOC content; therefore, this feature has been a key driver of product innovation both for producers and users of coating materials. As for the coating of wood products, the norm must be applied by manufacturers using an annual quantity of solvent of 15 tons or more with respect to the nominal production capacity of the plant. Manufacturing plants which are subjected to the norm must respect the limit values of both collected and fugitive emissions or the limit values of total emission; in addition, they must comply with the prescriptions included in the same norm.

In this respect, a pivotal role is played by another directive adopted by the European Union: the Directive 96/61/EC of the 24 September 1996 concerning Integrated Pollution Prevention and Control ("IPPC Directive") which was then updated and codified as "Directive 2008/1/EC" (European Parliament, 2008). The Solvent Emissions Directive directly refers to 96/61/EC as it states that the total emission values must be obtained by means of the application of the Best Available Techniques (BAT), namely technologies and practices with minimum environmental impacts and acceptable costs. According to the IPPC Directive, BAT form the basis for the identification of the limit values of emission and the licensing system of an industrial installation. Moreover, the selection and implementation of BAT not only may improve the environmental performance of production activities, they also may trigger an innovation process towards cleaner production, as confirmed by several studies (Breedveld, 2000; Cikankowitz and Laforest, 2013). Besides, the role of regulations as drivers of environmental improvement of industrial activities is confirmed in studies which were carried out in Canada (Taylor, 2006), Ireland and Italy (Testa et al., 2012).

It is noteworthy that BAT introduce two classes of techniques: "process-integrated techniques" and "end-of-pipe techniques". In the specific case of coating processes, end-of-pipe techniques include those technologies that are most effective, both in terms of cost and performance, to collect and abate gaseous pollutants. Conversely, process-integrated techniques include the utilization of raw materials with a limited content of organic solvents and the optimization of plant operation and management by reducing emissions at the source, namely using processes which can promote a more efficient use of resources. This last class of BAT can be associated to the concept of "cleaner technology" (European Environment Agency, 1999) and can have a key role in process innovation for wood furniture coating, as highlighted by Roux (2004).

A particularly effective process-integrated technique is the use of water-based coatings which have a solvent content lower than 10% to replace solvent-based coatings (which usually have a content of solvent between 60% and 80%). This solution may be economically viable even for small enterprises because, in many cases, water-borne coatings can be used without major modifications of pre-existing plants. Nonetheless, this technology should be carefully investigated: on the one hand, the effects of the change on the finished product should be verified and, on the other, the possible modifications to be introduced in the existing plant should be evaluated. Still, a first necessary step to the identification of the most promising technologies, is to assess the overall environmental effects of different solutions which could be applied in an existing facility, so as to identify the technologies which are in line with the environmental innovation goals of a company (Gustafsson and Börjesson, 2007). In the case study, the aim was to select, from a set of available technologies, the coating systems with the smaller environmental burden from a life cycle perspective and to identify the factors with the most significant impact. The investigated coating systems and the principal features of the LCA are presented in section 3.

2.2 Coating materials and processes for wooden surfaces

The selection of the most appropriate coating system should take into consideration some aspects which relate to the particular application (Bulian and Graystone, 2009). A primary parameter is the daily amount of surface to be coated. Small factories can adopt manual application systems while large facilities use automatic lines made up of different machines: roller coaters, curtain coaters, hot air ovens, infra-red (IR) or ultra-violet (UV -- mercury and gallium lamps) drying tunnels. It is also necessary to consider the type of protection to be provided by coating to the substrate that also play an important role from an aesthetic point of view. Therefore, it is important to select the appearance of the finished product, for example in terms of gloss (matt = less than 10 gloss, semi-matt =11 to 35 gloss, semi-gloss = 36 to 60 gloss, glossy = between 61 and 80 gloss and high gloss = higher than 81 gloss). Another key parameter is the coating thickness which determines different results in terms of appearance: closed pore, semi-open or open pore. The final result is achieved by means of different coating materials such as polyurethane, polyesters, nitrocellulose, photocuring, acrylic and so forth, even combined together in order to respond to the different market needs in terms of performance and fashion.

Each coating system requires certain conditions to be adequately implemented, so the relative humidity of the working environment and the moisture content of wood must be perfectly controlled before starting each process. The best results are obtained under controlled conditions with a relative humidity between 30% and 75% in the working environment and a moisture content of wood between 8% and 12%. Moreover, the temperature of the application and drying systems must be within the limits considered appropriate for the use of the specific coating materials. In addition, good coating needs properly prepared surfaces (sanding process). Finally, other relevant aspects are process automation and an effective insulation of the coating line area to avoid depressurizing with possible air drafts or dust contamination.

A parameter of pivotal importance is the transfer efficiency, which represents the amount of coating material actually deposited onto the substrate with respect to the total consumption by the application system for that application. Transfer efficiency is relevant both from an economic point of view and for the environmental impact of each application, being highly variable depending on the method used. In the case of coating materials based on organic solvents, the application method with the highest transfer efficiency will cause the lowest emissions because a reduced quantity of coating material will be utilized to obtain the same result in terms of surface finishing These considerations make the case for performing a life cycle assessment of the coating materials and processes.

A LCA study analyses the overall environmental impact of the product in several stages of its life, highlighting possible improvements of its sustainability. In particular, LCA makes it possible to compare two or more products or coating systems with different environmental burdens, so as to identify the most sustainable. Such information is crucial to make decisions regarding:

- opportunities for the optimization of the products;
- strategic planning, setting priorities, designing or redesigning products and processes;
- marketing strategies geared to environmental protection such as the achievement of green labels.

The different types of coating systems may be broadly subdivided into the following categories:

- coating systems for windows based on water-borne paints or clear coatings;
- coating systems for pre-finished flooring based photocurable clear coatings:
- coating systems for flat substrates (tables, furniture, doors, etc.) generally based on polyesters or photocurable paints and clear coatings;
- coating systems for profiles generally based on solvent-based or photocurable paints or clear coatings
- coating systems for shaped flat substrates (e.g. kitchen cabinet doors) based solvent-based, photocurable or water-borne paints or clear coatings;
- coating systems for three-dimensional elements (e.g. chairs) based on solvent-based or water-borne paints or clear coatings.

In sub-section 3.1 the investigated systems are outlined: they were selected as they are considered technically and economically viable by several small and medium-sized wood furniture enterprises and could affect the environmental performance of their production processes.

3 Materials and methods

3.1 The investigated coating technologies

The study took into consideration eight coating systems, including both solvent-based and water-borne products, which are of interest for the furniture manufacturers in Europe. The systems and the technical features of the related materials and processes are summarized in the following list and tables:

- Coating system 1 (Table 1): flat panel, line speed = 10 m/min; average production = 480 m^2/h
- Coating system 2 (Table 2): flat panel, line speed = 10 m/min; average production = 480 m^2/h
- Coating system 3 (Table 3): flat panel, line speed = 4 m/min; average production = 200 m^2/h
- Coating system 4 (Table 4): flat panel, average production = 160 m^2/h
- Coating system 5 (Table 5): flat panel, average production = 160 m^2/h
- Coating system 6 (Table 6): flat panel, average production = 160 m^2/h
- Coating system 7 (Table 7): 3D panel, average production = 200 m^2/h
- Coating system 8 (Table 8): flat panel, average production = 160 m^2/h

3.2 The LCA study: assumptions and methods

The life cycle study aimed to compare the environmental burden of the above mentioned coating processes in relative (not absolute) terms. It was a “cradle-to-gate” study, therefore the stages of use and final disposal of the product were not investigated. Each process included the following stages:

- manufacturing of coating and auxiliary materials;
- coating process (main process);
- processes supporting the main process;
- management and processing of waste from the whole process.

Several important assumptions regarding the process and the coating plant were made which are broadly satisfied in actual contexts. The functional unit, to which the overall environmental burden is referred, was a finished wood panel with a surface of 1.0 m^2. Energy consumption included both the whole coating process and machine setups. The energy used to produce the raw panel and to process it as waste was not computed. If the coating process complied with the Solvent Directive (water-borne technology), gaseous emissions were released to air; in order to limit VOC emission for solvent based technologies, a post-combustion system was used. In summary, air emissions taken into consideration were released during the following stages:

- manufacturing of coating and auxiliary materials;
- supply and use of natural resources, e.g. natural gas and electric power supply;
- management and processing of waste from the coating process.

The impacts related to the transport of coating materials were not included because they did not depend on the particular coating process. The input data from the Inventory Analysis are reported in Table 9: they were obtained by direct measurement at an experimental plant in which the eight coating systems were tested.

The Impact Assessment was performed by means of the LCA software GaBi 4.2 software developed by PE Consulting Group and using the CML 2001 baseline method (CML, 2001). Table 10 summarises the output data of the characterisation (impact categories) according to the CML method, while Figure 1 illustrates the overall impacts of the coating systems (1-8) normalised by CML2001 (Experts IKP - Southern Europe). Environmental related data of flows of materials and energy were obtained from the following database sources (PE: PE International; DE: data related to Germany; IT: data related to Italy):

- manufacturing of coating materials (DE: Base coat (H_2O; met) PE, DE: Clear coat (H_2O) PE, DE: Base coat (LM; met) PE, DE: Clear coat (LM) PE);
- electricity production (IT: Power grid mix ELCD/PE-GaBi);

- thermal energy (IT: Thermal energy from natural gas PE);
- emissions from coating (Generic PE);
- disposal of coating material (Polyurethane PU PE);
- manufacturing of containers (DE: Steel billet, electric furnace, PE);
- production of acetone (IT: Acetone PE);
- disposal of acetone (IT: Distillation of acetone).

4 Discussion of results and concluding remarks

The results of the study pointed up three aspects which are critically responsible for the environmental impacts in the coating process: energy consumption, VOC emission and coat application technique; they concern different stages of the coating process and make it possible to identify the most promising technologies among those compared.

Energy consumption represents a significant part of the overall environmental burden. In particular, the production of coating materials has a notable impact on all coating systems because of the large quantity of energy needed. The main other sources of electric energy consumption are the coating plant, heating and ventilation and the UV curing equipment; energy requirements depend on operation time, therefore the impact per unit of finished product hinge on the average rate of production of the line, which is significantly higher in systems 1 and 2 (480 m^2/h). Thermal energy is mainly used during the drying phases which are included in all systems but are particularly long (about 24 hours) for systems 5, 6 and 8. In Italy, a significant amount of electric energy is obtained from the combustion of natural gas which is also used in coating plants to produce thermal energy: this is responsible for the emission of carbon dioxide which, in turn, affects the normalised impact category “Global Warming Potential” of CML.

The second critical aspect is VOC emission during coating application. This problem is drastically reduced in coating systems with a solid content near to 100% or which are based on water-borne products. Systems 6 and 8, based on organic solvent, need to employ a post-combustor in order to comply with the limits of the Solvent Directive and this increases the quantity of carbon dioxide released during combustion.

Finally, it is worth remarking the importance of the technology employed for coat application. System 5, which is based on manual application by means of pneumatic gun, has the worst environmental performance (Figure 1) due to the poor efficiency in the overall application: three applications are needed to obtain a result comparable, in terms of uniformity and thickness of the material sprayed onto the surface, to those of the other systems.

In conclusion, the life cycle assessment allows the selection of the most promising coating systems for wood furniture from an environmental perspective. In the specific case, the advantages of systems 1, 2, 3 and 7 are related to their good performances with respect to all the three aspects mentioned above (energy consumption, VOC emission, coat application technique). These aspects should form the basis for the evaluation of coating technologies and can possibly support the design of new coating materials and plants.

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Table 1. Technical data of Coating system 1

Materials	Solid content (%)	Solvent content (%)	Transfer efficiency (%)
Stain	10	90	95
Photocuring acrylic base coat	100	-	95
Photocuring acrylic filler	100	-	95
Photocuring polyester top coat	99	1	95

Phase	Coating material	System	Application rate (g/m²)
Substrate preparation	Grain: 150/180	Automatic sander	-
Stain application	Solvent based stain (Cherry)	Roller coater	7
Base coat application	Photocuring acrylic clear base coat	Roller coater	40
Filler application	Photocuring acrylic clear filler	Reverse	100
Sanding	Grain: 320	Manual sander	-
Top coat application	Photocuring acrylic clear top coat	Curtain coater	240
Polishing	Grain: 1000/1200, polish	Manual	-

Table 2. Technical data of Coating system 2

Materials	Solid content (%)	Solvent content (%)	Transfer efficiency (%)
Stain	10	90	95
Photocuring acrylic base coat	100	-	95
Photocuring acrylic filler	100	-	95
Photocuring polyester base coat	99	1	95
Photocuring water based acrylic top coat	68.9	3.6	95

Phase	Coating material	System	Application rate (g/m²)
Substrate preparation	Grain: 150/180	Automatic sander	-
Stain application	Solvent based stain (Cherry)	Roller coater	7
Base coat application	Photocuring	Roller coater	40

	acrylic clear base coat		
Filler application	Photocuring acrylic clear filler	Reverse	100
Sanding	Grain: 320	Manual sander	-
Base coat application	Photocuring polyester clear base coat	Curtain coater	200
Sanding	Grain: 400/600	Automatic sander	-
Top coat application	Photocuring water based clear acrylic top coat	Curtain coater	50

Table 3. Technical data of Coating system 3

Materials	Solid content (%)	Solvent content (%)	Transfer efficiency (%)
Stain	10	90	95
Photocuring acrylic base coat	100	-	95
Photocuring acrylic filler	100	-	95
Photocuring polyester base coat	99	1	95
Photocuring water based acrylic top coat	60	3.6	40

Phase	Coating material	System	Application rate (g/m^2)
Substrate preparation	Grain: 150/180	Automatic sander	-
Stain application	Solvent based stain (Cherry)	Roller coater	7
Base coat application	Photocuring acrylic clear base coat	Roller coater	40
Filler application	Photocuring acrylic clear filler	Reverse	100
Sanding	Grain: 320	Manual sander	-
Base coat application	Photocuring polyester clear base coat	Curtain coater	200
Sanding	Grain: 400/600	Automatic sander	-
Top coat application	Photocuring water based clear acrylic top coat (matt)	Hydraulic air-assisted spray	100

Table 4. Technical data of Coating system 4

Materials	Solid content (%)	Solvent content (%)	Transfer efficiency (%)
Stain	10	90	95
Photocuring acrylic base coat	100		95
Photocuring acrylic filler	100		95
Photocuring polyester base coat	99	1	95
Acrylic (2K) top coat	30	70	40

Phase	Coating material	System	Application rate (g/m²)
Substrate preparation	Grain: 150/180	Automatic sander	-
Stain application	Solvent based stain (Cherry)	Roller coater	7
Base coat application	Photocuring acrylic clear base coat	Roller coater	40
Filler application	Photocuring acrylic clear filler	Reverse	100
Sanding	Grain: 320	Sanding (manual)	-
Base coat application	Photocuring polyester clear base coat	Curtain coater	200
Sanding	Grain: 400/600	Automatic sander	-
Top coat application	2K Solvent based acrylic clear top coat	Hydraulic air-assisted spray	100

Table 5. Technical data of Coating system 5

Materials	Solid content (%)	Solvent content (%)	Transfer efficiency (%)
Polyester base coat (paint)	35	65	40
Water borne photocuring top coat	60	3.5	40

Phase	Coating material	System	Application rate (g/m²)
Substrate preparation	Grain: 150/180	Automatic sander	-
Base coat application	Polyester base paint	Pneumatic gun (manual)	200
Base coat application	Polyester base	Pneumatic gun	300

	paint	(manual)	
Base coat application	Polyester base paint	Pneumatic gun (manual)	300
Sanding	Grain: 400/600	Automatic sander	-
Top coat application	Water borne photocuring top coat	Hydraulic air-assisted spray	80

Table 6. Technical data of Coating system 6

Materials	Solid content (%)	Solvent content (%)	Transfer efficiency (%)
Polyester base coat	65	35	40
2K Acrylic top coat	30	70	40

Phase	Coating material	System	Application rate (g/m^2)
Substrate preparation	Grain: 150/180	Automatic sander	-
Base coat application	Polyester base paint	Pneumatic gun (manual)	200
Base coat application	Polyester base paint	Pneumatic gun (manual)	300
Base coat application	Polyester base paint	Pneumatic gun (manual)	300
Sanding	Grain: 400/600	Automatic sander	-
Top coat application	2K Acrylic top coat	Hydraulic air-assisted spray	110

Table 7. Technical data of Coating system 7

Materials	Solid content (%)	Solvent content (%)	Transfer efficiency (%)
Water based stain	10	2	40
Water based photocuring base coat	85	3.5	40
Water borne photocuring top coat	60	3.5	40

Phase	Coating material	System	Application rate (g/m^2)
Substrate preparation	Grain: 150/180	Automatic sander	-
Stain application	Water based stain	Pneumatic gun (automatic)	-
Sanding	Scotch brite ®		-
Base coat application	Water based photocuring base	Hydraulic air-assisted spray	80

	coat		
Sanding	Scotch brite ®		-
Base coat application	Water based photocuring base coat	Hydraulic air-assisted spray	80
Sanding	Scotch brite ®		-
Top coat application	Water borne photocuring top coat	Hydraulic air-assisted spray	80

Table 8. Technical data of Coating system 8

Materials	Solid content (%)	Solvent content (%)	Transfer efficiency (%)
Polyester base coat	65	35	40
2K solvent based polyurethane top coat	35	65	40

Phase	Coating material	System	Application rate (g/m²)
Substrate preparation	Grain: 150/180	Automatic sander	-
Base coat application	Polyester base paint	Pneumatic gun (manual)	200
Base coat application	Polyester base paint	Pneumatic gun (manual)	300
Base coat application	Polyester base paint	Pneumatic gun (manual)	300
Sanding	Grain: 400/600	Automatic sander	-
Top coat application	2K solvent based polyurethane top coat (paint)	Pneumatic gun (manual)	120

Table 9. Inventory analysis: input data of coating systems

Input data	Coating system							
Inventory Analysis	1	2	3	4	5	6	7	8
Acetone (kg)	0.0031	0.0049	0.0049	0.0049	0.0030	0.0030	0.0000	0.0030
Base coat (kg)	0.1547	0.3653	0.3653	0.4074	2.0000	2.0000	0.4500	2.0000
Top coat (kg)	0.2526	0.0842	0.2500	0.2000	0.2000	0.2750	0.2000	0.3000
Electricity (MJ)	1.5339	2.1375	5.1300	3.0420	4.3920	4.5570	4.7088	4.5570
Containers (kg)	0.0269	0.0297	0.0406	0.0401	0.1453	0.1503	0.0429	0.1520

Thermal energy (MJ)	0.0436	0.1607	0.2821	30.2120	60.5119	60.5119	0.1111	60.5119

Table 10. Characterisation: output data according to the CML 2001 method

CML 2001 – Nov. 09	Coating system							
	1	2	3	4	5	6	7	8
Abiotic Depletion (ADP elements) [kg Sb-Equiv.]	3,99 E-007	3,47 E-007	5,65 E-007	6,46 E-007	1,76 E-006	1,87 E-006	5,85 E-007	1,90 E-006
Acidification Potential (AP) [kg SO2-Equiv.]	5,50 E-003	5,68 E-003	1,02 E-002	1,09 E-002	2,67 E-002	2,84 E-002	9,26 E-003	2,87 E-002
Eutrophication Potential (EP) [kg Phosphate-Equiv.]	5,15 E-004	4,67 E-004	7,96 E-004	1,02 E-003	2,83 E-003	2,99 E-003	7,49 E-004	3,03 E-003
Freshwater Aquatic Eco-toxicity Pot. (FAETP inf.) [kg DCB-Equiv.]	6,97 E-003	7,04 E-003	1,06 E-002	1,83 E-002	6,56 E-002	3,34 E-002	8,61 E-003	3,38 E-002
Global Warming Potential (GWP 100 years) [kg CO2-Equiv.]	2,33 E+000	2,11 E+000	3,49 E+000	5,42 E+000	1,49 E+001	1,80 E+001	3,29 E+000	1,82 E+001
Human Toxicity Potential (HTP inf.) [kg DCB-Equiv.]	9,76 E-002	1,20 E-001	2,26 E-001	2,10 E-001	5,15 E-001	4,94 E-001	2,12 E-001	4,97 E-001
Marine Aquatic Ecotoxicity Pot. (MAETP inf.) [kg DCB-Equiv.]	2,84 E+002	4,29 E+002	6,84 E+002	5,76 E+002	1,79 E+003	1,83 E+003	7,44 E+002	1,83 E+003
Ozone Layer Depletion Potential (ODP, steady state) [kg R11-Equiv.]	8,08 E-008	7,19 E-008	1,27 E-007	1,15 E-007	2,84 E-007	3,11 E-007	1,25 E-007	3,16 E-007
Photochem. Ozone Creation Potential (POCP) [kg Ethene-Equiv.]	4,41 E-003	5,73 E-003	8,43 E-003	5,65 E-002	2,63 E-001	9,25 E-003	1,01 E-002	9,30 E-003
Terrestrial Ecotoxicity Potential (TETP inf.) [kg DCB-Equiv.]	2,36 E-003	2,43 E-003	3,84 E-003	5,08 E-003	1,53 E-002	1,22 E-002	3,18 E-003	1,23 E-002
Radioactive Radiation (RAD) [DALY]	2,04 E-009	1,82 E-000	3,29 E-000	2,88 E-000	7,08 E-000	7,68 E-009	3,20 E-000	7,80 E-009

Figure 1. Overall normalised impacts of the coating systems 1 to 8 (arranged in increasing order of severity)