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MODEL FOR ANALYSIS OF ENVIRONMENTAL IMPACTS OF PRODUCTION PROCESSES IN FLOORING INDUSTRY BASED ON LCA

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Original scientific paper

The production of floor coverings, in terms of environmental impact, is a very complex process due to a large number of influential parameters – various chemical emissions, inevitability of waste, a great number of influential physical quantities such as noise and vibration, dust and radiation, energy consumption, recyclability, etc. Interest in the application of LCA within the production of floor coverings has been present for almost two decades and is intensely increasing. During this period different approaches and attempts of LCA implementation have been recorded in this broad field. This paper presents a general model for environmental impact assessment of the production process of floor coverings based on LCA. The developed model represents a contribution to the improvement and a further step towards the standardization of LCA analysis in this field of floor covering production. Verification has been carried out through a case study based on an industrial facility which produces PVC floor coverings.

Keywords: *environmental modelling, flooring coverings, life cycle assessment (LCA)*

Model za analizu utjecaja na okoliš procesa proizvodnje podnih obloga na bazi LCA

Izvorni znanstveni članak

Proizvodnja podnih obloga je, s aspekta utjecaja na okoliš, vrlo kompleksan proces zbog velikog broja utjecajnih parametara - različitih kemijskih emisija, neminovnosti otpada, većeg broja utjecajnih fizičkih veličina poput buke i vibracija, prašine i zračenja, zatim potrošnje energije, recikljivosti itd. Zanimanje za primjenu LCA u području proizvodnje podnih obloga traje već skoro dva desetljeća i postaje sve intenzivnije. Tijekom tog razdoblja evidentirani su različiti pristupi i pokušaji realizacije LCA u ovom širokom području. U ovom radu predstavljen je opći model za ocjenjivanje utjecaja na okoliš procesa proizvodnje podnih obloga zasnovan na LCA. Razvijeni model predstavlja doprinos unapređenju stanja u području i dodatni korak ka standardizaciji LCA analiza u području proizvodnje podnih obloga. Verifikacija je realizirana kroz studiju slučaja utemeljenog na realnom industrijskom postrojenju za proizvodnju PVC podnih obloga.

Ključne riječi: *modeliranje okoliša, podne obloge, procjena životnog ciklusa*

1 Introduction

Production and consumption, i.e. use of products are today's primary factors which cause adverse effects to the environment. At the same time, modern manufacturing processes are very complex in terms of their dependence on a great number of parameters, which are most often very diverse and whose individual influence on the final impact to the environment is very different [1, 2]. With that in mind, it is clear that the management of impacts of processes on environmental aspects represents a major challenge.

One of the important prerequisites for efficient management of the impact of processes on the environment is focusing on a specific category of processes. Production of floor coverings represents a significant segment of the modern industrial production, which has been developing intensively, both in terms of technological systems and in terms of applied materials. Also, the production of floor coverings, in terms of environmental impact, is a very complex process due to a large number of influential parameters – various chemical emissions, inevitability of waste, great number of influential physical quantities (noise, vibration, dust, radiation, etc.), energy consumption, recyclability, etc.

Methods for assessing the impact of processes on the environment are an important on-going segment of Environmental Management. This type of method has been developing for several decades, during which a great number of approaches have been devised. Among them, the life cycle assessment method (known as the LCA method) has proved to be the most comprehensive and most credible, and as such has been accepted as a standard in this field [3, 4]. The previous statement is supported with the following facts: the LCA method and its application are constantly regulated with the development of international standards (ISO 14040 i 14044) [5, 6]; the European Commission, through its Institute for environment and sustainability has declared the LCA method as one of the cornerstones of its sustainable development policy [7]; there is an evident growing interest in the application of the LCA method in recent years, in large number of the analysis of environmental load caused by various products and/or processes in developed countries, which is evidenced by a great number of published scientific and professional publications [8 ÷ 13].

Interest in the application of the LCA method, in the field of floor covering production, lasts for almost two decades and is intensely increasing. During this period different approaches and attempts to implement the LCA have been recorded in this field. Potting and Blok have observed [14] four types of floor coverings (linoleum, vinyl, and two types of carpets) presenting their environmental impact at all stages of the life cycle, whereby they have expressed no intention to compare floor coverings included in the analysis. Gunther and Langowski have conducted a similar study [15], comparing PVC, cushion PVC, olefin flooring and linoleum and have come to the conclusion that there is no material which can be singled out as "the best" or "the worst" in terms of environmental impact. In his study, Jones [16] has provided a comparison of different types of resilient floor coverings, such as vinyl, linoleum and cork flooring. Althaus and Richter [17] on the other hand have conducted a study which compares life cycle analysis of different cork floor coverings, which shows that cork floors with PVC coating imply a greater load on the environment than cork floors with varnish, despite the fact they do not require renovation. Gorree et al. [18] have conducted a detailed LCA study of linoleum, in which they have given a comparative overview of possible options for improvement within all phases of the life cycle and assessment of the results obtained with respect to methodological choice. Petersen and Solberg [19] have compared two alternative floor coverings, wood and natural stone for a new airport in Oslo and have only considered energy aspects and the greenhouse gas reduction potential, while later [20] they have compared the changes in ecological and economic impacts in the case of replacing the wood with other alternative materials. Bowyer et al. [21] in their report have reviewed and examined available data on life cycle evaluation for a large number of floor coverings, thereby summarizing research findings and data assessments from all over the world.

A general model for environmental impact assessment of the production process of floor coverings based on the LCA is presented in this paper. The developed model presents a contribution and a further step towards standardisation of the LCA analysis in the field of floor covering.

2 Development of the model for environmental impact analysis of production processes of floor coverings with the application of Life Cycle Assessment

Floor coverings are a complex product category, which includes a number of different types – from ceramic tiles, parquet and laminate, to PVC linoleum and carpet. However, despite the undisputable differences which characterize their composition and production, the life cycle of this product category is unique and distinctive; in Fig. 1 it is presented in its four main phases of the life cycle:

- Manufacturing phase: includes the production of raw materials, their transportation to the manufacturing plants, production of floor coverings and packaging;
- Installation phase: includes the transportation of the final product and the installation process;
- Use phase: includes scenarios of cleaning processes;
- End-of-life phase: includes scenarios for disposal and transportation to the landfill, incineration or recycling facilities.

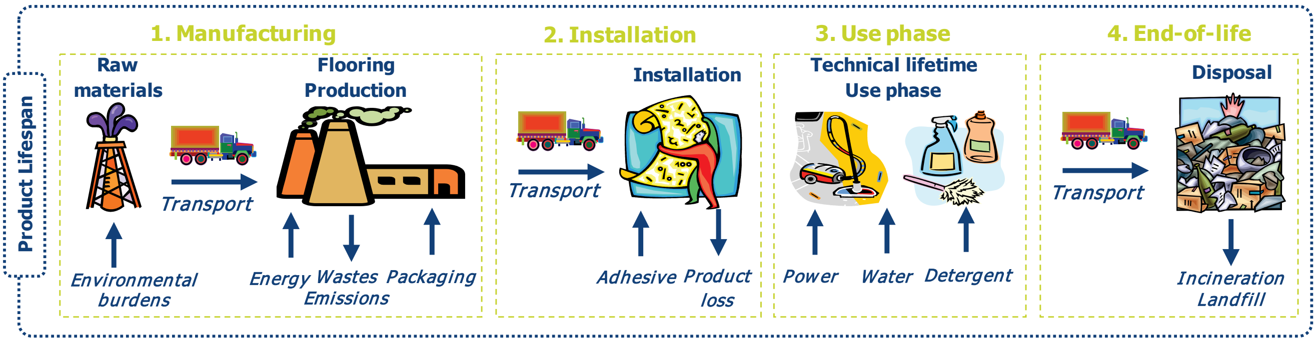

Figure 1 Life cycle of floor coverings – main phases

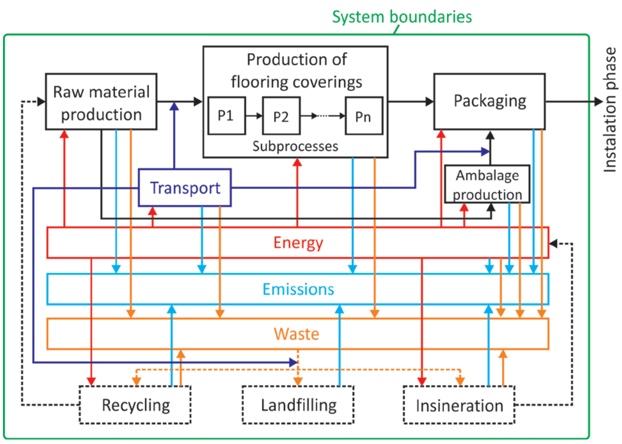

Figure 2 The general model for environmental management in the production process of floor coverings based on life cycle

Modelling the production process of floor coverings for the needs of environmental management included the development of the following elements:

- The general model for the environmental management in the production of floor coverings based on the life cycle assessment;
- Inventory model of the life cycle in the production of floor coverings;
- Model for assessing the impact of the life cycle in floor covering production.

Starting with the manufacturing phase of the floor covering life cycle (Fig. 1), respecting the instructions and recommendations of the standards ISO 14040 and 14044, an original general model for environmental management of the production processes of floor coverings based on the LCA method has been developed (Fig. 2). The model is characterised, primarily, by its generality which allows the LCA modelling of very different product systems in the field of floor cover production. This is followed by model flexibility, which reflects in the ability of modelling product systems at various levels of complexity of the manufacturing process, in terms of including sub-processes of lower hierarchical levels. When it comes to flexibility, the adaptability and applicability of the model in production processes are emphasized, this also includes "waste-to-energy" facilities, which has been demonstrated in the verification. The model is modularly constructed and is open to upgrade, mainly in the direction of including other phases of the life cycle.

2.1 Life Cycle Inventory model for the production of floor coverings

Life Cycle Inventory (LCI) model of the production of floor coverings includes 4 LCI submodels in relation to the phases of the life cycle of floor coverings (Fig. 3):

- LCI submodel of the manufacturing phase,
- LCI submodel of the installation phase,
- LCI submodel of the use phase,
- LCI submodel of the end-of-life phase.

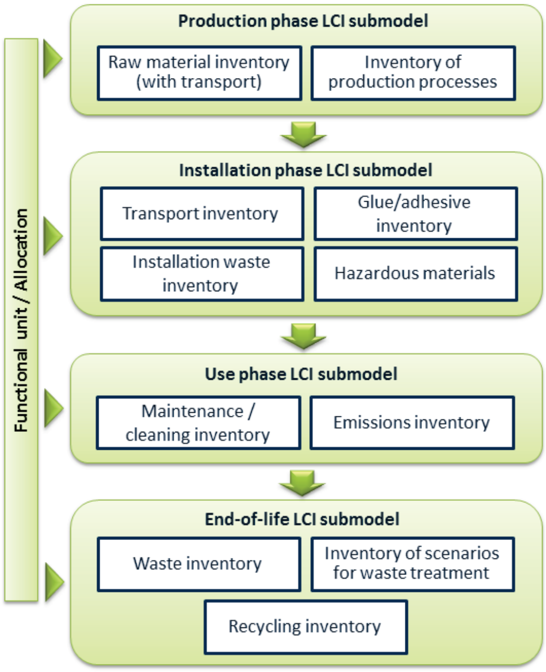

Figure 3 The structure of the life cycle inventory model in the production of floor coverings

Developed LCI submodel of the manufacturing phase is based on the developed documents for:

- Raw materials inventory (including transportation);
- Inventory of the manufacturing process.

The purpose of developed raw material inventory, presented in the case study within the verification (Fig 7), is defining the inputs for a "typical product" within a certain product family, including the type of transportation which is used for the delivery of raw materials to the manufacturing plant and the distance.

Inventory of the manufacturing process, also presented here in the case study (Fig. 8), enables the collection of relevant data regarding the input and output to and from the manufacturing process of floor covering, except for the data included in the inventory of raw materials.

LCI submodel of the installation phase is structured through four main components, typical for this stage of the life cycle for this type of product:

- Transportation inventory (from the manufacturing plant to the sales destination),
- Glue/adhesive inventory (optional in case of installation using glues/adhesives),
- Generated waste inventory (during installation) and
- Inventory of hazardous substances (optional in case of presence).

LCI submodel of the use phase consists of two main components, which can be considered typical for this stage of the life cycle, in the case of floor coverings:

- Maintenance/cleaning inventory and
- Emission inventory.

When it comes to the maintenance/cleaning inventory method and regime implied are those recommended, or prescribed by the manufacturer. Also, the calculations are carried out based on the technical implementation period, which is the implementation period determined by the manufacturer.

Emission inventory provides collecting of data on emission levels after 3 days, 28 days and 6 months, which is typical for this type of product in terms of the requirements imposed by standards in this area (EN15052, AgBB etc.), based on which, such data is also required from the program for environmental labelling (e.g., the German program Blue Angel). In context to the previous statement this inventory is meant to provide guidance for relevant standards, programs for environmental labelling and other documents which regulate emission field during the application of floor covering.

LCI submodel of the end-of-life phase consists of three components, i.e. documents:

- Waste inventory;
- Scenarios inventory for waste treatment and
- Recycling inventory (optional in case the part of the waste is being systematically recycled).

Waste inventory, in addition to specifying the amount of waste by type, requires the information on consumed energy during the process of dismantling the floor covering.

The second part of LCI submodel of the end-of-life phase deals with the scenarios that are applied within waste treatment, specified in the waste inventory. In the case that scenarios include recycling of certain types of waste, it is necessary to conduct a recycling inventory.

2.2 Life Cycle Impact Assessment model for the production of floor coverings

Life Cycle Impact Assessment (LCIA) model for floor coverings production is based on the results of SWOT analysis of current LCIA methodologies. The model allows the choice of suitable methodologies, depending, either on the requirements of a specific analysis, or on the characteristics of a LCIA methodology. When it comes to requirements of a specific analysis, their concern, above all, is with the connection between influences of the endpoint and especially midpoint impact categories (contained in the LCIA methodology) and characteristic production parameters of floor covering.

Fig. 4 represents a model based on which the selection of an adequate LCIA methodology is carried out. The model includes a feedback loop, in accordance with the iterative basis of the LCA, whose run is based on the results of interpretation.

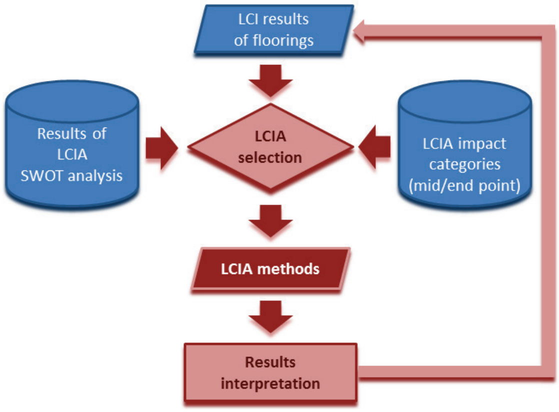

Figure 4 LCIA model of the production of floor coverings

3 Verification of the developed model

Verification of the developed model based on LCA for the environmental impact analysis of processes for production of floorings has been carried out through a case study of environmental impacts analysis of PVC (polyvinyl chloride) floor coverings production.

3.1 Defining the goal and scope

The goal of the case study is to analyse the total environmental load generated during the production of PVC floor covering, and based on that, identifying critical areas for improving environmental protection.

The scope of the study covers the analysis of the environmental impacts by the PVC flooring production, i.e. it is a "cradle-to-gate" study and considers the flows (inputs) from extraction of raw materials, to their processing and transportation to the place of production of the final product (background processes), in the so-called "upstream" part of the chain, but also the flows (outputs) after the production of the final product itself, as well as the power consumption, the resulting emissions, waste, etc. (foreground processes).

Setting the system boundaries partly depends on the questions that we want to answer, that is the goal of the study which is being conducted, and on the possibility of finding and obtaining data that will be used for evaluation. The limits which are set between the environment system (nature) and the observed production system (techno-sphere) involves the extraction of raw materials and their processing, i.e. production of input materials and their transportation, production of energy inputs, and then the production of the observed final product with all its unit processes, but also the resulting emissions and waste during the production. System boundaries, defined as described, ostensibly implicate two levels in the hierarchical structure of complexity. Previously described and appointed system makes a "higher level", while the "lower level" of analysis includes all unit processes (i.e. sub-processes) within the analysed system. This gives a detailed picture concerning the load on the environment by each unit process, reduces the uncertainty due to neglected flows and processes and provides a better insight into the identification of possible improvements to the product and the production system as a whole and reduces the negative load on the environment.

Based on the developed general model, with respect to the previously described specifications of the case study, a process model has been developed, which is shown in Fig. 5. The very process of production of PVC flooring is divided in total of nine process units, which are observed, and which will be discussed in more detail later on, within the inventory analysis. A functional unit is defined as 1 m^2 produced PVC flooring.

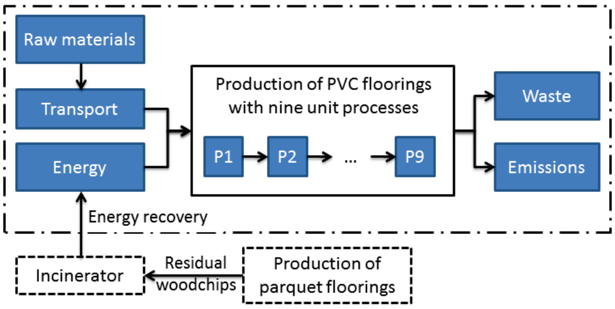

Figure 5 System products model with defined limitations

When it comes to allocation, in the process a number of raw materials enter the production process which produces several different products. In such cases the total negative impact has to be allocated, i.e. evenly distributed among all products. One suitable way, which has been applied here, is allocation based on the product mass [6, 7]. In this case study, although the facility for the production of PVC flooring produces several product outputs, thanks to their similarity in structure, mass and recipe, they are all combined into one product output. In that way, allocation in regards to various product outputs has been avoided. On the other hand, bearing in mind the process model, it was necessary to introduce allocation in regard to consumption of raw materials, energy and resulting emissions among the nine sub-processes based, as previously noted, on the product mass.

As limitations of this study, we can mention the exclusion of the installation, use and end-of-life phases, as well as the lack of data related to particular input raw materials. The latter is related to some of the chemical additives and pigments which are used in the production. Missing data is substituted with the approximate available replacements.

3.2 Life cycle inventory analysis

Data on the production system of PVC floor covering has largely derived from the analysed production facility and this is the so-called "foreground" data. In addition, other, very important sources of information, have been used, especially Eco Invent v2.2 database, also, professional literature, published scientific articles, as well as the studies previously done in the field of floor covering. In this way the so-called "background" data has been obtained.

PVC represents a major component in the recipe of PVC flooring. It is obtained from the chlorine in the gaseous form (Cl_2) generated by processing sodium chloride (NaCl) and ethylene, which is previously obtained by processing crude oil. Chlorine is then mixed with the ethylene to obtain vinyl chloride monomer (VCM), which after polymerisation gives PVC. Other components that are included in the PVC floor covering are so-called fillers, such as e.g. calcium carbonate, which is obtained by extraction and processing of limestone ore or chalk; then plasticizers (phthalate), which are commonly esters of polycarboxylic acids, followed by pigments (e.g., TiO_2, carbon black, cobalt, etc.), UV varnish, stabilizers, foaming agents, lubricants and a variety of other chemical additives. Combining and mixing the input chemical compounds, appropriate pastes are obtained, which are applied in several layers onto the carrier, usually a glass fleece.

In this observed case, application of the aforementioned pastes have been divided into six processes that have been separately analysed and called: Coating I, Coating II, Coating III, Coating VI, respectively (Fig. 6). Each of the processes mentioned are characterized by the appropriate paste compounds, which are slightly different in composition. After the application of each layer of paste onto the carrier, the process goes through a heating up phase, so that the new paste can better merge with the previous layer of paste, and then it is cooled down in order to harden and further stabilize, and prepare for the application of the next layer of paste. Using the process called Print, pigments and colours are applied in order to gain the desired design pattern. Another unit process can be singled out here, called Mechanical embossing, which has energy consumption, as the only item relevant to the analysis. Finally, in a process called UV coating, the final product, as the very name suggests, is being coated with a protective layer of UV varnish, which hardens under the influence of UV lamps, enabling a long-term protective layer to the floor coverings. After that the final product enters the preparation phase and packaging which is described by the unit process of the same name Packaging, within which inputs such as PE (polyethylene) film, PP (polypropylene), paper and cardboard tubes are involved.

Within the implemented analysis detailed information on each component has been collected, i.e. on each input raw material of the production recipe. Segmentation of the production process into smaller process units, helped in not disregarding any of the input or output components. Aside from the included input raw materials, the following have also been modelled: energy consumption, water consumption, and also waste generation and emissions for each process unit separately. The energy used can be divided into electric power, natural gas, diesel and bio-fuel (wood chips). Electric power and natural gas are obtained directly from the national distribution network. Natural gas is burned in a boiler to obtain useful heat required for the production process. Special emphasis is on bioenergy, which is obtained by burning wood waste (waste from another manufacturing process), that is burned in an incineration plant. This results in a certain amount of recovered energy, which is very important since it affects the reduction of environmental load (less waste generation) as well as reduction of costs (savings in the consumption of other fuels, primarily natural gas). It should be noted that energy consumption between the unit processes is allocated based on the mass of raw materials.

Emissions which have been observed and measured during the production are the CO_2, CO, SOx, NOx, particulate matter and VOC. The waste generated during the production of floor covering can be divided into hazardous and non-hazardous. Hazardous waste are the remnants of coating paste and the remains of various colours, which have to be separated from the waste water, generated from their washing and have to be subsequently treated. The non-hazardous waste includes municipal waste and waste generated during finishing (trimming) of the product and product packaging. One of the important items that should also be mentioned, and which is modelled, is transportation, both internal, within the facility itself, and external, with which feedstock from other manufacturers is delivered.

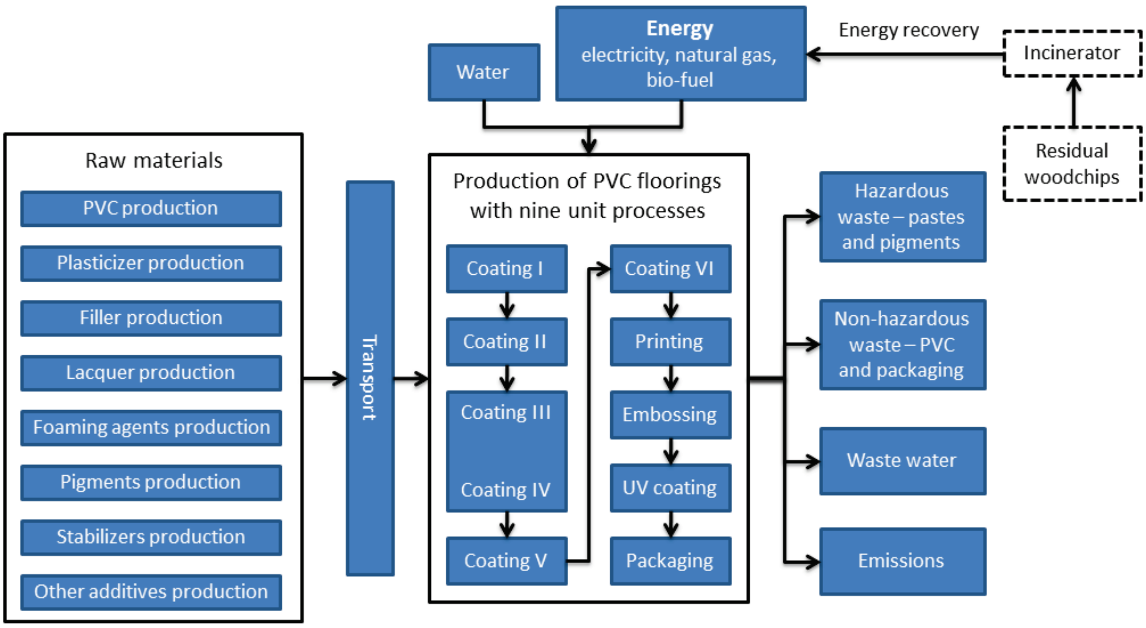

Figure 6 System products model with all unit processes covered

Art.	Component	Content wt%	Quantity kg/m²	Transport to company	
				Type	Distance km
Polymer	PVC Suspension	3,26	0,0814	road	790
	PVC Microsuspension	13,96	0,3490	road	1467
	PVC Microsuspension	3,05	0,0761	road	2113
	PVC Microsuspension	8,42	0,2105	road	1331
	PVC Emulsion	15,43	0,3859	road	790
Recycled materials	Recycled materials	0,00	0,0000	-	-
Plasticizer	DINP	10,55	0,2637	road	1467
	Monobenzoate	2,87	0,0716	road	1467
	Dibenzoate	0,45	0,0112	road	1432
	Ester of maleic acid	4,47	0,1117	road	1484
Stabilizer	Calcium/Zinc based	0,53	0,0134	road	1262
	Epoxidised soybean oil	0,20	0,0050	road	1242
	Biocide	0,00	0,0000	-	-
	Fungicide	0,00	0,0000	-	-
Filler	Calcium carbonate	34,57	0,8643	road	209
Pigment	TiO_2	0,07	0,0017	road	1319
	Pigment preparations	0,26	0,0064	road	1655
Other components	Polyurethane	0,27	0,0068	road	1408
	Glass fiber	1,40	0,0350	road	1628
	ZnO	0,15	0,0028	road	1510
	Azodicarbonamid	0,14	0,0035	road	951
Finished product		100,00	2,5000		

Figure 7 Design of document for raw material input inventory with data of the PVC floor coverings production

INPUTS			OUTPUTS		
Raw Material	2,75	kg/m²	**Products**	2,500	kg/m²
Energy			**Valorised Waste**		
Electricity	7,3	kW·h/m²	Internal recycled materials	0,00	g/m²
Fuel oil	0,1	kW·h/m²	External recycled materials	49,00	g/m²
Gas	0,7	kW·h/m²			
Bio fuel	11,6	kW·h/m²	**Non-Valorised Waste**		
Other	-	kW·h/m²	Landfill waste	28,00	g/m²
			Hazardous waste	10,00	g/m²
Water consumption	0,25	l/m²			
			Emissions to air		
Packaging	0,55	kg/m²	VOCs	677,0	g/m²
Wood	0,25	kg/m²	CO_2	503,0	g/m²
PE film	0,05	kg/m²	NO_x	2,5	g/m²
Cardboard	0,1	kg/m²	CO	5,0	g/m²
Paper	0,15	kg/m²	Particulate matter	4,5	g/m²
Others (if applicable, please specify)	-	kg/m²	**Others** (if applicable, please specify)	-	kg/m²
The quantifications of consumptions, products/auxiliaries and emissions/wastes should be on yearly average values per respective functional unit. If measured values are not available, please indicate shortly the calculation base per process step.					

Figure 8 Design of document for production process inventory with data of PVC floor covering production

In Fig. 6 all of the aforementioned processes involved in the production of PVC floor coverings are shown in schematic detail. Inventories of raw materials are given in Fig. 7 and 8, i.e. all the inputs/outputs of the production process of PVC floor coverings.

3.3 Life cycle impact assessment

Based on the inventory analysis and the collected data on the modelled processes, evaluation of the life cycle of PVC floor coverings production has been carried out. Modelling has been conducted using specialized software SimaPro 7, and the selected LCIA method was IMPACT 2002+. In addition to the lack of regional limitations and detailed description of scientific dependencies of the LCIA method, it should be mentioned here that one of the main reasons for this choice is the ability to connect and implement the combined approach of the midpoint/endpoint impact category approach. Accordingly all types of life cycle inventory results, elementary flows and other impacts are further connected, through fifteen midpoint impact categories which are summarized within the four damage, i.e. endpoint impact categories.

Fig. 9 shows the results of the characterization and the percentage of the relative values of each sub-process (as defined and described above within the process model of PVC floor covering production) for all midpoint impact categories. In other words, the total amount (100 %) of each impact category is distributed to the production sub-processes from which it originated. The more realistic insight of the situation is given in the results of the endpoint impact categories (damage assessment) [9]. From the results in Fig. 9 it is obvious which of the sub-processes has a significant impact, i.e. where are the greatest opportunities for reducing impact on the environmental.

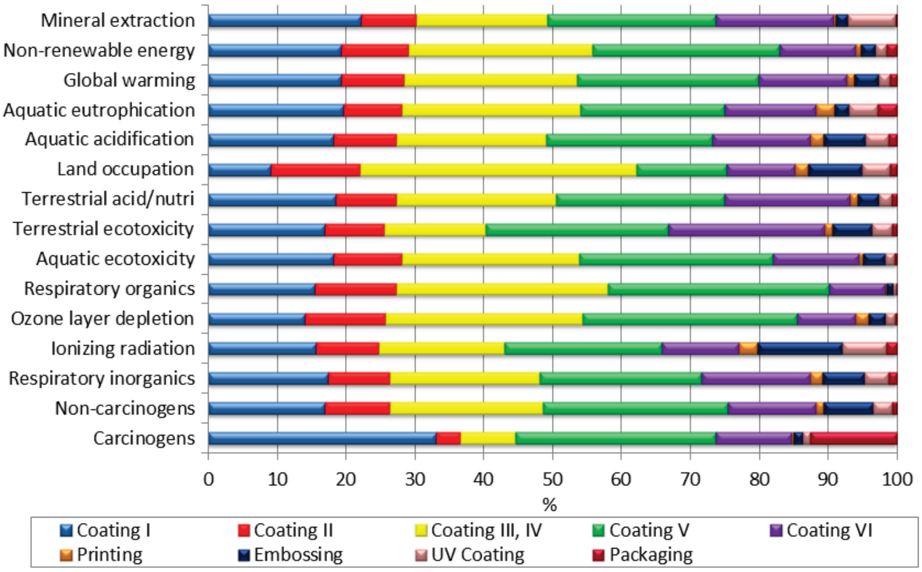

Figure 9 Results of characterization with shares of sub-processes in midpoint impact categories

3.4 Scenario analysis

In order to verify the effectiveness of the developed model in the environmental management, within this case study two scenarios have been presented and compared:

- "Scenario 1" represents a situation without the incinerator, i.e. without the use of bio-energy, i.e. production based on natural gas as a primary energy input.
- "Scenario 2" represents the scenario with the incinerator, i.e. the production of PVC floor covering which includes a bio-energy obtained by burning waste sawdust (from a different production process of wood flooring).

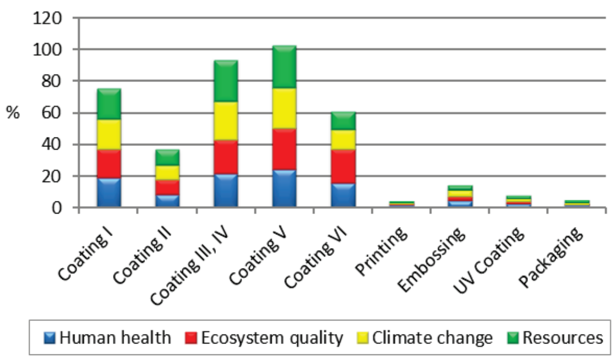

Figure 10 Results of the environmental load in scenario 1 for sub-processes in the production of PVC floor coverings in endpoint impact categories

Results for individual scenarios are presented in Fig. 10 and 11, and comparative analysis in Fig. 12 to 14.

In this way it is possible to analyse, in this case, the benefits of incorporating the incinerator within the facility, separately for each sub-process of production. Some of the sub-processes which have minimal differences, have been omitted from the comparative analysis, due to lower energy consumption, so the focus has been placed only on those sub-processes which have the largest share in the total load, which as it can be seen are the sub-processes Coating I to Coating VI.

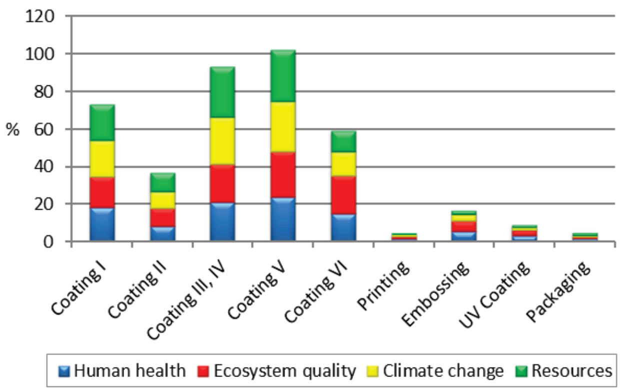

Figure 11 Results of the environmental load in scenario 2 for sub-processes in the production of PVC floor coverings in endpoint impact categories

Comparative review of results of the evaluation of environmental damage and results of the normalization of the entire production process for scenarios 1 and 2, through the endpoint impact category, are given in Fig. 13 and 14, all with the aim of presenting a clearer distinction. The purpose of normalizing the results is the analysis of the relevant share of each of the impact on the total damage within the considered impact category. This facilitates the interpretation of the results through the comparison of different categories on the same graph in the same units. Normalization is achieved by dividing the impact (in the damage category) with the corresponding normalization factor.

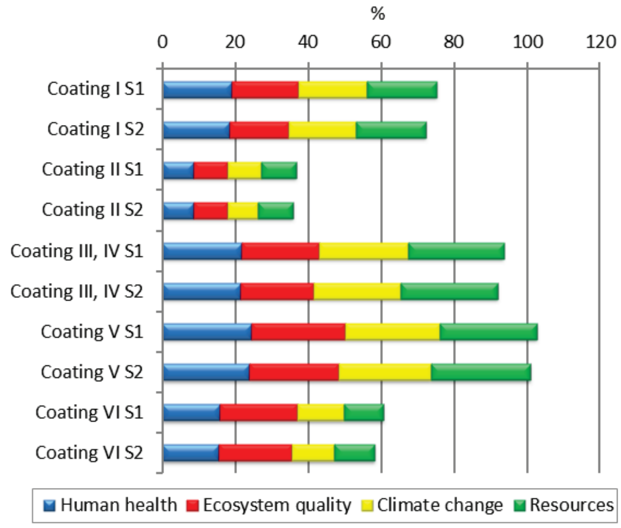

Figure 12 Comparative review of the results of the environmental load in scenario 1 (S1) and scenario 2 (S2) for sub-processes in the production of PVC floor coverings in endpoint impact categories

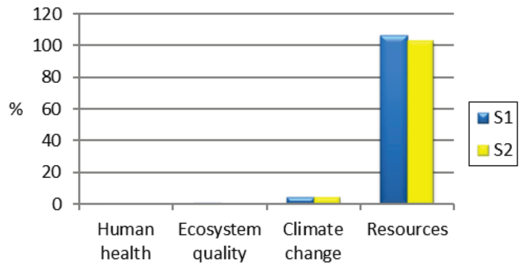

Figure 13 Comparative review of the results of the environmental load assessment in scenario 1 (S1) and scenario 2 (S2) in endpoint impact categories

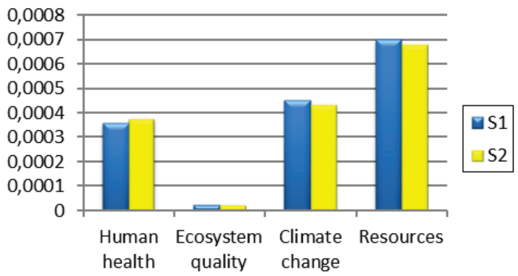

Figure 14 Comparative review of the results of normalization in the scenario 1 (S1) and scenario 2 (S2) in endpoint impact categories

In the Impact 2002+ method, normalization factor represents the total impact of a specific category divided by the total population of Europe [6, 7]. As it can be seen, the results of the normalization are drastically different from the results of the evaluation of damage, which indicate a negligible impact of both scenarios on human health and ecosystem quality, which, due to very small values ($2{,}55\times10^{-6}$ % and $2{,}68\times10^{-6}$ %) are not shown in Fig. 13. On the other hand, the normalized values show a respectable adverse effect on human health category, which is further exacerbated by the implementation of the incinerator.

3.5 Interpreting and discussing the results

The results obtained indicate that the maximum load comes from the sub-process Coating V, followed by Coating III and Coating IV, and then followed by Coating I, Coating II and Coating VI. Compared to these sub-processes, the load of the other sub-processes is negligible, which is why it has not been included in the discussion below. Observing results at the level of the midpoint impact categories, the greatest load has been recorded within the respiratory inorganics impact categories, global warming and non-renewable energy. The greater load generated within the respiratory inorganics impact category can be correlated with the presence of nitrogen oxides emissions, particulate matter and sulphur oxides in the production process. As far as the load on the impact category of global warming is concerned, it is mostly derived from the emission of CO_2 when burning fossil fuels, which are used as an energy input. When we talk of the impact category of non-renewable energy, the resulting load can be explained by the consumption of mainly primary raw production materials, i.e. PVC, which uses oil for production, and also the combustion of natural gas can be singled out, as the next process that has the biggest impact.

Observing the resulting loads, which can be attributed to the consumption of input raw materials for production, mainly PVC as primary raw material, but also the consumption of energy, primarily natural gas, can lead to potential improvements in these problems. This is also shown in the comparative analysis of the two scenarios, with and without bio-energy from burning sawdust. This solution, with the partial replacement of primary energy source (natural gas), a reduction occurs in the total load generated during the production of the PVC floor covering, within all sub-processes, by observing the sum of all impact categories, as can be seen in Fig. 9. However, this analysis also shows that the mentioned improvement is based, for the most part, on the level reduction of the climate change impact category, and to some extent the quality of the ecosystem impact category. In the remaining two endpoint impact categories, no significant improvement has been noted, and in some cases a slight deterioration has been noticed - the level of human health impact category in sub-processes Coating II. The reasons for such results are to be found in the increased emissions of particulate matter by burning wood waste. In this way, through this comparative analysis, the accompanying negative effect of the incineration facility is identified.

The greatest decrease in the total load within the endpoint climate change impact category, i.e. midpoint global warming impact category, can be explained with the reduced consumption of natural gas, which is replaced by biofuel, and whose combustion emits CO_2, which affects global warming. Also, the reduced consumption of natural gas, as a non-renewable source of energy, leads to a reduction in the load within the non-renewable energy sources impact category. Another positive effect when introducing the combustion of sawdust is solving the problems of partial waste disposal within the production. Negative effects on the environment, since the introduction of such a system for energy recovery, which are related to the increase in emissions of particulate matter in the process of combustion of sawdust, are possible to be eliminated by installing filters in the incinerator's chimney system.

4 Conclusion

The research results presented in this paper show that taking into account all the life cycle phases of the processes and the products, enables a broader context of problem analysis, i.e. provides a more complete picture. In this particular case, it has been shown on the example of the environmental impact of the production of floor covering. While the focus is on the flooring industry, as a very important branch of industrial production at the global level, this paper represents a relevant example, but also a good basis for the application of the concept of life-cycle assessment of processes and products in other areas of industrial production.

In a more specific sense, the model described in this paper represents a tool for effective environmental management in industrial systems for the production of floor coverings. The developed model provides science-based analysis of design, technology and material impacts on the environment. It also enalbes particular analysis of influence of changes in the production processes, of those that have already been made, as well as those that are in the planning process. The latter implies the possibility of using the model for the evaluation of future technological innovations in this type of industrial production.

Verification results prove the efficiency of the developed model and its practical value. Significant value of the verification results is reflected in the possibilities of "discovering" hidden negative aspects of technological innovation that could, with the use of the developed model, be improved. Part of the general model to which most of the credit for these features belongs, which has practically confirmed the possibility of analysing relevant production parameters, is the LCI model, which is characterized by the distinct comprehensive and systematic approach, both on the horizontal (life cycle phases) and on the vertical level (production processes and organization).

The achieved results represent a good basis for further research, both in the production of floor covering, and in the broader context of industrial production. When we speak of the possible directions of future research in the production of floor covering, one is certainly the expansion of the boundaries of the analysed system and involvement of installation, use and end-of-life phases. This will expand opportunities for environmental management based on the developed general model. The next possible direction for further research is the analysis of the impact of input raw materials, which are used in production, with an emphasis on identifying their potential substitution with adequate replacement raw materials. For example, by the introduction of recycled PVC, the consumption of the primary input PVC can be reduced up to 30 %. It is estimated that this would contribute to reduction of the environmental loads.

5 References

[1] Agarski, B.; Budak, I.; Kosec, B.; Hodolic, J. An Approach to Multi-criteria Environmental Evaluation with Multiple Weight Assignment. // Environmental Modeling & Assessment. 17, 3(2012), pp. 255-266.

[2] Krajnc, M.; Dolsak, B. Computer and experimental simulation of biomass production using drum chipper. // International Journal of Simulation Modelling. 12, 1(2013), pp. 39-49.

[3] Agarski, B.; Kljajin, M.; Budak, I.; Tadic, B.; Vukelic, D.; Bosak, M.; Hodolic, J. Application of multi-criteria assessment in evaluation of motor vehicles' environmental performances. // Tehnicki Vjesnik-Technical Gazette. 19, 2(2012), pp. 221-226.

[4] Simunovic, K.; Draganjac, T.; Simunovic, G. (2008). Application of different quantitative techniques to inventory classification. // Tehnicki Vjesnik-Technical Gazette. 15, 4(2008), pp. 41-47.

[5] ISO 14040. Environmental management - Life cycle assessment - Principles and framework. 2006.

[6] ISO 14044. Environmental management - Life cycle assessment - Requirements and guidelines. 2006.

[7] ILCD International Reference Life Cycle Data System (ILCD) handbook. General guide for life cycle assessment-detailed guidance - first edition. European Commission Joint Research Centre, Institute for Environment and Sustainability, 2010.

[8] Vujicic, A.; Zrnic, N.; Jerman, B.: Ports sustainability: A life cycle assessment of zero emission cargo handling equipment. // Strojniski Vestnik - Journal of Mechanical Engineering. 59, 9(2013), pp. 547-555.

[9] Finnveden, G.; Hauschild, M. Z.; Ekvall, T.; Guinee, J.; Heijungs; R., Hellweg, S.; Koehler, A.; Pennington, D.; Suh, S. Recent developments in Life Cycle Assessment. // Journal of Environmental Management. 91, 1(2009), pp. 1-21.

[10] Helias A.; De Haes U. Applications of Life Cycle Assessment: expectations, drawbacks and perspectives. // Journal of Cleaner Production. 1, 3-4(1993), pp. 131-137.

[11] Ayres, R. U. Life cycle analysis: A critique. // Resources, Conservation and Recycling. 14, 3-4(1995), pp. 199-223.

[12] Ehrenfeld, J. R. The importance of LCAs – Warts and All. // Journal of Industrial Ecology. 1, 2(1998), pp. 41-49.

[13] Krozer J.; Vis J. How to get LCA in the right direction. // Journal of Cleaner Production. 6, 1(1998), pp. 53-61.

[14] Potting J.; Blok K. Life-cycle assessment of four types of floor covering. // Journal of Cleaner Production. 3, 4(1995), pp. 201-213.

[15] Gunther A.; Langowski H. C. Life Cycle Assessment study on resilient floor coverings. // International Journal of Life Cycle Assessment. 2, 2(1997), pp. 73-80.

[16] Jones S. Resilient flooring: a comparison of vinyl, linoleum, and cork. Georgia Tech Research Institute. 1999.

[17] Althaus H. J.; Richter K. Life cycle analysis (LCA) of different cork floorings. Swiss Federal Laboratories for Materials Testing and Research, Materials and Systems for Civil Engineering (EMPA), 2001.

[18] Gorree M.; Guinee J. B.; Huppes G.; Van Oers L. Environmental life cycle assessment of linoleum. // International Journal of Life Cycle Assessment. 7, 3(2002), pp. 158-166.

[19] Petersen A. K.; Solberg B. Substitution between floor constructions in wood and natural stone: comparison of energy consumption, GHG emissions, and costs over the life cycle. // Canadian Journal of Forest Research. 33, 6(2003), pp. 1061-1075.

[20] Petersen A. K.; Solberg B. Environmental and economic impacts of substitution between wood products and alternative materials: A review of micro-level analyses

from Norway and Sweden. // Forest Policy and Economics. 7, 3(2005), pp. 249-259.
[21] Bowyer J.; Bratkovich S.; Fernholz K.; Lindburg A. Life cycle assessment of flooring materials - A guide to intelligent selection. Dovetail Partners, Inc., Minneapolis, 2009.

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