

Jana Kotovicová*

LIFE CYCLE OF FLOORS FOR AGRICULTURAL PREMISES

CYKL ŻYCIOWY PODŁÓG BUDYNKÓW ROLNICZYCH

Słowa kluczowe: LCA (analiza cyklu życia), posadzki przemysłowe, pomieszczenia rolnicze.

Key words: LCA, industrial floors, agricultural premises.

Ponieważ pojęcie „posadzki przemysłowe” może być rozumiane na wiele sposobów, konieczne okazało się doprecyzowanie i zdefiniowanie pewnych kryteriów badawczych, stosowanych w analizach cyklu życia (LCA).

Na potrzeby tego badania z wielu asortymentów wybrano posadzki budowane na bazie betonu, asfaltów oraz materiałów utwardzalnych. Taki podejście oznacza wybór rodzajów materiałów do bardziej szczegółowych analiz. Powód takiego ograniczenia wynika ze złożoności problemu przy jednoczesnej konieczności przedstawienia czytelnych i łatwych do interpretacji wyników badań. Powyższy wybór wynika również z analizy rynku: te rodzaje posadzek są najczęściej wykonywane i sprzedawane. Są one bowiem powszechnie stosowane w rolnictwie z powodu ich przydatności i niskiej, konkurencyjnej ceny. Wybrano posadzki utwardzane na sucho z powodów ich niskiej ceny i częstej stosowalności w pomieszczeniach rolniczych.

1. INTRODUCTION

Thanks to the growing public awareness of the quality of environment and gradual application of the instruments of environmental policy, we can observe an ever-growing interest of both industrial firms and general public in the impacts of production and services on the living environment and in the effort to minimize them. The reaction to the actual situation gave rise to the development of various methods and approaches to the assessment of the

* *Doc. RN Dr. Jana Kotovicová, Ph.D. – Ústav aplikované a krajinné ekologie, Agronomická fakulta, Mendelova zemědělská a lesnická univerzita v Brně, ut. zemědělská 1, 613 00 Brno, Česká Republika; tel.: +420 545 132 484; kotovicj@mendelu.cz*

environmental impacts of production and services, which dates back to the beginning of the 60s of the last century. The goal of these efforts is to select, promote and produce a product or a working process that would be the most favourable from the ecological aspect. Nevertheless, the developed methods required a great amount of information and often rendered variant and incomparable results. To bring into effect complete characteristics of the environmental impacts of behaviour of human society, it was necessary to consolidate the hitherto used methodology and to create a more or less uniform apparatus known at present under the term of Life Cycle Assessment (LCA). This method studies the environmental aspects of production and their possible impacts on the living environment in the course of the whole life of the product, starting from the obtainment of raw materials, through the production, utilization, the disposal and waste management, which is „from cradle to grave”.

2. MATERIAL AND METHODS

An ecological product should be able to declare its origin and its energy demand in its production. To compare the energy demand of various products, the method of “Life Cycle Assessment of Products” (LCA) is applied. Using this method, we can define the amount of energy necessary for the production and, at the end of the life cycle, also for recycling the definite product (a car, a kilogram of detergent or for example of thermal insulation) and also the amount of emissions released into the environment.

The manufacturing of concrete mixtures should not disturb its neighbourhood; it is therefore of prime importance to locate properly the producing plant and to use advanced manufacturing technology, which eliminates the negative impacts on the living environment.

Dustless and completely waste-free operation of concrete mixing plants should be environmentally-friendly and also regardful of the working environment of the employees. The recycling equipment cleans the residues of concrete mixtures from the washing of agitator trucks and concrete pumps. Clean material and recycled water are returned back to the production process.

The environmentally-friendly behaviour is given by the possibilities offered by the up-to-date technologies and not least, by a responsible and systematic approach of the manufacturer. It is of prime importance to select correctly the site of the concrete mixing plant and to apply advanced technology to eliminate the negative impact of the manufacturing process on the living environment, to green the surroundings of the producing plants so that the natural landscape pattern be not harmed. The present-day aesthetically designed producing plants thus become an important salient feature of their surroundings, they are built up as waste-free producing plants, fitted with efficient filtering equipment and they are very environmentally-friendly.

As in every industrial activity, also the mining of gravel sand affects the natural landscape pattern. Many companies strive to minimize these impacts, to seek new positive fac-

tors of the mining process and to take advantage of them. In the framework of reclaiming the technical land, the newly created water is incorporated into the landscape. In the exhausted areas, plantations are founded, grown-up trees are planted, shores are reinforced with newly-planted bushes, and this all in relation to the regional biocorridors in the given region. In many cases, the locality is after the exploitation environmentally more valuable than before the beginning of the exploitation.

To dispose of the concrete in an ecologically accepted manner, there are specialized firms equipped with special facilities. In most cases, the waste originator finances both the recycling and transportation of needless concrete to the site of the recycling line. A specialized firm assort the concrete (and/or debris) and tries to arrange it for further use. For example, as a component part of compost, to reinforce forest-roads and cart-roads or to reinforce building sites for various purposes. It is also possible to reuse the broken concrete to prepare concrete.

After a definite period of time, concrete may lose the properties it had when it was placed. It may crack and "spall" due to external actions and it may be generally harmed by frequent use. In this case, the users have several possibilities. They can either remove the given concrete or they can improve it with a new layer of concrete, which will cover the shortcomings of the old one. The disadvantage of this method is its profitability in dependence on the total service life of the structure.

As we have already mentioned, this study is limited mainly to poultry breeding and/or to its application in the farms specialized primarily in poultry breeding. This example can be used to demonstrate the service life of concrete. The standard service life of concrete when used in a traditional manner is approx, 30–50 years in dependence on the quality of material, placing, etc. The poultry's dejecta contain acid elements, which deteriorate the concrete and thus the standard service life is essentially reduced. Placed concrete thus have to be repaired at regular intervals (reconstruct) or it has to be placed once again. There exist many technical solutions to prevent or to reduce these problems. It is primarily a case of regular coatings and preventive repairing of local deterioration.

The term recycling in its general meaning means that the existing ripped-up (or milled-out) asphalt can be melted and placed back to the original place or to a new place. The material to be recycled is processed mechanically and thermally. Asphalts are recycled direct on site.

Dry-shakes essentially mean further treatment of concrete, so we can say that recycling is in this aspect practically identical to the recycling of concrete. It is thus a case of overlaying (reconstruction) of the existing concrete layer, when the old surface is used as a base for the placing of a new top layer. Another possibility is to remove the existing concrete and in this case the recycling would consist in the fact that expert firms will crush the material to obtain the required fraction, they will size it and use it as reinforcement or it will be added to the new concrete by the dry-shake treatment.

The concrete dry-shakes as a surface treatment of concrete are very advantageous, however, they are at the same time essentially more expensive than traditional concrete. Nevertheless, the concrete with dry-shake technology improves its structure and its properties in general. It also considerably extends its service life. This is the reason why at present a lot of firms select exactly this concrete variant with dry-shake technology. The acquisition costs are considerably higher, nevertheless, thanks to a longer service life and higher resistance of the floor, the costs related to the acquisition will return in the form of a longer use of the floor and in the form of lower costs related to its possible repairs.

3. DEFINITION OF THE SUBJECT MATTER OF ANALYSIS

The aim will therefore be to compare which of the three industrial floors has the best properties and especially which of them has the least environmental impact.

Table 1. Advantages and drawbacks of the compared industrial floors

Tabela 1. Zalety i wady w porównaniu posadzek

Feature	Concrete	Dry-shakes	Asphalt
Advantages	price	long service life	wear resistance
	strength	resistance to abrasion	noise damping
	stiffness	dustless	watertight
	planeness		resistant to heat-frost alternation
Drawbacks	dusting	technological exigence	deformation
	low resistance to abrasion	price	follow-up reconstruction with asphalt
	absorptivity		thermal instability

4. RESULTS AND DISCUSSION

The presented data related to the individual flows in the evaluated systems were obtained from the records of the companies, technological descriptions and/or verbal consultations with appointed workers of the technological department and from the records kept by the company environmentalist.

Table 2. Stocktaking matrix for the production of concrete and dry-shakes

Tabela 2. Bilans matrycy do produkcji betonu i suchych trziesięi

Technological operations	INPUTS			OUTPUTS		
	Petrol [litres]	Diesel oil [litres]	Electric power [kWh]	Emissions of CO ₂ [g]	Noise [dB]	Waste [kg]
Unit [per 1000 m ² of products]						
Collection of soil	–	32	–	2321	107	–
Soil haulage	–	194.25	–	14089	85	4000 ¹⁾

Aggregate haulage	–	166.5	–	12076	85	–
Aggregate cartage	–	13	–	943	107	–
Aggregate compaction	–	5	–	363	63	–
Mixing of concrete	–	–	131.35	–	–	76
Concrete cartage	–	177.6	–	12881	85	120
Placing concrete	–	–	87.5	–	73	150
Vibration of concrete	–	–	1.5	–	30	2
Application of dry-shakes						
Pulverisation of emulsions	5	–	–	340		–
Scouring	60	–	–	4075		2
Cutting of expansion joints	24.2	–	–	1643	108	–
Disposal	–	52	–	–	110	375000 ²⁾

Table 3. Stocktaking matrix for the production of asphalt

Tabela 3. Bilans matrycy do produkcji asfaltu

Technological operations	INPUTS			OUTPUTS			
	Unit [per 1000 m ² of products]	Ground gas [litres]	Diesel oil [litres]	Electric power [kWh]	Emissions [g]	Noise [dB]	Waste [kg]
Collection of soil	–	–	32	–	2321	107	–
Soil haulage	–	–	194.25	–	14089	85	4000 ¹⁾
Aggregate haulage	–	–	166.5	–	12076	85	–
Aggregate cartage	–	–	13	–	943	107	–
Aggregate compaction	–	–	5	–	363	63	–
Mixing of asphalt	1250	–	–	126	69375		
Haulage of asphalt	–	–	83.25	–	6038	85	–
Placing of asphalt	–	–	44	–	3191	86	
Rolling of asphalt	–	–	16	–	1160	74	
Disposal	–	–	58	–	4207	102	250000 ²⁾

Note: ¹⁾ In this case the soil was considered as waste in view of the fact that it was not further employed in the production of concrete floor, nevertheless, it can be used as back-fill or fill in further building activities and/or it may be deposited in a dumping place. ²⁾ Material produced in the disposal of old asphalt floor may be regarded as waste and deposited in a dumping site, nevertheless, in practice, this “waste” is considered to be valuable raw material for consequent utilization in placing asphalt surfaces.

5. EVALUATION OF ASSESSED TECHNOLOGIES

„*Evaluation of energy demand*”, i.e. the consumption of energy obtained by transformation of primary non-renewable resources. Data on the electric power consumption in the individual stages of both assessed technological processes necessary to produce 1 m² of products are presented in the following Table 4.

Table 4. Evaluation of energy demand**Tabela 4.** Ocena zapotrzebowania na energię

Operation	Unit	Concrete, Dry-shakes	Asphalt
Mixing	kWh/m ²	0.131	0.126
Placing	kWh/m ²	0.088	–
Vibration (compaction)	kWh/m ²	0.002	–
TOTAL	kWh/m ²	0.221	0.126

The first classification part also includes the consumption of primary energetic raw materials. Table 5 represents the amount of gasoline, diesel oil and ground gas necessary to assure all technological processes of the assessed technologies related to the production of 1 m² of products.

Table 5. Consumption of primary energetic raw materials to assure the technological processes**Tabela 5.** Zużycie podstawowych surowców energetycznych, aby zapewnić procesy technologiczne

Raw materials	Unit	Concrete	Dry-shakes	Asphalt
Gasoline	[l/m ²]	0.084	0.089	–
Crude oil	[l/m ²]	0.640	0.640	0.612
Earth-gas	[l/m ²]	–	–	1.250
TOTAL	[l/m ²]	0.724	0.729	1.862

Table 6. General review of productions outputs**Tabela 6.** Ogólny przegląd produktów wyjściowych

PRODUCTION OUTPUTS	Concrete	Dry-shakes	Asphalt
CO ₂ [g/m ²]	48.391	48.731	113.763
Waste [kg/m ²]	379.350	379.350	254
Mean noise value [dB] *	93.43	93.43	86.59

*Mean noise level was defined as a weighted mean in which the weights constituted mean operating time of the individual machines.

The contribution to the green house effect forms part of the third classified group. From the aspect of its action, the green house effect has a global character and it ranks therefore among the most important environmental impacts. It contributes to the increase in global temperature, without respect to the site of origin of the emissions.

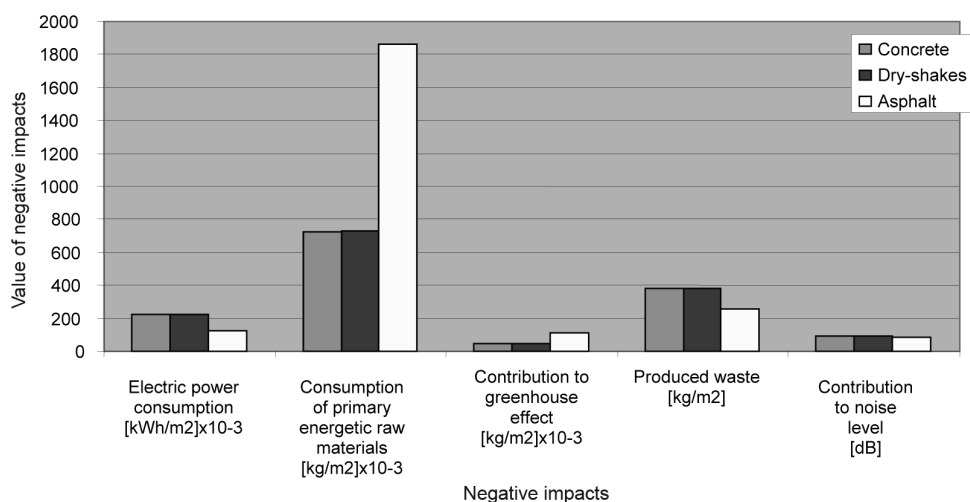
The amount of produced waste has been included into the fourth classified group, because the amount of waste plays an important role in the ecological and subsequently also in the economic aspects of production.

The measure of noise was included in the last classified group. It was defined by the weighted mean from the aspect of the operating time of the individual working machines. The noise level has a disastrous influence on the standard of living of the population and the workers.

Table 7. Total negative impacts acting on the living environment

Tabela 7. Suma negatywnych skutków działających na otoczenie

Classification group	Units	Concrete	Dry-shakes	Asphalt
Power consumption in examined processes	[kWh/m ²]	0.221	0.221	0.126
Consumption of primary energy raw materials	[kg/m ²]	0.724	0.729	1.862
Contribution to green house effect	[kg/m ²]	48.391×10 ⁻³	48.731×10 ⁻³	113.763×10 ⁻³
Produced waste	[kg/m ²]	379.350	379.350	254.000
Contribution to noise level	[dB]	93.43	93.43	86.59
Total negative impact	–	473.773	473.778	342.692



Graph. Total negative impacts acting on the living environment in the production of floors

Wykres. Suma negatywnych wpływów na otoczenie podczas produkcji podłóg

The assessed technologies, variants marked as X_1 , X_2 a X_3 may be evaluated according to the action of determined negative environmental impacts according to the criteria marked A_1 through A_5 , applying mathematical operational analysis. To the purpose, one of the methods of multicriterion evaluation was selected. Specifically, in question is the weighted sum method, whose essential part is the determination of the weights of the selected criteria. To determine the weights, the so-called scoring method was selected. For each criterion, all the interested persons determined point scoring evaluation using a 0 to 5 scale. The more important is the criterion for the given person, the higher is the scoring. The review of point scoring by the individual persons is represented in Table 8.

Table 8. Review of point scoring of the criteria

Tabela 8. Przegląd punktacji kryteriów

Designation of criterion*	Person 1	Person 2	Person 3
A ₁	2	3	3
A ₂	5	4	5
A ₃	4	3	4
A ₄	3	3	2
A ₅	1	1	2
Total:	15	14	16

***Explanatory notes:** A₁ – represents the electric power consumption; A₂ – represents the consumption of primary energetic raw materials, i.e. crude oil and ground gas; A₃ – designates contribution to the greenhouse effect; A₄ – designates the contribution of the produced waste; A₅ – designates contribution to the noise level.

On the base of the above data, the weights of the criteria were determined according to the individual participating persons. Described calculation is represented in Table 9.

Table 9. Calculation of weights for the defined criteria

Tabela 9. Obliczenie wagi dla określonych kryteriów

Criterion (v _{ij})	Person 1	Person 2	Person 3	Σv _{ij}	Total weight (v _i)
A ₁	0.133	0.214	0.188	0.535	0.178
A ₂	0.333	0.286	0.313	0.932	0.311
A ₃	0.267	0.214	0.250	0.731	0.244
A ₄	0.200	0.214	0.125	0.539	0.180
A ₅	0.067	0.071	0.125	0.263	0.088

The established vector of weights for the needs of this study is therefore as follows: V = (0.208; 0.291; 0.185; 0.213; 0.102).

Each VHV task is characterized by the so-called criteria matrix, in which the columns correspond to the criteria, in this case A₁ through A₆, and the lines correspond to the evaluated variants (X₁ a X₂). The elements of matrix a_{ij} express the evaluation of i-variant according to j-criterion. The criteria matrix has the following form:

$$Y = \begin{pmatrix} A_1 & A_2 & A_3 & A_4 & A_5 \\ 0.221 & 0.724 & 48.391 \times 10^{-3} & 379.350 & 93.43 & X_1 \\ 0.221 & 0.729 & 48.731 \times 10^{-3} & 379.350 & 93.43 & X_2 \\ 0.126 & 1.862 & 113.763 \times 10^{-3} & 254.0 & 86.59 & X_3 \end{pmatrix}$$

It is also necessary to determine the ideal and basal variants. The ideal variant is the hypothetical or real variant that attains the best possible values in all the criteria. The ideal variant in the set task is vector H = (0.221; 1.862; 113.763×10⁻³; 379.350; 93.43). In an analogous manner, a basal variant is the variant that has all the values of the criteria at the lowest level. In an analogous manner, the basal variant is vector D = (0.126; 0.724; 48.391×10⁻³; 254.0; 86.59).

The next step was the unification of the set criteria. Nevertheless, all the criteria of this study are considered to be minimizing criteria and the above-mentioned step was therefore omitted.

The values of the criteria matrix are expressed in various units and it is therefore necessary to normalize all these values according to the relation $r_{ij} = (y'_{ij} - D_j)/(H_j - D_j)$, where D_j represents the lowest value of j-criterion and H_j represents the highest value of j-criterion.

The resulting matrix is the so-called normalized matrix in the following form:

$$Y^* = \begin{pmatrix} 1 & 0 & 0 & 1 & 1 \\ 1 & 4.39 \times 10^{-3} & 5.2 \times 10^{-3} & 1 & 1 \\ 0 & 1 & 1 & 0 & 0 \end{pmatrix}$$

In the weighted sum method, the optimum variant is the variant that minimizes the sum of the products of weights and the respective criteria values in the event that all the set criteria are minimizing criteria. The resulting evaluation of variants is summed up in Table 10.

Table 10. Application of the weighted sum method

Tabela 10. Zastosowanie metody ważonej sumy

Variant	Sum of products of values of criteria matrix a_{ij} and the corresponding weights of the criteria (v_j)	Total	Order of variants
X_1	$1 \times 0.178 + 0 + 0 + 1 \times 0.180 + 1 \times 0.088$	0.446	1
X_2	$1 \times 0.178 + 4.39 \times 10^{-3} \times 0.311 + 5.2 \times 10^{-3} \times 0.244 + 1 \times 0.180 + 1 \times 0.088$	0.448	2
X_3	$0 + 1 \times 0.311 + 1 \times 0.244 + 0 + 0$	0.555	3

6. CONCLUSION

The aim of this study was to show possibilities of application of the life-cycle methodology using a concrete example from the technological practice for the purpose of ecologization of production and reduction of its environmental impact. This goal has been essentially attained. It has been proved that the LCA methodology may be used for the comparison of environmental impacts of three technological processes. The solution of the study was, however, complicated by several facts, namely the non-existence of analogous materials in available literature and the unavailability of some data from the partnership firm that are the subject of trade secret. A great obstacle we faced was also the fact that it was difficult to obtain concrete information from the manufacturers of construction machinery and mechanization. The precondition of reaching the primary goal was the attainment of secondary goals. Among them, the most difficult goal was the attainment of necessary data and their subsequent conversion to the set functional unit and in certain cases it was necessary to make use of an expert assessment by specialist workers.

At present, a unified methodological procedure to regulate the assessment of the impacts has not yet been defined. The relevant part of the considerations was therefore based on the subjective approach of the compiler, who discussed it with experts in the defined fields both at theoretical and practical level.

The assessment comprised the electric power consumption and the consumption of primary energetic raw materials (crude oil and ground gas), the contribution to the greenhouse effect, the production of waste and the contribution to the noise level. From the aspect of the

total negative environmental impact, only a negligible difference between the technology of concrete floor production and the production of dry-shake floors has been ascertained by means of mutual comparison. A major negative environmental impact of the technology of asphalt floor production against the technology of concrete floor and dry-shake floors production is due to a higher consumption of primary energetic raw materials, in particular of the ground gas. The total consumption of primary energetic raw materials is in the case of asphalt floor technology by approx. 155% higher than in the technology of concrete and dry-shake floors technology. This consumption is due to the technological parameters of the production of asphalts. Due to this increased energy demand, in particular in the case of the consumption of ground gas, this technology renders a higher contribution to the greenhouse effect, namely by approx. 133% against the consumption of concrete and dry-shake technologies. The positive feature of the production technology of asphalt floors is lower consumption of electric power and lower production of waste against the technology of concrete and dry-shake floors production. The electric power consumption is in the case of asphalt floors by approx. 57 % lower against concrete and dry-shake floors; from the aspect of waste production, the asphalt technology is by approx. 33 % more economical against the remaining compared technologies. From the aspect of their contribution to the noise level, there are only minimum differences between the assessed technologies; only the contribution of the asphalt technology to the noise level is by approx. 7.8% less. From the aspect of the total environmental impact, only minimum difference has been found between the concrete and dry-shake technology. The difference between the two technologies and the technology of asphalt production is by approx. 27.7% in favour of the asphalt technology.

To attain higher objectivity of obtained results, the assessed technologies were evaluated using the mathematical operations analysis. To this effect, one of the methods of multicriterion evaluation of variants was applied, namely the weighted sum method. The results proved that the optimum variant is the technology of the concrete floors production. The second optimum variant is the technology of the dry-shake floors production and as the third one the technology of the asphalt floors. It has to be also emphasized that the differences between the evaluated production technologies were of minimum extent.

Consequently, operations producing the greatest negative impact on the environment were identified. These are in the first place the transportation of raw materials by trucks, waste produced by the disposal of the floor at the end of its life cycle and also the consumption of electric power, in particular by auxiliary construction mechanization.

Nevertheless, the decision-making process in which mainly the investors participate comprises also other necessary aspects, particularly the economic information related mainly to the investment and operating costs and/or the market size, and also to the possible social impacts and safety precautions. A very important criterion to be taken into consideration in the decision-making process is the total service life of the product, in this case of the floors in agricultural premises. The expected service life of concrete floors is approx.

30 years. The dry-shake treatment of concrete floors increases the cost of realization of the floor (by approx. 60 – 100 Czech Crowns/m²); nevertheless, it highly improves the technical properties of the resulting product, primarily its resistance to external influences, its durability and its load-bearing capacity. Thanks to this treatment the dry-shake floor can attain much longer service life than standard concrete floors. The expected service life of asphalt floors is approx. 25 years.

The expected application of the results obtained by the solution of this study offers to the management of the respective firm further improvement of the ecological – economic characteristics of the technology of floor production in agricultural premises. At the same time, the results of the study also offer a primary instruction for the application of LCA methodology to the technologies of production of various types of industrial floors.

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