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DETERMINING THE LEVEL OF RESOURCES SAVINGS OF THE PRODUCT LIFE CYCLE

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Abstract. We proposed to use a useful life index to take into account the time of decay in the environment of the product and the time of useful product use. Application of a waste generation index to assess the level of waste generation at the stage of the product life cycle is suggested. The unitary index of efficient use of natural resources is calculated on the basis of the mentioned indices.

Key words: life cycle of the product, life cycle impact assessment, resource efficiency, index estimation.

1. Introduction

During the development of industry and the growth of economic activity, mankind uses an increasing amount of natural resources. This leads to total increase in anthropogenic pressure in the environment and disturbance of the balance in the natural environment. As a result, this exacerbates socio-economic problems. At the same time, the reserves of non-renewable raw materials and energy resources are exhausted and pollution of the environment is increasing. The most polluted are water resources and atmospheric air. Areas of forests and fertile lands are reduced, certain types of plants, animals, etc. disappear [1]. All this in the end undermines the natural resource potential of social production and adversely affects human health.

In accordance with the concept of sustainable development (SD) and the role of each enterprise in the life of the country, enterprises should strive for the implementation of sustainable functioning of high technology, environmentally sound technologies capable of delivering products that meet the requirements of international standards by taking into account all stages of the life cycle (LC) including the stages of using the resources, the stage of consumption and the stage of utilization. The importance of the environmental protection problem and the possible impacts are associated with the manufacture and consumption of products increased the interest in developing methods aimed at reducing these effects. One of the methods developed for this purpose is the life cycle assessment (LCA) [2].

The LCA method is at the development stage. Some constituents of the method, such as impact assessment (LCIA), are at an early stage, so you need to do lots of work and garner practical experience in order to move on to the next level of practical application of the LCA method [3]. Therefore, it is important to correctly interpret and apply the results of the LCA. It is relevant to conduct research of different stages of the product LC and develop methodological support for assessing the impact of the product LC, which is an integral part of planning SD technological systems involved in the production of a particular industrial product [4].

2. Results and Discussion

2.1. Resource efficiency index

When assessing the life cycle of a product (LCA), it is necessary to take into account the overall level of the efficiency of resources use that were spent on the production of a product unit [1]. It is necessary to estimate the percentage of the raw material involved in the final product, and how the useful life of the product depends on the resources spent, or whether the product can be properly disposed at the end of its useful life.

In order to assess the resource-efficiency of the production phases of the product, within the framework of evaluating the ecological component of the product LC, we suggest taking into account the amount of raw materials which are needed to produce a unit of product using the developed resource efficiency index (1):

$$J_{REF} = \frac{\sum_{i=1}^{n} M_{RWM_i}}{m_{PRD} \cdot n}, \tag{1}$$

where J_{REF} – the resource efficiency index; m_{PRD} – the unit weight, kg; M_{RWM_i} – the mass of raw materials of the i-th type, which was spent on the production of a unit of product, per time unit, kg/day; *n* – the number of product units that are manufactured per time unit, day^{-1}.

More value J_{REF} corresponds to a worse level of efficiency of the raw materials which is used in the product. The technological system has a very high level of resource efficiency, if the unit of product weight accounts for less than the twice excess of consumed raw materials mass. A very low level of resource efficiency involves ten or more times excess of the raw materials mass spent on product a unit. Accordingly, we suggest using the following scale to estimate the level of resource efficiency using the index J_{REF} (Table 1).

Table 1

Dependence of the J_{REF} index value on the level of the raw materials efficiency use

The J_{REF} index value	Level of the raw materials efficiency use
$J_{REF} < 2$	very high
$2 \le J_{REF} < 5$	high
$5 \le J_{REF} < 7$	middle
$7 \le J_{REF} < 10$	low
$J_{REF} \ge 10$	very low

On the basis of the resource efficiency index, we propose to use the unitary index of resource efficiency I_{RSE} created with the help of the Harrington desirability function (2) to bring the indexes to a single scale of LCA evaluation with limits from 0 to 1.

$$I_{RSE} = \exp\left(-\exp\left(a - b \cdot J_{REF}\right)\right), \qquad (2)$$

where $a = 1.266$ and $b = 3.952 \cdot 10^{-1}$ – the empirical coefficients.

The approximation of the unitary resource efficiency index to 1 corresponds to a significant increase in the cost of raw materials per product unit.

2.2. Useful life index

To take into account the time of decomposition of the product components in the environment and the product useful life, we propose the following dependence (3):

$$J_{ULF} = \frac{\sum_{i=1}^{n} t_{DCM_i}}{t_{LFT} \cdot n}, \qquad (3)$$

where J_{ULF} – the useful life index; t_{LFT} – the life time of products, years; t_{DCM_i} – the time of complete decomposition in the nature of the i-th component of the product, years; *n* – the number of components with long time decomposition in nature.

We suggest that the very high usefulness of a product is when the average decomposition time of the product components in the environment less than twice excesses the useful life of a product unit. For the very low useful times we suggest considering cases where the time of the product ingredients decomposition in the environment more than ten times exceeds the product life. According to this, the next scale was constructed to assess the usefulness of the product on the basis of the index J_{ULF} (Table 2).

Table 2

The dependence of the J_{ULF} index value on the time of product decomposition in nature

The J_{ULF} index value	Time of product decomposition in nature
$J_{ULF} < 2$	very low
$2 \le J_{ULF} < 4$	low
$4 \le J_{ULF} < 8$	middle
$8 \le J_{ULF} < 10$	high

On the basis of the useful life index we get a unitary index of useful life, turning it into a general scale of assessment with an interval of possible index values from 0 to 1 (4):

$$I_{USF} = \exp\left(-\exp\left(d - g \cdot J_{ULF}\right)\right), \qquad (4)$$

where $d = 1.135$ and $g = 3.293 \cdot 10^{-1}$ – the empirical coefficients.

The approximation of the unitary index of the useful life to 1 corresponds to the worst correlation between the product time of use and the time of its decomposition in nature.

2.3. Waste generation index

Wastes generated during the production of a unit of product, as well as the product itself after the expiration of the life time, can be used as a secondary raw material for the production of other types of products. Also, waste can be utilized - disposed at appropriate landfills or burned at the waste incineration plants.

Waste generation during production of a product unit should be taken into account when evaluating LCA. At the end of the useful life, the disposal of the product should be considered, as it is the last stage of the product LC.

The waste for time unit (day) per unit of product (the number of units of product manufactured at the same time) is estimated using the waste generation coefficient (5):

$$k_{WST} = \frac{\sum_{i=1}^{n} M_{WST_i}}{m_{PRD} \cdot l}, \qquad (5)$$

where M_{WST_i} – the weight of the i-th type of waste generated during the production of the product per time unit (day), kg; m_{PRD} – the unit weight, kg (if it is impossible to determine the weight of the product m_{PRD}, it is assumed to be equal to 1); l – the number of product units that are produced per time unit (day); n – the number of waste types.

To estimate the level of waste generation at the LC stage, both in the production of the product and on the stage of its utilization, taking into account the possibility of recycling, reuse or disposal, we propose to use of the waste generation index (6):

$$J_{WSG} = \frac{k_{WST}\,(2+k_{RCL})(k_{DSP}+0.25[1-k_{DSP}])}{0.5+k_{RCL}}, \quad (6)$$

where J_{WSG} – the waste generation index; k_{WST} – the coefficient of waste generation; k_{RCL} – the coefficient of recycling, the proportion of the product that is to be recycled or used as a secondary raw material; k_{DSP} – the coefficient of waste disposal, the amount of waste generated during the production of a product that is to be buried at the appropriate landfills or burned at waste incineration plants.

We suggest that the very low level of waste generation is in the case of almost complete recycling of generated waste. In this time, the value of the index J_{WSG} will be close to 1. The need for disposal of generated waste and the impossibility of their secondary use increase the index J_{WSG} value. If the mass of all generated waste excess the product weight twice, the value of the J_{WSG} index will be equal to 8. This level of waste generation will be considered very high. In accordance with the above, we propose to use the next scale for grading the waste level according to the J_{WSG} index values obtained (Table 3).

Table 3

Dependence of J_{WSG} value on the level of waste generation

The J_{WSG} index value	Level of waste generation
$J_{WSG} < 0.5$	very low
$0.5 \le J_{WSG} < 2$	low
$2 \le J_{WSG} < 4$	middle
$4 \le J_{WSG} < 8$	high
$J_{WSG} \ge 8$	very high

The greater of the waste generation index value corresponds to a higher level of waste generation during the product LC.

The evaluation of the degree of waste generation during the product LC on a common dimensionless scale is carried out using the unitary index of waste generation I_{WST} (7):

$$I_{WST} = \exp(-\exp(h - l \cdot J_{WSG})), \quad (7)$$

where $h = 6.077 \cdot 10^{-1}$ and $l = 2.635 \cdot 10^{-1}$ – the empirical coefficients.

The values of the I_{WST} unitary index are in the range from 0 to 1. Approximation of the unitary index of waste generation to 1 corresponds to a higher level of waste formation during the product LC.

2.4. Unitary index of efficient use of natural resources

To estimate the total cost of recycling and recycling of products and wastes, we propose to apply a unitary index of efficient use of natural resources. This index takes into account both the formation of waste at the production stage and the efficiency of the use of resources, based on the above unitary indices. The index is created by means of a generalized Harrington desirability function (8):

$$I_{ENR} = (I_{RSE} \cdot I_{USF} \cdot I_{WST})^{1/3}, \quad (8)$$

where I_{ENR} – the unitary index of efficient use of natural resources; I_{RSE} – the unitary index resource efficiency; I_{USF} – the unitary index of useful life; I_{WST} – the unitary index of waste generation.

The level of natural resources efficiency use in the estimation of the product LC is evaluated, depending on the index value on the scale shown in Table 4.

Table 4

Dependence of value I_{ENR} on the level of the natural resources efficiency use I_{ENR}

The I_{ENR} index value	The level of the natural resources efficiency use
$0 \le I_{ENR} < 0.2$	very high
$0.2 \le I_{ENR} < 0.37$	high
$0.37 \le I_{ENR} < 0.63$	middle
$0.63 \le I_{ENR} < 0.8$	low
$0.8 \le I_{ENR} < 1$	very low

The closer the value of the unitary index of the efficient use of natural resources I_{ENR} to 1, the more costs and resources are needed to utilize the product unit and the waste generated during the production of the product unit, and the less efficiently the resources were used.

3. Conclusions

Resource cost estimation is one of the environmental criteria for evaluating the product LC. Evaluation of the ecology of the product's LC is necessary when developing and implementing environmental standards that will determine the benefits of a particular category of products or services in relation to their effects on the state of the environment and human health during the LC. The ecological standard for products of a certain category is voluntary and sets of additional ecological requirements – environmental criteria, to those established by the current legislation. Compliance with the environmental criteria is a confirmation of the environmental benefits of the products. Assessment of resource efficiency of the product LC can be used in the environmental labelling of goods. The basic provisions and principles of the development of environmental criteria are defined by the international standard ISO 14024 (DSTU ISO 14024) “Environmental labels and declarations – Type I environmental labelling - Principles and procedures” [5]. According to the standard, objects of standardization are food products, goods, products, materials and services, their components and the impact on the state of the environment and health at all stages of the life cycle.

In Ukraine, as in the other part of the world, the development, examination and approval of international (regional), national and other standards are relied upon by the technical committees of standardization in the field of activity. The method developed by us can be applied both for the implementation of environmental labelling of a product in the sphere of resource efficiency of its life cycle within the framework of the work of the committees on environmental standardization, and for searching the opportunities to increase the environmental quality of the product.

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