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ECODESIGN ANALYSIS OF MILK PACKAGING LIFE CYCLE

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Introduction

The presented work applies ecodesign tool - eco-indicators from „The Eco-indicator 99" methodology [1] to assess environmental impact of milk packaging life cycle and develop calculation equations which can help the dairy processing plant to reduce that impact. The studied industry – Latvian dairy JSC "Valmieras Piens" does not develop the packaging itself but purchases it from Swedish company „Tetra Pak"; however, it has the possibility to optimise logistics and handling of packaging within its borders of influence. The plant has also control over organisation of the milk packaging process itself. More importantly, the company can influence the type of packaging it uses for its product, i.e. design, printing and materials used for it. Therefore, the industry is in fact planning or designing an important part of the packaging life cycle which basically constructs environmental impact of the plant's main product - milk. During the study it became apparent that ecodesign analysis of industrial process first of all reveals the right questions that have to be asked in order to understand environmental load of produced product. Process of seeking answers to these questions lead an industry to systematic analysis of environmental consequences of manufacturing decisions and processes, and ultimately to more sustainable solutions of the core product. Results of the work show eco-indicators of environmental impact of milk packaging created at different life cycle stages, and the calculations are based on data obtained from the dairy plant. The obtained figures of environmental impact of packaging with different volumes are compared in the work. One of the goals of the work was to obtain a practical tool that the enterprise could use for a relatively simple evaluation of changes

in environmental impact at various stages of the cycle of packaging, calculated on 1 kg of milk, if some of the environmental impact factors are changed. This goal is achieved by developing formulas for calculation of total environmental impact, and includes main environmental impact factors and relevant eco-indicators.

Principle of calculations of environmental impact for life cycle stages of milk packaging

Two types of milk packaging are currently dominating the market – plastic pouches and cardboard packs [2]. 1 litre volume "tetrapak" ("TetraBrik baseline" product of "TetraPak") was used as the main object of studies in the present work since it is the main type of milk packaging used by the dairy. Comparison of environmental impact created during life cycle stages of the above mentioned "tetrapak" with "tetrapaks" with volumes of 0,5 and 1,5 litre is also made since these are popular types of packaging as well and used by the studied dairy plant. The process tree which was used for calculations of environmental impact of "tetrapak" is shown in Figure 1.

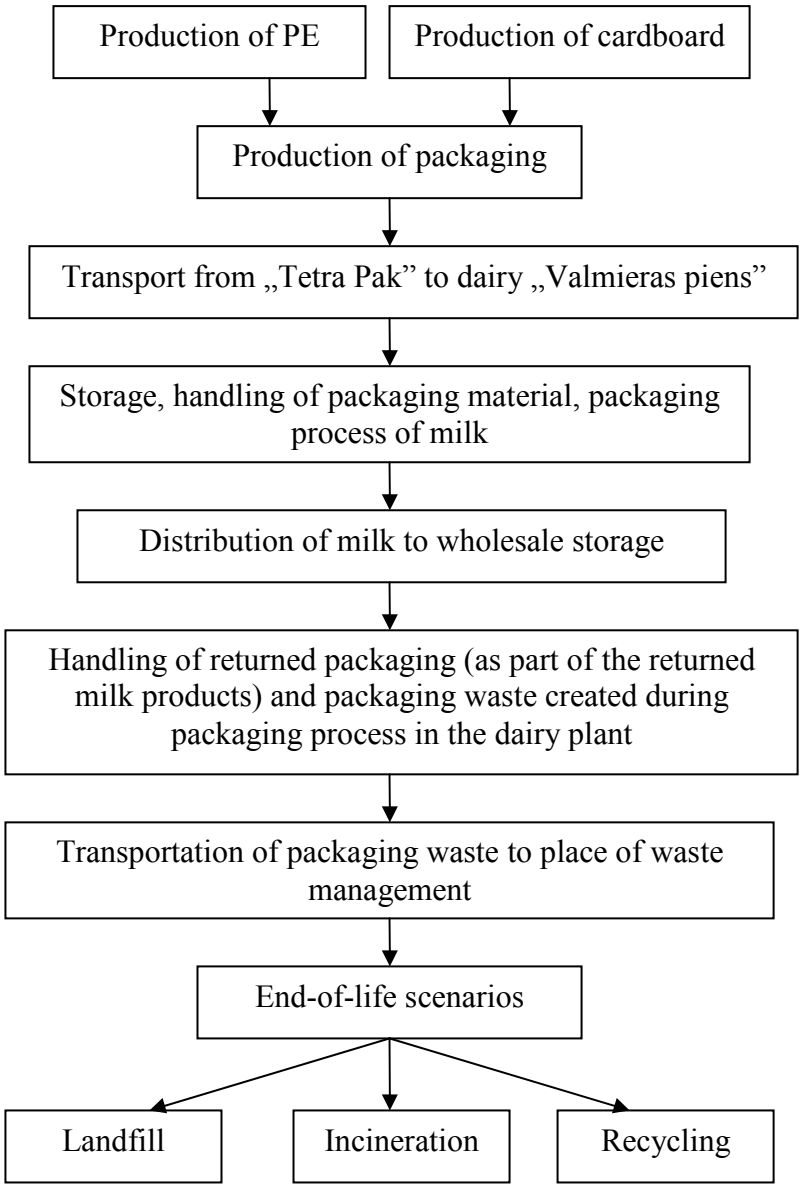

Figure 1. Simplified process tree used for analysis of milk packaging („tetrapak") life cycle

The values of environmental impact are obtained for 1 kg of milk. Due to lack of information, no environmental impact is calculated for materials and processes of printing the packaging. Road (truck 40 t) and water transportation (freighter inland) is used for calculation of environmental impact of delivery of the packaging material from Sweden to the dairy. There were no data available on electricity consumption of the storage facilities of the packaging material and transportation of the packaging from storage to the packaging site of milk with electric car. After approximate estimates, it was concluded that these factors could be omitted due to relatively small influence on total environmental impact. No heating is used for the storage facilities of the packaging. Electricity consumption of the packaging machine is not separately measured in the dairy therefore approximate estimate of electricity consumption for the packaging process was made based on installed electrical capacity of the packaging machine and operating hours, and no other environmental impact is considered for the packaging stage. The amount of packaging waste created during production process and by returned milk products is only approximately 0,1 g per each kg of milk, and therefore is omitted from the calculations of environmental impact. It was impossible to obtain accurate data about distribution stage of life cycle, i.e. distances covered by each transportation type, and therefore simplified calculations were made. Delivery of milk products to the wholesale storage in distance of 100 km by 40 t truck was considered in the calculations. However, the actual environmental impact created in distribution stage of milk products is considerably larger since the dairy uses also road transport with smaller carrying capacity. Transportation packaging of milk products is plastic boxes with approximate mass of 150 g per each kg of milk. Three possible scenarios are used in calculations for the end-of-life stage – all packaging waste is landfilled, or incinerated or recycled. Currently, all packaging is landfilled; however, it is important to show by calculations and consider in the calculation formulas also solutions that could potentially considerably reduce environmental impact. The average distance for transportation of packaging waste is assumed to be 50 km, and road transport with 16 t carrying capacity is used for the transportation.
If there are n elements in the packaging, then the environmental impact of the production and processing stage of the packaging material can be calculated as follows:

$$EI_{prod} = \sum_{k=1}^{n} M_{elem_k} \left(e_{elem_k}^{prod} + e_{elem_k}^{proc} \right), \quad (1)$$

where M_{elem_k} – mass of the element k, calculated for 1 kg of milk [kg];

$e_{elem_k}^{prod}$ – eco-indicator of production of the element k [mpt/kg];

$e_{elem_k}^{proc}$ – eco-indicator of processing of the element k [mpt/kg].

The general equation for calculation of the environmental impact of transportation of packaging if t types of transport are used is the following:

$$EI_{transp} = \sum_{k=1}^{n} \frac{M_{elem_k}}{1000} \sum_{i=1}^{t} L_{T_i} e_{T_i} , \quad (2)$$

where L_{T_i} – transportation distance with type of transport i [km];

e_{T_i} – Eco-indicator for transportation with transports i [mpt/tkm].

The environmental impact of the milk packaging process caused by electricity consumption of the packaging machine per package (and consequently, for 1 kg of milk if 1 l volume packaging is used) can be calculated as:

$$EI_{pack} = \frac{E_{el}^{pack} e_{el}}{n_{pack}}, \tag{3}$$

where n_{pack} – number of packages processed during the considered operating time period of packaging machine [pcs];

E_{el}^{pack} – electricity consumption of the packaging machine during the considered operating time period [kWh];

e_{el} – eco-indicator of low voltage electricity [mpt/kWh].

The environmental impact created at the end-of-life stage can be calculated as follows:

$$EI_{EoL} = \sum_{k=1}^{n} M_{elem_k} \cdot \tag{4}$$
$$\cdot \left[x_{landf} \left(\frac{L_{landf} e_{landf}^{tr}}{1000} + e_{elem_k}^{landf} \right) + x_{incin} \left(\frac{L_{incin} e_{incin}^{tr}}{1000} + e_{elem_k}^{incin} \right) + x_{rec} \left(\frac{L_{rec} e_{rec}^{tr}}{1000} + e_{elem_k}^{rec} \right) \right]$$

where x_{landf}, x_{incin}, x_{rec} – fractions of landfilled, incinerated or recycled packaging waste [range of values 0 -1];

L_{landf}, L_{incin}, L_{rec} – transportation distances to sites of landfill, incineration and recycling [km];

e_{landf}^{tr}, e_{incin}^{tr}, e_{rec}^{tr} – eco-indicators of transportation to sites of landfill, incineration and recycling [mpt/tkm];

$e_{elem_k}^{landf}$, $e_{elem_k}^{incin}$, $e_{elem_k}^{rec}$ – eco-indicators of landfill, incineration and recycling of the considered element [mpt/kg].

The total environmental impact of the life cycle of packaging per 1 kg of milk EI_{total} is calculated by the sum of the environmental impacts estimated by equations (1) to (4).

Results of calculations of environmental impact

Results of the calculation of environmental impact at different life cycle stages (Fig. 2.) show that studied packaging is a material-intensive product. The life cycle stage “transport A” represents transportation of the packaging material from the company “TetraPak” to the dairy plant, but “transport B” – distribution of milk products to wholesale storage.

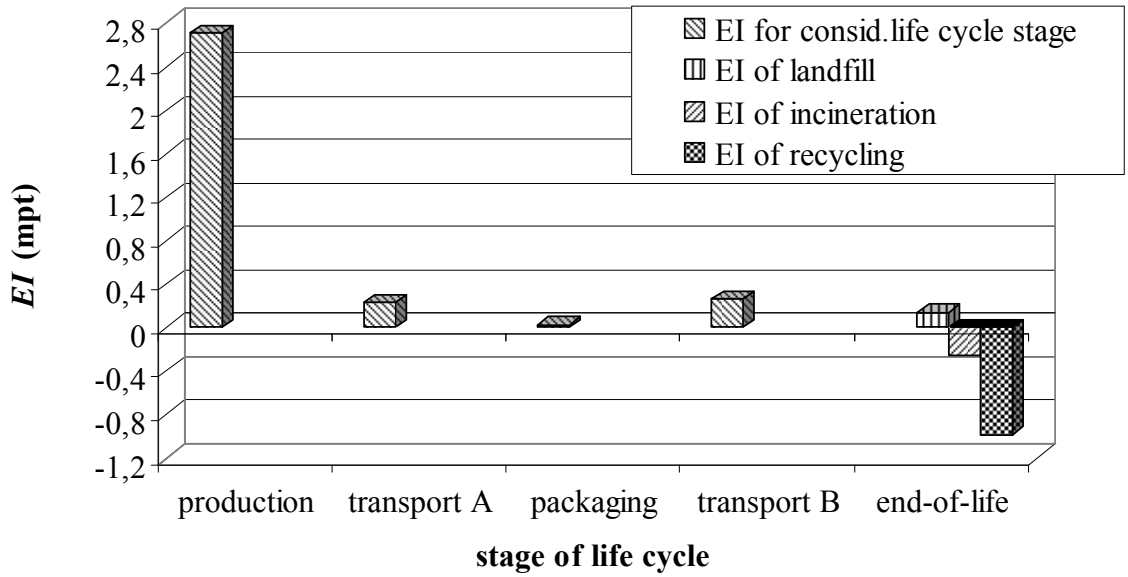

Figure 2. Results of calculations of environmental impact created at various life cycle stages of 1 l "tetrapak" milk packaging, obtained by using data of the studied dairy plant

Since the "tetrapak" packaging is a material-intensive product, and two main elements of the "tetrapak" packaging are cardboard (paper board) and polyethylene (PE), it is useful to obtain extent of change of the total environmental impact if the mass of cardboard M_{cardb} and the mass of PE M_{PE} changes by 1 unit. That can be determined from partial derivatives of equation for calculation of the total environmental impact which for the studied case are the following:

$$\frac{\partial(EI_{total})}{\partial(M_{cardb})} = e_{cardb}^{prod} + e_{cardb}^{proc} + \\ + \frac{1}{1000}\left[L_{road}^{transpA} e_{road}^{transpA} + L_{water}^{transpA} e_{water}^{transpA} + L_{road}^{transpB} e_{road}^{transpB} + L_{road}^{EoL} e_{road}^{EoL}\right] + \\ + x_{landf} e_{cardb}^{landf} + x_{incin} e_{cardb}^{incin} + x_{rec} e_{cardb}^{rec}; \quad (5)$$

$$\frac{\partial(EI_{total})}{\partial(M_{PE})} = e_{PE}^{prod} + e_{PE}^{proc} + \\ + \frac{1}{1000}\left[L_{road}^{transpA} e_{road}^{transpA} + L_{water}^{transpA} e_{water}^{transpA} + L_{road}^{transpB} e_{road}^{transpB} + L_{road}^{EoL} e_{road}^{EoL}\right] + \\ + x_{landf} e_{PE}^{landf} + x_{incin} e_{PE}^{incin} + x_{rec} e_{PE}^{rec}, \quad (6)$$

where $L_{road}^{transpA}$, $L_{road}^{transpB}$ - transportation distance covered by road transport in life cycle stages „transport A" and „transport B" respectively;

$L_{water}^{transpA}$ - Transportation distance covered by water transport in life cycle stage „transport A";

L_{road}^{EoL} - transportation distances to sites of landfill, incineration and recycling, which is assumed to be the same regardless of end-of-life scenario, and it is covered by road transportation in all cases;

$e_{road}^{transpA}$, $e_{road}^{transpB}$ - eco-indicators of transportation in life cycle stages „transport A" and „transport B" respectively;

$e_{water}^{transpA}$ - Eco-indicator of transportation in life cycle stage „transport A";

e_{road}^{EoL} - Eco-indicator of transportation to sites of landfill, incineration and recycling.

Then, extent of changes of the total environmental impact if mass of cardboard M_{cardb} and mass of PE M_{PE} changes by 1 unit, assuming that all packaging is landfilled at the end-of-life stage (this end-of-life scenario corresponds to the existing situation), for the studied case are the following:

$$\frac{\partial(EI_{total})}{\partial(M_{cardb})} = 85{,}9 \text{ [mpt/kg] if } x_{landf}=1;\ x_{incin} = x_{rec}=0$$

$$\frac{\partial(EI_{total})}{\partial(M_{PE})} = 348{,}4 \text{ [mpt/kg] if } x_{landf}=1;\ x_{incin} = x_{rec}=0$$

Figure 3 represents results of calculation of environmental impact per 1 kg of milk created during the production of packaging with various volumes which are currently used for milk packaging by the studied dairy plant.

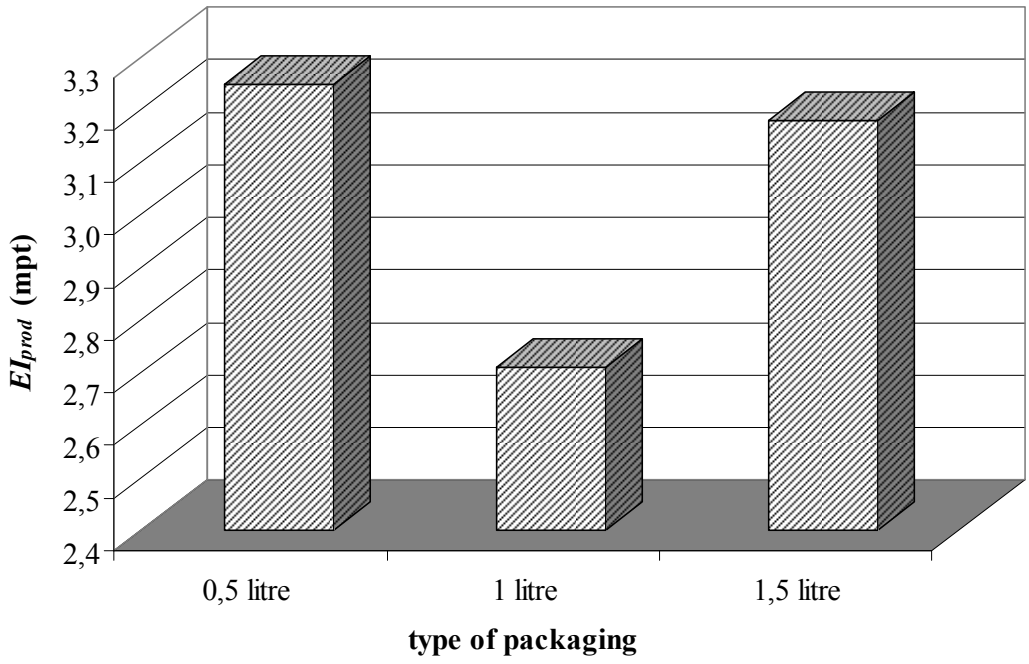

Figure 3. Comparison of environmental impact of production stage of life cycle for milk packaging with different volumes

It can be seen from the results of calculations (Fig. 3.), that 1 l packaging has by 20% lower environmental impact per 1 kg of product then 0,5 l packaging and by 17% lower environmental impact then 1,5 l packaging during production stage of packaging alone. The reason behind larger environmental impact for 1,5 l packaging relative to 1 l packaging, is that the 1,5 l packaging uses thicker and stronger paperboard walls.
For convenience of users, the dairy plant plans to introduce plastic screw cap to the package. Calculations of environmental impact per 1 kg of milk created during the production of packaging with and without plastic screw cap revealed that adding the plastic screw cap to the package, increases the environmental impact by approximately 37% in the production stage of life cycle alone. If other stages of life cycle are considered then this increase is even larger. In addition, the plastic screw cap reduces uniformity of the package and therefore hampers recycling of it. Ecodesign solution would be to use the same material for the cap as is used for the package itself, so that the cap would not have to be separated prior to recycling.

Conclusions

Studies of environmental impact created at various stages of life cycle of "tetrapak" milk packaging for the case of the dairy plant JSC "Valmieras Piens" in Latvia reveals that the largest impact per 1 kg of milk originates in the production phase of the packaging itself. Transportation during the distribution of milk products for sale causes by 14% larger environmental impact than the transportation of packaging material to the dairy plant, considering the assumptions used in the calculations. If more accurate data about transportation of milk products would be available, especially regarding delivery with trucks of lower carrying capacity, the difference between the environmental impact of life cycle stages "transport A" and "transport B" would, most likely, be even larger. The environmental impact of the handling of packaging and the packaging process within the plant creates a relatively small environmental impact. This leads to the conclusion that the dairy plant has to be very cautious to the changes in design of packaging which may be requested to producer of the packaging, and which would result in an increase in the amount or types of used materials. Calculations of the environmental impact show that adding a plastic screw cap to the package increases the environmental impact of the production stage of the packaging by approximately 37%. There are certainly possibilities to optimise logistics of transportation both of packaging material itself and milk products to obtain reduction of environmental impact, especially in the distribution stage of the life cycle. It was also found in the work that 1 l packaging has by 20% lower environmental impact per 1 kg of milk product then 0,5 l packaging and by 17% lower impact then 1,5 l packaging during production stage of packaging alone. The results of the environmental impact calculations show that the total environmental impact of the life cycle of 1 l packaging per 1 kg of milk could be reduced by 33% if recycling instead of currently used landfilling would be the end-of-life scenario for the packaging.

References

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2. „Evolution of milk packaging in Ontario from 1968-1995", Environment and Plastics Institute of Canada and Ontario Ministry of Agricultural and Food, 35 p

Čunčule D., Bažbauers G. Piena iepakojuma dzīves cikla ekodizaina analīze.
Darbā veikts piena iepakojumu aprites cikla ietekmes uz vidi novērtējums ar ekoindikatoru metodi „The Eco-indicator 99". Aprites cikla ietekmes uz vidi aprēķini veikti, pamatojoties uz datiem, kas iegūti, pateicoties sadarbībai ar piena kombinātu a/s "Valmieras Piens". Ietekmes uz vidi analīze veikta šobrīd visvairāk izmantotajam piena iepakojuma veidam – uzņēmuma "TetraPak" ražotajam 1 l ietilpības "TetraBrik Baseline" iepakojumam. Darba gaitā izveidotas aprēķina izteiksmes, kas ļauj noteikt ietekmes uz vidi izmaiņas aplūkotā iepakojuma aprites cikla posmos, ja mainās kādi no vidi ietekmējošajiem faktoriem. Aprēķinu rezultāti parāda, ka vislielākā ietekme uz vidi tiek radīta paša iepakojuma ražošanas procesā. Gatavās produkcijas transportēšanas posmā radītā ietekme uz vidi ir par 14% lielāka nekā iepakojuma piegādes posmā piena kombinātam atbilstoši esošajiem pieņēmumiem. Iepakojuma uzglabāšanas, pārvietošanas un piena pakošanas procesā radītā ietekme uz vidi ir salīdzinoši neliela. Iepakojuma kopējo ietekmi uz vidi būtu iespējams samazināt par aptuveni 33%, ja izlietotais iepakojums tiktu reģenerēts, nevis noglabāts atkritumu izgāztuvē, kā tas notiek šobrīd. Ietekmes uz vidi aprēķini parāda, ka 0,5 l tetrapaka rada aptuveni par 20% lielāku ietekmi uz vidi nekā 1 l iepakojums, rēķinot uz 1 kg piena, bet 1,5 l iepakojuma gadījumā šī atšķirība ir 17%, aplūkojot tikai paša iepakojuma ražošanas aprites cikla posmu. Skrūvējama plastmasas korķīša pievienošana iepakojumam palielina tā ietekmi uz vidi iepakojuma ražošanas aprites cikla posmā vien par aptuveni 37%.

Čunčule D., Bažbauers G., Ecodesign analysis of milk packaging life cycle.
The presented work applies ecodesign tool - eco-indicators from „The Ecoindicator 99" methodology to assess environmental impact of milk packaging life cycle. Calculations of environmental impact were done based on cooperation with the dairy plant JSC "Valmieras Piens." Assesment of environmental impact is performed for the type of packaging which is currently used most by the enterprise – 1 litre "TetraBrik Baseline" produced by the company "TetraPak." Calculation formulas which allow calculating changes of environmental impact at various stages of life cycle if some of the environmental impact factors are changed are developed in result of the present work. Results of calculations reveal that production process of studied packaging creates the largest environmental impact. During transportation of milk products at distribution stage of life cycle the environmental impact is by 14% larger then during transportation of the packaging material to the dairy plant from "TetraPak" considering the assumptions used for calculations. Environmental impact caused during storage, handling and milk packaging process is relatively small. It would be possible to reduce total environmental impact by approximately 33% if packaging waste would be recycled instead of currently used landfill end-of-life scenario. Calculations of environmental impact of packaging production stage of life cycle show that 0,5 l packaging creates by approximately 20% larger impact per 1 kg of milk than 1 l packaging but in case of 1,5 l packaging this difference reduces to 17%. Modification of design of packaging by adding plastic screw cap increases environmental impact by approximately 37%.

Чунчуле Д., Бажбауэр Г., Анализ экодизайна жизненного цикла упаковки молока.
В работе произведена оценка влияния жизненного цикла упаковки молока на окружающую среду с помощью эко-индикаторов метода „The Eco-indicator 99". Расчеты влияния жизненного цикла упаковки молока на окружающую среду сделанны на основе данных, которые полученны благодаря сотрудничеству с молочным комбинатом а/о"Valmieras Piens". Оценка влияния на окружающую среду произведена для в данном моменте наибольше использованного типа упаковки молока - "TetraBrik Baseline" объема 1 л производства предприятия "TetraPak". В работе выведены формулы расчета, позволяющие определить изменения влияния на окружающую среду, которое создаётся на разных ступенях жизненного цикла упаковки, если меняются некоторые из параметров влияния на окружающую среду. Результаты анализа показывают, что наибольшее влияние на окружающую среду у производства самой упаковки. Влияние на окружающую среду созданное в этапе транспортировки готовой продукции на 14% больше чем в этапе поставки упаковочного материала молочному комбинату учитывая существующие предположения. Хранение и транспортировка упаковки в пределах молочного комбината, а также процесс паковки молока создают сравнительно небольшое оценка влияние на окружающую среду. Общее влияние жизненного цикла упаковки молока на окружающую среду можно было бы уменьшить на примерно 33% если использованная упаковка было бы регенерированна нежели захаранена на свалке, как это происходит в данном моменте. Расчеты влияния на окружающую среду показывают, что влияние на окружающую среду созданное упаковкой объема 0,5 л, рассчитанное на 1 кг молока, на примерно 20% больше чем упаковкой объема 1 л. В случае использование упаковки объема 1,5 л, разница уменьшается на 17%. В данных расчетах рассматривался только этап производство самой упаковки. Дизайн упаковки с пластиковой пробкой увеличивает влияние на окружающую среду созданное на примерно 37% если рассматривается только этап производство самой упаковки.