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ENVIRONMENTAL IMPACT ASSESSMENTS OF CO_2 EMISSIONS OF POLLUTANTS PRODUCED USING DIFFERENT TRANSPORTATION FLEETS FOR "GREEN" DAIRY SUPPLY CHAIN DESIGN

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Abstract: *This study represents a continuation of the optimization approach for short-term design of "green" products portfolio of three echelon "green" supply chain (GSC) of the production complex from the dairy industry. The approach takes into consideration three main subjects - products manufacturing, SC management and environmental impact. The latter involves environmental impact assessments of wastes produced along the chain and released in air and water. They are evaluated in terms of costs such as the best trade-off between environmental and economic performance of the designed green products portfolio to be achieved. The approach is extended by including additional environmental impact assessments for the CO_2 emissions produced during transportation of raw material and products when fleets with different payload capacity and fuel engines are used. The latter aims to show how this factor influences designing the optimal environmental dairy products portfolio and they can be used in the decision-making process.*

Key words: *GSC management, Products' portfolio design, Environmental impact assessments, CO_2 emissions, Transportation fleets, Optimization*

INTRODUCTION

The production of milk and dairy products occupies a significant share of the European Union's economy (European Commission, 2016). However, their realization is related to the release of significant quantities of pollutants into the environment. One of the most effective ways to increase their sustainability is by applying the Life Cycle Analysis principles in the optimal design of so called "green" supply chains. It includes optimization of all activities along the chains from the supply of raw materials through the products production to the end users and the transport of raw materials and products, while meeting the environmental (Djekic, I. et al., 2014; Sharma, V., et al., 2015; Palmieri, et al., 2017) and/or economic (Jouzdani et al., 2013; Glover et al., 2014; Chen et al., 2014) requirements. However, the most of developed approaches consider different aspects of dairy GSCs in terms of environmental impact and economic performance where some level of trade-off is satisfied and they are focused on the impact only of the CO_2 emissions produced during transportation (Validi, S., et al., 2014).

Recently, Kirilova and Vaklieva-Bancheva, (2017) have developed an optimization approach for production portfolio design of a GSC for curd production. It involves a broader objective function including, along with environmental impact assessments of CO_2 impact associated to the energy consumed and generated during transportation, and assessments for each production task accounting for associated wastewater (including these from the used raw material). The optimization criterion is defined in terms of money such as to find the best tradeoff between the total profit of the dairy complex and the costs incurred for the environmental impact due to its operation.

The aim of the present study is an extention of the approach of Kirilova and Vaklieva-Bancheva, (2017) by including additional environmental impact assessments for the CO_2 emissions produced during transportation of raw material and products when fleets with different payload capacity and fuel engines are used. The latter aims to show how this factor influences designing the optimal environmental dairy products portfolio and they can be used in the decision-making process.

EXPOSITION

1. General formulation of the optimization problem

The approach of Kirilova and Vaklieva-Bancheva, (2017) is outlined below. It has been developed to plan the activities in three eshelon SC including milk suppliers, dairies and markets to satisfy, in a short term, a certain consumer demand for a group of products. As a result of its implementation the optimal green production portfolio of the production complex, satisfying trade-off between environmental and economic objectives is found. The approach includes three interconnected models for: (i) description of the products production; (ii) SC design; and (iii) description of the SC environmental impact. The latter is assessed in terms of two areas:

1). Wastewater generated at each processing task of the dairy production, including these related to the raw material used;

2). CO_2 emissions related to: the energy consumption by the dairies and the transport of raw material and products between suppliers, dairies and markets.

- **Needed data**

In order to develop the mathematical models three groups of data should be known:

- *raw material and products data* - the composition of used raw material and target products.

- *SC data* – data for the production system; markets' demands; capacities of the milk suppliers; selling prices of milk and products; production costs, distances between milk suppliers, dairies and markets; transportation costs; fleets' capacities.

- *environmental impact data* - related to the environmental impact of pollutants obtained from the implementation of the SC activities with respect to two areas of impact - air and water. For assessments indicators as BOD_5 for the wastewater and CO_2 for the air emissions of pollutants are used.

- **Control variables**

- *Binary variables* to structure SC;

- *Continuous variables* to transfer the raw material from suppliers to the dairies and products form the dairies to the markets.

- *Continuous variables* for key compound concentration in the used raw materials.

- **Mathematical models**

***SC* mathematical description**

- *Material balance equations for the subsystems suppliers-dairies and dairies-markets* – they prevent from accumulation of raw materials in the suppliers and products in the dairies;

- *Equations for determination of the quantities of raw materials* required from each dairy to produce the planned quantities of products.

Dairy production modeling

It includes dependencies for the composition of used raw materials and products, as well as an equation for the target product yield as a function of the composition of the key compound. The model also provides a connection between the production tasks using size factors calculated.

Environmental impact modeling

The environmental impact model includes dependencies for the two type of pollutants:

- BOD_5 associated with wastewater produced during realization of the production tasks and pre-processing of used raw materials. It depends on concentration of the key compound of the raw materials used.
- CO_2 related to the energy consumed during the dairy production for the raw materials processing.
- CO_2 associated with the fuel combustion during the transport of raw materials and products. It depends on the payload capacity and the type of the used fleets as well as the distances in km.

CO_2 emitted from the fleets to transport 1 kg standardized whole milk and 1 kg curd/km is:

$$TMCO_2 = 2 \cdot \frac{TCO_2}{VCm}, \quad \left[\frac{\text{kg } CO_2}{\text{km.kg milk}} \right] \quad TPCO_2 = 2 \frac{TCO_2}{VCp}, \quad \left[\frac{\text{kg } CO_2}{\text{km.kg curd}} \right] \qquad (1)$$

where TCO_2 is the amount of CO_2 emissions produced by fuel combustion, [kg CO_2/ km]. $TMCO_2$ and $TPCO_2$ easy can be calculated based on data about the energy content of 1 liter fuel [MWh/l], the CO_2 emissions produced by fuel combustion [kg CO_2/MWh] and the fuel consumption [l/km], and the payload capacity of the fleet used - VCm [kg] and VCp [kg].

- **Constraints**

- for realization of the production portfolio in the time hosizon;
- for the capacity of suppliers of raw materials;
- for the capacity of the markets for realization of planned quantities of products;
- for the environmental impact costs that have to be paid for treatment of the pollutants.

- **Optimization criteria**

A single-objective optimization criterion is used F_{Profit}, [BGN]. It represents the difference between the production profit and all costs including the environmental ones, as follows:

$$F_{Profit} = F_R - (F_{P\_Cost} + F_{M\_Cost} + F_{T\_Cost} + F_{BOD\_Cost} + F_{CO_2\_E\_Cost} + F_{CO_2\_T\_Cost}) . \qquad (2)$$

where F_R is the revenue from the sale of the products at the markets; F_{P_Cost} is the total production costs for the dairy complex; F_{M_Cost} is the total costs incurred by the dairy complex for purchasing the necessary quantities of milk from suppliers for the products production; F_{T_Cost} is the total costs for the transportation of the milk and products between milk supply centers, dairies and markets; F_{BOD_Cost} is the total BOD_5 costs paid for treatment of the wastewater generated during production of the products; $F_{CO_2\_E\_Cost}$ is the total CO_2 emissions costs associated with the energy consumed by pasteurization process; $F_{CO_2\_T\_\text{Cost}}$ is the total CO_2 costs associated with emissions of pollutants generated during milk and product transportation.

The latter term of the optimization criterion (2) (the rest terms are given in detail in Kirilova and Vaklieva-Bancheva, 2017) is:

$$F_{CO_2\_T\_\text{Cost}} = \sum_{i=1}^{I} TCO_2cost \cdot \left(TMCO_2 \cdot \sum_{s=1}^{S} Y_{i,s} \cdot SDis_{i,s} + TPCO_2 \cdot \sum_{p=1}^{P} \sum_{m=1}^{M} X_{i,p,m} \cdot MDis_{i,m} \right) \qquad (3)$$

where $TCO_2\,cost$ is the cost for CO_2 due to the transportation of milk and products, [BGN/kg CO_2]. $SDis_{i,s}$, and $MDis_{i,m}$ are the distances between supply centers, dairies and markets, [km] $TMCO_2$ and $TPCO_2$ are calculated using Eq. (1). $i \in 1...I$, $s \in 1...S$, $p \in 1...P$, $m \in 1...M$ are data sets about the dairies, suppliers, products and markets.

A detailed description of the represenetd above optimization approach with the included models for: i) describing the products production; ii) planning the activities in SC; iii) describing the environmental impact of SC are given in detail in Kirilova and Vaklieva-Bancheva, (2017).

2. Case study

In order to found how the fleets used (with different payload capacity and fuel engines) influences the optimal environmental dairy products portfolio design, the represented above approach of Kirilova and Vaklieva-Bancheva, (2017) is implemented on a real case study comprising production complex for production of two types of curd in one technology over the time horizon of one month. SC includes two milk suppliers, two dairies for the products production and two markets for the realization of the produced products. All data needed for the optimal environmental dairy products portfolio design are given in detail in Kirilova and Vaklieva-Bancheva, (2017). Here, only data needed for determination of the environmental impact assessments for the CO_2 emissions produced during transportation of raw material and products using fleets with different payload capacity and fuel engines are given.

In Table 1, the distances between supply centers, dairies and markets are presented. In Table 2, data about the energy content of 1 liter fuel [MWh/l], the CO_2 emissions produced by fuel combustion [kg CO_2/MWh] and the fuel consumption [l/km], and the payload capacity of the fleets used - VCm [kg] and VCp [kg] are listed (https://autoline.info;http://1automarket.ru/en/; https://www.mercedes-benz.com/en/mercedes-benz/vehicles/trucks/fuel-comparison-tests-in-europe/; http://www.cngas.co.uk/cngvehicles.php).

The latter are needed for calculation of the CO_2 emissions generated during transportation of raw material and products $TMCO_2$ and $TPCO_2$, using different type of fleets.

Taking into account the data given in Table 1, Table 2 and data about the CO_2 cost due to transportation which is 1 BGN/kg CO_2, the environmental costs related with transportation of raw material and products using different type of fleets can be obtained.

Table 1. Distances between suppliers, dairies and markets in SC.

Distance, [km]				
	Supplier 1	Supplier 2	Market 1	Market 2
Dairy 1	41	36	226	92
Dairy 2	31	61	238	89

Table 2. Data about the fleets.

Type of fleet	Type of fuel	Payload capacity, [l] or [kg]	Energy of fuel combustion, [MWh/l]	CO_2 amount, [kg CO_2/MWh]	Fuel consumption, [l/100km] or [kWh/100km]
Milk tanker truck	Gasoline	2500	0.008056	249	32.2
	Diesel	2000	0.0095833	267	23
Refrigenerator truck	Diesel	4000	0.0095833	267	23
	Electro	3575	-	0.46	88
	LPG	1500	0.00702778	227	14
	Gasoline	1000	0.008056	249	11

RESULTS AND DISCUSSIONS

Eight optimization problems for all possible combinations of the fleets data used for transportation of raw material and products are formulated and solved using GAMS optimization software. The obtained results for the optimal green products portfolios are given in Table 3. One can see that Product 1 is only produced in the Dairy 1, while Product 2 is produced in both dairies. The latter is produced in 20 times greater quantity in Dairy 1 than in Dairy 2. Moreover, the two dairies supply the necessary quantities of raw material only from Supplier 2. Form the data listed in Table 3, it also can be seen that the optimal green products portfolios differ only in the values of the provided by the suppliers’ quantities of milk for Dairy 2 and the quantities of the Product 2 produced in the Dairy 2 respectively.

Table 3. Results for optimal production portfolios obtained at eight combination of fleets used for transport of raw material and products.

Optimal “green” product portfolio		**Optimal “green” product portfolio**	
Combination 1 *Milk tanker - diesel and refrigenerator truck - diesel (VCm=2000 l; VCp=4000 kg)*		***Combination 2*** *Milk tanker - diesel and refrigenerator truck - gasoline (VCm=2000 l; VCp=1000 kg)*	
Market 2	Supplier 2	Market 2	Supplier 2
dairy1.product1 7704	dairy1 165881	dairy1.product1 7704	dairy1 165881
dairy1.product2 34591	dairy2 6568	dairy1.product2 34591	dairy2 861
dairy2.product2 1649		dairy2.product2 216	
Combination 3 *Milk tanker - diesel and refrigenerator truck -LPG (VCm=2000 l; VCp=1500 kg)*		***Combination 4*** *Milk tanker - diesel and refrigenerator truck - electro (VCm=2000 l; VCp=3575 kg)*	
Market 2	Supplier 2	Market 2	Supplier2
dairy1.product1 7704	dairy1 165881	dairy1.product1 7704	dairy1 165881
dairy1.product2 34591	dairy2 6427	dairy1.product2 34591	dairy2 9326
dairy2.product2 1613		dairy2.product2 2341	
Combination 5 *Milk tanker - gasoline and refrigenerator truck - diesel (VCm=2500 l; VCp=4000 kg)*		***Combination 6*** *Milk tanker - gasoline and refrigenerator truck - gasoline (VCm=2500 l; VCp=1000 kg)*	
Market2	Supplier2	Market 2	Supplier 2
dairy1.product1 7704	dairy1 165881	dairy1.product1 7704	dairy1 165881
dairy1.product2 34591	dairy2 11314	dairy1.product2 34591	dairy2 5200
dairy2.product2 2840		dairy2.product2 1305	
Combination 7 *Milk tanker - gasoline and refrigenerator truck - LPG (VCm=2500 l; VCp=1500 kg)*		***Combination 8*** *Milk tanker - gasoline and refrigenerator truck - electro (VCm=2500 l; VCp=3575 kg)*	
Market 2	Supplier 2	Market 2	Supplier 1 Supplier 2
dairy1.product1 7704	dairy1 165881	dairy1.product1 7704	dairy1 165881
dairy1.product2 34591	dairy2 11162	dairy1.product2 34591	dairy2 3175 11619
dairy2.product2 2802		dairy2.product2 3714	

In Fig. 1 all costs values, corresponding to the eights optimal green products portfolios are shown.

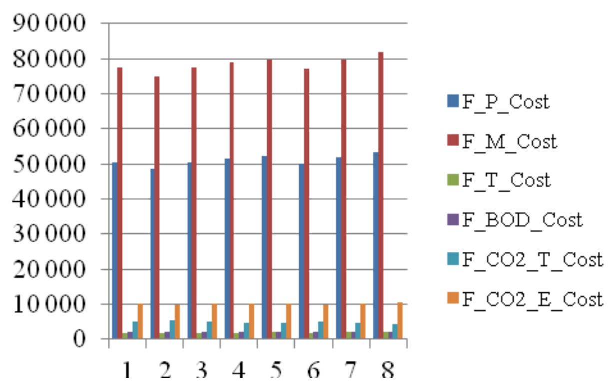

Fig.1. Costs values for the eight combinations of the fleets.

Fig. 1 shows that the costs of purchasing raw material and the production costs have the largest share in the total costs and the environmental costs and transport costs are significantly lower than the rest ones.

One can see in Fig. 2 that combinations 2 (milk tanker with diesel fuel and refrigenerator truck with gasoline fuel) results in the highest environmental costs, while combination 8 (milk tanker with gasoline fuel and refrigenerator truck with electro engine) corresponds to the lowest. The latter leads to the highest optimal green production portfolio, respectively (see Fig. 3).

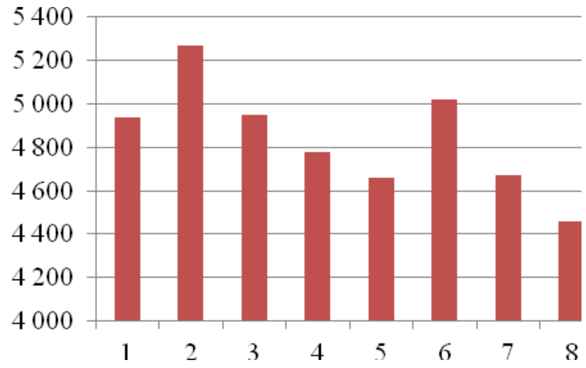

Fig. 2. Environmental transportation costs values for the eight combinations of the fleets.

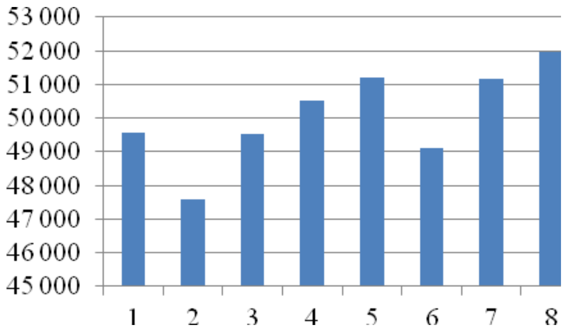

Fig. 3. Optimal "green" production profits for the eight combinations of the fleets.

CONCLUSIONS

The study represents an implementation of the approach of Kirilova and Vaklieva-Bancheva, (2017) for optimal green production portfolio design of dairy supply chain for eight combinations of fleets with different payload capacity and fuel engines. The obtained results have shown that the combination of milk tanker with diesel fuel and refrigenerator truck with gasoline fuel leads to the optimal green production portfolio with the greatest environmental impact.

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