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Environmentally friendly management of dairy supply chain for designing a green products' portfolio

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ABSTRACT

The study proposes an optimization approach for design of "green" products' portfolio of a supply chain for curd production. It includes three interconnected models for describing curd production, supply chain and its environmental impact. The latter is assessed in terms of wastewater and CO_2 emissions associated with the curd production and the transportation of raw material and products. The models are included in a broader optimization framework whereby the environmental criteria are defined in terms of costs such as the best trade-off between total profit and environmental impact to be achieved. The proposed approach is applied to a Bulgarian case study for production of two types of curd in dairy supply chain involving suppliers, dairies and markets. Two optimization problems for "green" products portfolio and profit products' portfolio design are formulated and solved. The obtained results show that the "green" products portfolio is limited by the environmental impact consideration and the optimal profit products' portfolio is limited by the plants' capacities. The successful implementation of the proposed approach opens the prospect of expanding not only to the whole range of dairy products but also the entire supply chain that includes players which are in a competition with each other.

1. Introduction

Production of milk and dairy products takes place in all EU Member States and represents a significant proportion of the value of EU agricultural output. For some Member States it forms a significant part of the agricultural economy (European Commission, 2016). However, dairy production involves considerable amounts of wastewaters and pollutants across the whole dairy network. Improving its sustainability requires implementation of so called Green Supply Chain Management (GSCM) strategy. The greater part of developed GSCM methods has applied the principles of Life Cycle Analysis (LCA) with the aim of improving the effectiveness of decision-making process and to facilitate successful implementation of the GSCM strategy (Sharma et al., 2015). The LCA appears a suitable tool as it allows environmental consideration of the supply chains within larger boundaries, i.e. capturing the processes from the dairy farms through dairy production to wastewater treatment plants, accounting for all material flows, resources requirements and all pollutants which can be expected across the network. For example, Sonesson & Berlin (2003) have implemented LCA to show which actors have the greatest impact on the environment and how the environmental impact of the dairy chains is influenced by variation of different social and economic factors such as population size, markets demands etc. across the whole network. Djekic et al. (2014) have recognized the key indicators which influence the sustainability of the dairy network as the choice of the production/packing portfolio, energy fuel profile and water usage. Palmieri et al. (2017) have extended the environmental boundaries of the system aiming to assess the environmental impact of the network in terms of animal diets considering the entire life cycle of the cows inside the dairy farms.

The successful performance of green dairy networks depends not only on the environmental impact assessment of the main actors involved but also on the exploration of their economic impact on the supply chain sustainability. In this order, Glover et al. (2014) have shown the dominant role of supermarkets as the main actor in GSCM, exerting strong financial pressure on the smaller organizations across the supply chain to co-operate and contribute to energy reduction in order to achieve cost reduction and profit maximization.

An incorporation of eco-innovations can be used successfully for improvement of dairy supply chain sustainability. For that reason it

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is very important to be identified the factors that influence to a great extent the decision-making process of supply-chain members and their willingness to make changes and adopt eco-innovations (Mandolesi et al., 2015; Mylan et al., 2015).

The decision-making process in GSCM can also be improved by applying the approach for assessment of the risk during the realization of supply chain activities in the dairy industry. It can be used for identification of the risk factors that can influence sustainability of the supply chain as the risk of non-fulfillment of the demands in terms of quality and quantity; the risk of dairy contamination by bacteria and antibiotics; the risk of lower dairy production etc. (Septiani et al., 2014).

One of the most effective ways to improve the supply chain sustainability is to use the LCA to optimal supply chain design that allow simultaneous consideration of different aspects of supply chain players as the best trade-off between the traditional costs and environmental impact to be achieved. For example, distribution of goods consumes fuel and makes a significant contribution to global warming. For minimization the location costs, traffic congestion and transportation of raw/processed milk and dairy products, Jouzdani et al. (2013) have proposed an approach for dynamic location of dairy facility and supply chain planning under demand uncertainty. In this sense, Validi et al. (2014) have proposed a green multi-objective optimization model for designing the dairy market supply chain in terms of the trade-off between transportation costs and CO_2 emissions generated during the milk transportation.

As can be seen the developed approaches consider different aspects of GSCM of the dairy activities in terms of the environmental impact and economic performance where some level of trade-off has been satisfied. On the other hand, the environmental considerations are mainly focused on the impact of CO_2 emissions produced during transportation of raw materials and products, and due to energy consumed in products manufacturing.

The aim of this study is to propose an optimization approach for "green" products' portfolio design of a curd supply chain. 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 trade-off between the total profit of the dairy complex and the costs incurred for the environmental impact due to its operation.

The rest of the paper is organized as follows: next section provides a detailed description of the "green" product portfolio modeling, which involves: problem statement, data required, curd production model, supply chain model and modeling the environmental impact. The proposed objective function evaluates the trade-off between economic and environmental issues in terms of money. Section 3 presents a real case study for supply chain for manufacturing of two types of curd and gives the results obtained. Finally, short concluding remarks are provided.

2. "Green" product portfolio modeling

2.1. Problem statement

A production complex comprising I dairies for manufacturing of P different types of curd (further called products) within predefined time horizon H is considered. The dairies are supplied with milk from S suppliers (milk collection centers). Manufactured products sell at M markets, see Fig. 1.

Additionally, it is known that each dairy involves equipment of N types with different volumes. A single technology (recipe) is used for the manufacturing of each product. The production costs are different for the dairies, but invariable within the time horizon. Standardized whole milk is used as a raw material. It is skimmed to the same level to produce a given type of product in each dairy. Consistent quality of products should be maintained. A common mathematical description will be used to model the yield of each product. The transportation of milk and products is organized and paid by the dairy complex. The distances between milk collection centers, dairies and markets are known. Transportation costs depend on the capacity of the vehicles used. Transportation costs and the prices of milk and products are also invariable in the time horizon. Capacities of milk collection centers and market demands are fixed over the time horizon.

Assuming that the structure of the supply chain which has to be designed is a constant within the time horizon, and accepting that no stocks and milk accumulations are permitted in the plants, a deterministic supply chain mathematical model will be developed. Its aim is to describe the required total site products' portfolio and its distribution across the involved plants as amounts of products that have to be produced in each dairy.

Simultaneously, all emissions generated over the designed supply chain related to the operation of the dairy complex should be evaluated. In Fig. 2 the boundaries determining the environmental framework of the curd supply chain are shown. It is obvious from Fig. 2 that these boundaries cover the emissions generated in the plants during product manufacturing, the amounts of CO_2 associated with the energy consumed by the processes and these which are due to the transportation of both raw milk and products.

Dairy manufacturing is associated with "generation" of a huge amount of wastewater that contains considerable amounts of proteins, fat, sugars and other organic residues. The main indicator for its assessment is Biochemical Oxygen Demand (BOD) accounted for five days. Wastewater produced in the dairies is treated in Wastewater Treatment Plants (WWTPs) at a given cost. The expenses associated with the considered products that have to be paid to the WWTPs are limited for each dairy. Air Pollution Tax (APT) is also imposed on the products manufacturing. It aims to maintain the amount of the emitted CO_2 below an acceptable level. Exceeding CO_2 emissions above this level results in imposition of financial penalties. The impact of the pollutants generated along the designed supply chain is evaluated in terms of costs which have to be paid.

From the above it is clear that three interconnected models have to be developed and involved in a common optimization framework. They cover manufacturing of products with consistent quality, design of the supply chain activities and the environmental impact of the emissions of pollutants in air and water produced during manufacturing and transportation of raw materials and products. Using the money that have to be paid for the produced wastes permits us to apply a "single" objective function in terms of costs instead of a multi-objective one looking for the trade-off between economic and environmental issues. The total site profit is used as an optimization criterion. It is defined as a cost function represented by the income from the market sale of products after the deduction of all expenses incurred such as production costs, raw materials costs, transportation costs, and environmental costs.

2.2. Data required

In order to develop the mathematical models three groups of data have to be known.

The raw material and products data are related to the composition of used raw material and final products. *The supply chain data* contain the horizon of interest; summarized data for dairy units and processing times; markets' demands; capacities of the milk suppliers; selling prices of milk and products; production costs;