A POSSIBILISTIC PROGRAMMING APPROACH TOWARD DAIRY WASTE SCUM-BASED BIODIESEL SUPPLY CHAIN NETWORK DESIGN UNDER SUSTAINABLE ENVIRONMENT

Desislava St. Nikolova, Konstantina G. Galcheva

Prof. d-r. Assen Zlatarov University, Burgas, Bulgaria

Abstract

In the last few decades, biodiesel has been introduced as an environmentally friendly fuel derived from a practically inexhaustible raw material (biomass) and can be considered as an analogue of traditional energy carriers. It has a number of advantages over fossil fuels, but high production costs are one of the main difficulties that hinder its economic feasibility. An approach to integrating sustainability into a supply chain for biodiesel obtained from waste generated in the dairy industry was developed. The designing an effective supply chain in order to minimize the overall operating costs and to provide the optimal scenario for reducing the environmental impact of the whole supply chain was explored. In the present study the feature of the considered supply chain was outlined and the wastes generated by the dairy industry as raw material for biodiesel production were characterized. A mathematical model of mixed integer linear programming (MILP) with an optimization criterion defined in terms of economic sustainability was proposed. Environmental assessment data were implemented as part of it. The optimal compromise between economic and environmental problems was intended.

Keywords: *biodiesel, waste milk scum, supply chain, sustainable development, MILP model*

1. INTRODUCTION

In the world of limited resources in which we live, the scientific community faces global challenges to overcome climate change, degradation (deterioration) of lands and ecosystems. In addition, there is a need to achieve sustainability that meets the needs of the growing population of the Earth and the need to modernize and strengthen industry. The rapid increase in demand for fuels leads to the irreversible depletion of non-renewable natural resources. Biofuels are emerging as the most promising energy alternative. The negative sides of conventional fuels, such as environmental pollution, disrupted supplies around the world and energy security reinforce the role of biofuels as a possible alternative to fossil fuels [1]. At present, the role of biofuels could be defined as the "Gold rush" of industry in the 21st century. The biodiesel is classified as a monoalkyl ester obtained by transesterification of methanol with higher fatty acids, which may be of plant animal origin. The main raw materials for its production are soybean oil, rapeseed oil, sunflower oil, cooking waste oil, animal fats and other edible or inedible fats [1,2]. The replacement of traditional diesel fuels with biodiesel leads to minimization of emissions of greenhouse gases and dust particles into the air [2,3]. On the other hand, biodiesel is more expensive than petrodiesel. Its price is the main obstacle to its commercialization [4]. The price of raw materials is 75-85% of the production cost of biodiesel [5].

What, however, is the actual price to be paid to be this green energy really alternative to fossil fuels? The cultivation of oilseed crops used as feedstock for biodiesel production leads to reduce the area planted with food crops. The problem comes from the fact that even now a large part of the world's population is starving or not fully fed. Another big problem is that honey producers are also affected. The insecticides are often used to increase yields, which negatively affect the existence of bees. Advanced raw materials of the second, third and fourth generation, such as cellular biomass, microbial oils, algae and others, are provoking growing interest because they have a shorter life cycle, do not require arable land and can use organic waste as a carbon source [6,7]. The food industry and in particular milk processing and the dairy production (drinking milk, cheese, yoghurt, milk powder, ice cream, melted butter, breading, etc.) also generate large amounts of high-fat waste biomass. This waste biomase can be used as a potential feedstock in biodiesel production. A large milk processing plant, which processes 500,000 liters of milk per day, generates about 250-300 kg. dairy waste scum daily.

An amount that seriously complicates their disposal [8]. Many dairies dump this waste in solid waste storage sites or burn it [9], which is economically unprofitable and could be seen as a "squandering" of hidden energy carriers. Waste from the dairy industry causes direct and indirect barriers to wastewater treatment and can lead to eutrophication in water bodies. In the literature, many authors view dairy waste as a progressive potential source for biodiesel production. A group of authors [4] study the potential of dairy waste as a starting material for biodiesel production and characterize it as an alternative to petrodiesel. Later, another team of scientists [10] compared the physical properties (density, kinematic viscosity, flash point, etc.) of biodiesel from milk waste with those of biodiesel obtained from different raw materials and conventional diesel, and identified it as their possible substitute. The rich content of triglycerides in dairy waste scum (more than 80%) gives grounds to consider the oil obtained from this waste as a progressive raw material for biodiesel production [8].

The commercialization of biodiesel is associated with the construction of efficient supply chain, representing a system for organization of people, information and resources. The activity of supply chain includes the transformation of the initial raw materials and components into a final product product and its delivery to the end user. One of the possibilities for achieving sustainable development is the optimization of all activities of the supply chain by implementing a strategy for optimizing the economic benefits, taking into account the requirements of the environment. [11] have proposed a MILP optimization model for strategic design of a sustainable Integrated Biodiesel/diesel Supply Chain (IBSC) using 1st & 2nd generations bioresources for biodiesel production providing all aspects of the sustainability – economic, environmental and social. There is a development in the literature [12], which presents a matematical model of mixed integer programming for optimal design of a supply chain for biofuels from 36 potential sources of raw materials (forest residues, agricultural residues / straw, sawmill waste, root biomass, corn, rapeseed potatoes, etc.), taking into account all European political regulations. The work of Habib S., et al. [13] is one of the first to create a model for dynamic optimization in the field of supply chains for biofuels produced from waste fats. The authors extend the tactical and strategic decisions by setting up a multi-purpose optimization procedure seeking a compromise that maximally satisfies the social, environmental and economic activities along the supply chain in the conditions of biodiesel production from waste animal fats (sheep and cow fat and waste fat chicken). In order to achieve resistance to supply chain of biodiesel generated by waste milk skum it is necessary to include the optimization of the product film in the dairy supply chain. [14] have developed an approach for design of optimal product portfolio of dairy supply chain comprising milk suppliers, dairies and markets for the production of different types of dairy products according to different production recipes satisfying economic and environmental criteria.

Many studies in the available literature consider the production of biodiesel from various food and non-food raw materials, including the production of biodiesel from dairy waste. The issue of including milk processing waste and the production of various dairy products in an efficient resource chain has not yet been explored in order to minimize the chain 's overall costs and identify the best scenarios for reducing the environmental impact for the whole chain.

The presented study proposes an approach for optimization of the strategic design of an efficient supply chain of biodiesel from dairy waste scum. The presented objective function is multiplied to minimize the total annual costs including the total annual capital costs, the annual operating costs, the annual government incentives and the emission costs CO_2. In order to find the best compromise between economic and environmental problems, the optimization criterion is defined in terms of economic sustainability, and environmental assessment data are implemented as part of it.

2. MATERIALS AND METHODS

2.1. Materials

Large dairy companies use a wide range of plants and equipment for processing, storage, packaging and transportation of various types of milk and dairy products. During the production process, packaging and transportation, a large amount of water is consumed, which after processing is collected in the treatment plants. The recycling of wastewater produces a semi-solid floating mass (Scum) with a dull

white color, which usually contains a mixture of fats, lipids, proteins, packaging materials, etc. This makes it difficult to dispose of and can cause direct or indirect operational difficulties in wastewater treatment. The staff of the resulting milk waste scum was analyzed by gas chromatography [4]. The percentage of the chemical compounds in the waste feedstock may vary depending on the type of milk and dairy products. According [4], the content of Palmitic acid is the highest (about 40% of the total amount), followed by Oleic acid, Stearic acid and Myristic acid. The total amount of other fatty acids is about 4.5%. The physico - chemical properties of dairy waste give grounds to consider it as a potential source for biodiesel production.

2.2. Methods

The main focus of this study is the design of a sustainable supply chain, minimizing the total operating costs of the chain and providing the best case scenario for reducing the environmental impact of the entire supply chain. This level of solution leads to the optimization of the source of raw material to ensure efficient and effective configuration of the supply chain, the appropriate technology used in the process, location and capacity of processing plants for utilization of liquid waste through biodiesel production, and issues for sustainability. The present study deals with the issue of process management by creating an optimal schedule for the operation of the entire system and the design of a system for managing the waste generated in the production process. Tools have been developed to formulate a mathematical model to describe the parameter, constraints and objective function.

2.3. Problem description

This study considers a combined biodiesel / milk supply chain represented in Figure 1.

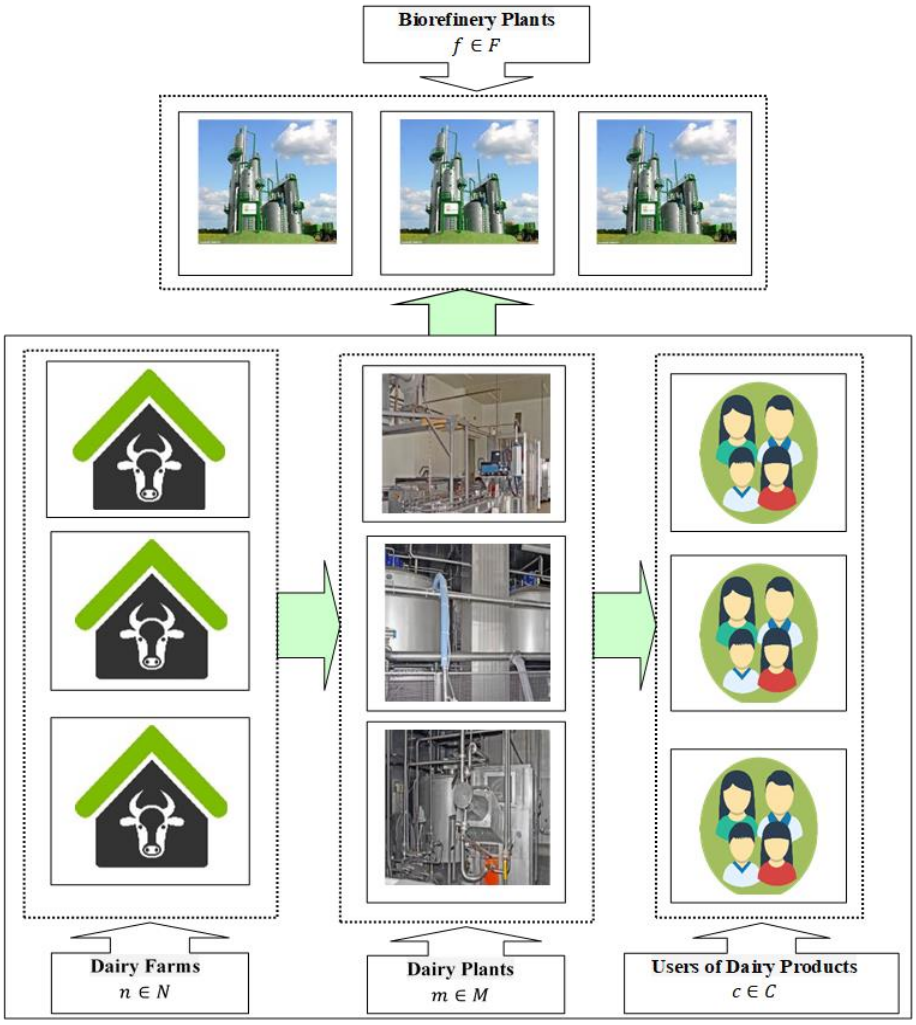


Fig. 1. Combined biodiesel / milk supply chain

The problem considered in this paper can be formulated as follows: A set of different types of milk used as a raw material for the production of many finished dairy products is given. The different types of milk (cow, goat, sheep, etc.) can be produced from dairy farms located in different places in the territory under consideration, each of these farms with limited productivity and nomenclature that are known in advance, and is also the selling price of the different types of milk is also known. For each of the farms there is a known type of transport that can be used to transport milk. On the other hand, it is assumed that there are a number of dairy plants located in different places in the area in question. For each of these dairiy plants, the possibilities for the production of the respective end products (eg fresh drinking milk 4.5%, yoghurt 3.6%, white brined cheese, yellow cheese) and the technologies for their production are known, as well as and waste products generated during production which can be considered as biofuel raw materials. It is assumed that the technologies for utilization of these waste products for biodiesel production are known. At the same time, the potential places where biodiesel plants can be installed are known. Possible types of biorefineries are known that can be used to install eligible sites for this purpose. The places for delivery of the produced final products are determined, as well as their type and admissible quantity at set lower and upper limits. The transport logistics for each type of raw material, final product and waste raw materials is set and for each transport connection the transport capacity, the available types of transport, the distance and the emissions from each type of transport are known.

The task is to determine the optimal operating conditions of the system as a whole, which includes: a portfolio for the operation of each of the dairy plants; a portfolio for each of the dairy farms; many biorefineries that need to be built in designated places; optimal productivity of biorefineries; transport scheme for delivery of raw materials needed for the operation of biorefineries.

The objective function for assessment the operation of the system includes all costs for the supply of raw materials, production and transport costs, as well as costs for the construction of the necessary biorefineries. In order to find the best compromise between economic and environmental problems, the optimization criterion is defined in terms of economic sustainability, and environmental assessment data are implemented as part of it.

In the scenario presented in this way, the task is to determine the optimal operating conditions of the system, which will ensure a minimum of the objective function while respecting the technological, environmental and time constraints. The optimization problem can be solved with the help of the GAMS software product and is a tool for making complete decisions. The proposed strategy can be applied to different countries or regions, adjusting the necessary modeling data.

2.4. Mathematical model

The MILP model includes a definition of parameters that are constant (known) and variables that are subject to optimization. First, the set of time intervals on the planning horizon is introduced t={0,1,2,…,T}. The index t indicates the variable or parameter corresponding to the t-th scheduling interval. A long planning horizon H (10 years) is considered. The whole time horizon H is divided into a set of discrete time intervals t. This time interval is divided into several equal time subintervals t = {0,1,2,…, T}, each of which lasts ∇t. Over the planning horizon, it is assumed that the consumption of dairy products will change by an estimated value. The supply chain assessment will be made on the basis of the economic criterion while the environmental assessment data are implanted as part of this criterion.

2.4.1. Environmental assessment model

The environmental impact of the resource supply chain is measured in terms of total greenhouse gas emissions ($kg\ CO_2 - eq$), resulting from the life-cycle activity. They are converted into carbon credits by multiplying by the market price of carbon emissions ($kg\ CO_2 - eq$).

The environmental objective is to minimize the total amount of equivalent greenhouse gas emissions resulting from the operation of the supply chain. The formulation of this objective is based on a "life cycle" analysis, which takes into account the stages from the production of the final products to their use and includes:

- *Greenhouse gas emissions released during the production of the dairy products in the dairy plants;*
- *Greenhouse gas emissions from the transport of raw materials, dairy products and dairy waste scum to biodiesel production facilities;*
- *Greenhouse gas emissions from the use of unused dairy waste scum for biodiesel production;*
- *Greenhouse gas emissions from biodiesel production using dairy waste scum as feedstock.*

The environmental assessment criteria represent the overall environmental impact of the operation of the combined dairy and biodiesel/diesel supply chain, through the resulting greenhouse gas emissions for each time interval $t \in T$. These greenhouse gas emissions are equal to the sum of the environmental impacts of each stage of the life cycle. Greenhouse gas emissions are usually determined as follows for each time interval $t \in T$.

$$EIJ_t = EPI_t + EPB_t + EWS_t + ETF_t, \quad \forall t \tag{1}$$

where,

EIJ_t - total environmental impact of the operation of the combined dairy and biodiesel/diesel supply chain for the whole life cycle, $[kgCO_{2eq}/d]$;

EPI_t - environmental impact in the production of dairy products in dairy plants, $[kgCO_{2eq}/d]$;

EPB_t - emissions from biodiesel production using dairy waste scum as feedstock, $[kgCO_{2eq}/d]$;

EWS_t - emissions from unused dairy waste scum for biodiesel production, $[kgCO_{2eq}/d]$;

ETF_t - emissions released during transport of raw materials, products and dairy waste scum to the respective facilities, $[kgCO_{2eq}/d]$.

2.4.2. Economic assessment model

The annual operating costs of the considered supply chain include: the costs for production of raw materials (milk), the costs for the production of dairy products, the costs for the biodiesel production from dairy waste scum and the costs for transportation of raw materials and products. Production costs include: fixed annual operating costs, as a percentage of total investment capital, and variable costs, which are proportional to the processing amounts. Transport costs take into account both loading and unloading activities (fixed costs) which don't depend on the distance and the price of the fuel, driving and maintenance costs (variable costs) which depend on the distance. The economic assessment determines depending on the total investment costs for the biodiesel production facilities, costs for building the biodiesel production facilities and the operation of the combined dairy and biodiesel/diesel supply chain for the planned time horizon.

They determine for each time interval $t \in T$ as follows:

$$TDC_t = TIC_t + TPC_t + TDWS_t + TDKN_t + TPI_t + TPW_t + TTC_t + TCO2_t - TB_t - TL_t, \forall t \tag{2}$$

where,

TDC_t - total costs of the combined dairy and biodiesel/diesel supply chain per year $[\$/y]$;

TIC_t - total investment costs for production capacity of the combined dairy and biodiesel/diesel supply chain compared to the period of operation and the purchase of the biodiesel plant per year, $[\$/y]$;

TPC_t - production costs for the total amount of biodiesel, $[\$/y]$;

$TDWS_t$ - costs of purchasing dairy waste scum feedstock for biodiesel production, $[\$/y]$;

$TDKN_t$ - costs of purchasing milk for the production of dairy products$[\$/y]$;

TPI_t - costs for the production of dairy products, $[\$/y]$;

TPW_t - production costs for use of unused dairy waste scum for biodiesel production, $[\$/y]$;

TTC_t - total transportation costs for the combined dairy and biodiesel/diesel supply chain, $[\$/y]$;

$TCO2_t$ - carbon tax charged according to the total amount $[CO_2]$ generated during the operation of the combined dairy and biodiesel/diesel supply chain, $[\$/y]$;

TB_t - revenue from the sale of biodiesel produced by all built bio-refineries, $[\$/y]$;

TL_t - government incentives for biodiesel production and building, $[\$/y]$;

2.4.3. Constraints

The constraints providing the feasibility of the obtained optimal supply chain which are defined as linear functions of the all decision variables are with respect to:

- the capacity of biorefineries;
- the flows rates;
- the dairy products demands;
- the amounts of milk needed to produce the dairy products;
- logistical and transport constraints;
- the use of total amounts of generated in the dairy plants dairy waste scum for biodiesel production;
- the material balance for the combined dairy and biodiesel/diesel supply chain;
- the implementation of the annual capacities of the dairy plants;
- the maximum annual farm capacity $n \in N$ for the production of milk of type $k \in K, [t/y]$;

2.4.4. Aim

The economic optimization criterion is considered. The environmental impact assessment is defined as a constraint. The economic objective is to minimize the total annual costs of the supply chain, including the total annual capital costs, the annual operating costs, the annual government incentives and the emission costs, [$]. The optimization problem for determining the optimal location of the facilities in the regions and their parameters is formulated as follows:

$$Find: X_t[Decision\ variables]\ MINIMIZE\{COST(T_t)\}\ s.t.: \{Constraint\ s\} \quad (3)$$

$$COST = \sum_{t \in T}(LT_t TDC_t) \quad (4)$$

where

LT_t - duration of time intervals $t \in T$, [year].

The objective function (3) and all constraints are linear functions of all decision variables.

3. RESULTS AND DISCUSSION

The MILP models have been solved using GAMS 31.2.0. The obtained results are listed in Figure 1 and Figure 2.

The analysis of the distribution of greenhouse gas emissions shows that the total greenhouse gas emissions generated by the operation of the combined biodiesel / milk supply chain for all time intervals of the period under review are mainly realized in the production of finished products in dairies EPI_t and in the utilization of unused dairy waste scum for biodiesel production EWS_t.

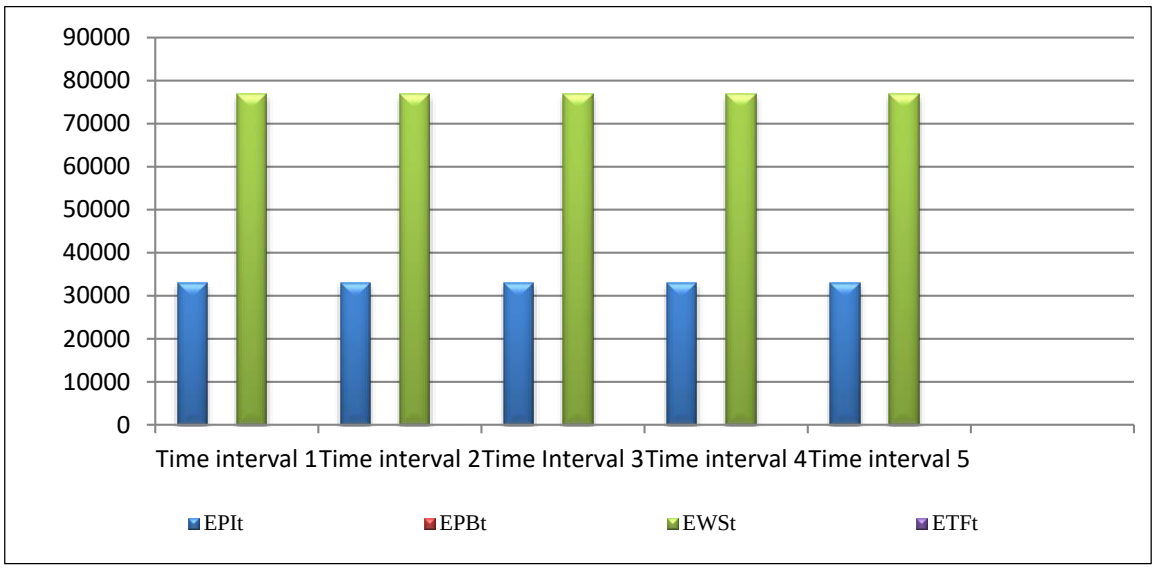


Fig. 1. The distribution of greenhouse gas emissions for life cycle stages in waste milk scum biodiesel production

Figure 2 shows the cost structure of the resource supply chain for waste scum-based biodiesel under the criteria "Minimum total annual costs", and the data for the environmental assessment are implanted as part of this criterion. Figure 2 shows that the highest value is the total cost of production of waste scum-based biodiesel TDC_t, followed by the cost of disposal of unused dairy waste scum TPW_t. The proposed study shows that the total cost of the combined biodiesel / milk supply chain for the whole period considered amounts to 10593364.13 [$].

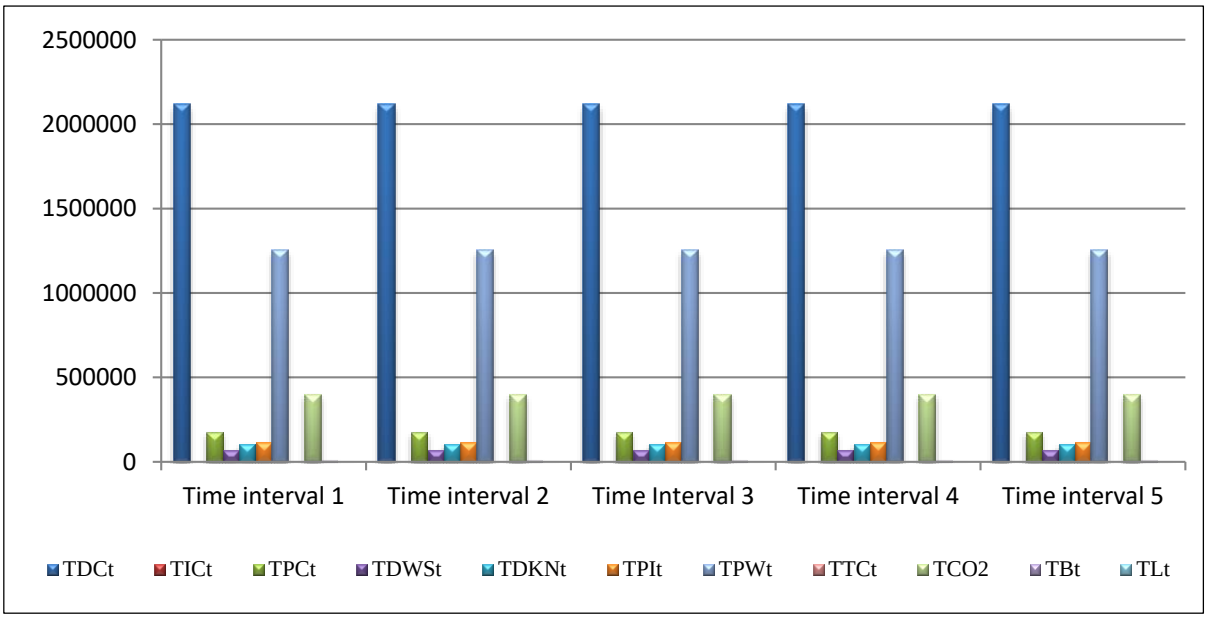


Fig. 2. The cost structure of the biodiesel supply chain

4. CONCLUSIONS

The main conclusions of the present study are that in order to achieve "sustainable" design and management of the system for production and distribution of biodiesel from waste biomass generated in the dairy industry, it is necessary to take into account the interactions between all components involved in production and the spread of biofuel. At the same time, the requirements of EU Directive 20/20/20 must be met. Analyzing the results of the study, it was found that the competitive production of biodiesel from an economic point of view depends on the optimization of the entire integrated supply chain throughout the planning horizon. Optimizing only parts of the supply chain will not lead to an understanding of the trade-offs over time, the geographical location of production and the supply elements needed to optimize biodiesel production. The approach proposed in the present study can be applied in different geographical regions that have the capacity to produce biological resources. The model may also take into account changing policy standards and changing technologies for biodiesel production over long planning periods.

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