

Assumptions of the decision support system for the transport of biogas plant substrates

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Abstract. The study presents research aimed at developing a decision model allowing to reduce Carbon dioxide emission to the atmosphere during corn harvesting for the needs of agricultural biogas plants. In order to develop this model, it is important to determine the optimal number of transport sets used during the transport process. It has been proved that it is possible to build a criterion function based on the time of transport (transfer to the place of loading, loading itself, transit to the place of storage, unloading), which results in the minimum number of transport sets used in this process. Presenting the possibilities of determining the optimum number of sets minimizing the set criterion function is the purpose of the study. The analysed criterion function represents the average cost (Carbon dioxide emission) per the time unit of the subject system composed of a forage harvester and transport assemblies.

1. Introduction

The farm-scale biogas plants process the renewable energy such as biomass into electric power and heat. Just like each an undertaking, also this one should be economically substantiated. Also, reduction of CO₂ emission in the course of the whole process of energy conversion is of no importance [7, 9, 14]. The transportation process of the harvested biomass is the process which considerably may influence these volumes. The transport of biomass for energy purposes is burdened with problems related to the low concentration of energy in its volume. Therefore, in such cases, means of transport with an increased volume of the cargo space are used. Also in transport of substrates for biogas plants, this type of transport is used. Most often they are agricultural tractors with volume trailers. Despite the use of the presented solutions, biomass transport continues to cause significant emission of CO₂ to the atmosphere.

These are big volumes of transported substrates and the utilized sludge. It is estimated, that to the farm biogas plant based on green maize and slurry it is approx. 3000 tons of green maize's chaff. However, in this case high concentration of the transportation process in the course of forming piles with ensilaged chaff from green maize is one of the more important issues [3, 2]. It results most of all from the necessity of quick pile's closing just to avoid unwanted oxygen fermentation's processes. The development of the unwanted organisms may result in formation of mycotoxins removal of which from the environment is not possible. The decrease of the energetical potential of the ensilaged substrate also takes place in such a manner [10, 4, 15].

In order to conduct the process of the pile's formation in a correct manner, the volume of individual elements is selected according to the throughput of the collecting forage harvester, which is the



leading machine in this technology. The appropriate volume of means applied for the pile's forming is one of the most important problems. These are the tractors with appropriate accessories allowing for simultaneous forming of new layers on the formed pile and their pressing. However, selection of an appropriate number of the transport means is an essential problem. This number depends on many factors such as their load carrying capacity or transport distance. Due to the specificity of agriculture, trailers used in transporting biomass have a diverse payload. It would therefore be natural to use only transport sets with the best parameters. However, such a situation is unacceptable due to social reasons, as biomass transport is carried out by farmers' cooperatives for whom profits from carrying out transport works are important for ecological and economic reasons.

The use of inappropriate means of transport results in an increase in carbon dioxide emissions resulting from increased fuel consumption per tonne of transported biomass. This solution also reduces the time needed to load the trailer. Shortening this time to the minimum value makes it necessary to increase the number of transport sets used for biomass harvesting. This solution significantly increases the amount of carbon dioxide emitted in the atmosphere during the transport of biomass to the storage points.

Economic costs, but also ecological cost of transport of cargo from the collection places to recipients can be optimized. The first step in solving the problem is the transport issue. However, in practice, there are also other problems related to the optimization of transport costs. In particular, in practice, problems of transport cost optimization occur in uncertainty. Some parameters of such an optimization task are random variables. Such tasks include issues from the theory of queues. The criterion function in this case is the expected value of the cost [5].

Mathematical modeling allows to obtain knowledge that can be used both in the planning process, conducting experimental research and the operation of real objects [13, 8, 6, 11, 12]. Construction of the model of a forage harvester's operation by transportation assemblies taking back the forage harvester's output to the place of storage constitutes the purpose of the study. For the analysis purposes it has been assumed, that the unit cost of the forage harvester's operation is decisively higher than the unit cost of a transport assembly's hire. The situation when a collecting forage harvester stops its operation waiting for a means of transport is inadmissible from the point of the system's operation. However, hiring of too many assemblies may be too expensive. Due to that, there arises a problem, whether for a (defined) specified situation there exists a number of assemblies minimizing the cost of the system's operation. To solve this problem, one should answer quickly the question how to determine the optimum number of assemblies. To make it possible, the tested system should be defined by introducing real assumptions. These assumptions concern the distance that each assembly has to travel from loading till providing for re-loading [5].

The aim of the article is to develop a model - a criterion function, that will result in further work on the development of a decision-making model allowing for reduction of carbon dioxide emissions and resulting from the transport of biomass to agricultural biogas plants.

2. Methods

In order to construct the mathematical model of the transportation problem, the designations as in the drawing 1 have been assumed.

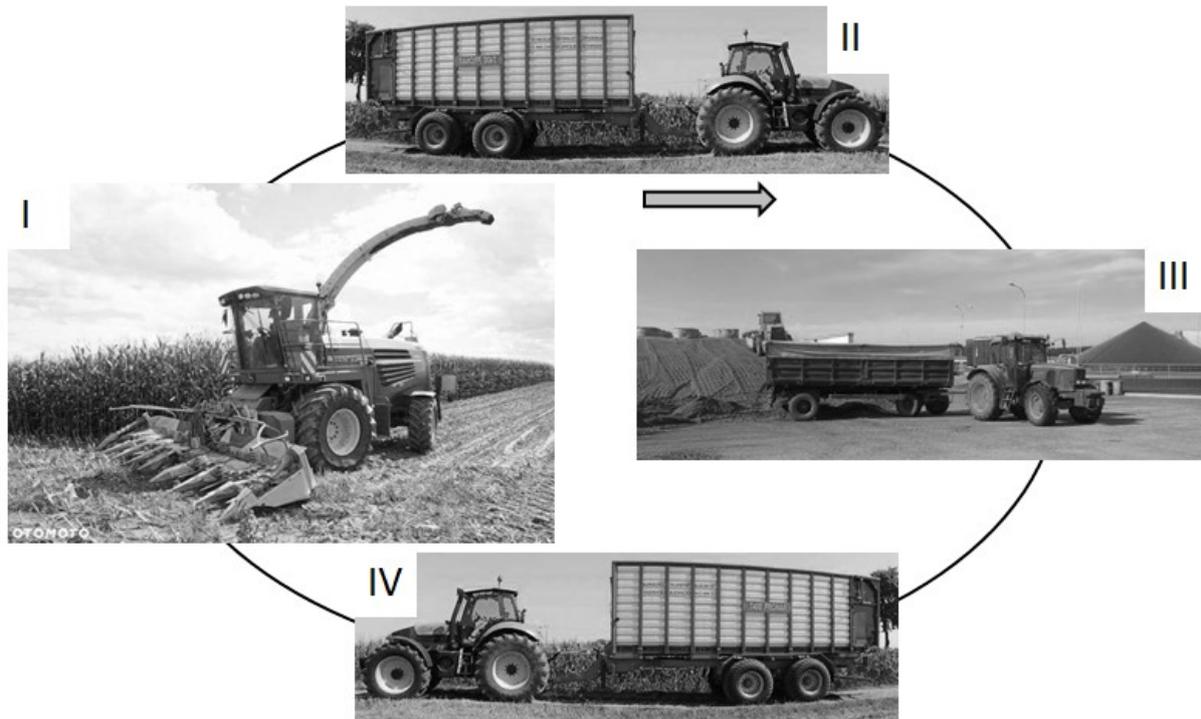


Figure 1. Scheme of the system of chaff from green maize's transportation: I – harvesting and loading of maize, II – transport of maize, III – unloading at the place of storage, IV – return to the place of loading.

Management of such a complicated undertaking, which is the supply of substrates, requires decision support. DeGroot in his work [1] considers various decision-making models. The following designations markings are used in the work:

- d – distance that a forage harvester covers at the time of loading in of one forage harvester's tank,
- D – fixed distance for each assembly from loading to travel to and from the loading point.

It is assumed, that at the moment $t = 0$ a forage harvester has loaded in the assembly k – th. It is assumed, that the distance from the forage harvester for k of that assembly equals to $X^{(k)} = 0$,

$K - 1$ the assembly is $X_1^{(k-1)}$ from the forage harvester,

$k - 2$ the assembly is $X_1^{(k-2)} + X_2^{(k-2)}$ from the forage harvester,

1 – st assembly is $X_1^{(1)} + X_2^{(1)} + \dots + X_{k-1}^{(1)}$ from the forage harvester.

The following designations are assumed:

- S_s – the unit cost of the forage harvester's standstill due to the absence of the assembly,
- S_z – the unit cost of one assembly's hire.

It is assumed, that random variables $X_j^{(i)}$ $j = 1, 2, \dots, k-1, i = 1, 2, \dots, k$ are independent and have just the same distribution, the mean value of the random variable $X_j^{(i)}$ is equal to $EX_j^{(i)} = m$, the standard deviation $DX_j^{(i)} = \sigma$.

let $Y = \Sigma X_i^{(1)}$.

If the first assembly has not reached the place of loading, then $Y_1 < D$. The average value of the cost of operating the transport system is equal to:

$$G(k) = E(D - Y \mid D \geq Y)S_s + K S_z, \quad (1)$$

where $E(D - Y \mid D \geq Y)$ is the conditional mean value of the distance of the first assembly from the loading place on condition, that the assembly has not reached that place. If $D < Y$, then the assembly shall wait for loading. The first component of the function is the cost generated in a situation, when the first transportation assembly has not reached on time the place of loading what means, that the forage harvester does not work. The second component represents the cost of hire k of the assemblies. The function $G(k)$ is proposal of the criterion function.

Developing of the function minimization's method $G(k)$ is the purpose of the study. It is assumed, that in special cases, at certain assumptions, the function $G(k)$ reaches the minimum value. In order to reach that purpose, it shall be necessary to develop the method of determining the conditional mean value.

$$E(D - Y \mid D \geq Y) = E(D \mid D \geq Y) - E(Y \mid D \geq Y), \quad (2)$$

It is known, that

$$E(D \mid D \geq Y) = D / F(D), \quad (3)$$

where $F(D)$ is the distribution of the random value Y , while

$$E(Y \mid D \geq Y) = \int y f(y) dy / F(D), \quad (4)$$

where $f(y)$ is the density of the random value Y .

The random value Y is the sum $k - 1$ of independent variables, from where it results, that

$$E(Y \mid D \geq Y) = (k - 1) m / F(D), \quad (5)$$

On the basis of (2), (3) and (4) there is

$$E(D - Y \mid D \geq Y) = [D - (k - 1) m] / F(D) \quad (6)$$

Calculation of the given mean value with the formula (6) is complicated by the fact, that the random variable Y is the sum of random variables (the cumulative distribution function $F(D)$ is the resultant of the cumulative distribution functions $X_i^{(1)}$). Only in case when the random variables $X_i^{(1)}$ have the same exponential distribution with parameter λ and density

$$f(x) = (1/\lambda) \exp(-\lambda x) \text{ for } x \geq 0 \quad (7)$$

the density of the random variable Y_1 may be analytically determined.

From the property of the exponential distribution and independence of random variables $X_j^{(i)}$ it results, that the random variable Y_1 has the gamma distribution with parameters $p = k - 1$, $b = 1/\lambda$. The parameter p is the integer, from what it results, that we have a special case of gamma distribution – Erlang's distribution. For gamma distribution there are available numerical procedures of the cumulative distribution function $F(D)$ value's calculation. Below there are presented the results of numerical calculations for three series of parameters (D, S_s, S_z) . These are the series $(10, 5, 1)$, $(10, 6, 1)$ and $(10, 4, 1)$.

In Fig. 2 there are presented the graphs of criterion function $G(k)$ for different values of the parameter S_s . In figure 3 there are presented the graphs of criterion function $G(k)$ for different values of the parameter D $\{10, 11, 12\}$ at $S_s = 5$, $S_z = 1$.

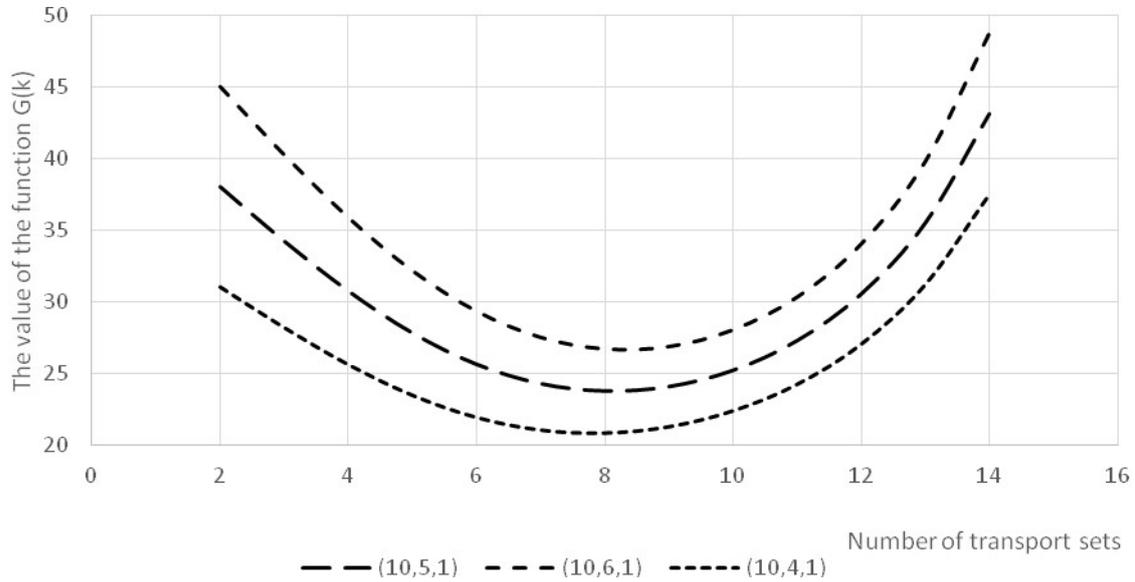


Figure 2. Realizations of the criterion function for $S_s \in \{4, 5, 6\}$.

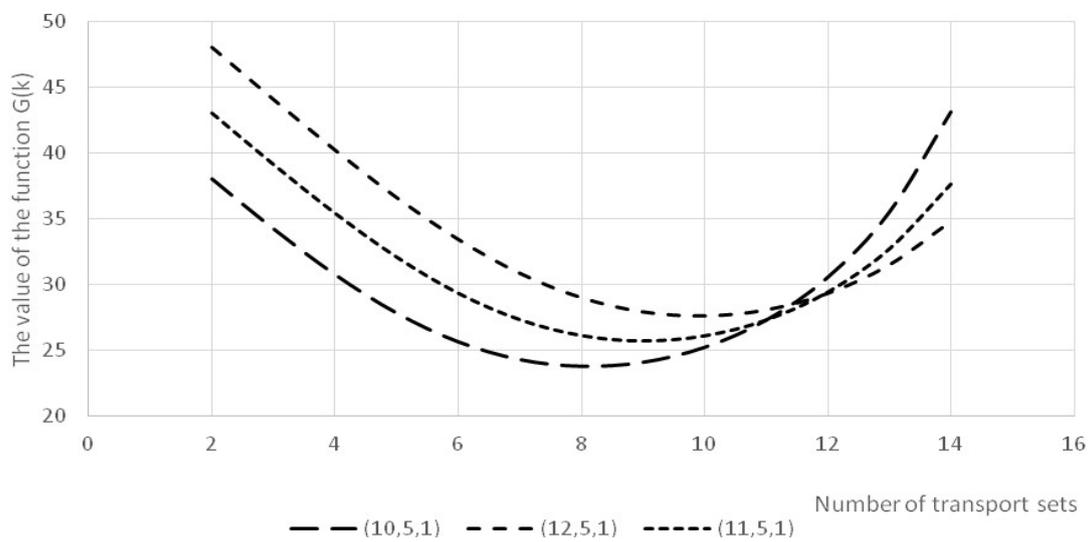


Figure 3. Realizations of the criterion function $D \in \{10, 11, 12\}$.

3. Conclusions

As it results from the graphs, each of the three criterion functions for both the analyzed cases, reaches the minimum. This example shows, that there exists the dependence of the minimum value of the criterion function on the parameter S_s and on the distance D from the place of loading (forage harvester) via the place of storage (biogas plant) back to the place of loading (forage harvester).

As it results from the presented numerical simulation, it is possible to construct the model describing the system of the collecting forage harvester's operating by the transport assemblies in the aspect of the road covered by them. The presented study is the introduction for developing of the model allowing for improvement of the system of maize chaff's collecting for a farm biogas plant. That model shall be used for developing of a specialist advisory system for reducing CO₂ emissions.

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