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Methodology for Investment Decision-Making in the Area of Automated Waste Sorting Systems

Summary. *The paper presents methodology for supporting the investment decisions in the sphere of construction of complex automated systems for sorting waste. The basis of the methodology is the technical-economic modelling of various options of complex systems, both from the perspective of the types of sorted waste and their degree of automation.*

Streszczenie. *Artykuł przedstawia metodologię do wspierania podejmowania decyzji inwestycyjnych w sferze budowy złożonych zautomatyzowanych systemów sortowania odpadów. Podstawą metodologii jest modelowanie techniczno-ekonomiczne różnych wariantów podanych systemów. (**Metodologia podejmowania decyzji inwestycyjnych w sferze zautomatyzowanych systemów sortowania odpadów**).*

Keywords: automated sorting systems, investment decision-making, waste
Słowa kluczowe: zautomatyzowane systemy sortowania, podejmowanie decyzji inwestycyjnych, odpady

Introduction

Waste management is a relatively young but rapidly developing area of the national economy. Industrially and economically developed countries have been intensively engaged in waste management only in the last 20 to 30 years. The reason is especially the negative impact of waste on the environment. From this perspective, the most effective method is waste recycling. The European Parliament defines recycling as "any recovery operation by which waste materials are reprocessed into products, materials or substances whether for the original or other purposes" [1]. Another option to be taken in this sphere is the utilization of waste as material (e.g. backfilling materials) or energy (e.g. alternative fuels). The worst option, from ecological point of view, but still the most widely used one is landfilling [2].

For the purpose of recycling (or any other use), waste must be properly treated. The basic step of this process is sorting – the division of waste into individual commodities suitable for further processing. Sorting usually takes place in two stages [3]: pre-sorting realized by subjects that create waste and sorting performed in organizations possessing special sorting technologies. The constantly increasing quantity and especially the number of types of processed waste materials make it necessary to gather the individual sorting lines into sorting systems that are interlinked both from the material and the process point of view. Organizations dealing with waste sorting use rapid technological development in this area and they invest in new technologies, characterized by a high degree of automation of the sorting process.

Investments into complex automated sorting systems are usually very financially demanding and, in terms of future return on investment, they are also very risky. Investment decisions in the sphere of construction of complex automated sorting systems should therefore be made on the basis of sophisticated methods and procedures. The objective of this article is to propose a methodology for supporting the investment decisions in the sphere of construction of complex automated systems for sorting waste. The basis of the methodology is the technical-economic modelling of various options of complex systems, both from the perspective of the types of sorted waste (each system may contain a different number of individual, interconnected lines for sorting different types of waste) and their degree of automation (from manual to fully automated sorting).

Automation of sorting processes

Increasing the degree of automation process is performed through reducing human's part in the process. In the last resort, human part is fully eliminated (including managing and monitoring functions). The automation in the field of waste sorting lies nowadays on transition from manual positive sorting, which is based on the manual selection of required fraction from input waste, to semi-automated or fully automated sorting systems. These systems use various types of technologies and devices, but the aim is always to increase the efficiency of sorting operations and to decrease human labour for one unit of required output (saving of personal costs).

Other positive effects of sorting automation are (modified according to [4, 5]):

- High quality of waste output – current automated waste sorting technologies guarantee up to 99% purity of required output, fulfilling the requests of potential customers.
- High homogeneity of waste output – automation fully eliminates human factor that causes unstable output quality because of inattention, tiredness or employee fluctuation.
- High percentage of sorted material and low amount of waste – automated sorting allows to increase the percentage of sorted fractions, which directly influences earnings and lowers undesirable waste landfilling costs.
- Enlarged capacity of sorting line – automated sorting technology generally enables to increase the amount of waste input whilst the area for sorting line remains unchanged.
- Removal of highly difficult and monotonous manual labour.

Automation of sorting waste includes also negative sides, which always have to be considered when implementing the chosen solution. The main disadvantage is high financial investment, which causes the increase of fixed costs of the process and possible increase of operating costs (for example maintenance costs of expensive specialized devices). Economic effectiveness of automated sorting processes is based on maximum capacity utilization that provides sufficient and stable amount of waste input. Another disadvantage is the possibility of decreased flexibility of sorting process, which is designed to a particular type of waste input.

Technology and devices used for sorting waste in specialized plants can be divided into two categories. The first category contains low-tech devices, which are found even in manual sorting processes, for example conveyors, presses or magnetic separators. The second category of technologies, which are used in high-tech automatic plants, contains optical sorting systems, ballistic and vibrating screens or the technology of eddy currents [6]:

- Optical sorting – technology based on scanning the flow of waste by weak x-ray and infrared sensors [7]. The implemented software recognizes the type of waste; the identified object is then ejected into appropriate collecting container or to a conveyor (in accordance to chosen solution). The biggest differences between various technologies, which can be found in contemporary market, are in accuracy of recognition and ejecting technology. The accuracy of recognition mainly depends on the amount of scanpoints – the accuracy of recognition is increasing with higher number of scanpoints. Nowadays, the maximum amount of scanpoint is several millions per second. The difference in ejecting is determined by how precisely the object is hit [8]. The first option is to hit the object right in the gravity center; the second option is to hit the object along its length.
- Ballistic and vibrating screens – technology based on different ballistic curves (physical attributes) of various materials when being injected to vibrating screens. Input waste can be divided into higher number of different fractions by combination of various ballistic and dimensional attributes.
- Eddy current – technology based on magnetizing non-ferrous conductive objects in alternating magnetic field. Arisen magnetic field has opposite orientation then original magnetic field and conductive object is ejected from conveyor.

Methodological basis for economic evaluation

Company investments are those expenditures on the renovation and expansion of assets that are expected to change into future cash revenues in a longer period of time (longer than one year) [9]. Good investment decisions must take into account three basic criteria – economic efficiency, risk and liquidity [10]. An ideal investment attempts to achieve the highest economic efficiency while maintaining the highest liquidity under minimal risk. Two groups of instruments can be used to assess the economic efficiency of investments – the methods of investment appraisal and tools of cost accounting. The methods of investment appraisal are particularly appropriate when selecting an optimal option from a group of new, previously unrealized investment projects [11], [12]. However, if it is desirable to compare the economic efficiency of an investment into a new complex automated sorting system with currently used waste sorting technologies, it is preferable to use the methods based on cost accounting. The reason is that the cost accounting is typically used to evaluate the economic efficiency of the existing production and business processes.

Cost–volume–profit analysis [13], which is based on costs classification depending on the amount of sorted waste, was selected as the main basis of the proposed methodology to support investment decision-making in the construction of complex automated systems for waste sorting. This approach provides foundations for determining the expected costs and revenues from waste sorting, both the total and unit (related to a ton of sorted waste), and it also provides evaluation of their structure. Based on these data, it is possible to make economic evaluation of an investment using properly selected indicators. The authors of the article recommend the following indicators to be used within the scope of the proposed methodology:

- Unit profit/loss

(1)
$$UP = UR - UC$$

where: UP - Unit profit/loss (€), UR - unit revenues (€), UC - unit costs (€).

- Unit contribution margin [14]:

(2)
$$UCM = UR - UVC$$

where: UCM – unit contribution margin (€·t^{-1} sorted waste), UR – unit revenues (€·t^{-1} sorted waste), UVC – unit variable costs (€·t^{-1} sorted waste).

- Break-even point [15]:

(3)
$$BEP = \frac{FC}{UCM}$$

where: BEP – Break-even point (t sorted waste), FC – fixed costs (€), UCM – unit contribution margin (€·t^{-1} sorted waste).

The unit contribution margin represents a decisive indicator for evaluating the economic efficiency of a complex automated sorting system and its components. A negative value of this indicator means that the revenues do not even cover the variable costs of the system and any amount of sorted waste will always generate a loss. In this case, you can clearly state that the sorting system or its parts are not economically efficient to operate. If the sorting system or its parts show a positive value of the unit contribution margin, it is possible to determine the break-even point. This point identifies an amount of sorted waste, which generates neither a profit nor a loss (there is a zero profit). Below the break-even point, the system or its part will generate a loss, above this point, it will generate a profit.

Proposed methodology

The methodology is intended for organizations dealing with waste treatment, considering investing into a new complex automated sorting system. The investment decisions are usually made in the event that the present sorting system is or will be unsatisfactory or when the waste market offers promising opportunities. A complex automated sorting system is defined as a set of interrelated sub-lines with a high degree of automation, designed to sort different types of waste. A complex system including the sorting lines for plastics, paper, municipal waste, biodegradable waste and alternative fuels can serve as an example. In addition, there are various versions of these lines in terms of the degree of their automation (used technology).

The proposed methodology is shown in Figure 1, in a form of a flowchart. The individual blocks of activities have the following description:

1. ***Input analysis*** – is realized in three steps:
   A) Analysis of the current status – evaluation of the current sorting system from the economic, market, technical and technological point of view.
   B) Definition of the target status – an investment decision is aimed at changing the status quo. For this reason, it is necessary to define the target status of the above mentioned aspects.
   C) Basic specification of the requirements – from the comparison of the current and target status, you can set the basic specification of the requirements for the new complex automated sorting system.

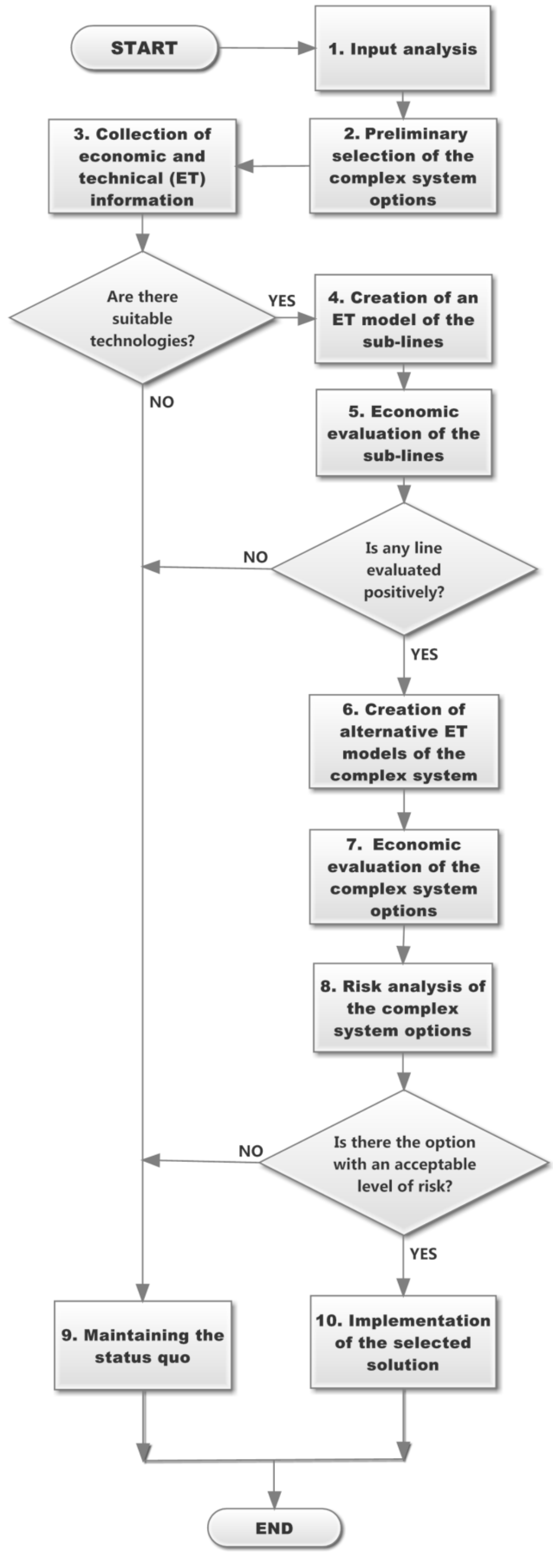

Fig.1. Flowchart of the methodology

2. ***Preliminary selection of the complex system options*** – the sub-lines and their degree of automation (technology used), which meet the specified requirements, are selected in this stage. If no line meeting the given requirements is found, the decision is to keep the status quo.
3. ***Collection of economic and technical (ET) information*** – to make sufficiently good decision regarding the selection of the final type of the complex automated sorting system, it is necessary to obtain detailed economic, market, technical and technological information on the pre-selected sub-lines. The information sources are mainly internal sources in organizations, the suppliers of lines and the organizations already using them. The economic and market information must be predicted.
4. ***Creation of an ET model of the sub-lines*** – at this stage, it is necessary to determine which of the sub-lines and their realization will be economically profitable to include in the complex system. ET models of all the available solutions are prepared to serve this purpose.
5. ***Economic evaluation of the sub-lines*** – is carried out from two points of view:
   A) Evaluation of the economic indicators defined in the methodological bases: unit operating profit, unit contribution margin, and break-even point.
   B) Comparison with the current status (economic effects of the current methods of waste sorting).

   If none of the lines under consideration is evaluated positively, it is decided to keep the current system of waste sorting.
6. ***Creation of alternative ET models of the complex system*** – the sub-lines with positive evaluation are selected for the complex automated sorting system. In a situation, where various versions of the line have positive evaluation for sorting the same type of waste in terms of the degree of automation, the version with the best economic results is selected. It is suitable to create alternative ET models of the complex system to increase decision-making quality.
7. ***Economic evaluation of the complex system options*** – it is performed using the economic indicators listed in paragraph 5 A).
8. ***Risk analysis of the complex system options*** – ET models of the complex automated sorting system are based on the forecast of the economic and market parameters. In case these parameters are characterized by high uncertainty, it is necessary to perform a risk analysis. Its realization can be recommended in two steps:
   A) Identification of the risk parameters – parameters with the highest anticipated volatility are selected and a sensitivity analysis is carried out (determination of the influence of changes of selected parameters on the stability of evaluation of the economic indicators). Usually, the market parameters (the amount of sorted waste, costs) are the most common risk factors.
   B) Creating a pessimistic scenario – the key risk parameters in the ET models are set up to the worst expected values and the economic evaluation is performed one more time. The risk of implementation of the individual options is the higher, the more negative their resulting economic evaluation is.

   The option with an acceptable level of risk is selected for the final realization. If such an option is not found, it is decided to maintain the status quo.
9. ***Maintaining the status quo*** – investments into the complex automated sorting system is rejected.
10. ***Implementation of the selected solution*** – the selected complex automated sorting system can be recommended for implementation.

Case study

The verification of the proposed methodology was realized in an organization dealing with waste treatment of citizens and businesses.

Input analysis – the original system was mostly based on manual sorting of waste. There were no sorting lines at all built for certain commodities (for example mixed paper), other lines did not meet the capacity demands anymore (e.g. the sorting line for plastics). From the economic point of view, the original system generated a loss (the losses were offset by other business activities of the organization). For these reasons, the organization was considering building a complex automated system consisting of four individual, but materially interrelated sorting lines:

1. Alternative fuel line – waste of citizens and business (external) and the residual fraction after sorting from other lines (internal) represent the input. The energetically usable output is alternative fuel freely loaded in trucks or compressed. The residual fraction is stored in landfills. Maximum capacity of the line is 20 000 t·year^{-1}.
2. Plastics line – the input is represented by pre-sorted plastic waste of citizens. The usable material outputs are compressed PET bottles of different colours, high density polyethylene, beverage carton, and foil. The residual fraction is used as an internal input into alternative fuel line. Maximum capacity of the line is 10 000 t·year^{-1}.
3. Paper line – the input is represented by pre-sorted waste paper of citizens. The usable material output is cardboard and paper suitable for deinking. The residual fraction is used as an internal input into alternative fuel line. Maximum capacity of the line is 3 500 t·year^{-1}.
4. Wood line – the input is represented by waste of citizens and businesses, manually pre-sorted before entering the line. The output is crushed wood of sufficient quality for further material use. The residual fraction is used as an internal input into alternative fuel line. Maximum capacity of the line is 5 000 t·year^{-1}.

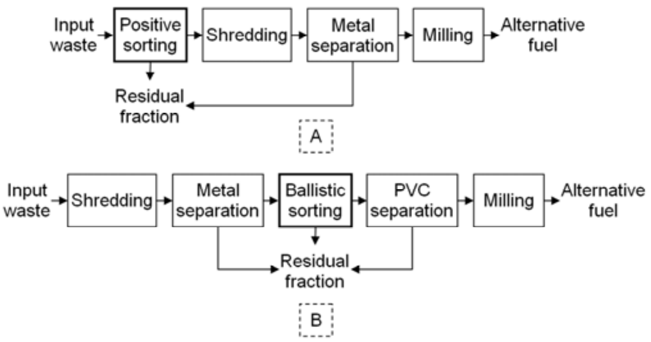

Fig.2. Scheme of alternative fuel production: A) Variant A, B) Variant B

Preliminary selection of the complex system options – the suppliers of sorting technologies who suggested suitable options of technological solutions with different degree of automation for the individual lines had been inquired during the following stage. As an example, two basic line design of alternative fuel can be presented:

1. Variant A: low degree of sorting automation – line is based on positive manual sorting (see Fig. 2 A). Only suitable content is picked from input waste, which is shred (the rest is landfilled), and after metal separation it is being milled into alternative fuel. This variant demands lower investment, but it shows decreased degree of sorting (resulting in higher landfilling costs, lower earnings from alternative fuel sale), and it requires higher number of human labour (increased personal costs).

Variant B: high degree of sorting automation – line uses automatized ballistic sorting (see Fig. 2 B). Input material is first shredded and after metal separation, material is ballisticly sorted into light and heavy fraction. Light fraction is, after PVC separation, milled into alternative fuel. Heavy fraction is landfilled. Relatively high investments guarantee high degree of sorting and fully automatized plant.

Collection of ET information – relevant ET information was collected for each sub-line. The information is closely related to the specifics of each line, and the concrete situation in the surveyed organization. That is why our attention will be limited only to the example of information needed to create an ET model of the alternative fuel line in variant B:

- The investments and sources of financing: an anticipated grant amounting to 40% of the total investment, 60% from their own resources, a lifetime of 12 years.
- The amount of sorted waste (inputs): a realistic scenario expects 11 505 t-^{1}·year, of which 6 000 t^{-1}·year will be external waste.
- The final products (outputs): 92.5% alternative fuel, 7.5% residual fraction. 50% of the alternative fuel is pressed.
- The prices: market prices for buyout of input waste, sales of alternative fuel and landfilling of the residual fraction.
- The operating capacity of the key facilities: automated line 8 t·hour^{-1}, press 4 t·hour^{-1}.
- The power consumption: installed power input of the line is 456.5 kW, 8.6 kW is the power input of the press. The market price of electricity.
- The line operators: one worker performing the controlling function. Downtime is 20% of the operating time.
- The handling machines: handling inputs and outputs realized by a grapple with an internal cost rate, expected additional handling 25% of alternative fuel during dispatching.
- The overhead costs for premises: the line and the necessary storage facilities occupy an area of 1725 m^2, valued using an internal rate of rent.
- The repairs and maintenance: regular maintenance is 1% of the investment, replacement of mill and crusher knives and bearings after 150 hours of line operation.

Creation of a sub-lines ET model – ET models of all four sub-lines and each automation degree variant were created at this stage. An ET model of alternative fuel line in variant B will be used as an example. The model is based on identifying the main items of the variable and fixed costs and revenues:

Variable costs:

– Consumption of electricity:

$$EC = TA \cdot UEC\left(\frac{LP}{CL} + \frac{PP \cdot SF \cdot SCF}{CP}\right) \tag{4}$$

where: EC – consumption of electricity costs (€·year^{-1}), TA – total amount of sorted waste (t·year^{-1}), UEC – price of electricity (€·kW^{-1}·hour^{-1}), LP – line power input (kW), PP – press power input (kW), CL – operating capacity of the line (t·hour^{-1}), CP – operating capacity of the press (t·hour^{-1}), SF – share of alternative fuel, SCF – share of compressed alternative fuel.

– Handling costs:

$$HC = TA \cdot UHC\left(\frac{1}{CL} + \frac{SF \cdot SAH}{CP}\right) \tag{5}$$

where: HC – handling costs (€·year^{-1}), TA – total amount of sorted waste (t·year^{-1}), UHC – unit handling costs (€·hour^{-1}), CL – operating capacity of the line (t·hour^{-1}), CP – operating capacity of the press (t·hour^{-1}), SF – share of alternative fuel, SAH – share of additional handling.

– Personnel costs:

(6) $$PC = \frac{TA \cdot UPC \cdot NE}{CL}(1 + SD)$$

where: PC – personnel costs (€·year^{-1}), TA – total amount of sorted waste (t·year^{-1}), SD – share of downtime, UPC – unit personnel costs (€·hour^{-1}), NE – number of employees, CL – operating capacity of the line (t·hour^{-1}).

– Replacement of knives and bearings:

(7) $$RC = \frac{TA \cdot URC}{CL \cdot TR}$$

where: RC – replacement of knives and bearings costs (€·year^{-1}), TA – total amount of sorted waste (t·year^{-1}), URC – costs of one replacement (€), CL – operating capacity of the line (t·hour^{-1}), TR – time of one replacement (hour).

– Costs of residual fraction landfilling:

(8) $$LC = TA \cdot ULC \cdot SR$$

where: LC – costs of residual fraction landfilling (€·year^{-1}), TA – total amount of sorted waste (t·year^{-1}), ULC – price of landfilling (€·t^{-1}), SR – share of residual fraction.

Fixed costs:
– Regular maintenance:

(9) $$MC = IC \cdot SI$$

where: MC – regular maintenance costs (€·year^{-1}), IC – line investment costs (€), SI – share of investment price (year^{-1}).

– Rent of premises:

(10) $$RPC = UIR \cdot AL$$

where: RPC – rent of premises costs (€·year^{-1}), UIR – rate of internal rent (€·m^{-2}·year^{-1}), AL – area of the line and warehousing premises (m^2).

– Depreciation:

(11) $$DC = \frac{IC}{IL}(1 - SG)$$

where: DC – depreciation costs (€·year^{-1}), IC – line investment costs (€), SG – share of grant, IL – investment lifetime (year).

Revenues:
– Purchase of sorted waste:

(12) $$PR = TA \cdot UPR$$

where: PR – purchase of sorted waste (€·year^{-1}), TA – total amount of sorted waste (t·year^{-1}), UPR – purchase price of waste (€·t^{-1}).

– Sales of alternative fuel:

(13) $$SR = TA \cdot USR \cdot SF$$

where: SR – sales of alternative fuel (€·year^{-1}), TA – total amount of sorted waste (t·year^{-1}), USR – price of alternative fuel (€·t^{-1}), SF – share of alternative fuel.

Economic evaluation of the sub-lines – every line and its variant was economically evaluated using formulae (1), (2) and (3). Results for the best evaluated variants of the sub-lines are summarized in Table 1 (in case of alternative fuel line, the Variant A was in a loss, therefore the table includes the results of economical evaluation of Variant B).

Table 1. Indicators of economic evaluation of the sub-lines

Line	Sorted waste (t·year^{-1})	UP (€·t^{-1})	UCM (€·t^{-1})	BEP (t·year^{-1})
Alternative fuel	6 000 (external)	291	627	6 156
Plastics	5 000	-158	860	5 923
Paper	3 500	126	520	2 637
Wood	2 800	-1 428	-888	x

If the sub-lines are evaluated solely on the basis of these indicators, the recommended lines for the complex automated sorting system will be the alternative fuel line (the line will be profitable even if it processes only external inputs) and the paper line. The plastics line will be profitable only if there is an increase in the volume of sorted plastics. The wood line is not even able to cover its variable costs, which is why it will generate a loss with any volume of sorted wood.

A comparison with the current situation provides another view of the acquired evaluation. The manual plastics line has insufficient capacity and its operating is more unprofitable then suggested scenario. The organization does not sort paper and it is able to sell the mixed paper itself at the market price.

Creation of alternative ET models of the complex system – with regards to the previous economic evaluation, it was decided to create and evaluate these two options of the complex system:

1. Option I: alternative fuel line and plastics line - wood unsuitable for resale is stored in landfills (it does not enter the fuel line) and instead of mixed paper sorting, it is sold directly.
2. Option II: alternative fuel line, plastics line and paper line - wood unsuitable for resale is stored in landfills.

Economic evaluation of the complex system options – the evaluations of the results of the created options are shown in Table 2 in the part describing the realistic scenario of the volume of sorted waste and a 40% grant.

Table 2. Unit profit/loss (€·t^{-1}) for the contemplated complex system options, including the risk analysis

Volume scenario	Option	Grant 40%	Grant 0%
Realistic	I	280	25
	II	32	-233
Pessimistic	I	-47	-430
	II	-420	-818

The unit profit / loss can be used as a benchmark. Both of the contemplated options are profitable according to the realistic scenario and the anticipated grant of 40%. Option I is economically more advantageous. The reason is especially a very attractive price for direct sales of mixed paper.

Risk analysis of the complex system options – the first activity within the scope of the risk analysis was the identification of the input ET model parameters, characterized by great instability – the amount of sorted waste, the purchasing and selling prices of waste and the sorted commodities and the grants. A sensitivity analysis was performed for these parameters from the perspective of the unit profit / loss, which resulted in the identification of two key risk parameters: the amount of sorted waste and the grants. Minimal change of these parameters has a significant impact on the profitability of the considered options of the complex automated sorting system. A pessimistic scenario was prepared for the assessment of risk of the entire investment:

– The amount of sorted waste: external input for alternative fuel line 3 000 t·year^{-1}, pre-sorted plastics 2 500 t·year^{-1}, pre-sorted paper 3 500 t·year^{-1} and pre-sorted wood 2 500 t·year^{-1}.
– It will not be possible to acquire a grant.

The outcomes of the risk analysis are presented in Table 2. The investment risk is acceptable only for Option 1 and in case that both risk factors do not arise in their extreme values at the same time.

Implementation of the selected solution – management of the organization joined the final decision regarding the realization with the possibility of obtaining grants. If a grant is provided, the complex automated sorting system including the alternative fuel line and the plastics line will be built. Otherwise, more economic versions of both of these lines will be searched for.

Conclusion

The results of the case study have demonstrated the viability of the proposed methodology to support investment decision-making in the sphere of construction of complex automated systems for sorting waste. The main benefits of the method can be seen in the fact that it allows:

– Considering a wide range of options of the complex automated sorting system in terms of the number of sub-lines (types of sorted waste) and their degree of automation (design).
– Evaluating the investments on the basis of clear economic indicators with a possibility of comparing them with the current sorting system.
– Improving the quality of decisions without the need to use time-consuming economic and technical modelling of all the available combinations of sorting systems.

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