ECONOMIC AND ENVIRONMENTAL APPRAISAL OF RESEARCH AND DEVELOPMENT PROJECT: NEW DIGESTATE TREATMENT TECHNOLOGY

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Abstract

Need to increase the intensity of agricultural production brings increased demand on policy makers´ decisions and agricultural practice. In this context in recent years has increased the importance of management tools and indicators for assessing and managing the farming activities. The subject of matter is the appraisal and management of not only the economic impacts, but also the environmental and social impacts. Input-output tables are used for various types of analysis. They were initially used for economical appraisal and later were extended to include more complex appraisal of the technology and working patterns and of new or substantially improved products. Within appraisal, the focus is not only on economic consequences but also on environmental and social aspects. The paper focuses on the economic and environmental appraisal of a particular outcome of a R&D project. With the growing number of biogas stations, there are in the literature increasingly emerging studies aimed to analyse the economic and environmental impacts of treatment of digestate, which is generated as a waste product of biogas production and is used in agriculture as fertilizer. The main aim of the paper is to present, using the balance models, economic and environmental appraisal of new digestate treatment technology.

Key words: research and development, environmental aspects, economic appraisal, digestate

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Introduction

Permanent requirements to increase the intensity of agriculture production, caused by the population growth, do indeed increase the pressure on the environment (land cultivation, fertilizers application) (Payraudeau and van der Werf, 2005). Agriculture practice and policy makers are forced to make decisions that might well have long-term consequences. Therefore, there is a definite need for information and management tools, such as management accounting, environmental reporting, and subsequently the calculation of environmental impacts has had to increase incredibly in accordance (Payraudeau and van der Werf, 2005). The comparison of various methods and collecting required information in some European countries might well bring an inspiriting insight, so a brief summary is provided in Table 1.

Tab. 1: Environmental assessment of agriculture practice

Region, country	**Required information**
Europe	assessment of social, economic and environmental values of new farming practices
United Kingdom	environmental performance evaluation to promote best practice
Germany	inputs and outputs balance models (material and energy) of a particular product
	agricultural practices indicators of crops
Austria	arable land assessment to set the level of associated payments
Switzerland	adjusting Life Cycle Assessment for agricultural practice impact assessment

Source: Adjusted according to Galan, Peschard and Boizard (2007)

A great variety of indicators to assess the sustainability of agriculture production has recently been developed. Galan, Peschard and Boizard (2007) identify indicators related to the amount of substances applied on the field (e.g. nitrogen balance); relating to the overall capacity (e.g. storage space) or the environmental impact regarding polluted soil or water. Biogas provides a renewable energy resource, the increase of biogas stations (hereinafter “BGS”) is reflected in a growing number of scientific papers that analyze the economic and environmental impacts of biogas production. As a sustainable resource, biogas production requires a closed cycle of material and therefore requires sustainable recycling of digestate (Poeschl, Ward and Owende, 2012). Digestate can be defined as a byproduct of the fermentation process in the BGS. It consists of both solid and liquid components. The term fugate is used for the liquid component. Application of digestate and fugate on land is regulated by laws (mainly by the Nitrate Directive), that precisely specify the total amount of digestate and specific conditions at the time of application. Digestate can not be applied to over humid, frozen or snow covered soil, it must be applied only within the season; hence building a storage capacity in accordance with current legislation is required. Scientific papers are also used to support the normative (legislative) limit of digestate application (eg. in Flanders) – see Vasquez-Rowe et al. (2015). Currently, at least 50% of BGS in the Czech Republic store digestate without any treatment in a storage reservoir. The other half of BGSs applies a separator, which mechanically separates solid and liquid fraction (fugate) which goes into the storage reservoir. As these treatments cannot effectively reduce ballast liquid fraction, beneficial components (particularly nitrogen, phosphorus, potassium, etc.) cannot be recycled and reused for land fertilization. There are notable calls for safe soil management and to encourage the application of nutrients to fields. Analysis of various technical options for digestate treatment have also been provided, whereas the net effect on the agricultural land is still inadequately mapped (Vasquez-Rowe et al., 2015).

The main objective of this paper is to present the utilization of input-output tables (balance models) in the framework of the evaluation of results of the R&D project: new technology for treatment of digestate (or fugate respectively). Approaches to this new technology appraisal are discussed not only from the point of view of a future potential user of this technology but also from the point of view of a region sustainable development management.

1 Materials and methods

Balance models, input-output tables (hereinafter referred to as "IOT) are used for treatment of various types of analysis. Initially, the IOT were used for purely economic appraisal and consequently results were provided only in monetary units. As the economic information was not sufficient, recent non-monetary units have been implemented.

Merciai and Heijungs (2014) provide practical use and introduce physical IOT (hereinafter "PIOT") and hybrid IOT, that combine physical and monetary IOT. The balancing models can be found also in the analysis Bojacá et al. (2012), who use them to optimize agricultural activity and evaluate energy efficiency. IOT combine material flows and a concept of a "black box" that can help to evaluate the effective use of materials and energy; Liang et al. (2012) use this concept to estimate the total emissions of CO_2, SO_2 and NO_x in agriculture, construction, manufacturing and electricity and heat production.

In compliance with the main objective of this paper, a case study was outlined. The case study presents a R&D project carried out by a company focused on the design, construction and operation of the BGS. This company is currently working on project development of a new technology for the chemical treatment of liquid digestate component (fugate). The desired output of the new technology of digestate treatment is treated water and sludge, rich in biogenic elements. The aim of the technology is still to decrease the amount of the chemical oxygen demand (COD) and total nitrogen load though coagulation and flocculation of natural sorbents and pH adjusting. This new technology is currently under operative testing. The economic and environmental appraisal provided in this stage can reveal the strengths and also the weaknesses of the innovative technology.

A model of the BGS that is not connected to the agricultural activity and does not own fields for the distribution of digestate was used as a case study. The produced biogas is used to produce electricity and heat in a cogeneration unit. Appraisal of new digestate treatment technology will be carried out as a comparative analysis of the zero option (through the assessment of the operating costs of existing solution) with option A, which will assess only the economic impacts and option B, which will compare environmental impacts of the technology.

In the following text attention is given to the presentation of approaches to appraisal of the new technology of digestate treatment with usage of IOT. The appraisal is done for the treatment of 100 dm^3 of fugate (=1 batch). Information on the existing state is taken from real data of a regular BGS, other data are from results acquired in the pilot plant (pre-operation plant) for the new technology for fugate treatment.

2 Results and discussion

Digestate is a by-product of biogas production in a BGS. Under the current way of digestate management (option zero) digestate is further treated in a separator where the liquid part (fugate) is separated, this liquid part (fugate) contains approximately 5% of dry matter. BGS (based on agreements with farmers) transports fugate to fields. Transportation costs for 100 dm^3 fugate are on average 50 CZK. BGS also pays fees for placing untreated fugate on fields (this fee is 30 CZK/100 dm^3 fugate). Operational costs related to managing fugate are, under the existing conditions, 80 CZK/100 dm^3 fugate.

New technology for digestate (fugate respectively) treatment is based on reducing organic substances contained in aqueous solution. The pollution is measured by means of indicators BSK and CHSK. BSK (=biochemical consumption of oxygen) represents the volume of oxygen needed for full oxidation of biologically degradable substances contained in the inspected water. CHSK (=chemical consumption of oxygen) is the value of oxygen consumption needed for the oxidation of all organic substances, not only those, that can be degraded/eliminated by the biologic way. As a general rule it is valid that the higher the value of the indicators the more contaminated is the water with dissolved organic substances.

The newly proposed fugate treatment is executed in an equipment/facility that works in a dis-continuation manner. The treatment of fugate is done in batches. Fugate that is diluted by water (in ratio of 1:3) enters the facility. Then five chemicals in a given volume are added to the facility (herein after marked are *a*, *b*, *c*, *d* and *e*). After the treatment process is finished wastewater is discharged from the facility. This wastewater shall be collected in a lagoon with reed vegetation. The water from the lagoon can be re-used in the next batch to dilute the treated fugate. However this water can be also used a technological water or water for irrigation and thus reduce the operating costs. Separated sediment is also discharged from the facility and this sediment can be used as a fertilizer. The entire process utilizing IOT is illustrated in Figure 1. Table 2 demonstrates pollution of the liquid element at the entry into the facility and after the treatment that is at the exit from the facility.

Fig. 1: Balance of inputs and outputs of the new digestate treatment technology (treatment of 100 dm^3 fugate=1 batch)

INPUTS		
Substance	**Unit of measure**	**Amount**
Fugate	dm^3	100
Water	dm^3	300
a	dm^3	18
b	dm^3	7
c	dm^3	5
d	dm^3	22
e	dm^3	10

Energy	kWh	0.5

OUTPUTS		
Substance	**Unit of measure**	**Amount**
Water	dm^3	210
Sediment	dm^3	252

Source: The authors

Tab. 2: Pollution indicators

		INPUT	OUTPUT
Indicator	**Unit**	**Fugate**	**Treated fugate**
$CHSK_{cr}$	mg/ dm^3	16 000.0	385.0
BSK_5	mg/ dm^3	1 400.0	206.0
Nitrogen total	mg/ dm^3	1 200.0	208.0
Phosphorus total	mg/ dm^3	140.0	1.2

Source: The authors

2. 1 Economic appraisal of the new technology (option A)

A preliminary variable costing of processing 1 batch (100 dm^3 fugate) was executed in the framework of the economic appraisal of the new technology. The variable costs for fugate processing/treatment calculated based on IOT are based on the existing pilot plant conditions‘ results and they include:

- Material costs (consumption of chemicals and water). The calculation is based on the chemicals and the water consumption (see Figure 1) and on their acquisition costs.

- Costs of consumed electric energy. Electric energy is consumed for the operation of pump and stirrer; energy consumption demands for fugate treatment are illustrated in Figure 1. The cost calculation is also based on energy purchase cost.

Preliminary variable costing for the treatment of 1 batch (100 dm^3 fugate) is demonstrated in Table 3.

Tab. 3: Preliminary variable costing for treatment of 100 dm^3 fugate

Cost items	**CZK**
Water consumption	20
Chemical *a* consumption	88
Chemical *b* consumption	55
Chemical *c* consumption	60
Chemical *d* consumption	77
Chemical *e* consumption	2 100
Material consumption total	**2 400**
Energy consumption	**50**
Variable costs total	**2 450**

Source: The authors

When only economic impacts of the implementation of this new technology into practical usage in BGS are taken into account then it can be stated unambiguously that this new technology is not-profitable. With the implementation of this new technology the variable costs of processing digestate (fugate respectively) would increase by 2 370 CZK/100 dm^3 fugate. At the same time the fixed costs of BGS would also increase (equipment depreciation, costs of preventive and corrective maintenance, labour costs). The positive benefits of this new technology would thus be only revenues from sales of separated sediment. Under the conditions of a general BGS that produces on average 7 million dm^3 fugate annually, the introduction and operation of the digestate (fugate respectively) treatment facility would mean decline in economic results by approximately 170 million CZK.

2. 2 Appraisal of environmental impacts (option B)

When appraising the new technology we must also appraise its environmental impacts. The appraisal of environmental impacts is based again on IOT (see Table 2). The new technology dramatically reduces the level of pollution that is measured by indicators $CHSK_{cr}$ a BSK_5. To illustrate this we can compare fugate pollution indicators at the entry into the facility and at the exit of the facility (that means after the treatment) with an average pollution of sewage water (see Table 4).

The Table 4 unambiguously illustrates how very polluted fugate is at the entry into the fugate treatment facility. The value of $CHSK_{cr}$ more than 40-times exceeds the average pollution rate of sewage waters; the value of BSK_5 exceeds the average more than 1.7 times.

Tab. 4: Comparison of CHSK and BSK fugate and sewage water values

Indicator	Unit	Fugate INPUT	Treated fugate OUTPUT	Sewage waters
$CHSK_{cr}$	mg/dm^3	16 000	385	150 - 400
BSK_5	mg/dm^3	1 400	206	300 - 800

Source: The authors

Comparison of values of BSK_5 fugate (at the entry to the facility) with values of BSK_5 of industrial waters from various branches of industries and the recalculation of this pollution to an equivalent inhabitant (EI) – see Table 5 – provide another information for decision making. The recalculation is based on the value of average pollution produced by 1 inhabitant per 1 day, which is 60 g BSK_5 /day/EI (Groda et al., 2007).

Tab. 5: Comparison of BSK_5 values for industry waters from various industry branches and recalculation per an equivalent inhabitant

Branch	Unit	BSK_5 [kg]	EI [number of inhabitants]
Yeast production	1 000 kg yeast	300 – 400	5000 – 7000
Distillery	1 m^3 grain	120 – 210	2000 – 3500
Malting plant	1 000 kg malt	0.6 – 6	10 – 100
Wine production	1 m^3 wine	6 – 8.4	100 – 140
BGS	1 m^3 fugate	0.8 – 1.4	13 – 23
BGS	7 000 m^3 fugate	5 760 – 10 080	96 000 – 168 000

Note below: Fugate values are indicative, depends on the type of batch and season of the year.

Source: The authors using Groda et al. data (2007)

Even when the values of fugate pollution are very variable (depends on the type of batch and season of the year), it issues from the result that any regular BGS without fugate treatment facility produces annually pollution corresponding to pollution produced by 96 – 168 thousands inhabitants.

The new technology for fugate treatment shows high efficiency of separation in comparison to other wastewater treatment technologies. The efficiency is for $CHSK_{cr}$ 97.6%, for BSK_5 85.3% and for phosphorus 99.1%.

2. 3 Discussion

Literature dedicated to performance management describes a wide range of quantitative and qualitative approaches to R&D projects appraisal (Kerssens - van Drongelen, Nixon and Pearson, 2000). The way of the performance appraisal of a concrete project should always correspond to the nature of the project (Pearson, Nixon and Kerssens - van Drongelen, 2000) and the used tool should correspond to the concrete decision making task (Král et al., 2012). IOT and their modifications make possible to appraise both the economic and the environmental performance of the project in mutual relations. They can be used primarily in the development stage where they allow for the identification of problems that could dramatically influence the project effectiveness, the results of the project respectively.

The ever-increasing emphasis on sustainable growth requires the utilization of comprehensive management tools to support decision making in private sector as well as in definition of public policies and their implementation (Curran, 2013). Sustainable development is such a complex issue that it requires a comprehensive multidisciplinary approach (Funtowicz and Ravetz, 1994). Issues related to planning and control to be done in accord with sustainable development principles require the cooperation of all important stakeholders – from setting the system of management and the strategic goals definition, through tactical-operative management and decision making to communication processes (e.g. by means of sustainability reporting). The presented approach to new technology appraisal may become a very important information source not only for the project manager but also for public administration as a co-actor of regional development. Environmental impacts of the project and the status and the problems of the given region where the BGS operates should be taken into consideration.

Public administration utilizes in many cases formal procedures issuing from valid legislation and regulations. However in recent years some innovative approaches and management methods have been implemented by public administration, methods inspired by the private sector (Kominis and Dudau, 2012). It is IOT utilization that offers a strong tool for public administration decision-making.

Conclusion

Economic appraisal of the new digestate treatment technology shows that its practical implementation to BGS operation would bring about dramatic negative impacts to BGS economic results. BGSs, that already have storage tanks for produced digestate, would not profit from implementing this new fugate treatment technology. Because the new technology is only in the development stage the preliminary costing can be used for its potential modification so that it is more economically acceptable. The preliminary costing can be, in the R&D phase, the tool for cost optimization, and not only for the project costs, but also for optimization of the operating costs of future users of the project results/outputs.

The newly designed technology shows dramatic environmental benefits. Sewage water can be utilized as industrial water or irrigation water and that is a major benefit for the environment. The technology allows to recycle nutrients – potassium, nitrogen and first of all phosphorus. The issue of nutrients recycling is currently studied by the European Commission (2015). The presented technology is a practical illustration how to achieve such recycling.

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