

Efficiency and Factors for Agricultural Use of Sludge in Circular Bulgarian Economy

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Abstract:

Despite their relevance, in-depth studies of diverse effects and factors of sludge utilization in Bulgarian agriculture are at an early stage. This paper presents results of a large-scale study aimed at determining socio-economic effects of sludge utilization in Bulgarian agriculture. First, an approach is presented to assess the multilateral effects, efficiencies and factors of sludge utilization in agriculture. Then various factors stimulating and limiting the utilization of sludge in Bulgarian farms are identified. Results of a case study of a holding using sludge as fertilizer are then presented. Based on a qualitative analysis of regulations and institutional structure, and surveys with managers and experts of urban wastewater treatment plants, and farmers using and not-using sludge, the institutional, political, organizational, personal, educational, informational, social, economic, and environmental factors influencing agricultural sludge utilization in two regions (Sofia and Burgas) are identified. Impact factors are generally divided: factors influencing the behavior of agents, and factors determining the type and extent of the effects of sludge use in agriculture. Research is to continue and deepen to establish the economic, sectoral and regional specificities on the basis of more representative information from all participants and interested parties in effective utilization of sludge in the country.

Keywords: sludge; us; agriculture; factors; efficiency; Bulgaria.

JEL Classification: Q12; Q13; Q15; Q18; Q28; Q38.

Introduction

The issue of utilization of sludge from wastewater treatment is an important socio-economic and environmental problem in Bulgaria and the European Union (EC 2021). The total amount of the European production of sludge is 8.7 Million tons DS/y (EurEau 2021). The significance of that issue in Bulgaria is determined by the fact that the amount of sludge formed in the country is constantly growing, and reaches 53 thousand tons of dry matter in 2018 (IAOC 2019). At the same time, according to the national goals by the end of 2020 as much as 65% of the sludge from Municipal Wastewater Treatment Plants is to be recycled and materially utilized, and the remaining 35% of them is to be energetically utilized (NSPSMWTP 2014). One of the main ways to utilize sludge from wastewater treatment is its use as fertilizer in agriculture (Marinova 2008, Usman *et al.* 2012).

Currently, agricultural destination or use of sludge in Europe accounts for 47% of the total or 4.1 Mt DS/y (EurEau 2021). Our study found that a small proportion of Bulgarian farms utilize sludge on their farms (Bachev *et al.* 2021, Bachev 2012, 2021). This paper presents results of the first part of a large-scale study aimed at determining the socio-economic effects of sludge utilization in Bulgarian agriculture. First, a framework is presented to assess the multilateral effects, efficiencies and factors of sludge utilization in agriculture. Then the various factors stimulating and limiting the utilization of sludge in Bulgarian farms are identified. The results of a case study of a holding using sludge as fertilizer are finally presented.

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1. Research Background

Sludge use in general, and in agriculture in particular, is not an automatic but a complex process that depends on many institutional, production, economic, psychological, social, environmental, *etc.* factors. As a result of the specific combination of the critical factors in the individual countries of the European Union (EU), there is a great diversity in the degree of sludge use in agriculture - from almost zero in Malta, Slovenia and Slovakia to 80% in Ireland (EU 2021).

Around the globe, there are numerous studies on the factors and efficiency of sludge use in agriculture (Daniels 2011, Iticescu *et al.* 2021, EC 2008, 2021, Ekane *et al.* 2021, Hudcová *et al.* 2019, Rosiek 2020, Rosemarin *et al.* 2020, Taşeli 2020, Tesfamariam *et al.* 2020, Usman *et al.* 2012). Interest in this area is growing even more in connection with the new challenges related to environmental pollution, climate change, protection of human and animal health, the current COVID pandemic and others. Strict regulation and standards for sludge use have been introduced in most countries and the EU, including in agricultural sector. Many countries (such as Germany, the Czech Republic, Hungary, France, *etc.*) have introduced greater restrictions than the EU minimum, and some countries (such as Switzerland, certain US states, *etc.*) have even banned the use in agriculture (Hudcová *et al.* 2019). Recent concerns about coronavirus have led some countries (such as France) to introduce mandatory disinfection of 4 sludge before use in agriculture (ANSES 2020).

In Bulgaria, regardless of their relevance, in-depth studies of the diverse effects and critical factors of sludge utilization in agriculture are a new phenomenon, single, unilateral (mainly bio-chemical and agronomic use) and at an early stage (Ivanov *et al.* 2021, IAI 2021, Marinova 2008, Sarov 2020, Ivanov and Bachev 2021).

2. Methodology

Impact factors can generally be divided into two types: factors influencing (motivating and demotivating) the behavior of agents, and factors determining the type and size (formation technology) of the effects of sludge use in agriculture. If the system of incentives of the various agents involved in the process is not properly formed ("managed"), the potential positive socio-economic effect of the use of sludge in agriculture will not be realized (Bachev 2009, 2013, 2014, 2017, 2018). Therefore, the specific interests and incentives of the main participants in the process (striving for maximum positive and minimum negative economic effects) should be analyzed and the extent to which the existing governance system contributes to the public interest (maximum positive and minimum negative public effects) should be assessed. In the specific conditions of each region, farm, *etc.* impact factors have different significance, and in many cases are interconnected or subordinate (Bachev and Terziev 2018). The later requires the use of multifactorial and comparative structural analysis to correctly identify the factors and establish their significance, relationships, subordination, dynamics over time, *etc.*

This study is based on a qualitative analysis of the specific regulations and institutional structure related to the utilization of sludge in agriculture. It also uses the results of surveys conducted during 2020-21 with managers and experts of Municipal Wastewater Treatment Plants (WTPs) in Sofia and Burgas region, and with agricultural producers recovering and not using sludge from the two regions of the country.

Nearly half of the total amount of sludge in the country is produced in the studied two regions (Table 1). According to the 2018 official information in agriculture about 56% of the total sludge formed in Bulgaria are utilized (IAOC 2019). In recent years, the sludge of "Sofiyska Voda" AD (a part of French company VEOLIA) has been mainly applied in agriculture, where all of the sludge formed by this treatment plant for 2018 is utilized. The Sofia region also utilizes the largest share of sludge used in the country's agriculture - 43.4% of the total. The sludge in this area has been utilized on 2169,7 ha of arable land as in 2018. A total of 38,440 tDS have been distributed, including quantities of temporarily stored sludge from 2017 (EEA 2019).

Table 1. Amount and share of the produced sludge on the territories of Regional Environment and Waters Inspections (REWI) in Sofia and Burgas 2018

REWI	Amount tons of dry sludge	Share in total %
Sofia	23.101,00	43,52
Burgas	3.319,94	6,25
Bulgaria	53.082,62	100,00

Source: EEA 2020

The effects of sludge utilization in agriculture are understood as all results (direct and indirect) and consequences arising from the use of sludge in agriculture. These effects can be classified and defined as: positive (*e.g.* improving soil fertility, saving on fertilization costs, *etc.*), negative (*e.g.* soil, water and air pollution, *etc.*), or

neutral (for example, no change in the required workforce, level of public subsidies, etc.). The calculation of the effects of the use of sludge in agriculture usually includes only positive or negative results, while the neutral effects are analyzed only when they affect the overall efficiency. For example, often the replacement of mineral fertilizers with the use of sludge does not lead to a change in the average yield or quality of production, but this is a positive result in terms of maintaining farm efficiency (total yield, land productivity, labor productivity, etc.). At the same time, the effects can be qualified and measured to a certain extent and through a ring assessment of the degree of positive and negative result. It is this ring score, which is located in the ranking scale, that serves to classify the effects.

The effects of sludge utilization can be of different types - production and agronomic (improving soil fertility, increasing yield and product quality, trampling the soil when importing sludge, changing technology and organization, etc.), economic (reduction of production costs and working capital or borrowing needs, increase of income, increase of transaction costs, etc.), social (reduction of the amount of waste, deteriorated working conditions during periods of sludge application, increased public concern, etc.), ecological (change of the chemical and mineral composition of the soil, improvement of the soil moisture retention, infiltration into the groundwater, pollution of the roads and air, etc.), etc.

The different types of effects are most often incommensurable with each other - income and expenses are in BGN, yields are in kg, reduced comfort of the population and air and soil pollution is in degree, etc. Moreover, even effects of a certain type are often difficult to measure - for example, the economic effect in the form of increased farm income from sludge use, and the additional costs of regulatory study, experimentation, monitoring, training, relations with supplier and controlling authorities, etc. This is one challenge that should address the diverse and multifaceted aspects of the observed and identified effects, while the other challenge for reliable and sound evaluation is related to the development of criteria and reference scales on which to interpret the results and effects.

In order to solve these issues, the following approach is adopted, which will be able to unite to the greatest extent the heterogeneous and heterogeneous dimensions arising from the individual indicators and which will contain a criterion system that will help in the ranking of the assessments. The approach that has been developed to study the socio-economic effects of sludge utilization in agriculture is an integrated-comparative assessment method. This method is a tool for normalization of heterogeneous and multilayer results and values of the observed and covered indicators of the factors of production, economic, social and environmental impact in the use of sludge in agriculture. The integrated-comparative method works with quantitative ring evaluation, which is obtained by comparing the results and evaluations on the same indicator in two technological methods of agricultural production - conventional fertilization with mineral fertilizers and alternative fertilization with sludge.

This can be represented by the formula:

$$RSIn = \ln SST / \ln SCT \quad (1)$$

where: $RSIn$ - ring assessment for each indicator and for the identified impact factors; $\ln SST$ - the specific indicator and its normalized assessment for sludge fertilization in agricultural production; $\ln SCT$ - the specific indicator and its normalized assessment in conventional fertilization with mineral fertilizers.

The normalization of the scores for each indicator is done using the formula:

$$\ln SST/CT = PVIn / MAXPVIn * RS \quad (2)$$

where: $PVIn$ - the primary and original value of the indicator, which can be in different units of measurement and classification; $MAXPVIn$ - the maximum threshold value in the favorable spectrum of impact, which can take the result of the specific indicator, taking into account the primary measure and classification unit used; RS - the ranking assessment and the maximum assessment on this ring scale on which the integration of the assessments on indicators reflecting and revealing the effects of the utilization of sludge in agriculture is performed.

The specific effects are monitored and measured by specific and individual indicators, thus compiling a system of specific and specific indicators representing the multifaceted effects of sludge use, which is taken into account both at the farm level and at the territorial and sectoral level. The developed integrated-comparative assessment method presents the analysis and measurement of the effects of sludge utilization in agriculture, comparing the mirror effects on the selected indicators in an alternative method of production and conventional fertilization, which serves as a criterion. Thus, the assessment is relative in nature and cannot exist and be considered on its own.

In order to formulate the system of indicators for assessment of the various effects of sludge utilization in agriculture, which are generally considered in 4 areas and typologies, the specific properties and characteristics

are established. For each of the principal types of effects, the most important and significant characteristics and properties are used in the four identified directions, where specific effects and consequences are established. For example, for the economic effect, the main characteristics and properties are the impact on income, production costs, change in transaction costs, etc. From these properties and characteristics, which generally describe the typology of the effects of sludge utilization in agriculture, specific and specific indicators for measuring the effect in Bulgarian conditions are included and selected. For example, as indicators for assessing the effect of the characteristics related to the "impact on income" are selected: change in income as a result of changes in yield, and change in income as a result of changed product quality and sales prices.

Table 2 presents the system of indicators for assessing the effects of sludge utilization in Bulgarian agriculture.

Table 2. The system of indicators for assessment of the effects of sludge use in Bulgarian agriculture

Type of effects	Properties and characteristics of effects	Measurement Indicator
Production	Change in the quality of used agricultural land	Soil structure
		Soil aeration
		Organic substances in the soil
		Soil compaction
	Change in soil moisture retention	Degree of water retention
		Volume of irrigation
	Yield change	Average yield
		Imputed mineral fertilizers on the farm
	Changes in the quality of production	Product quality
		Quantity of hazardous elements in the production
	Changes in the technology, organization and management of the farm	Degree of change in technology and agricultural techniques
		Degree of change in the organization of production and labor
Degree of change in farm management		
Economic	Impact on income	Gross Production
		Sale prices
		Leaf mass
	Impact on production costs	Expenses for purchase and delivery of sludge
		Costs for mineral fertilizers
		Labor costs
	Change in the amount of own or borrowed working capital	Own funds for working capital
		Borrowings for working capital and interest
	Change in the cost of training, information, sharing experiences, experimenting, and testing	Expenditure on information, exchange of experience and training related to sludge use
		Costs for experimentation and tests related to sludge use
	Change in transaction costs	Costs of negotiating and executing contracts for the supply of sludge
		Costs for studying regulations and obtaining permits
		Expenses for relationships with landowners
		Costs for marketing of produce

Type of effects	Properties and characteristics of effects	Measurement Indicator
	Efficiency of one-time investments and transition to non-traditional fertilization	Payback period for return of investments in sludge from the profit
		Rate of return on investment in sludge
		Costs of discontinuing the practice of sludge use
	Change in competitiveness	Level of competitiveness
	Sustainability of innovation	Period of use of sludge on the farm
Social	Change in working conditions	Deterioration of working conditions
	Change in living conditions	Deteriorated comfort of the population
	Change in relations with other agents	Conflicts with landowners
		Conflicts with other farmers and stakeholders
	Change in sustainability of farms	Farm viability
	Waste reduction	Amount of sludge used on the holding
Ecological	Maintaining and improving soil quality	Level of soil fertility
		Amount of hazardous elements in the soil
	Water storage and savings	Degree of irrigation
	Air and road pollution	Degree of pollution
	Change in environmental sustainability	Level of environmental sustainability
	Waste management	Used sludge in the region, in the sub-sector, in the country
	Greenhouse gas emission change	Reduction of the amount of used mineral fertilizers in the country
	Change in soil erosion	Degree of soil erosion

Source: authors

In view of the fact that the different effects and indicators are measured and presented in different units of measurement and classification, a ring evaluation and a method for normalization of the primary and original values or qualitative effects are used - large, good, medium, small, unsatisfactory, unacceptable, *etc.* The determination of the primary and original values or qualitative effects on the individual indicators is very differentiated, which depends on the indicator itself, on the availability of specific data and information, on the degree of complexity, on how the specific data can be obtained and the initial quantitative or qualitative classification of the effect and of the reference properties of the indicator. In this way, the initial values and the classification of the individual indicators are made as an external or internal evaluation. An external evaluation is one in which the data are external to that study and are taken from statistical, normative, literary or other sources and an internal evaluation that uses expert judgment.

For many of the social and environmental effects, qualitative classifications are used to assess the effect. For many of these effects, there are also normatively (institutionally) defined standards that show minimum or maximum limits within which certain (mostly negative) effects are socially and / or environmentally acceptable and permissible. For example, if the permissible "contamination" of the soil or product exceeds certain safe limits, the effect is considered negative or unacceptable.

The integration of the indicators is achieved by normalizing the initial and original values and classifications of the individual indicators and transforming them into a ring score, which compares and compares how much better (for ring score > 1) or less favorable (for ring score < 1) for each indicator is the effect of sludge utilization in agriculture compared to the conventional method of production and fertilization in agriculture. This can be represented by the formula:

$$\text{OIRS_ST} = (\sum_{n=k} \text{RS_In})/n_I \quad (3)$$

where: OIRS_ST - the integrated ring assessment in the utilization of sludge in agriculture compared to the conventional production practice and technology.

The criterion used to perform this assessment is comparative, as the rank ratings require the normalization to be set so that RS is in the range from 0 to 1, where the unfavorable defined and defined result and consequence is scaled close to 0, and the favorable positive impact and consequence is close to 1. This requires in certain cases, such as in environmental areas and typology of effects to propose a reversible calculation by the formula:

$$\ln SST/CT = \text{MINPVIn} / \text{PVIn} * \text{RS} \quad (4)$$

where: the lower the original and primary values and classification definitions for the specific indicator PVIn, the more favorable is the obtained and available effect. This is precisely the criterion logic that is used to operationalize and adjust the evaluation system.

The effects of the use of sludge in agriculture usually occur in a certain (long) period of time. For example, in the year of sludge input, savings are made from the purchase of mineral fertilizers while at the same time making costs for negotiating, obtaining permits, delivery and spreading of sludge; a positive effect on crop yields is usually observed between the second and fifth year, etc. In this regard, a distinction should be made between current effect during a given (economic) season or year, and long-term (aggregate) effect for the entire period of the effect. The main effect of the use of sludge in agriculture is in (partial or complete) replacement of mineral fertilizers and the associated change in farm costs and income. Therefore, the impact assessment will use a period in which the initial "one-off" investments (sludge input and associated costs) are "pay-back" by maintaining or increasing the yield and quality of production (about 3-5 years). In this way it will be taken into account the cumulative effects when reporting the results of specific indicators.

When assessing the effect of sludge use in agriculture, a distinction should be made between private economic effect (effects for the farmer who uses sludge in his economic activity), sectoral effects (extrapolation effects in agriculture, taking into account the effects for sludge user and non-user farms) and external (external) effects (effects on other farmers, non-farmers, the public in the region, and the country as a whole). The assessment of external (spill-over) effects is important, as farmers are usually only interested in the direct benefits and costs of using sludge on their own farms. At the same time, the use of sludge on a holding may be associated with side effects for other farms and / or entire communities, or may have significant positive social and environmental effects for the region, sub-sector, country as a whole and even internationally.

The effects of sludge utilization in agriculture do not in themselves give an idea of the effectiveness of this process. Only when the effects of the use of sludge in agriculture exceed the costs associated with this use can we talk about increased efficiency or effectiveness. When assessing effectiveness, account should be taken of the different types (social, economic, environmental, etc.) and the unequal "social" value of the different effects and costs. For example, the accumulation of sludge as waste is socially unacceptable at the current stage of the country's development. This makes the additional (economic) costs for their proper treatment and use in agriculture and other sectors of public life highly effective.

When considering the efficiency of sludge use in agriculture, the analysis that can be used to assess this efficiency is the cost-benefit method. Cost-benefit analysis is a concept that refers both to impact assessment and comparison of different scenarios and as a decision-making approach. Through the analysis of the benefits and costs, it was possible to measure the complex consequences and to assess the favorable multiplier effects of the practice for the use of sludge in agriculture. The multiplier effects in this case relate to the assessment of the possibilities for increasing the positive results and to the selection of selection criteria in order to select practices and activities that will give greater results. The cost-benefit analysis can also be applied by examining the changes in the benefits of the corresponding changes in costs. This is done because absolute values are not always sufficient to take into account the results and efficiency and to assess to what extent in a given situation the achieved efficiency is satisfactory or unsatisfactory. The analysis of benefits and costs serves to measure the efficiency; therefore, this method will be perceived as a method for assessing the efficiency of sludge utilization in agriculture.

$$EFFE = \frac{\frac{BF_{ST}^{t+1} - BF_{ST}^{t-1}}{BF_{AES}^{t-1}}}{\frac{CO_{ST}^{t+1} - CO_{ST}^{t-1}}{CO_{ST}^{t-1}}} \quad (5)$$

where: EFFE is the coefficient of elastic efficiency, while BF and CO are the respective initial indicators measuring the benefits and negatives of the applied technology and practice of sludge fertilization in the next and previous period of time.

The higher the EFFE values and levels, the greater the elastic efficiency of the practice and technology in question. Conversely, it can be argued that the elasticity of the effectiveness of this practice is low and the adverse effects and disadvantages outweigh the benefits. This method is suitable for making comparisons between different types of technologies and for making evaluations of applied ones. On the basis of this method of assessment can be weighed the very practice of sludge utilization in agriculture, its benefits and advantages to the disadvantages and adverse effects of individual indicators. In this way, BF and CO will again cover all indicators included in the assessment, and the normalized specific indicator with its InSST assessment is qualified as BF or CO. The reverse calculation formula that takes into account the positive or negative effect of the integrated comparison method will not be used to calculate InSST.

The multifaceted, complex, contradictory and uncertain nature of the effects and costs of sludge recovery in general, and in agriculture in particular, requires a multi-criterion, multi-level, multi-faceted quantitative and qualitative analysis of the socio-economic effects of sludge use in agriculture. Such an attempt will be made in the next stage of project implementation.

When assessing the efficiency of sludge use in agriculture, the comparative and absolute benefits and costs of sludge recovery in the industry should be taken into account. The comparative efficiency of sludge utilization in agriculture shows the effectiveness of sludge use in agriculture compared to the effectiveness of other alternative uses (e.g. biogas production, compost, land reclamation, etc.). The analysis of this efficiency is very important, both for farms and nationally. For example, due to high treatment costs and low WTP prices, agricultural sludge use may be inefficient. Conversely, the lack of land or landfill bans can encourage WTPs to expand the provision of sludge to farmers, even free of charge, even ensuring that it is transported at their own expense.

The absolute efficiency of sludge utilization in agriculture shows the efficiency of sludge use in agricultural holdings compared to the efficiency before this use. When assessing the efficiency of the use of sludge in agriculture, it is very important to properly take into account the time factor in view of the different nature of the costs incurred and the effects obtained.

There is not enough information in the country for a comprehensive assessment of the various effects of sludge utilization in agriculture. Therefore, the assessments of the effects of the use of sludge in agriculture in the present study will be based on a variety of information from scientific experiments, field and business experiments, expert assessments, government and business programs, laboratory analyzes, and in-depth interviews with farmers, WTP experts and other stakeholders. Depending on the type of source data used, a distinction should be made between actual effects and efficiencies from estimated (regulatory, forecasting, planning, etc.) effects and efficiencies of sludge use in agriculture.

3. Assessment on Political, Institutional and Market Factors

In order to identify and assess institutional factors, the specific institutional environment ("rules of the game") and structures (agents and relationships between them) related to sludge utilization in agriculture are to be analyzed. Account should also be taken of the development of important factors of the external social, market and natural environment that influence the management of the process of agricultural use of sludge - EU and state policies, the development of the research system, education, and information, evolution of markets and demand, etc. Depending on the efficiency of the management system (institutions, market, private, public and hybrid forms) there will be different degree and efficiency of sludge utilization in agriculture (Bachev 2011, 2014, 2018).

The specific institutional environment includes the various legislative and regulatory provisions and the system for their enforcements, which regulate the rights, methods, processes, and control of sludge utilization in agriculture. This analysis should also include the informal rules of the game, predetermined by the ideology of conservation farmers, interest groups and consumers, which occupy a growing place in the system of governance of society and agriculture.

One of the most important factors for the effective utilization of sludge in agriculture is the existence of modern legislation and regulations (Table 3). It is to define the rights and obligations of the various agents involved in the process (regulatory and control bodies, WTPs, farmers, etc.), standards for sludge quality and safety, soil fertility and human and animal health, norms and restrictions of application, etc. The institutional set-up also includes various state policies, programs, plans, and incentive instruments for achieving certain social goals regarding the utilization of sludge in agriculture and other sectors of production.

Well-defined "rules of the game" and adequate government intervention will create conditions for inducing effective behavior of key agents and effective (and not only) use of sludge in agriculture (maximizing the positive effects and minimizing the negative effects). Conversely, in the case of inefficient regulation (for example, complex

procedures and high costs of obtaining permits for use from farms), there will be no sufficient interest in participating in the process.

In the EU there are strict regulations for the utilization of sludge in agriculture established by the European Union Directive of 1986 (Directive 86/278/EEC) and other documents on the protection of the environment and human health. The EU directive encourages the use of sludge in agriculture only if it is used in areas where it does not have a negative impact on soil and agricultural products. The main requirements in the Directive are limited to compliance with limits related to the content of heavy metals and nutrients in sludge and soil, as well as limits on the annual load of agricultural land with sludge. It is also mandatory to treat the sludge before using it for fertilization.

The requirements of the European Directive are also introduced in the national legislation in the Ordinance on the procedure and manner of utilization of sledges from wastewater treatment through their use in agriculture (adopted by c ПМС № 201 of 04.08.2016). It determines the order and the manner of utilization of the sludge from treatment plants and wastewater treatment facilities through their use in agriculture; the requirements that sludge must meet in order to ensure that it does not have a detrimental effect on human health and the environment, including the soil; and the procedure for reporting the used sludge.

Table 3. Institutional, personal and educational factors for sludge utilization in Bulgarian agriculture

Type	Positive	Negative
Politically and institutional	<ul style="list-style-type: none"> ▪ Long - term policy on safe sludge use in the EU; ▪ Modern legislation with clear procedures and standards; ▪ Long-term state and regional strategies; ▪ Restrictions on utilization on agricultural land; ▪ Mandatory standards for the protection of soil, water, air, biodiversity, and human and animal health. 	<ul style="list-style-type: none"> ▪ Need for a special management system; ▪ Long and complicated licensing procedures; ▪ Possibility for impunity for violation of procedures and standards; ▪ Possibility for development of dependency and corruption; ▪ Imperfect contracting (additional coordination costs, little possibility for enforcement); ▪ Restriction of users (sole traders and legal entities); ▪ Restrictive goals and uncertainty related to the EU Green Deal.
Personal and organizational	<ul style="list-style-type: none"> ▪ Vision and proactive strategy of WTP; ▪ Logistical and material support from WTP; ▪ Innovation ▪ Entrepreneurship of the farmer; ▪ Qualification and experience of farmer; ▪ Size of the holding; ▪ Good and long-term relations between WTP and using farmers; ▪ High efficiency of self-learning and learning by doing of good managers; ▪ High bilateral dependency between WTP and sludge using farms. 	<ul style="list-style-type: none"> ▪ Passive strategy of WTP; ▪ Tendency not to take risks; ▪ High costs for proper treatment, storage and delivery; ▪ Need for precise organization and management of production; ▪ Difficulty to introduce in non-innovative and risk-averse farmers; ▪ Difficulty to introduce in cooperative farms with numerous members; ▪ Practice of one-year rent contract for supply of agricultural lands; ▪ Standard contracts for supply of sludge from WTP.
Information and educational	<ul style="list-style-type: none"> ▪ Up-to-date, comprehensive, reliable and accessible information; ▪ Independent evaluations and information; ▪ "Fast" training by doing of good managers; ▪ Provision of information and advice by the WTP; ▪ Close distance between user farms and WTP. 	<ul style="list-style-type: none"> ▪ Lack of sufficient scientific literature on the technology of growing crops with sludge; ▪ Lack of special training; ▪ Lack of a system for special consultation and advice; ▪ Need for additional information, training, consulting and exchange of experience of farmers. ▪ Reluctance to share positive experiences; ▪ High asymmetry between WTP and farmers, and with control bodies.

Source: interview with WTP managers and farmers

According to the regulation, "sludge users" can only be sole traders and legal entities. The ordinance does not allow the utilization of sludge on: meadows, pastures or areas sown with fodder crops, when used for grazing or the fodder is harvested in a period shorter than 45 days after the use of the sludge; soils on which fruits and vegetables are grown, with the exception of fruit trees and vineyards; soils intended for the cultivation of fruit, vegetables and other crops which are in direct contact with the soil and are consumed in the raw state, for a period of 10 months before and during the harvest; coastal floodplains, riverbeds and protective dikes; zone I and zone II

of sanitary protection zones of water sources and facilities for drinking and domestic water supply and around water sources of mineral waters used for medical, prophylactic, drinking and hygienic needs; and in agricultural land in protected areas.

The utilization of sludge in agriculture is allowed on the basis of a permit. For the issuance of a permit, sludge users provide to the Bulgarian Food Safety Agency (BFSA) information and results of analyzes of the soil from the places where the sludge will be used, of the soil characteristics: soil type, bulk density, soil particle size distribution, and total soil porosity. The sampling and their subsequent testing is performed by accredited laboratories according to certain indicators. Soil testing is mandatory before the initial use of sludge, and after their use - every 5 years. The permit contains: the quantities of sludge meeting the MDK for heavy metals in the sludge, expressed in tons of dry matter, which may be imported annually into the soil per unit area; the location and size of the land plots on which the sludge will be used. The permit is issued for a single application of a certain amount of sludge for a specific plot.

The bodies related to the implementation of an ordinance and control of its implementation are a key element of the institutional structure. The control over the application of the ordinance is assigned to the Minister of Agriculture, Food and Forestry, to the Minister of Environment and Water and to the Minister of Health in accordance with their competencies. In fact, these functions are performed by the specialized agencies of these ministries, whose functions are described in detail in the regulatory documents.

Regulatory requirements for the management of sewage sludge are also contained in other official documents, most of which are related to the legislation on waste and water management. It can be concluded that in Bulgaria there is a modern legislative and regulatory framework for safe use of sludge in agriculture, which is based on modern European standards. The ordinance regulates and restricts the use (permits for doses and plots) and users (sole traders and legal entities) of sludges from wastewater treatment in agriculture.

It is to be taken into account that the institutional requirements and restrictions, and the standards for quality and safety of food and feed, protection of the natural environment and biodiversity, animal welfare, *etc.* in the EU and Bulgaria are constantly evolving and "tightened". This modernization also affects the monitoring and control system and is closely linked to the support of farmers with CAP instruments (cross compliance, eco-payments, eco-contracts, overall "greening", *etc.*). *For example*, the newly adopted by the EU in 2019 Green Deal sets ambitious goals in terms of reducing greenhouse gases, using mineral fertilizers and pesticides, and increasing the area with organic production by 2030 (The European Green Deal 2019). Discussions are still ongoing in the EU countries and in the Union's governing bodies, and procedures are being developed to achieve these goals through the CAP instruments, the Strategic Development Plans until 2030, and other policies and mechanisms. In this regard, there is considerable lack of precision and "institutional uncertainty" on many issues related to the achievement of European goals, and in particular how the reduction will be distributed among the individual EU member states, production sub-sectors, agricultural and agri-environmental regions and types of farmers, whether the total reduction will include and how the use of manure and sludge, *etc.* The degree of use of sludge in agriculture in the coming years will largely depend on the solution of all these issues.

Another factor is the possibility and the degree of implementation and control of the procedures, standards and restrictions for the use of sludge in agriculture by the competent state authorities. In the years of the country's membership in the EU, there are many examples of incomplete and "Bulgarian way" implementation of the common policies of the union. Moreover, there is no long-term and widespread experience in the use of sludge in agriculture in the country and almost all agents are outside or at the beginning of the "knowledge curve". The later leads to unintentional errors in the implementation and/or search for "effective" practical solutions outside the regulatory framework, *etc.* Finally, many of the eco-activities and eco-standards in agriculture are difficult to effectively control by enforcing authorities due to high cost or practical impossibility (Bachev 2014, 2017). This is related to the well-known "mass" non-compliance with certain official eco-standards and norms, *etc.*

Agents involved in the management of sludge use in agriculture are regulatory and controlling (state, regional, *etc.*) authorities, WTPs, sludge using farmers, other farmers and agents (landowners, traders, processors, *etc.*), population and business in the area, end users, interest groups, *etc.* An important component of the analysis of institutional factors is the interests and incentives of the participating agents and the nature of their relationship.

The state regulatory and controlling bodies are the main agent in the system. They apply the provisions of the legislator and the policies pursued by the government. One can only assume that (like other state structures) mistakes are likely to be made due to lack of experience in this "new" area, poor governance, and incompetence of employees. In addition, corruption is possible, as is the practice in all cases of licensing, control of certain practices and standards, *etc.* The same applies to some of the accredited laboratories, whose activity is not always in accordance with the regulations (imprecise tests, purchase and falsification of results, *etc.*).

In addition to the regulatory and controlling bodies, the main agents of the system are WTPs and sludge using farmers. The relations of WTPs and sludge utilization farms with the state authorities are of "unilateral" dependency. Applying for permits is voluntary, but permits are given, and this involves procedures, time, labor costs, payments for tests, *etc.* In addition to permits, other parameters of the process are determined (restricted) – technology of application, mandatory standards, time periods, *etc.* However, the control over the implementation of the regulations is divided between many structures, which complicates the coordination between them and creates difficulties for the other participants. At the same time, there is a situation of few players, and the agents "know" each other well, which should facilitate the relationship in the interest of "overall" efficiency. This situation often contributes to the easy development of "personal ties" and "coalitions" that are detrimental to the effective implementation of the legislation. A major problem identified by the present study is the slow issuance of new permits by public authorities.

The high asymmetry of the information between the interested agents (the state, WTP, farmers, consumers, *etc.*) provides a great opportunity and creates incentives for non-compliance (violation) of the requirements of the regulations, both by WTPs and by farmers using sludge. For example, it is practically possible that there are cases when incompletely treated sludge is provided to farmers by WTPs and imported into agricultural lands, that sludge per unit area is applied higher than the allowed norms, that sludge is also applied to unauthorized agricultural plots, and that sludge is applied in the not indicated manner (with simultaneous burying), *etc.* All this is associated with a number of risks and actual negative effects in terms of cleanliness of roads, soil, water and air, the health of farm workers, consumers of products, *etc.*

The contradictions and conflicts of the interested agents (and the individual, economic and social effects) in the process require the development of a special system for management and control of sludge utilization in general and in agriculture in particular. This is associated with additional costs for individual agents and society as a whole (taxpayers) - for maintaining government agencies, for studying and complying with regulations, for soil testing, for obtaining permits, for relationships with government institutions, *etc.*

The introduction of a system of permits and control is also associated with the development of "dependency relationships", as well as the possibility of unregulated payments (and corruption) for fast and/or illegal obtaining of permits, for reduced or inefficient control of the implementation of legal norms and restrictions, and as a result of insufficient or inefficient utilization of sludge in agriculture. The degree of actual non-compliance with regulatory constraints is difficult to assess, as the agents involved are not interested in sharing this type of information and it is impossible to accurately "measure" this type of effect from third parties (researchers, *etc.*).

The relationship between the WTP and the beneficiary farmers is contractual, based on one-year or multi-annual agreements. Like all contracts, the parties are free to specify the terms of the exchange and terminate their relationship in the absence of benefit. Moreover, in most cases the relations between the WTP and the utilizing farmers are of "bilateral" (symmetrical) dependency - capacity, location, time of supply, *etc.* It is determined by the fact that the agricultural utilization of sludge in the country is in the initial stages, and with a consistent strategy in this regard the assets of the WTP for treatment and the obtained "product" are in partial or complete high bilateral dependency with the assets (agricultural land with permits obtained) of the sludge using holdings. The degree of this dependency is determined by the amount of sludge for "agricultural" use, and the (limited) number of permits for sludge use in the plots of certain farmers. Long-term relationships between the same partners with symmetrical asset dependencies help to get to know each other well, develop trust, seek cooperation, limit opportunism, share information, and develop mechanisms for coordinating and resolving conflicts, and minimizing transaction costs. This further facilitates the relationship, reduces the associated costs, and increases the efficiency of sludge utilization in agriculture. In this regard, it is important to establish how the WTP selects the particular farmers with whom the sludge is experimented with or widely-utilized, especially when there is a "deficit" of valuable sludge resources in a given area.

Other interested parties (landowners, neighboring farms and businesses, the population in the area, interest groups, consumers, *etc.*) are also involved in a "relationship" with the WTP, sludge-using farmers and public authorities. However, individual agents do not have the "power" to change dominant practices due to the small size of the (negative) effect on them, the high individual costs and opportunities for "free riding" (one invests costs and everyone benefits if successful), the difficulty of common "collective actions" of agents with divergent interests, power positions and "dependency" by large (sludge-using) producers in the region, *etc.* Only when the effect is highly negative and direct (for example, a strong odor when delivering and spreading sludge) the strong collective actions of the population in the area are possible and often lead to the cessation of sludge supply for short periods of time.

The efficiency and incentives for the application of sludge instead of mineral fertilizers will depend strongly (in direct proportion) on the price dynamics of mineral fertilizers of different types (mainly N and P, whose substitute is sludge). In addition, interest in the use of sludge may increase with mandatory or voluntary (for getting public subsidies) restrictions on the use of mineral fertilizers in certain areas, sub-sectors or types of farms in the EU.

There is a psychological barrier, due to the "special nature" of this fertilizer, both in the farmers themselves and in the landowners and the residents of the area, for the negative effects of the use of sludge in agricultural land. These informal "rules of the game" and how they affect each of the stakeholders are to be analyzed. In other EU countries, for example, in areas with highly developed livestock and mass application of manure, there is a higher tolerance for the application of sludge in agriculture, both by farmers and the general population.

The market and buyers are also not yet "open" to the widespread use of sludge in agriculture. Many wholesale buyers and end users question the safety of products produced with sludge use. This is often associated with lower sales prices of farm products and high marketing costs. Last but not least, farmers and other stakeholders themselves are concerned about the long-term effects of sludge use on the environment - cleanliness and quality of soils and waters, trampling of agricultural land, protection of natural biodiversity, maintaining the ecological sustainability of farms, *etc.*

The specific institutional structure and the participating agents, in turn, can and do participate in the modernization of national and European policies. However, the repercussions of these elements are severely limited because the "political process" is slow, with different priorities, and not always in the interests of overall efficiency. The same applies to the direct impact of these agents on the development of product and resource markets (fertilizers, agricultural land, *etc.*) and the natural environment due to lack of complete information, complexity, high uncertainty, and the need for expensive and long-term collective actions on a huge scale and scope.

The main agents involved in the management of the process of sludge use in agriculture are WTPs and farmers. In principle, all WTPs should have an interest and developed strategies for effective management, and at the present stage for effective utilization of sludge. It can be assumed that to achieve economies of scale and scale (for both WTPs and farmers), certain optimal amounts of sludge produced will be needed to invest in modern equipment for effective treatment, as well as certain minimum sizes of land plots and farms in order to make efficient transportation and import of fertilizers with specialized equipment.

The individual WTPs in the country to varying degrees implement effective strategies for sludge utilization in general, and in agriculture in particular. For example, the Management of "Sofiyska Voda" AD has a clear vision and takes comprehensive measures for the utilization of sludge in agriculture. The quantities of sludge are significant, which makes technologically modern and economically advantageous treatment possible. For years, good relations have been maintained with large farmers in areas where sludge is provided free of charge. The company's experts are also involved in acquiring permits for sludge utilization for the respective land plots in the area. In addition, the company provides transportation and spreading of sludge. In this way, the company creates favorable conditions for the utilization of sludge produced in WTP and strong incentives for farmers to use sludge on farms. In order to minimize the transaction and other costs for relations with state bodies and farmers, it works with a limited number of large agricultural producers in the region.

This company also works closely with research institutes to explore ways to increase the efficiency of the sludge process. Media appearances are also made to inform the public and promote the utilization of sludge among the agricultural producers. The company's long-term strategy is to commercialize the "produced" sludge and sell it on the fertilizer market to offset the significant costs of treatment and storage. Therefore, the experience so far is a kind of experimentation and demonstration of the socio-economic efficiency of agricultural sludge use in the long-term profit strategy for the company. However, it is not known how the "increase in the price" of sludge will change the incentives of farmers for their economic utilization. In the absence of additional incentives (e.g. public subsidies, personal conviction, *etc.*), any increase in costs (prices) for farms will lead to a reduction in economic effects and incentives for agricultural use of sludge.

After the study of WTPs in the region of Burgas, it was found that the utilization of sludge is still a challenge for most of them. In some places, a much broader information campaign is needed among farmers. At this stage, there are reservations of some managers of treatment plants and farmers to use the disposed sludge in agriculture, mainly related to the proximity of the area to the sea-coast and developed tourism. Some WTPs do not yet have complete equipment for effective sludge treatment, while others do not have sufficient quantities for possible treatment and extensive use. In the past, a large agricultural producer in the region applied sewage sludge (102 ha with coriander, rapeseed, *etc.*), but gave up due to the complicated monitoring for soil and sludge testing. Currently,

there is also interest from a farmer, who is pay for drilling and testing soil samples, transporting the sludge, and spraying and mixing the sludge with the soil.

Our study found out that for different WTPs there is a different comparative efficiency of agricultural sludge utilization depending on the volume of sludge, available landfills, existing treatment facilities and equipment, and the level of costs for effective treatment, state and public pressure and tolerance, the possibilities for alternative use, etc. With relatively low economic efficiency for agricultural use, WTPs do not have strong incentives and strategies for the development of this process, and state intervention will be required - support, financing, information, etc.

Farmers, on the other hand, have an economic interest in using innovations like sludge to fertilize the soil in order to increase production efficiency. The use of sludge can also have positive agronomic, production, ecological and other effects (improvement of the structure, aeration and moisture retention of the soil, reduction of erosion, faster germination and vegetation development of the plant, higher quality of production, etc.) which further stimulate economic use. Therefore, the attitudes and capabilities of different types of farmers regarding the application of the innovation "fertilizer sludge" is to be studied.

In addition, it can be assumed that a certain minimum size of land plots and farms is necessary not only to achieve economies of scale and scale in the transportation and application of fertilizers with specialized equipment, but also to justify the additional costs of training, information, experimenting, taking on possible losses, relationships with organizations, etc. Some specialization is also likely to be required for the efficient use of sludge to produce one or two of the permitted crops.

4. Assessment of Personal, Educational and Informational Factors

A very important factor for the efficient utilization of sludge in agriculture are the personal characteristics of farm managers (Table 3). All of the long-term sludge using farmers are good entrepreneurs and managers, with a high innovative spirit and qualification, and a tendency to seek solutions, experiment and take risks to increase profits. They have "discovered" great economic potential in the use of sludge as fertilizers, assume a certain production and financial risk and losses, invest in new knowledge, adapt technology and organization of production, develop relations with WTP, etc. for its realization. Like any innovation, "fertilizer sludge utilization" is associated with a certain economic risk and the need for non-standard management decisions, and entrepreneurial (risk-taking) farmers are not many in this regard.

Another important factor for increasing the utilization of sludge in agriculture is the availability of comprehensive, up-to-date and reliable information on the opportunities, ways, conditions, effects, challenges and risks associated with sludge utilization in agriculture. Adequate regulatory, scientific, experimental and practical information is important not only for farmers, but also for all other participants in this process - government agencies and employees, WTPs, farmers, stakeholders, end users and the general public.

Our study found that such information in Bulgarian (only accessible to most agents) and the specific conditions of the country and its individual regions is very scarce and often contradictory. Very few publications are widely available, mostly in academic publications little read by farmers, businesses, the general public, etc., which are mainly based on experimental and laboratory experiments, most often presented in a foreign language. For example, a Google search can find a small number of publications in recent years by a limited number of authors. Occasional information may appear in the media, mainly about regulatory documents or publications induced by interested parties.

Moreover, there are virtually no comprehensive assessments of the actual socio-economic and complementary effects of sludge use on farms of different types, specializations and locations. In addition, the results of published scientific, experimental and laboratory tests and trials are based on ideal conditions (optimal farming techniques, correct fertilization rates, good management, etc.), which differs significantly from the actual practice of farms. For example, experiments are made with perfectly treated sludge, while in practice the sludge is often delivered and imported in a different state from the regulatory requirements - not treated or partially treated, with high humidity, etc.

The study found that many farmers are partially aware of the possibility of sludge utilization, but there is a strong lack of information on the necessary conditions, potential effects, risks, costs, etc. The lack of adequate information on these issues also has a negative impact on the attitudes of the population, producers in the area, and intermediates and end buyers of the product. The information deficit is most often "filled" with false information about the possible effects of agricultural use, and resistance from both farmers and other stakeholders.

In some scientific institutes of Agricultural Academy and other institutions there have been long-term research on the chemical, biological and agronomic effects of the use of sludge in agriculture. However, the volume

and nature of these studies do not correspond to the modern needs of farmers and society. There are no interdisciplinary studies on this important issue. There is a lack of independent tests and demonstrations, and promotion of practical utilization of sludge in experimental or economic conditions, and specific guidelines for optimal application in farms with different specialization, size, ecological and geographical location, *etc.*

The utilization of sludge in agriculture is a complex and dynamic process that requires long-term specialized training and consultation of farmers. Our research found that there is no specialized training and consulting in the country dedicated to the utilization of sludge in agriculture. For example, in the Agrarian and related universities, Agricultural Academy and National Agricultural Advisory Service there are no highly qualified experts for long-term training and consulting of interested farmers. Some farmers also state that they "do not trust the local institutes" and therefore do not seek their services. All this makes it very difficult to make an effective transition to sludge utilization in agriculture.

Some farmers who use sludge in agriculture conduct their own experiments, find their own solutions and/or seek and find the necessary information and training, including from abroad. Some of them consult each other, exchanging experience and useful information, or seek external advice from private consultants, WTP experts, researchers, *etc.* At the same time, depending on personal characteristics (managerial experience, qualifications, innovation, *etc.*), self-training or "learning by doing experience" requires different time and gives different results for individual farmers, and in some cases can lead to incorrect or inefficient use of sludge, and not infrequently to the cessation of sludge use on farms.

However, our study found that most sludge using farmers are reluctant to share their experiences for a variety of reasons - lack of time, reluctance to publicize, firm secrets about yields and profits from competitors, *etc.* An important reason for this is that they do not want to increase the interest of new farmers in the use of sludge, as this will increase demand in the area, increase the "price" and reduce "profitable" access to the limited resource "sludge". This further slows down the spread of this new practice in the country.

5. Assessment of Production, Socio-economic and Environmental Factors

The main incentives for the use of sludge by farmers are the production and economic benefits (Table 4). Our study found that all users of sludge are large producers who have a strong interest in minimizing the cost of fertilization and have the capacity to bear the additional costs of "external" relations with WTPs and government agencies, experimentation, training, reorganization of the production process and management, risk-taking and possible losses, *etc.*

Table 4. Production, socio-economic and environmental factors for sludge utilization in Bulgarian agriculture

Type	Positive	Negative
Agronomic, technological and production	<ul style="list-style-type: none"> ▪ Improve soil structure; ▪ Improve aeration and soil moisture retention; ▪ Faster germination and vegetative development of the plant; ▪ No need for deep plowing, mineral fertilization and irrigation; ▪ Better compensation of N and P uptakes and soil enrichment; ▪ Increase land productivity and yield; ▪ Improve the quality of produce; ▪ Water retention; ▪ Easy to apply to large farms specializing in field crops; ▪ More efficient use of land, material, labor and financial resources. 	<ul style="list-style-type: none"> ▪ Technologically limited period of time for transportation and import of large amounts of sludge on many farms; ▪ Compaction of the soil when applying the sludge; ▪ Needs to monitor for heavy metals and soil acidity; ▪ Different results depending on the characteristics of the soil, cultivated crops and varieties, and the amount of rain or irrigation; ▪ Difficulties for use by small and medium farms; ▪ Impossibility for use in all crops (vegetables, <i>etc.</i>); ▪ Diverse results depending on production conditions and crops; ▪ Potential sludge shortage for all interested farmers in the area.
Social	<ul style="list-style-type: none"> ▪ Increasing amount of sludge produced in the region; ▪ Lack of alternative use of sludge and lands for disposal; ▪ Public and international (EU) pressure; ▪ Increase in the income of farmers; ▪ Increase of sustainability of agricultural holdings; 	<ul style="list-style-type: none"> ▪ Conflict between economic and social effects ▪ Deteriorate working conditions during periods of sludge application ▪ Decrease comfort of the population during periods of sludge application; ▪ Unfavorable wind direction during delivery, spreading and plowing of sludge; ▪ Public dissatisfaction with the appearance of a

Type	Positive	Negative
	<ul style="list-style-type: none"> ▪ Reduce the amount of waste and the total cost of waste storage and disposal; ▪ Improve competitiveness; ▪ Easy to apply to large and remote from settlements and other businesses farms; ▪ Quick burial of the sludge to eliminate the unpleasant odor. 	<ul style="list-style-type: none"> specific odor; ▪ Landowners reluctance to provide land for rent; ▪ Need for public regulation and control; ▪ Conflicts with other farmers and stakeholders; ▪ Reluctance of beneficiary farmers to share their positive experiences for various reasons; ▪ Unacceptable for use in fruits, vegetables, <i>etc.</i> crops for direct human consumption; ▪ New EU goals for significant reduction of greenhouse gases, use of fertilizers and increase of organic farming; ▪ Needs for long-term social dialogue and costs to promote agricultural use.
Economic	<ul style="list-style-type: none"> ▪ The growth of mineral fertilizer prices; ▪ Minimize or remove the cost of mineral fertilizers for a long period of time; ▪ Increase the average yield; ▪ Larger cobs, ears, grains and leaves (for silage, straw); ▪ Negotiating a better selling price for better quality grain; ▪ Bigger profit; ▪ Savings on material and labor costs; ▪ Increase sustainability; ▪ Improve competitiveness; ▪ Reduce the needs for working capital and/or external lending and payment of interest and liabilities; ▪ Inclusion of farms in the circular economy; ▪ Better use of farm resources. 	<ul style="list-style-type: none"> ▪ Increased costs for negotiation and relations with WTP; ▪ Increased costs for study and implementation of regulations; ▪ Costs of time and funds for obtaining permits and relations with state bodies; ▪ Increased costs of information, exchange of experience, training and management related to the use of sludge; ▪ Increased costs for experimentation and for studying the effects in the conditions of each farm; ▪ Additional costs for laboratory tests of soil, produce, <i>etc.</i> ▪ Increased costs for relationships with landowners, buyers, local government, and the public; ▪ Additional costs for transportation, covering and plowing of sludge; ▪ Need to pay for sludge (in the near future); ▪ Increased labor compensation costs; ▪ Need for a certain concentration and specialization of production in the farm.
Ecological	<ul style="list-style-type: none"> ▪ Maintaining and improving the fertility and quality of agricultural land; ▪ Reducing soil erosion; ▪ Increased water storage on farms; ▪ Application of sludge in the summer to reduce soil compaction; ▪ Increased ecological sustainability of agriculture; ▪ Improved and more efficient waste management; ▪ Reduction of greenhouse gases in the production and supply of mineral fertilizers; ▪ Restrictions on use in protected areas. 	<ul style="list-style-type: none"> ▪ Greenhouse gases emission in sludge treatment and use; ▪ Air and road pollution; ▪ Risks to natural biodiversity; ▪ Groundwater pollution; ▪ Pollution with heavy metals; ▪ Soil trampling; ▪ Need for careful use and precise control in coastal, riparian, lakeside and water supply areas; ▪ Uncertainty related to long-term effects; ▪ Pre-existing before sludge use contamination of soil and waters.

Source: interview with WTP managers and farmers

All sludge users report that the effect of replacing mineral fertilizers with sludge occurs over a long period of time. In the first years after the application of sludge, the yield usually decreases, and subsequently recovers and even increases without the need for annual fertilization with mineral fertilizers. One-time fertilization with sludge allows to replace the mineral fertilization for the entire regulatory period of 5 years, before re-application of sludge on the same plots. Therefore, the one-off costs associated with obtaining permits, supplying and depositing sludge is to be compared with the current savings from the reduced (removed) mineral fertilization during the period of effect realization.

“Sofiyska Voda” AD provides (personnel, covers costs, *etc.*) for obtaining permits for sludge utilization, and provides free of charge sludge and transportation to the farm, additionally providing a machine and operator for sludge covering (only the fuel is paid by the using farmer). The costs for mineral fertilizers represent the main part

of the production costs of the farms in the region - about 35-40%. Therefore, replacing mineral fertilizers with sludge fertilizer can lead to significant economies in large scale utilization.

It is reported that the effect is obtained in all types of soils, except sand, and the best results are obtained with corn in the same arrays – 6000-7000 kg/ha with irrigation. Without irrigation, there is no difference in yield, but only different costs of fertilization with mineral fertilizers and sludge, and yields strongly depend on an "external" factor - the amount of rain during the year. In cereals (wheat and barley) the effect is at the earliest in the third year, as the first- and second-year burn.

In the utilization of sludge, significant savings are additionally made to the need for deep plowing, for the application of fertilizers, for irrigation (for needy crops such as corn), for the payment of interest on loans for the purchase of mineral fertilizers, to save on and more productive use of own working capital, available equipment and manpower, *etc.* These supplementary effects are of great importance since the financial condition of most farms in the country is not good.

In addition to fertilizer savings, the application of sludge also leads to an increase in the total yield during the period, and depending on the crop and the amount of sludge, this increase can be 2 or more times. It should be borne in mind that in the first 1-2-3 years after the introduction of sludge there is a sharp decline in average yields, and loss of profitability of the affected plots of farms. Given the massive underuse of mineral fertilizers in the country, it can be assumed that the total effect of sludge imports is significant, as simultaneously with increasing yields it effectively recovers the N, P, and K uptakes and maintain (and improve) soil fertility. Besides, the use of sludge is associated with additional environmental benefits such as improving the structure and quality of soils, reducing soil erosion and more.

The study found that the effect of fertilization with sludge on yield depends on the crop and varieties used, crop rotation, type and stocking of soils with N, P, K and other elements, *etc.* Yield also depends on the varieties grown, with many farmers preferring foreign varieties because of significantly higher yields other things being equal. A critical factor is the amount of rain, on farms that do not use crop irrigation due to the needs of high investment, the high price of water for irrigation, lack of permits for groundwater extraction, *etc.* It should be borne in mind that there are cases in which the legally permitted norms of sludge per unit area are increased (up to 3 times) and/or sludge is imported on more than the designated areas in order to maximize the yield.

Farmers also report increasing cob size and grades, improving product quality, increasing green mass (for silage and/or hay), which increases sales prices, increases profits and/or facilitates product marketing. These effects are especially important, given the high costs and difficulties associated with the sale of products on many Bulgarian farms.

The utilization of sludge in farms is also associated with maintaining soil fertility, as due to high prices mineral fertilizers are not used sufficiently (optimally). This is also an important indicator of the good environmental sustainability of the farmer. At the same time, however, some farms emphasize that "if possible, they will only apply mineral fertilizers, as they are safer."

The study also found that the application of sludge helps to improve (even double) the retention of moisture in the soil, and can achieve significant additional savings from irrigation and increase yields, in conditions of constant decreases in rainfall in recent years and high costs or lack of technical possibility for irrigation. At the same time, during the delivery and spreading of the sludge, the soil is compacted, its structure is compacted, and the aeration is disturbed, hindering the development of the plants and reducing the yield in the first years. To reduce compaction, the sludge is applied in the summer, after harvest, when it is driest.

The import of sludge requires not only a change in agricultural technology, but also a new better organization and management of production. For example, there is a relatively short technological period after the harvest (July-August) for the delivery, spreading and plowing of the sludge. Upon delivery and especially with delayed plowing, an unpleasant odor spreads, which causes dissatisfaction from neighboring farms and businesses and even residents of nearby settlements. In case of strong odors, it is even necessary to interrupt the process in order to "calm the dissatisfaction of the population", which further shortens the practically possible period for the introduction of sludge.

Along with the economic benefits for the farms, the utilization of sludge is also associated with additional costs for relations with WTPs, controlling bodies, soil sampling, *etc.* For example, contracts between WWTPs and farmers are not complete, require additional costs to coordinate and resolve potential conflicts, and so on. Non-exhaustive contracts also allow for unilateral "breach" of the agreement by the WTP at the expense of farmers - untimely delivery, delivery of sludge in various quantities and quality, temporary suspension of supplies to calm public discontent, *etc.* In addition, WTPs usually apply standard contracts that are not adapted to the specific

conditions of a particular farm. This further increases the costs in the process of sludge utilization for adaptation, coordination between partners, contestation, *etc.*

On the other hand, (profit-oriented) WTPs also seek to minimize their costs for agricultural sludge utilization and prefer large farms near sludge landfills as contractors - cost savings for contracting and relationships, for obtaining permits (no fees are charged), on the paperwork and long procedures, soil samples, for transportation of sludge, *etc.* In all cases where the transaction costs for farmers and/or WTPs are very high, agricultural sludge utilization is reduced or completely blocked, regardless of the potential (production, economic, *etc.*) benefits for both parties.

The widely used practice of one-year land lease agreements of large farms with numerous landowners also creates an additional risk of damage (loss of one-time long-term investments related to the supply and use of sludge) in case of refusal of the landlords to renew the contract on land plots with sludge or permits, during the new business season (alternative use, sale, provision to another tenant, reluctance to deposit sludge, *etc.*).

Many of the above costs cannot be measured in monetary terms, but it is obvious that the one-off investment in the supply and import of sludge as fertilizers is recouped many times over from the additional profit received. Moreover, this type of investment has a much higher return (absolute and comparative efficiency) than other (traditional) capital investments in agriculture.

Most sludge using farms do this for a long period of time, in some cases up to two decades. This shows that good relations have been developed between farmers and WTPs, a good reputation and trust has been built between the partners, and mechanisms for coordination and conflict resolution, and for minimizing transaction costs. In addition, the long period of use of sludge from a holding is an important indicator of efficiency, as with insufficient additional benefits (effects) and high associated costs, farms quickly stop this practice ("low exit costs").

The study found that the revenues of sludge recovery farms are between BGN 350-500/ha after deducting rent, depreciation and wages. The investment is cost-effective, and if allowed, many farmers would fertilize all areas with sludge. The use of sludge increases income, financial opportunities, competitiveness and economic sustainability of the enterprises. This also leads to higher social sustainability, as it provides employment in the region, and increases the viability of agriculture.

The studies also identified the main factors that increase or decrease the interest in the utilization of sludge by farmers who do not currently use sludge (IAE 2021). Most of them are "generally" aware of the possibilities for using WTP sludge as fertilizer and its potential benefits. They receive this information informally either from the media, or from other producers, or from scientists, or from various publications in the press, or from direct monitoring of sludge farms. At the same time, however, very few non-using farmers have in-depth knowledge of the multifaceted socio-economic and environmental effects of agricultural sludge utilization.

A major factor restricting experimentation with or transition to sludge utilization is the release of the specific odor and negative public opinion. The study found that the main reason for this is that sludge is used only by large farms and for a short period of time large quantities are delivered and imputed in certain land plots or areas. In addition, the regulations for maximum permissible sludge moisture, maximum quantities per unit area, obligation to plow on the same day of delivery and laying, *etc.* are not always observed. To reduce these effects, in case of strong odors, many farmers stop introducing sludge for 1-2 days, and/or comply with the direction of the wind not to be towards the settlements. At the same time, if the sludge is provided to several smaller holdings and distributed to larger areas, and if the established doses and regulations are observed, the odor will not be a significant problem.

Concerns about the possible negative effects on soil quality, the health of workers, the population and animals, guests (tourists, *etc.*) in the area, *etc.* are also often mentioned. Many land-leasing holdings and cooperative farms worry that landowners and cooperative members will block such a decision by terminating leases or voting in the general meeting. At the same time, producers whose lands are in remote areas of the settlements point out that the smell is not a significant limiting factor. In addition, in order to reduce the unpleasant odor and dissatisfaction of the population, farmers practice rapid burial after the delivery and spreading of sludge in agricultural plots.

Many farmers also believe that if the sludge is not provided free of charge but sold as a fertilizer product, this would further limit its agricultural use. There is no market for such a product in the country, and the supply will be monopolized (a single supplier) in the respective WTPs regions. At the same time, this product is not very specific to the farm, as there are many alternatives among other (mineral, manure, *etc.*) fertilizers. Moreover, competition with and from companies supplying mineral fertilizers is high, with mineral fertilizers usually sold in a "package" with additional services (lending, delayed payment, consulting, seed provision, *etc.*). In addition, it is found that some non-sludge farmers in the area are convinced that farms that use sludge (defined as "waste") receive payment for it from the WTP. Therefore, a strong development of the "sludge market" and trade in sludge

at high prices cannot be expected in the coming years. Increased costs for efficient sludge utilization in general and in agriculture in particular will continue to be mainly covered by WTPs (and water users respectively) and/or public programs (respectively by European, national or local taxpayers).

6. Case Study of Good Experience for Utilization of Wastewater Treatment Plants (WTP) Sludge in Agriculture

To analyze the various economic, technological, behavioral, *etc.* effects and factors a case study on "Experience or good practice for utilization of WTP sludge in agriculture" was conducted.

6.1. General Description of the Case (Model)

The surveyed farmer is a middle-aged man without special agricultural education. It is registered as a company (OD), located in the region of Sofia and has been engaged in farming since 1992. Initially, he grew vegetables and flowers on 2 ha, but gave up due to lack of labor, marketing problems and insufficient state support.

Currently, the farm specializes in the production of cereals and cultivates 1200 ha of land (45% corn, 40% wheat and barley, and 15% sunflower), located in many plots. Crop varieties are foreign due to higher yields other things being equal. He points out that watering is a problem due to high investment and high water prices. The production is sold to wholesalers and not a small part is exported abroad.

Most of the agricultural land is leased by numerous (over 1000) owners on the basis of annual agreements, as 99% of the owners refuse a lease agreement. The farm has modern equipment and is in good financial condition.

The farm has been applying sludge from WTP since 2002. The agricultural plots of the farm are located at a close distance from the landfills of WTP Sofiyska Voda AD, from where the sludge is delivered. The farm does not have a long-term contract with the company, but annual agreements for the supply of sludge are made. Sludge is utilized on 120 ha, on which corn, wheat and barley are grown in four soil types (chernozem-smolnitsa, alluvial-meadow, deluvial-meadow and brown forest). The cycle lasts 5 years while preserving the crop in the same plots.

The farm receives a permit from the Ministry of Environment and Water, according to the regulations it is "waste" and the agricultural area is "waste disposal site". A separate permit for the use of sludge has been obtained annually for each plot of arable land. Experts of Sofiyska Voda AD deal with the procedures for obtaining the necessary permits.

The sludge is provided and transported free of charge by Sofiyska Voda AD. After delivery to the farm, the sludge is spread and plowed with equipment and personnel from Sofiyska Voda AD, as the farmer pays only for the fuel. The process takes place in the summer after the harvest month (July-August). Annually, during the two possible months, 50 ha are fertilized with sludge. The delivered sludge usually has 65-85% water content. The farm uses 30 tons of sludge per year, which is a good part of the total sludge used in agriculture of Sofiyska Voda AD.

The farmer is well informed on issues related to sludge utilization in agriculture, including by visiting and studying the experience in other countries (USA, Austria, Germany, *etc.*). On his initiative for many years numerous soil samples are made for content of N, P and K, heavy metals, *etc.*, as the costs of 0.16 BGN/ha are at the expense of the farm. In the past, samples were sent even abroad (England, Germany) to determine the accuracy of Bulgarian laboratories.

6.2. Evolution and Driving Factors

The change of the initial specialization of the farm (from vegetables and flowers to cereals) is an important factor allowing the use of sludge, as the regulations do not allow this to happen in crops for direct human consumption. The farm started using sludge in 2002 only one year from the first farmers in the area from the village of Chelopechene. At the beginning, 6-7 ha of sludge from Kremikovtzi were experimented for 1 year.

The success of this innovation is facilitated by the entrepreneurship, innovation and awareness of the farmer, as well as the large size and financial capabilities of the farm. All of them allow to search, find and adapt innovations to increase the efficiency of the farm, and to "take" the associated risk, additional costs and damages, and wait for the necessary period to realize the benefits.

In the first years, the farmer experiments with different doses, crops and soil types. He has tried with 2, 3 and 4 times the doses that are allowed according to the regulations. It also closely monitors the effect of varieties, the impact on soil compaction, the development of yields and costs over time, the dependence on the amount of rainfall during the year, *etc.* Since 2008, detailed statistics have been kept on fertilization, yields, N, P, and K reserves, and the amount of heavy metals and trace elements on the farm. The farmer knows very well how much N he puts into the soil and how much he harvests with the harvest.

The farmer studies (steals) the experience in other countries such as the USA, Germany and Austria. At the same time, he does not use the experience of other farms in the region or the country. He also sent samples abroad to make sure that Bulgarian laboratories were not lying. The results of the samples from Bulgarian laboratories and those in England and Germany (2014) show only a deviation in zinc (5-6 times more). The farmer has little confidence in scientific institutes such as Pushkarov, as the results he receives differ significantly, and due to their strict compliance with regulations. It closely monitors publications related to the utilization of sludge in agriculture, as well as trends in market developments, traders' preferences, innovation, *etc.*

As a result of all this, the farmer has established that higher than the allowed 2-3 tons of dry matter per declare doses of the sludge should be applied in order to have an effect on the yield. With 0.6 t/ha of dry matter sludge, the effect is obtained every 2 years and the need to apply mineral fertilizers for 5 years is eliminated, and the investment is returned. Due to trampling of the soil in the process of delivery, spreading and plowing of the sludge, in the first year the yield decreases, as the structure of the soil, bacteria, *etc.* are restored. In the 5th year the application of mineral fertilizers begins. If the official norms are applied, sludge is insufficiently stored in only 2 mm of the area and in the fourth year N is extracted and the yields fall ("N cannot make the circle").

An important factor for the efficient utilization of sludge are the good relations with the experts of Sofiyska Voda AD, the constant logistical support by the company, the free provision and transportation of sludge, and the provision of equipment and personnel for spreading and plowing the sludge in the farm.

The main problem is the permits for the utilization of sludge in agriculture, which must be obtained annually. The "paperwork" is large, but this is not a problem, as the permits are obtained by employees of Sofiyska Voda AD and there are no fees. However, the permitting process is slow, and no permits are issued for new areas, which prevents all areas on the farm from being "rotated". Farmers and Sofiyska Voda AD are trying to change the situation, but so far without success. Under these restrictions, it takes 10 years to rotate all areas of the farm.

EU policies, which oblige the sowing of crops for soil enrichment, set-aside, compliance with eco and other standards, *etc.*, as a condition for receiving public subsidies, also contribute to this process.

Years ago, yields on the farm were low, but now only foreign varieties are used, which have significantly higher yields, other things being equal. For example, the yield increases from 5000 to 7000 kg/ha when using Austrian varieties. Yield also strongly depends on the amount of rain during the year, as watering is a "problem" due to the need for large investments, high water prices, difficulties and costs for permits, *etc.*

The main problem when using sludge is the unpleasant odor during delivery and introduction of sludge. According to the regulations, in the same day of delivery of the sludge it has to be plowed, but in practice this happens after 3 days, which causes a strong odor. For this reason, many complaints are made annually by the population in the town hall. Under these conditions, the process of delivery and introduction of sludge is stopped for 1-2 days in order to calm the dissatisfaction of the population. According to the farmer, this is not due to coercion, but for "moral" reasons. Also, he makes sure that the wind direction is not towards the village when the sludge is spread and plowed.

The sludge is delivered and imputed in the summer when it is driest, so that the soil is less compacted. Usually in dry weather the sludge is delivered to the poorest soils or to the road, while in rain it is delivered inwards so as not to remove the mud.

The farmer keeps a company secret about his experience and the utilization of sludge, although he knows that many producers in the area are aware of the economic benefits. He avoids sharing experience and publicity, fearing that the sludge is insufficient and, if widely used, "it will not be possible to classify it as sludge in the WTP".

The utilization of sludge on the farm allows the replacement of expensive mineral fertilizers and the realization of significant profits. It is highly efficient for the farm and the farmer plans to continue this practice in the future. The farmer signs a declaration that he does not use GMOs, but believes that the use of GMOs should be allowed in the country. Current varieties can not be used for more than 10 years, while foreign ones are resistant to diseases and pests.

6.3. Effects, Efficiency and Sustainability

At the increased doses of sludge application (6 t/dca dry matter) the mineral fertilization is replaced for 5 years. The cost of mineral N, P, and K fertilizers is 40% of the cost per unit area. For 5 years 30% of the costs of the farm are saved at least 2 times and up to 3 times above the allowed doses of sludge. The effect is obtained on all types of soils, except sand.

The best results are obtained with corn in the same arrays 6000-7000 kg/ha with watering. There is also a rapid development of plants, more green mass, increasing the size of the cob and improving the quality of production. There are problems with watering due to the size of investments and the high price of water (BGN

150/t). Without watering there is no difference in yield, only different costs of fertilizing with mineral fertilizers and sludge. Yields strongly depend on an "external" factor - the amount of rain during the year.

There are additional benefits from using sludge - when plowing the sludge goes deep, and retains moisture 2 times better soil ("like a sponge for washing dishes"), and the water is sufficient for plants. In this way, a yield increase of up to 3 times is achieved. The use of sludge produces more green mass for silage and hay, larger cobs and ears, and improves the quality of the harvest. All this leads to more effective marketing of the products - easy sales, additional revenue, etc.

The sludge is brought in by heavy trucks, and heavy spreading and plowing techniques are used, which degrades the soil. As a result of compaction in the first year there is no yield effect. In cereals (wheat and barley) the effect is at the earliest in the third year, as the first- and second-year burn. In the fourth year there is no problem.

The additional investments of the farm are BGN 60 for labor and BGN 15 for sludge - for standard plowing the fuel consumption is 2.5 l/dca, and for plowing sludge more 4-5 l/dca. The additional cost of seeds for high-yielding foreign varieties is the "smallest problem". Foreign varieties under the same other conditions increase the yield by 2000 kg to 7000 kg/ha. In order to reach this yield, more than BGN 1200 are needed for mineral fertilizers. In addition, mineral fertilization requires a minimum of 60 days to transform substances from one form to another.

The income of the farm is 350-500 BGN/ha after deducting rent, depreciation and salaries. The investment is cost-effective, and if possible, the farmer would fertilize all areas with sludge. It takes 10 years to rotate all areas of the farm. The use of sludge increased income, financial opportunities, competitiveness and economic sustainability of the holding. This also leads to higher social sustainability, as employment is provided in the region.

The utilization of sludge in the farm is also related to the maintenance of soil fertility, as due to the high prices the mineral fertilizers are not applied to a sufficient degree. This is also an indicator of the good environmental sustainability of the farmer. At the same time, however, the farmer states, "that, if possible, he will apply only with mineral fertilizers, as they are more harmless."

Table 5. Type and magnitude of the effects of sludge utilization on the case-study farm

Type of the effects	Size of the effects
Yield change (grain and green mass)	++
Fertilization cost savings	+++
Product quality	++
Additional plowing costs	+
Effective product marketing	++
Profit	++
Economic sustainability and competitiveness	+++
Soil compaction	++
Moisture retention in the soil	+++
Plant development	++
Soil pollution	+
Air Pollution	++
Environmental sustainability	+
Dissatisfaction of the population	++
Employment of workforce	+

Source: interview with the farm manager

Long-term tests on the farm show that for heavy metals only zinc has an increase in quantities. According to the farmer, plants (corn, sunflower) absorb all trace elements.

Soil compaction is a problem after the application of sludge is overcome and the quality of the soil and the normal development of plants are restored after the first year. The only problem with the use of sludge is the smell, which, however, "does not mean pollution." According to the farmer, it is said that "sludge will poison the land", and at the same time farmers "cannot be classified as sludge due to a big demand".

The farmer considers the continued use of sludge for economic gain. However, he does not think that the use of sludge can be expanded in the future due to the "small potential of the water treatment plant". Only he currently uses 30 tons per 100 ha and is one of only 7 agricultural producers using sludge in the region of Sofia. He believes that if the sludge becomes a "commodity", it will not be able to settle due to competition with other

farms. Another problem is that no permits for new areas are issued by the competent authorities. If he could, the farmer would fertilize constantly with mineral fertilizers, as he considers this to be "safer".

Another uncertainty in the medium term is associated with the modernization of the EU CAP related to the ambitious goals of the Green Deal, and the resulting "new" rights and restrictions for farmers.

Conclusion

This study is only the first stage of a larger study to establish the diverse effects and factors of sludge utilization in Bulgarian agriculture. The factors and effects of the circular economy are strictly specific to the conditions of each economic organization, the individual sub-sectors of agriculture, the different ecosystems and regions in which the usage takes place. Therefore, efforts will be focused on the next stage of development to clarify the farm, sectoral and regional specificities.

Given their relevance, research of this kind should be continued and deepened and should be based on more representative information from all participating agents and stakeholders. In addition to identifying the factors and their direction (positive, negative), the degree of their significance should be assessed by an interdisciplinary panel of experts in the field. On this basis, specific recommendations can be prepared to improve the utilization of sludge in agriculture to improve the policies, public support and institutional arrangements, and management strategies of WTPs and potential and sludge-using farmers.

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