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Convergent analysis of waste water practices among EU countries

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Abstract

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The purpose of this article is to study the degree of convergence in the production and the disposal of sewage sludge, as well as to focus on the sludge disposal in agriculture among selected EU countries and to compare trends and the position that Bulgaria ranks in this aspects.The wastewater in sewage system is a crucial issue for EU and Bulgaria for many years and it strengthens the importance in the context of sustainable development, bioeconomy and mitigating the climate changes. Due to complex and unequivocal properties of sludge, the disposal and utilization is subject to restrictions and special regulation governance. The applied method for measuring the convergence stands on the classical way of Beta and Sigma convergence but instead of using correlation, standard deviation and variation, it uses the proportions between countries and the subtractions between them in a particular year based on previous one. Bulgaria manages to achieve a significant progress in the period 2007-2018 compared to selected EU countries in the covered three indicators – production of sludge, disposal and application to agriculture. It means the convergence is notable and for the period, Bulgaria closes the gap in sludge utilization with selected countries, while the application in agriculture is the indicator, where the progress in convergence is most tangible and it is the most used sludge utilization alternative.

Keywords: wastewater; agriculture; convergence; sludge disposal; environment pollution

Introduction

Agriculture application, incineration or landfilling is the main routes for sludge management across Europe (Milieu et al., 2010). The amount of sludge that is incinerated may substantially hike up whenever the application of sludge and wastewater is repealed or banned. Increasingly, the landfill option is becoming restricted to the disposal of ash from the incineration of sludge (Milieu et al., 2010). Other feasibility for sludge utilization comprises practices for land or for polluted site reclamation. Very rarely, the sludge isincorporated into construction materials and ingredients. The introduction of whole sludge into bricks has also been applied. Those are seen as alternative practices of agricultural utilization of sludge, which is driven by two main reasons: first, for the sake to deal with some negative characteristics of sludge containing to some extent toxic and averse elements and second, as a way to seek for a better economic or effective application.

Measures for the utilization and subsequent treatment of sludge is of crucial importance in view of setting objectives for achieving sustainability and reducing pollution, in order to mitigate climate change (EC, 2021). Besides, Bachev et al. (2017) conclude that "sustainability is a key concept that will have greater importance in the future, having in mind the problems the world population is facing with the climate and all unexpected effects of its change". Finding the use of the collected sewage sludge is an issue, both to prevent environmental pollution and to benefit on the useful elements and ingredients in it. Sarov&Tsvyatkova (2021) state that sludge is composed of not only valuable components for agriculture (including organic matter, nitrogen, phosphorus, potassium, and to a lesser extent, calcium, sulphur and magnesium), but also pollutants, which usually include heavy metals, organic pollutants and pathogens". Along with it, it is envisaged that "the effective use of sludge for agricultural activity requires monitoring of chemical changes occurring in the soil, both the benefits and risks associated with their application" (Marinova&Katidjotes, 2006). "Sludge is a biomass and is an organic reserve in relation with the shortage of organic sources in our country. They can be used in the practice complying with certain conditions, according to the legislation"(Marinova, 2002). Banov et al. (2016) formulate the hypothesis to use for agricultural purposes of land, regardless of their low fertility, which can be attributed to promoting further sludge disposal in agriculture.

It should be underlined that agriculture is natural designation of sludge utilization for many decades. Regarding the environmental and pollution issues, EU enacted special legislation for sludge use. The Sewage Sludge Directive 86/278/EEC was set up to encourage the use of sewage sludge in agriculture and to regulate its use in such a way as to prevent harmful effects on soil, vegetation, animals and man (Milieu et al., 2010). The legislation ushered bans for using untreated sludge on agricultural land unless it is injected or mingledwith the soil. The Directive also required that sludge should be used in such a way that account is taken of the nutrient requirements of plants and that the quality of the soil and of the surface and groundwater is not impaired. The Directive specifies that for sludge to be defined as treated it should have undergone biological, chemical or heat treatment, long-term storage or any other appropriate process so as to significantly reduce its fermentability and the health hazards associated with its use (Milieu et al., 2010).

In regards to those specifications, which are considered and viewed widely, individual Member States implement and act differently due to particular local conditions and characteristics. In general, untreated sludge is no longer applied. In the Czech Republic, Denmark, Spain, Finland, Germany, Hungary, Italy, Luxembourg, the Netherlands, Slovakia, Slovenia, and in the UK it is prohibited to spread any untreated sludge on land (EC, 2006). In Bulgaria, the recent conditions and rules for using the wastewater sludge in agriculture is set out by Order of Ministries' Council from 2016. It permits the utilization of sludge in agriculture only in compliances with the requirements of the mentioned Order. The regime for producers and users of the sludge in agriculture is permitted only to entities possessing clearance by authorities. The legislation concerning the sludge use in agriculture between EU countries and those included in the analysis is quite similar based on the Sewage Sludge Directive 86/278.According to Collivignarelli et al. (2019), the EU countries might be classified into two categories in relation to national legislations stringency for sludge disposal in agriculture compared to EU directive. Bulgaria is put in the second group with requirements similar to EU directive, while France, Germany, Hungary and Poland are regulated more restrictively compared to basic EU legislation.

An EC report (2017) in 2014 found that 8.7 million tonnes of dry solids were produced in the EU, representing approximately 17 kg per capita. In Bulgaria, Cyprus, Italy, Portugal and Romania, the ratios are below 10 kg per capita, which implies an insufficient level of collection and treatment. It turns out that about 58% of the generated sludge is reused, mostly in agriculture. Although in recent years the trends in the EU have been towards reducing the use of sludge in agriculture, this practice continues to be leading and occupies a predominant place in the utilization of sewage sludge. About 50% of wastewater and sludge is used through various technologies for mixing with agricultural soils, 28% is incinerated and 18% is still landfilled (EC, 2017). According to Sarov&Tsvyatkova (2021) in Bulgaria the amounts of sludge used in agriculture amount to approximately 33%.

In the EU and the rest of the world, other methods of disposal are common through other methods such as: pyrolysis, storage (eg Greece, Italy and Poland), reuse in green areas and forestry (eg Ireland, Latvia and Slovakia). On the other hand, there are countries with low sewage sludge production due to smaller populations (eg Malta, Latvia, Estonia and Luxembourg) or due to the low coverage rate with Wastewater Treatment Plants (WWTPs) connecting households and urban centres. For example, in 2014 in Bulgaria almost 26% of the agglomerations were connected and wastewater collected to WWTP according to EC data (EC, 2017).

In Bulgaria, the use of sludge in agricultural practice is considered as a good and working opportunity, which according to Ivanov et al. (2020) can lead to the following benefits: removal of sludge from the area of Wastewater Treatment Plants (WWTP), providing organic materials important in compensating the shortage of organic sources in our country and achieving better economic efficiency. For the period 2007-2017, according to Eurostat data, the production of sludge obtained from WWTP in Bulgaria increased by almost 80%. In absolute values, the obtained dry material from sludge increases from 38 Ktons at the beginning of the period up to 68.6 Ktons at the end of the period. In percentage terms, this increase represents a leap from 16% to 33% in 2017. Over the years, significant fluctuations have been observed in both sludge production and agricultural disposal, as the percentage of deviation in annual quantities collated to the average levels for the period 2007-2017 is about 28%. The reasons for this are different, but the main one is that the application of sludge in agriculture is related both to the suitability of the sludge itself to meet the relevant parameters of the national regulatory framework and to the willingness and the attitudes of farmers to use it. The use of sludge in agriculture is a function, both the agricultural technology and the availability of sufficient demand in specific periods of time. In confirmation of this, Sarov&Tsvyatkova(2021) note that "as a result of agrotechnical requirements there is a window of two months in the summer - these are the months from July to August, after harvesting, during which period is needed a perfect plan for days, for the delivery of the sludge, spreading on the field and ploughing immediately ". Bachev (2010) referring to Williamson (1996) points out that in choosing the type of negotiation and fulfillement of the transactions, the role has "critical dimensions" affecting the size of transactional factors - frequency, uncertainty and specificity of assets. Although there is a high frequency of transactions carried out between WWTPs and farmers, which are done on well-known basis, each side know other side, due to the specificity of sludge use, which is high, the long-term contractual form is not widespread enough, although WWTPs work with an almost constant contingent of farmers. The reason is that although the recurrence and specificity are high, both parties are trying to maximize their interest in the transaction. Thus, the WWTP likely consider that they can get a better price for the product they offer, whereas farmers to protect themselves from additional liabilities, which can arise up if they can't utilize the preliminary provisioned quantity of sludge. In this respect, the lack of long-term and set up contractual agreements between the WWTP and farmers, together with the specificity of technological conditions for the use of sludge in agriculture explicates to a great extent the variations in the use during particular years in a row.

Regarding the development of Bulgarian agriculture, in terms of potential, it has significant reserves, which are embedded in natural and land resources, low levels of productivity, taking into account the levels reached in developed countries, access to technology and markets after EU accession and tied to the available significant public support " (Ivanov, 2021). What Bulgarian agriculture needs is to achieve a greater result, expressed in added value and greater benefit to society and consumers. Low productivity leads to low efficiency and higher production costs, which reduces competitiveness. Achieving higher competitiveness and increasing the added value can be done by strengthening innovative solutions, drawing attention and abide with the social and environmental aspects of farming (Ivanov, 2021). The development of the bioeconomy, which gives a new light on the issue of sludge use "is becoming a factor for sustainability and competitiveness based on innovation" (Ivanov et al., 2020).

The purpose of this article is to study the degree of convergence in the production and the disposal of sewage sludge, as well as to focus on the sludge disposal in agriculture among selected EU countries and to compare trends and the position that Bulgaria ranks in this aspects. It is thought to serve for deriving conclusions and outlining perspectives for the future development in sludge utilization and designation in Bulgaria. Convergence is envisaged as a closing of gaps and is an important and indicative tool that allows for comparative analysis, both between countries on a particular issue, and to trace up changes in dynamics, through evaluating the pace of changes over time. The theme of the use of sludge and what importance it takes in agriculture can help to assess the extent to which there is a common response and universal practices at EU level for sludge utilization, which along with environmental challenges, poses a number of socio-economic issues.

Methodology

Convergence is a method that makes it possible to see the convergence between compared subjects and variables that are assumed to find out the similarities and coherence in their positions and dynamics. Convergence in the study is made on three main indicators concerning the use of sludge: production, disposal of extracted sludge from WWTP and application in agriculture. The convergence coefficient is introduced, which measures the convergence of one country to another on each of these three indicators. The countries involved in the study, perceived as counterpart of Bulgaria in terms of observed indicators and their situation are: France, Germany, Poland and Hungary. These countries are selected as sufficiently representative at the EU level, and the representation refers in different layers: as in geographical aspect: Western and Eastern European countries; EU membership - old to new countries; countries with GDP per capita above the EU average and below average. These are the criteria by which these countries are selected, as the reason for the parallel demarcation is the differences existing among them. The preposition to focus and pick on those countries is that they are the leading countries in the EU in terms of agriculture, which is explicated for the share and importance the industry consists in those countries compared to EU average.

Whenever the convergence is thought and explored in the literature, it is assumed β (beta) and σ (sigma) convergence (Young et al., 2008). On the other hand, σ (sigma) convergence stands for the degree of dispersion that exists in a certain group and its change in time horizon. The more it decreases, the higher convergence of the observed indicator appears and vice versa, the enhancement of deviation between variable sets indicates divergence processes. In turn, β (beta) convergence is understood as the correlation between data variables, measuring the initial and final levels of a given indicator, as the negative correlation indicates the presence of β convergence. Otherwise, the β-convergence occurs if β<0, which means that regression coefficient decreases in dynamic and the linear function is downward.

There are many authors who do such research and refer to convergence analysis, such as Barro& Sala-i-Martin (1992) and Mankiw et al. (1992), who work on such studies and conclude that β convergence is anticipated whenever, the correlation is a negative coefficient outcome. Besides, both Barro& Sala-i-Martin (1992) and Friedman (1992) argue that the study of σ convergence of non-uniform distribution and deviations in real values becomes more important because the reduction of differences and gaps between compared subjects is a feature of their closing. Sala-i-Martin (1995) proposes the following formula for calculating β convergence:

$$\ln(y_{it} = a + (1-\beta) * \ln\left(y_{i,t-1}\right) + u_{it} \quad (1)$$

where 0 < β < 1, while α is a constant, u_{it} is a standard error, which is assumed theoretically for 0. In order to evaluate the dispersion convergence is used equation (2), where the mean of the whole population – μ_t is included.In this respect, as high is the σ, so bigger and wider is the variation and dispersion, which manifests and implies for less convergence. Between β and σ has a significant difference, which points out as less is the coefficient of β convergence, so higher is the outcome for σ, which means the lack of correlation leads to elevation of σ deviation.

$$\sigma_t^2 = \left(\frac{1}{N}\right) * \sum_{i=1}^{N}\{Ln(y_{it}) - \mu_t\}^2 \quad (2)$$

The equation (2) can be made through weighting, where is the relative share of the population of compared countries and regions, which are covered in convergence study.

$$\sigma_t^2 = \frac{1}{N}\sum_{i=1}^{N}(y_{it} - \mu_t)^2 * (p_i - 1) \quad (3)$$

The σ convergence is judged by the changes in coefficient of variation (CV) too. When $CV_{t+1} < CV_t$ or $\sigma_{t+1} < \sigma_t$ is assumed that there is a convergence and vice versa, the opposite proportion denotes the presence of divergence.

$$CV = \frac{\sigma}{\bar{y}} \quad (4)$$

In addition to the described classical way of calculating convergence, Ivanov (2020) and Ivanov (2021) offer a different way of calculating that tries to combine the two mentioned indices for eliciting and displaying convergence. This method takes into account both the ratio between the absolute levels in the levels of production, disposal share of sludge in agriculture per capita in the compared countries, and takes into account the dynamic change of these indicators in the periods t and t-1, as well as this component works and measures the magnitude in absolute values of the changes. The equation for obtaining the convergence coefficient is:

$$K_{CNV} = \frac{\frac{IV_{subST}^{t}}{IV_{BscST}^{t}} + \left(\frac{\left(\left(IV_{SubST}^{t} - IV_{SubST}^{t-1}\right) - \left(IV_{BscST}^{t} - IV_{BscST}^{t-1}\right)\right)}{\frac{\left(IV_{SubST}^{t-1} + IV_{BscST}^{t-1}\right)}{2}} * \frac{IV_{subST}^{t}}{IV_{BscST}^{t}} + \frac{IV_{subST}^{t-1}}{IV_{BscST}^{t-1}}\right)}{2} \quad (5)$$

The closer to 1 is this coefficient, as much closer and similar are the countries in terms of the selected indicator (Ivanov, 2020; Ivanov, 2021). The convergence factor is denoted by K_{CNV} and can take values from 0 and greater than 1. The variables involved are IV_{subST} - this is the indicator value, which in this case is the amount of sludge per capita in the three main indicators covered in the study - production of sludge from the WWTP, the use of sludge for various purposes per capita in the selected countries, where Bulgaria is the subject whereas other countries are counterparts and the use of sludge for agricultural purposes per capita. On the other hand, IV_{bscST} is the related indicator of the baseline counterpart country with which the comparison is made. In this methodology, discretely only 2 countries can be compared, which is one of the constraints of its application simultaneously, but the result can be individualized by revealing the dynamics of convergence by years, which is not possible with the classical and accepted method of β and σ convergence. This methodology offers a relatively easy way and process for fulfilment and does not require complex calculations algorithm (Ivanov, 2020). Indirectly, the obtained convergence coefficient K_{CNV} refers to the object country (Bulgaria), as referred to any other counterpart country with which the convergence is measured. Indirectly through the subject country, i.e Bulgaria, the counterpart countries can be compared as well because they are in some relationship with the subject country therefore they are positioned differently to each other.

Results

Sludge is yielded from the treatment of household or industrial wastewater transported via sewerage system to treatment plants. They are the result of the biological activity of microorganisms. The continuous increase in the volume of sludge generated by water purification is associated with demographic growth and expansion of urban areas and has a serious impact on the development of urban centres, industry and environmental protection. The treatment of sewage sludge is done in order to reduce their volume and turn them into valuable products. Due to their nature, sludge is a production factor for crops: nutrients, organic matter.

A study by Ivanov et al. (2020) devoted to the evaluation of the efficiency and effectiveness of mineral fertilization and sludge fertilization found that "the efficiency of sludge use is calculated at 35.9 kg of corn quantity per BGN 1 of investment in the sludge way of fertilization, while the mineral fertilization efficiency is 11.5 kg corn production per unit of fertilization costs on average for 3 years". The main reason for this result is attributed to the lack of costs for the provision of applied nutrients, which are contained in organic biomass of sludge (Ivanov et al., 2020).

The main thesis and argument prompting the agricultural use of sludge is ensued in the availability of phosphates in the sludge extracted from wastewater.Nitrogen and phosphorus are the most valuable nutrients in sewage sludge, which give sludge advantages for using in Bulgaria, especially with 1/4 of the arable land occupied with sunflower, where the phosphorous is a crucial element. Other water-soluble nutrients such as potassium (K), calcium (Ca) and magnesium (Mg) are less efficiently removed during wastewater treatment (Kirchmann et al., 2017). The use of sewage sludge in agriculture reduces the need to use these resources and therefore reduces the incorporation of conventional phosphorus fertilizers. In about 30 years, phosphate deposits, which are exploited at the current rate and with nowadays technology, will be depleted (Figure 1).

The convergence of sludge production and wastewater treatment from urban Waste-Water Treatment Plants shows that Bulgaria lags significantly behind selected EU countries. At the end of the period, Bulgaria has the closest convergence in sludge production with Poland – 0.65, followed by France – 0.61 and going back after Germany with a convergence coefficient of 0.49 and Hungary – 0.47. This means that per capita, the production and processing of wastewater from the sewerage system in Bulgaria are approximately 40-50% lower than they are in the selected countries. However, the convergence dynamic is positive, with significant growth for the period 2007-2018, amounting to 2.2 times growth rate in catching up with Germany. On average, Bulgaria manages to close the gap and lag behind the selected countries by about 70%. At the beginning of the period 2007-2008, the levels of convergence and similarity of Bulgaria in terms of sludge production is between 0.22-0.38 of the levels in the selected countries, which shows significant progress during this time. It should be noted that theoretically the convergence factor of 1 means the amount of sludge extracted per capita in the compared subject and counterpart countries will be the same and equal.

The Figure 2 shows the results of convergence in terms of sludge disposal designated for different purposes. What again can be noted and underlined is that the situation of the subject country has significantly improvement over the years. The average levels from which it started in 2007-2008 have a convergence coefficient between 0.15-0.29, while at the end of the period the values of the same coefficient are 0.29-0.57. The increase of the coefficient for the period 2007-2018 is about 85%, which is a higher growth compared to the indicator of sludge production from WWTPs, despite the fact that the levels in this category are lower than in the production of sludge. It should also be noted that throughout the period the ratio between the sludge extracted from the WWTP and used for different needs remains approximate-

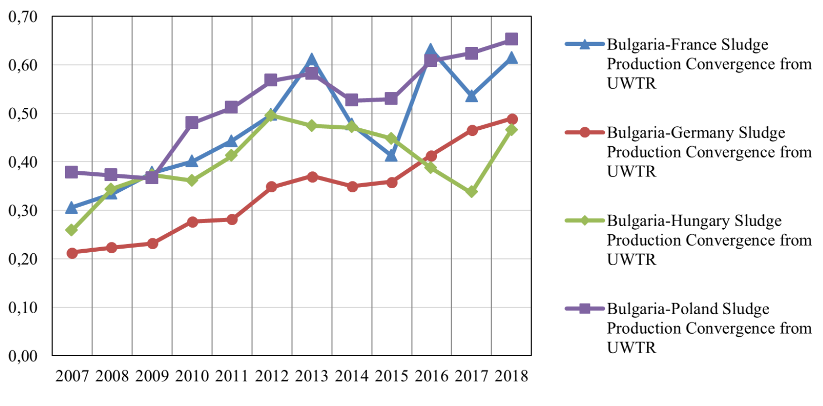

Fig. 1. Convergence dynamic of sludge production per capita in Bulgaria with EU countries
Source: Author calculations on Eurostat data

ly equal n Bulgaria, as this percentage is about 65%. For comparison, in the selected countries the ratio between the sludge extracted and used for different purposes is about 75% for France, about 90% for Hungary, 95% in Germany and 100% for Poland.

The reason for these differences is in the current legislation in different countries, as the more restrictive it is regarding the use of the obtained sludge and the less developed are the sectors belonging to the recycling (circular) economy, the lower is the percentage of disposal and utilization of the extracted quantities. It should be noted that according to a study conducted by Milieu et al. (2010) in the first few years after 2000, Bulgaria landfilled about 60% (2006) of the sludge produced, while Poland landfilled 87% (2000). For France and Germany, the percentages are roughly similar, revealing that the new Member States, which have lagged significantly behind in the use and input of sludge, have made significant progress over the last 15 years.

The retention and the measures taken at EU level for the ways and possible applications for the use of the sludge produced by the WWTP depend on the texture. The content of pollutants in wastewater raises concerns. Sewage sludge is also a concerning pollutant. In the long term, substances can impair soil fertility or enter the food chain and thus have a negative impact on animal and human health. According Kirchmann et al. (2017) "there are two inherent characteristics that restrict recycling of urban organic wastes in agriculture: the low plant availability of the nutrients applied and secondly, high water and low nutrient content and consequently large waste volumes per nutrient to be distributed".

Comparing the convergence for the use and application of WWTP sludge in agriculture, Bulgaria ranges the highest coefficient of the considered 3 indicators. Bulgaria has higher values of sludge use in agriculture per hectare than Hungary, as the convergence ratio between BG-HU is 1.04 in 2018, while at the beginning of the period (2007) it was only 0.19. This shows the enormous progress in convergence that has been achieved with other EU countries over the covered period. The average increase for the period (2007-2018) to all 4 selected countries is about 4.5 times, which demonstrates that in Bulgaria, the use and recycling of WWTP sludge through soils and agricultural land is among the most

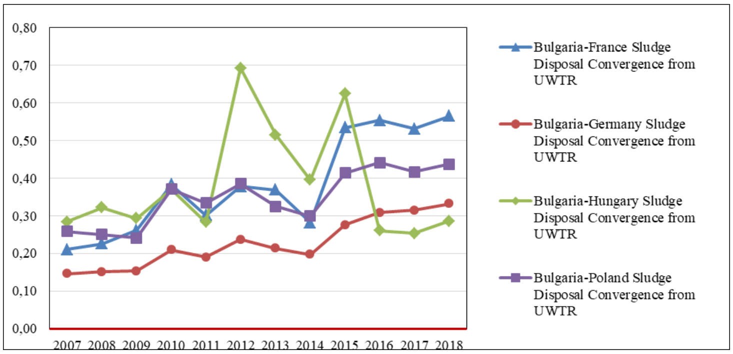

Fig. 2. Convergence dynamic of sludge disposal per capita in Bulgaria with EU countries
Source: Author calculations on Eurostat data

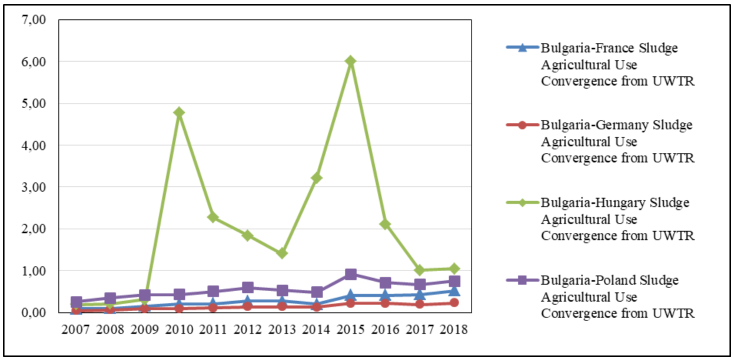

Fig. 3. Convergence dynamic of sludge agricultural use in Bulgaria with EU countries per ha
Source: Author calculations on Eurostat data

designated methods. What also can be underlined unlike other countries is the sustained growth in opposition to the amount of sludge used in agriculture in Hungary, where it varies widely, which is very specific to this country. The Bulgarian agriculture turns out to utilize in different years between 35-40% of the yielded sludge from WWTP's, whereas in other compared countries it receives between 25-30%, as the smallest rate is reported in recent years for Hungary – less than 15%.

What may serve to explain the large variations in the use of sludge in agriculture in Hungary, based on the analysis of Milieu et al. (2010) is that there is a transformation of quantities disposed into agriculture, but in certain years this is directly in the form of a dried substance, and in others, as compost. In general, Bulgaria is at levels of about 75% of the average for the selected EU countries in terms of sludge application in agriculture at the end of the period, which ranks the country with one of the highest convergence rates in this indicator out of the three included. This shows that the use of sludge in agriculture in Bulgaria is not only important and leading in the utilization of sludge from WWTP, but also the country for the period 2007-2018 shows the greatest convergence progress in this aspect with other EU countries (Figure 3).

Conclusions

The theme with production, treatment, disposal and use of sludge in agriculture continues to be extremely relevant and to rise up its importance in the context of achieving sustainable development and precluding environmental pollution. The studied and analyzed aspects of production, utilization and application of sludge in agriculture in the period 2007-2018 reveals a significant progress in Bulgaria compared to counterpart EU countries, which is evidence of a positive convergence. Bulgaria managed to significantly catch-up the distance and the lag in the utilization of sludge from WWTP, as at the beginning of the covered period, the lag behind the countries selected for comparison - France, Germany, Poland and Hungary tallies up more than 3 times. At the end of the period, Bulgaria continues to lag behind the achieved levels in these countries, but the difference is sufficiently shortened and in the worst case is not more than 2 times smaller, whereas in the use and application of sludge in agriculture the difference is about 30%.

It should also be noted that Bulgaria achieves convergence and successfully catches up with all countries selected for comparison, as the most sensitive progress is found out in the field of sludge use in agriculture. This shows that the country realizes and sees great advantages for the use of sludge in agriculture and is back to back to some of the best EU examples in this direction, for example, with Germany. Agriculture is not only a suitable recipient for sewage sludge, but also it is one of the cheapest and most efficient ways for its post-treatment utilization. For Bulgaria, the importance and place of agriculture in the country's economy, although declining, remains important regarding rural development, job creation and incomes, as well as to meet the needs and demand of food for population and raw input for other industries in the value chain. Bulgarian agriculture needs to achieve growth in production and productivity, which will lead to improve competitiveness and added value, and sludge can be considered as a contributing product subserving this goal.

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