



Financial, environmental and social sustainability of rural sanitary wastewater system: case study

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Abstract

Undeveloped sanitary wastewater systems and sanitation often based on septic tanks of unproven tightness, especially in the eastern part of Poland, pose the significant threat to the natural environment and public health. On the other hand, designing the sanitation systems for rural settlements with low population density, limited volume of wastewater, large distances and variable topography may be a difficult task because the proposed design, corresponding to actual law and standards, should not only limit anthropopressure on the environment but also should gain the local population acceptance due to investment as well as operation and maintenance costs. Thus, in our opinion, the variant analysis concerning financial, environmental and social sustainability of proposed sanitary systems is required at the initial stage of the design process. This paper presents variant analysis of financial, environmental and social sustainability of three variants of sanitary wastewater system proposed for the selected rural located in eastern part of Poland. The studied variants covered: vacuum sewage system, pressure sewage system and gravity sewage system combined with the individual, on-site devices for wastewater treatment. The financial analysis was based on three popular indicators of investment cost efficiency: Dynamic Generation Cost (DGC), Net Present Value (NPV) and Benefit–Cost Rate (BCR), while environmental analysis focused on possible intensity and pathways of emissions. Possible employment as well as social involvement and acceptance were selected as indicators for the determination of social sustainability. Then, the obtained results of partial analyses were introduced to weighed sum model (WSM) allowing to determine the most suitable design, attractive for investors as well as for the local population.

Keywords Sustainability · Sanitary sewage · Variate analysis

Introduction

Nowadays the shortage of water, in face of climate change, and degradation of the natural environment are recognized as the two most important problems of the modern society (Mariolakos 2007; Peter and Nkambule 2012; Hutton and Chase 2016). Sustainable development of rural population is highly related to availability of natural environmental resources, including drinking water, clean arable soil and fresh air, thus the proper management of sanitary sewerage is a sine qua non-condition from the point of sustainability (Chinyama et al. 2012; Benzerra et al. 2012; Istenic et al. 2015; Prysycz and Mrowiec 2015; Piasecki 2019). Untreated, or partially treated, human excreta delivered to

surface water, soil or groundwater pose a significant biological threat to their quality and human health, also clearly reducing availability of resources. So, development of sanitary sewerage in rural areas is highly expected.

Generally, according to Eurostat data for 2018 (https://ec.europa.eu/eurostat/databrowser/view/ENV_WW_CON_custom_1727989/default/table?lang=en) the percentage share of total population connected to wastewater treatment plants in the European Union is not uniform. The highest values, 100% of population, were reported for e.g. Denmark, France, Germany, the Netherlands and Austria. On the other hand, relatively low percentage of population connected to treatment plants was reported for Romania, Lithuania and Poland, 53.4%, 78.8% and 70.8%, respectively. The values of percentage share of rural population connected to organized sanitation in Romania, Lithuania and Poland are even lower, reaching the level up to 30–40%.

Actually, centralized and decentralized sanitary sewage management in rural parts of Poland is highly undeveloped.

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According to actual data available in the governmental statistics, database Statistics Poland (<https://bdl.stat.gov.pl/BDL/dane/podgrup/temat>, <https://bdl.stat.gov.pl/bdl/dane/teryt/jednostka>) rural population in Poland reaches approx. 15,300,000, i.e. 39.5% of total population of Poland. Centralized water supply in Poland covers 92.1% of population, living in 84.6% of buildings. More, 96.6% of population in cities, living in 97.4% of buildings is connected to water distribution networks. In comparison, 85.3% of rural population in Poland, occupying 74.6% of buildings, is connected to water supply network. The remaining population use the own, local sources of water supply. The above is reflected in different mean annual drinking water consumption per capita in Polish cities and rural settlements, 35.2 m³ and 30.6 m³, respectively (<https://bdl.stat.gov.pl/BDL/dane/podgrup/temat>, <https://bdl.stat.gov.pl/bdl/dane/teryt/jednostka>). Unfortunately, in relation to drinking water supply, sanitary sewage management in Poland is less developed, especially in rural regions. Approx. 70.8% of total population of Poland, living in 50.6% of buildings, is directly connected to centralized sanitary sewerage. However, in case of availability of sanitation, disproportion between residents of cities and rural regions is wide. The 90.3% of cities residents, living in 74.6% of buildings, have direct access to sanitary sewerage. In contrast, only 41.3% of rural residents in Poland, occupying 36.2% of buildings, have access to centralized sanitary wastewater systems. Additionally, it is worth noted that there are recognized regions in which this number is significantly lower, e.g. Podlaskie Voivodeship with 22.5% population and 18.7% of buildings and Lubelskie Voivodeship with 21.8% residents and 18.0% of households connected to sanitary sewerage, respectively. The rest of rural population of Poland uses 2,162,662 septic tanks, mostly of uncontrolled sealing, 256,811 on-site sanitary wastewater treatment plants and 2,341 sewage delivery stations. It was estimated that at the end of 2018 sanitary sewage form only 42.9% of rural population (6,584,143 people) was delivered by pipelines or septic cars to wastewater treatment plants. The remaining 57.1% (approx. 5,000,000 people) live without the range of organized sanitary wastewater management systems. Thus, the potential environmental pressure (the malfunctioned septic tanks were reported as one of main sources of groundwater pollution in the USA during the last decade of XXth century (Epa 1988; Engin and Demir 2006) and related ecological and social problems, resulting from undeveloped sanitation may seriously affect life standards, agricultural productivity, public health and population growth in rural areas (Hu et al. 2016). According to the official rapport of Polish Inspectorate of Environmental Protection (Wiech et al. 2018), the general groundwater quality in Poland in 2016 covered 77.18% of good groundwater quality including classes I, II and III and 22.82% of poor quality groundwater covering IV and V

classes (Minister and for Maritime Affairs and Inland Waterways 2015, 2019). The precise thresholds values of 55 water quality indicators for each groundwater quality class are presented in Minister and for Maritime Affairs and Inland Waterways (2015) and Minister and for Maritime Affairs and Inland Waterways (2019). Moreover, the first unconfined aquifer groundwater, with free water table, supplied directly by infiltration water, presented higher percentage of poor quality water than confined aquifer groundwater, i.e. 25.76% versus 20.61%, respectively. According to the above-mentioned report (Wiech et al. 2018), the main reason for poor groundwater quality was exceeding the threshold values of good water quality mainly for the following indicators: K (15 mg K/dm³), B (1 mg B/dm³), NO₃ (50 mg NO₃/dm³), NH₄ (1.5 mg NH₄/dm³) and SO₄ (250 mg SO₄/dm³). The insufficient isolation of groundwater from the surface water, disorganized water and sewage management, road and railways as well as the inappropriate waste management were recognized as the local sources of groundwater pollution.

Table 1 presents results of annual operational groundwater monitoring for selected sampling points in rural areas (rural development, arable lands, meadows, vegetation and forests) provided by The Polish Geological Institute–National Research Institute (<https://mjwp.gios.gov.pl/wyniki-badan/wyniki-badan-2020.html>) for period 2010–2020. The percentage of the above-described rural areas in Poland to the total area of the country in period varied from 87.5 in 2010 to 89.7% in 2020 (<https://bdl.stat.gov.pl/BDL/dane/podgrup/temat>). The total number of rural monitoring stations for groundwater quality determination in each studied year from the testing period 2010–2020 was 613, 298, 819, 264, 254, 241, 1,050, 309, 307, 1,067, 307, respectively.

It is visible that for the last decade, the quality of groundwater in the rural areas varied due to the number of applied sampling stations and their location (<https://mjwp.gios.gov.pl/wyniki-badan/wyniki-badan-2020.html>). The share of groundwater good quality and poor quality was observed as 79.4–63.4% and 36.6–20.6%, respectively. It should be also noted, that for years 2016 and 2019, when the maximum number of monitoring sampling stations was applied to the report, the percentage share of poor quality groundwater (classes IV and V) reached the similar level approx. 20%, i.e. 21.3% and 20.6%.

The above-described insufficient sanitary sewage management should be improved by development of new centralized wastewater systems or/and decentralized, on-site wastewater treatment. However, the possible design should be carefully assessed in relation to their sustainability three circles of consideration, including environmental, social and economic (Lewicka et al. 2016; Kundzewicz and Miłaszewski 2011; Harding 2006; Harris et al. 2001).

Table 1 Results of groundwater quality monitoring in rural areas of Poland for period 2010–2020, combined after (<https://mjwp.gios.gov.pl/wyniki-badan/wyniki-badan-2020.html>)

Groundwater quality class (Minister and for Maritime Affairs and Inland Waterways 2015, 2019)	Percentage share of quality class in all rural monitoring locations [%]										
	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020
I—very good quality	0.0	0.0	1.3	0.0	0.8	0.8	3.4	1.9	2.6	2.9	2.6
II—good quality	19.7	7.0	16.2	8.0	26.8	31.1	41.9	30.1	31.6	40.7	30.3
III—satisfactory quality	50.9	56.4	59.8	62.5	44.1	37.3	33.3	38.5	31.6	35.8	39.1
IV—unsatisfactory quality	17.3	26.2	15.5	21.2	19.3	21.6	15.0	19.4	22.8	15.1	20.8
V—bad quality	12.1	10.4	7.1	8.3	9.1	9.1	6.3	10.0	11.4	5.5	7.2
Percentage of rural monitoring stations (https://mjwp.gios.gov.pl/wyniki-badan/wyniki-badan-2020.html)	78.5	81.6	78.8	82.5	78.4	77.5	81.6	78.2	79.9	82.7	78.7
Percentage of agricultural areas in Poland (https://bdl.stat.gov.pl/BDL/dane/podgrup/temat)	87.5	86.8	87.5	88.6	89.3	89.2	89.6	89.1	89.4	89.9	89.7

The safe management and disposal of human excreta over the long term is a main purpose of sustainable sanitation (Chinyama et al. 2012). The additional principles of sustainable sanitary sewage management, including the issues of human health, affordability, environmental sustainability and institutional appropriateness were defined by Mara et al. (2007). So, the sustainable sanitary sewage management designs should be assessed due to their environmental and public health impacts (deterioration of air, water and soil quality by odors and sewage), technology and operation, cost efficiency as well as social and institutional aspects (Peter and Nkambule 2012; Hutton and Chase 2016; Chinyama et al. 2012; Seleman and Bhat 2016).

Taking into consideration the actual state of knowledge, available technologies and good practices of management, it is possible, by e.g. application of pressure or vacuum sewerage systems, to significantly limit anthropopressure exerted by sanitary sewage on the natural environment. However, sustainability of sanitary sewage systems may be affected by several economic and social factors, including non-technical, such as financial affordability allowing to operate and maintain the investment as well as willingness to pay the sewage fees of local populations and governments, possible employment and involvement of local residents (Panfil et al. 2013; Kwangware et al. 2014; Frone and Frone 2015; Elawwad et al. 2015). In many cases, sustainability of large centralized rural sanitary wastewater system using pipelines to collect and transport the sewage and central wastewater treatments plants to utilize them may be dubious, due to high investment and operation and maintenance costs, low financial efficiency, required high sewage fees and resultant low level of public acceptance and social involvement (Lewicka et al. 2016; Kwangware et al. 2014; Frone and Frone 2015). On the other hand, the centralized systems in low-density rural communities may be replaced by decentralized, on-site designs, limiting significantly the costs of sewerage collection and transport and allowing comparable degree of sewage treatment (Massoud et al. 2009).

This paper presents the attempt at practical assessment of multivariate analysis, based on financial, environmental and social indicators of sustainability, in assessment of several proposed systems of sustainable sanitation for the selected rural settlement located in SE part of Poland.

Materials and methods

Object of the study

The presented multivariate analysis of rural sanitary sewage system sustainability was performed for area located in SE part of Poland, Lubelskie voivodship, commune Mełgiew. According to the actual data presented by GUS (<https://ec>.

europa.eu/eurostat/databrowser/view/ENV_WW_CON__custom_1727989/default/table?lang=en, <https://bdl.stat.gov.pl/BDL/dane/podgrup/temat>) the stormwater system in the Mełgiew commune, of total population 9,819 residents, is highly undeveloped in comparison to water supply system. In 2018 the total length of sanitary sewerage in Mełgiew reached value of 2.8 km, in relation to 145.5 km of water supply system. Only 2.0% of commune residents (in 1.6% of households) were directly connected to organized sanitary sewerage. On the other hand, 93.4% of local population, living in 92.5% of households, had access to organized water supply system. Thus, the sanitary wastewater management in Mełgiew commune is based on 1,593 officially registered septic tanks and 324 domestic wastewater treatment plants, mainly septic tanks equipped with drainage systems. Annual volume of reported sanitary wastewater collected from the Mełgiew commune residents in 2018 was 20,129.3 m³, while volume of drinking water delivered by the water supply system at the same time was equal 313,400 m³.

Three variants of sanitary wastewater removal and treatment for selected part of Mełgiew commune had the same scope, they were designed to collect and treat the annual mean volume of 54,221.44 m³ of sanitary wastewater for 219 households and 23 public services buildings, including school, kindergarten, various shops, municipal offices, bars, bank, barber, pharmacy, workshops etc. The following variants allowing to obtain the above-mentioned aim, based on actually available state of knowledge and recent technologies, were proposed: (1) vacuum sewer, (2) pressure sewer, (3) gravity sewer supported with domestic, on-site, wastewater plants. The sanitary wastewater treatment designed in the presented study is in agreement with the current bidding environmental law in Poland (Minister and for Maritime Affairs and Inland Waterways, 2019) and allows discharge of treated sewage directly to surface water i.e. the Mełgiewka River.

Variant I, vacuum sewer with stellated pipelines layout (with three branches) and centrally located vacuum station, delivering wastewater to container wastewater treatment plant, was designed as composing of 80–150 mm PE pipelines of total length 10,136 m (plus 3,630 m of gravity households connections pipes). The depth of pipelines below ground surface was designed in range 1.4–2.0 m. The proposed central vacuum station was equipped with three vacuum pumps R 5 RA 0063/0100 F by BUSCH, with closed oil circuit and nominal volumetric flow rate 63 m³/h, three submersible sewage pumps WQ 50-10-4 by PPH OMNIGENA SJ of engine power 4 kW each, two vertical vacuum tanks ZC6/1600 of 6 m³ volume each, biological air filter BIOWENT BW-400 and regulation, control and measurement fittings. The collected sanitary municipal sewage was treated in container wastewater

treatment plant Bioblok by Biomech, Poland, power consumption 48 kW, of daily capacity equal 300 m³/day and afterwards discharged to the Mełgiewka River.

Variant II covered pressure sewer of total length 10,822 m (plus 3,630 m of gravity households connections pipes) based on 242 domestic and 3 network pump stations. The sewerage network pipelines were designed as PE 100 PN 10 SDR 17 pipes of diameters from range DN 63–DN 110. The depth of pipelines below ground surface was designed in range 1.4–1.8 m. Domestic pumping stations were consisted of Tegra 600 tank equippe Pirania 08 W, Wavin pumps with power consumption 1.41 kW, while network pumping stations used Wilo Drain MTS 40/24, maximal power consumption 1.45 kW and Wilo Rexa UNI V06/11, 1.53 kW, pumps. As in Variant I, the collected sanitary municipal sewage were treated in container wastewater treatment plant Bioblok by Biomech, Poland (power consumption 48 kW and daily capacity 300 m³/day) and discharged to the Mełgiewka River.

The last tested scenario, Variant III, assumed gravity sewer of total length 5,895 m (plus 2,820 m of households connections) collecting sanitary wastewater from 166 households and 22 public services buildings, additionally supported by 54 local, on-site, domestic wastewater treatment plants. The network pipelines were designed as DN 200 SN8 PVC-U pipes, with depth 2.5–6.19 m, equipped in 124 polymer manhole chambers of diameter 400 mm. The self-purification velocity of sewage flow was not achieved inside most pipelines of the network so, the flushing of pipes was required. According to bidding legal regulations in Poland and technical guidelines for gravity sewers construction (Płuciennik and Wilbik 2003), the minimal diameter of sanitary sewer pipeline is 200 mm. In case of rural settlements, where the discharge of sanitary wastewater is minimal, the only possible way to increase the velocity of flow is to increase the slope of pipeline. But such pipeline rather quickly reaches the threshold depth of 5–6 m, below which, the construction is economically unreasonable. Thus, flushing of pipelines with low volumetric flow rate is a standard procedure for gravity sanitary wastewater systems, especially for rural, dispersed buildings development.

The households distant to the designed gravity sewer were equipped in up-to-date and sophisticated domestic BioKem 6EN, Wavin, energy saving (annual power consumption 339 kWh), wastewater treatment plants utilizing sequencing batch reactor (SBR) technology. The sanitary municipal sewage collected by gravity sewer were treated in container wastewater treatment plant Bioblok by Biomech, Poland (daily capacity 250 m³/day) and discharged to the Mełgiewka River.

Study method

The presented comparison of presented variants was performed for three ranges of sustainability: financial, environmental and social. The financial efficiency of proposed rural sanitation variants was assessed basing on three popular dynamic indicators of investment cost efficiency: Dynamic Generation Cost (DGC), Net Present Value (NPV) and Benefit–Cost Rate (BCR) determined using the following formulas (Miłaszewski 2003; Rączka 2002; Berry et al. 2007):

$$DGC = p_{EE} = \frac{\sum_{t=0}^{t=n} \frac{IC_t+EC_t}{(1+i)^t}}{\sum_{t=0}^{t=n} \frac{EE_t}{(1+i)^t}} \tag{1}$$

where IC_t —annual investment costs in given year (Euro), EC_t —annual exploitation (operation and maintenance) costs in given year (Euro), t —year of investment time duration, from 0 to n , where n is the last assessed year of investment activity (year), i —discount rate (%), p_{EE} —price of the ecological unit effect of the investment (Euro m^{-3}), EE_t —annual ecological unit in given year (m^3),

$$NPV = \sum_{t=0}^n \frac{R_t}{(1+i)^t} \tag{2}$$

where R_t —net cash flow for a i year of investment operation (Euro), i —discount rate (%), t —year,

$$BCR = \frac{PV_b}{PV_c} \tag{3}$$

where PV_b —present value of benefits (Euro), PV_c —present value of costs (Euro).

The DGC determines the cost of ecological effect, in this case cubic meter of collected and treated sanitary wastewater, including investment as well as operation and maintenance (O&M) costs, thus the lowest value of DGC the higher costs efficiency of the system. Net Present Value indicator presents sum of discounted cash flows, benefits and costs, reduced by the investment capital costs (Berry et al. 2007). The NPV for a positively assesses design should fit $NPV \geq 0$, in case of negative NPV values the investment brings only financial losses. Finally, Benefit–Cost Rate is a dimensionless relation benefits of investment to its costs (investment and O&M) in studied year. The value of BCR indicator for profitable investment should be $BCR \geq 1$, the BCR value lower than 1.0 show that costs of investment are greater than possible profits.

In order to determine the above mentioned indicators of cost-efficiency (DGC) and benefits-costs indicators (NPV and BCR), the preliminary investment and O&M costs estimations were performed for all tested variants. The determined values of investment and O&M costs for all studied variants of rural sanitary sewerage are presented in Table 2. The assumed investment costs used for all studied indicators covered, according to Sartori (2014),

Table 2 Investment and O&M costs for developed sanitary sewerage variants

Variant	Total investment costs (Euro)	Partial investment costs (Euro)	Total annual operation and maintenance costs (Euro)	Partial annual operation and maintenance costs (Euro)				
I	1,674,130	Design, management and supervision	3,000	33,214	Energy consumption	18,752		
		Sewage vacuum network (pipes and fittings)	520,714					
		Earthworks	528,873					
		Vacuum station	235,714				Services and spare parts	7,320
		Valves chamber	144,047					
		Container wastewater treatment plant	241,782				Employees' salary	7,142
II	1,923,757	Design, management and supervision	3,000	77,580	Energy consumption	27,581		
		Sewage pressure network (pipes and fittings)	519,228					
		Earthworks	583,486				Services and spare parts	42,857
		Domestic and network pumping stations	576,261					
		Container wastewater treatment plant	241,782				Employees' salary	7,142
III	1,708,913	Design, management and supervision	3,000	27,964	Energy consumption	17,522		
		Sewage gravity network (pipes and manholes)	314,335					
		Earthworks	1,030,093				Services and pipes flushing	3,300
		Household Sewage Treatment Plants	160,000					
		Container wastewater treatment plant	201,485				Employees' salary	7,142

fixed assets such as sanitary network and wastewater treatment plant materials, fittings and equipment (pipelines, pump stations, manhole chambers, armature, vacuum station, domestic wastewater treatment plants, drainage and gravel, container wastewater treatment plant etc.), preparatory works, earthworks and drilling costs, manpower work costs, the other technical costs including designing, legal assistance and supervision, management. The estimated O&M costs covered salaries, environmental payments, control, gravity pipelines flushing, servicing, spare parts, resources, repairs and electric power consumption.

The investment cost of individual on-site devices of sewage treatment, including domestic SBR wastewater treatment plant and drainage box installation were assumed as 2,790 Euro. Additional annual O&M costs were determined as 116 Euro per year (233 each third year due to required replacement of worn diffusers). The sewage treated on site would be delivered to soil environment by section of drainage boxes.

Additionally, the following input data were assumed to determination of financial efficiency indicators: investment time duration 30 years (typical for water supply and wastewater removal investments, according to Commission Delegated Regulation (2014), discount rate 6%, mean annual volume of sanitary sewerage 54,221.44 m³/year (Variant III 46,067.84 m³/year), sanitary wastewater fee 1.40 Euro/m³, as the mean value of charge in Lublin Voivodeship. The assumed discount rate is higher than 4% suggested by EU guidelines (Commission Delegated Regulation 2014), however such higher value is in agreement with the mentioned guidelines allowing the increase in assumed discount rate due to the local macroeconomic situation of member state as well as type and sector of investment.

In the performed costs and benefits analyses for users of decentralized domestic wastewater treatment plants, instead of financial incomes gathered by commune on sewerage fees paid by the users, to assess the NPV and BCR, the possible savings resulting from avoiding regular fee payments for sewage discharge were used.

All the presented variants show the same ecological effect, i.e. annual volume of collected and treated sanitary municipal sewerage, so the performed environmental analysis focused on possible intensity and pathways of emissions, while possible employment and social involvement and acceptance were selected as indicators for the determination of social sustainability.

The direct comparison of all studied variants of rural sanitary sewerage for selected part of Mełgiew commune, including financial sustainability, environmental and social aspects the weighed sum model (WSM) was applied (Benzerra et al. 2012; Lewicka et al. 2016):

$$PC_j = \sum_{i=1}^n PI_{ji} w_{ji} \quad (4)$$

where PC_j —performance value of j criterion; n —number of indicators included in the criterion; PI_{ji} —performance value of indicator in the criterion, w_{ji} —weight factor of the indicator in the criterion.

According to Bouabid and Louis (Bouabid and Louis 2015) the selection of weight factors should be determined by the decision makers of the local community. We are aware that assumed values of weight factors for each studied criterion in the weighed sum model may significantly affect the obtained results of PC function, thus the selection of the assumed percentage values of weight factors, presented in Table 3, were based on our previous experience, local conditions and literature studies (Feasibility study POIiŚ Priority axis 2016).

It is visible that cost of ecological effect was selected as the most important indicator in economic analysis, due to a very low possible profitability of organized sanitation in rural catchments and low funds available, not only in conditions of the eastern Poland (Peter and Nkambule 2012; Chinyama et al. 2012; Engin and Demir 2006; Frone and Frone 2015; Massoud et al. 2009; Bouabid and Louis 2015; Widomski et al. 2017, 2012; Suchorab et al. 2015; Chmielewska et al. 2013). Similarly, possible odors emission, as the most popular and onerous side effect of sanitary sewerage management was chosen as the most important indicator in environmental analysis, due to the advanced and up-to-date technology of sewage transport and treatment applied.

Table 3 Assumed percentage weight factors for WSM model for each criterion of assessment

Criterion	Indicator	Weight factor [%]
Financial	DGC	20
	NPV	10
	BCR	10
Environmental	Infiltration	10
	Exfiltration	10
	Odors	20
Social	Employment	10
	Social involvement	10
	Sum	100

Results

Table 4 presets determined indicators of cost-efficiency of three tested variants of organized rural sanitary sewerage. Additionally, the calculated economic indicators for the individual users of on-site sanitary wastewater treatment plants are also presented in Table 4.

It is visible, that among the three tested variants, the lowest cost of ecological effect, i.e. one cubic meter of collected and treated sanitary sewage, reflected by the DGC indicator was obtained for Variant I, vacuum sewer and container wastewater treatment plant. However, the difference between variants I and III (gravity sewer supported by on-site treatment and drainage devices) is rather low and equals 0.19 Euro m⁻³. The similar situation may be observed for two indicators of cost-benefits indicators, NPV and BCR. In all cases determined values of NPV (negative values of benefits and costs sum) and BCR (ratio of benefits to costs) lower than 1.0 shows that accepted variants of organized sanitary sewage management are unprofitable. On the other hand, the less unfavorable values of both applied indicators were observed for variants I and III.

Table 4 contains also determined values of cost efficiency indicators for a single user of on-site domestic devices of sanitary sewage management, i.e. domestic SBD treatment plant supported by drainage chambers allowing infiltration of treated wastewater to soil. It is visible that the on-site decentralized solution presents the lowest cost of environmental effect, even in case of highly sophisticated and rather expensive assumed SBR wastewater treatment plant and section of drainage boxes. Thus, it is possible that the decentralized design of sanitary sewage would gain the social

acceptance due to the limited fees. However, it should be noted that costs and benefits indicators in case of individual user of domestic decentralized sewerage suggest unprofitable investment, i.e. NPV has negative value and BCR has value < 1.0. The performance points required for WSM calculations allowed for cost-efficiency indicators of each proposed variants are presented in Table 5.

The results of environmental assessment of proposed variants presented as allowed WSM performance points are also presented in Table 5. Both Variants I and II of sealed pressure and vacuum pipelines present low risk of infiltration or exfiltration, in comparison to gravity sewer and on-site treatment plants equipped with drainage chambers, thus the highest values of available performance points were ascribed here. The sealed and equipped with biological air filters vacuum sewerage system present the highest ability in limiting odors (the highest possible assessment). The lowest odors limiting capability, i.e. the highest possible odors emissions, are related to unsealed gravity systems supported by on-site treatment plants (the lowest value of performance points).

The variants assuming up-to-date modern technologies of unconventional sanitary sewerage, i.e. Variant I and II, allow limited possibility of new employments required for operation, control and service of container sanitary wastewater treatment plant, central vacuum station, domestic and network pump stations. Contrary, in our opinion Variant III, based on partial application of domestic, on-site sanitary sewage treatment plants and drainage boxes requires the highest social involvement expressed by necessary acceptance of investment, willingness to pay as well as readiness to control and sustain operation of on-site treatment devices, including SBR sanitary wastewater treatment plants and treated sewers drainage system based on draining boxes.

Figure 1 presents the results of weight sum model (WSM) determined for three developed variants of rural centralized sanitary sewerage, based on ascribed values of performance points and weight factors shown in Table 5. As it is visible, Variant I assuming vacuum sewerage, under the local conditions, spatial distribution of households, volume of sanitary wastewater etc. showed the best results, obtaining 2.6 points, while remaining two, 1.9 and 1.7, respectively. Thus, according to the proposed methodology of assessment and assumed weight factors of each performance criterion variant assuming centralized vacuum sanitary sewer connected

Table 4 Determined indicators of financial sustainability for developed variants

Variant	DGC [Euro m ⁻³]	NPV [Euro]	BCR [-]
I	2.70	-1,058,488	0.511
II	3.06	-1,345,249	0.451
III	2.89	-1,025,914	0.478
Individual user	2.34	-2,071	0.590

Table 5 Performance points assigned to each developed variant of sanitary sewerage in three circles of sustainability: financial, environmental and social

Variant	DGC	NPV	BCR	Infiltration	Exfiltration	Odors	Employment	Social involvement
I	3	2	3	3	3	3	2	1
II	1	1	1	3	3	2	3	2
III	2	3	2	1	1	1	1	3

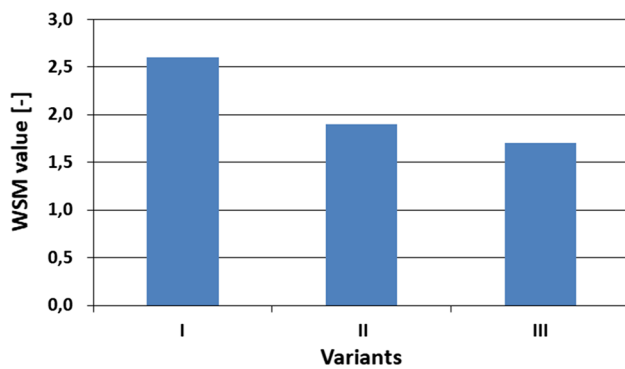


Fig. 1 Determined values of weight sum model for three developed variants of rural centralized sanitary sewerage

to container wastewater treatment plant should be selected as the most appropriate.

Conclusions

The performed multivariate analysis allow to select the most suitable, due to financial, environmental and social criteria of assessment, variant of centralized rural sanitation system. According to the performed analyses, under the local conditions, the most suitable design of organized rural sanitary sewage management consisted of vacuum sewer with central vacuum station connected to local container wastewater treatment plant. The selected most suitable proposal obtained the lowest determined cost of ecological effect, i.e. one cubic meter of collected, transported and treated sanitary sewage as well as the highest assessment of limiting environmental impacts related to infiltration, exfiltration and odors emission.

However, it is worth to underline that none of the proposed designs of centralized sanitary wastewater management was assessed as profitable investment. According to determined negative values of NPV and BCR indicator lower than 1.0, the investment, under the local conditions and assumed value of sewage fee will bring only losses to the investor, i.e. the local government. Increase in local sewage fee may significantly affect the social aspects of sustainable sewage management, highly reducing social acceptance of the investment and willingness to pay of the local population. Thus, outside co-founding of centralized sanitary sewage management in rural settlements is highly expected. On the other hand, financial calculations performed for the single individual user of on-site decentralized wastewater management, based on sophisticated, highly developed and rather costly SBR technology and draining boxes, showed the lowest ecological effect cost and the highest, although insufficient, cost-benefits indicators. Application of less developed and more affordable, but allowing lower degree

of sewage purification, on site devices based on septic tank and drainage field may allow reaching the significantly lower value of unit ecological cost and positive values of costs-benefits indicators, so increase in public acceptance is highly possible. Thus, in our opinion, the decentralized designs of sanitary sewerage management, based on various on-site devices of wastewater treatment and discharge to soil or surface waters environment in many cases may be preferred to the centralized systems by local rural populations, especially in less developed regions.

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Availability of data and material The data were collected and analyzed primarily by us.

Declarations

Conflict of interest The authors declare that they have no conflict of interest.

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