ARCHITECTURE CIVIL ENGINEERING ENVIRONMENT
The Silesian University of Technology No. 3/2017

ECONOMIC ASPECTS OF SUSTAINABLE SANITATION IN RURAL SETTLEMENTS

Marcin K. WIDOMSKI [a], Ewelina ŁADZIAK [b], Grzegorz ŁAGÓD [c*]

[a] Assistant Prof., DSc; Faculty of Environmental Engineering, Nadbystrzycka Street 40B, 20-618, Lublin, Poland
[b] Graduate, MSc; Faculty of Environmental Engineering, Nadbystrzycka Street 40B, 20-618, Lublin, Poland
[c] Assistant Prof., PhD; Faculty of Environmental Engineering, Nadbystrzycka Street 40B, 20-618, Lublin, Poland
*E-mail address: *G.Lagod@pollub.pl*

Received: 5.06.2017; Revised: 27.06.2017; Accepted: 13.07.2017

Abstract
This paper presents discussion of the problem of rural sanitation economic sustainability, affecting the overall investment agreement with the principles of sustainable development. In our opinion, economic aspects of sustainability, understood as affordability and profitability of the investment are crucial because they affect the social acceptance and willingness to pay by the members of rural communities. Additionally, it was proposed to use the well-known decision-making indicators of cost efficiency to assess the economic sustainability of rural sanitation. Four different variants of rural sanitation, centralized and decentralized, utilizing up-to-date state of art and technologies, were developed and tested with use of NPV, BCR and DGC indicators. The performed multivariate analysis using Weighted Sum Model showed the low profitability of centralized systems of rural sanitation, thus their sustainability may be questioned from economic and social point of view.

Streszczenie
Praca niniejsza przedstawia dyskusję problemu ekonomicznej zrównoważoności wiejskiej kanalizacji sanitarnej wpływającej na zgodność inwestycji z zasadami zrównoważonego rozwoju. Naszym zdaniem ekonomiczne aspekty zrównoważoności, rozumiane jako możliwości finansowe społeczności i opłacalność inwestycji, są kluczowe gdyż wpływają bezpośrednio na społeczną akceptację danego rozwiązania oraz wyrażenie chęci ponoszenia jego kosztów przez członków wiejskich społeczności. Dodatkowo, w pracy zaproponowano zastosowanie znanych z procesów decyzyjnych wskaźników efektywności ekonomicznej inwestycji do oceny ekonomicznej zrównoważoności wiejskiej kanalizacji sanitarnej. Dla czterech opracowanych wariantów wiejskiej kanalizacji sanitarnej, zbiorowej i indywidualnej, bazujących na aktualnym stanie wiedzy i wykorzystujące nowoczesne technologie, przeprowadzono analizy ekonomiczne wykorzystujące popularne wskaźniki NPV, BCR i DGC. Przeprowadzone analizy wielowariantowe, oparte o metodę sum ważonych, wykazały niską opłacalność zbiorowej kanalizacji sanitarnej dla wiejskich jednostek osadniczych, wyraźnie stawiająca pod znakiem zapytania zrównoważoność kanalizacji zbiorowej z punktu widzenia ekonomicznych i społecznych wymagań zrównoważonego rozwoju.

Keywords: **Affordability; Economics; Rural sanitation; Sustainable development; Sustainable sanitation.**

1. INTRODUCTION

The concept of sustainable development, defined in the 1980's, assumes development meeting the needs of the present generation without compromising the ability of the future generations to meet their own needs [1, 2]. According to Mihelic et al. [3] sustainable development ensures the usage of natural resources not leading to diminished quality of life due to losses in future economic possibilities and to unfavorable impacts on environment, social conditions and public health. Thus, the concept of sustainable development is usually related to the three platforms of consideration, including environmental, social and economic [4, 5].

The above three main circles of sustainability are being recently supported by moral, technical, legal and political aspects [6].

The main, most serious threats to sustainable development of the recent and future generations are posed by limited access to the basic human services, including clear air, fresh water, food and shelter combined with sanitation (understood as handling of humans' excreta), household energy and personal security [7, 8]. So, the proper water, wastewater and solid wastes management limiting the risk of natural resources pollution and assuring the comfort and safety of population seems to be crucial from the point of sustainability (e.g. [7, 9]), because the water shortage and degradation of the natural environment are recognized as the two most important problems of the modern society [10]. Therefore, the proper and functional sanitation, significantly reduces possibility of water resources and soil environment pollution, appears to be one of the most important issues among the technical aspect of sustainable development [11].

Nowadays, it is assumed that nearly a half of the global population (approx. 40%) lives without access to the sound environmental sanitation, especially in the developing countries (e.g. [8, 12]). Moreover, the coverage of sanitation systems is usually significantly lower in rural areas then in urban ones and huge disparities between access to water supply and sanitation were reported [13, 14].

The mean value of inhabitants connected to organized water supply systems in the European Union reported recently by Eurostat is equal approx. 93%. According to the statistical data the percentage values varies between 100% for the most developed EU member countries to approx. 62%–88% for developing countries, like Romania and Slovakia, respectively. The mean reported by Eurostat percentage of urban population connected to sanitary systems was equal to approx. 82%. The values for particular member countries, according to last reports varied between 99%–100% for the Netherlands and Luxemburg from one the hand and 47%–65% for Romania, Slovenia and Slovakia. Unfortunately, no separate data for rural areas is available.

Currently, due to the increased development of Poland since 2004, described precisely by Widomski et al. [15], according to GUS data, 91.6% of Poland's population has access to water supply and 68.7% has access to wastewater collection and treatment systems. But, the described differences between coverage of water supply and sanitation systems is also visible in Poland. The urban population in Poland, covering 60.3 % of total residents of the country, has in 96.4% access to water supply and in 89.3% to wastewater systems. Meanwhile, the remaining rural population, over 15 270 000 people, 39.7% of total population, has access to water supply in 84.3% and only in 37.3% to centralized sanitation systems. Moreover, in the less developed region of Poland, the Lublin Voivodship, only 20.7% of rural population had in 2015 access to centralized sanitary sewage collection and treatment systems. The historical changes in availability of water supply and sanitation systems for Poland's rural population are presented in Figure 1.

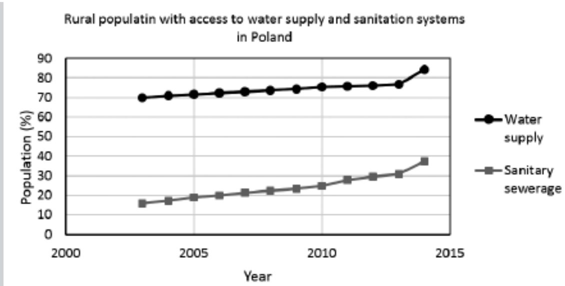

Figure 1.
Historical development of water supply and sanitation in rural regions of Poland (based on GUS data)

The remaining rural population of Poland, with no access to centralized sanitation uses (according to recent GUS data) 149 263 individual rural waste water treatment plants, 2 192 116 septic tanks (of usually uncontrolled quality), 181 295 domestic wastewater treatment plants (usually simple drainage fields) and 2 305 sewage storage stations. Thus, environmental pollution and related ecological and social problems, resultant from the undeveloped sanitation in Poland, are possible because degradation of the natural environment, decrease in available resources and limitation of population growth may result from the poor sanitation (e.g. [12]). For instance, the malfunctioned septic tanks were reported as the third source of groundwater contamination in the USA during the last decade of XX century [16, 17]. Additionally, some part of the existing sanitary sewage systems, even in the developed countries, are being criticized from the sustainable development point of view [2].

The basic definition of sustainable sanitation assumes the safe management and disposal of human excreta over the long term [7]. The wider developed principles of sustainable sanitation, related to all previously mentioned circles of sustainability, also applicable for rural regions, defined by Mara et al. [18] cover the issues of human health, affordability, environmental sustainability and institutional appropriateness. Thus, criteria of sustainable sanitation assessment should cover populations' health and environmental impacts, technology and operation, economy consideration as well as social and institutional aspects, e.g. [14, 19]. From the sustainability point of view, in relation to environmental and social aspects of sustainable development, the sustainable sanitation should secure human and environmental health against threats caused by human excreta presence for a significant time duration [7]. To build the appropriate sanitary infrastructure and to sustain the prolonged durability of sanitation system over the long term, the financial resources and proper management are required. So, the sustainable sanitation systems should be affordable in construction, operation and maintenance even for the local rural communities using their own resources or outside, e.g. governmental, founding.

Taking into account the actual state of art in engineering knowledge and available modern up-to-date technologies (covering e.g. unconventional wastewater systems), from the technological point of view it is possible to ensure the sustainability and durability of centralized or decentralized rural sanitation systems understood as limiting or even totally preventing the anthropogenic pressure on the natural environment caused by sanitary wastewater management. The proper systems management based on knowledge and good practices transfer is also possible. But sustainability is being affected by many factors, including several non-technical. The ability of rural communities to operate and maintain sewage facilities, secure spare parts and technical staff, collect users fees fostering willingness-to-pay are strongly related to sustainability of rural sanitation systems [20, 21].

Nonetheless, in many cases, sustainability of rural systems of sanitary wastewater management and disposal seems to be dubious, due to required high investment costs and low level of costs recovery related to operation and maintenance of sanitation systems. Thus, despite the fact of the successful investments and the appropriate technology, economic sustainability of rural sanitary sewerages may be not sustained over the long period, due to the low, or even minimal, cost efficiency of the design, affecting its financial sustainability [20-23]. Another barrier for development of sustainable rural wastewater system may be posed by the short-term thinking and actions related to all aspects of sustainability, from economics and investments to institutional and technical aspects [24].

As it was reported, the large centralized sanitation systems, using pipelines to collect and transport the sewages and wastewater treatments plants to utilize them, usually present a major investment of high capital costs, extended by operation and maintenance loads, restricting local budgets and requiring proper practices, may appear unsuitable for low-density rural communities and may be substituted by various local decentralized systems, limiting significantly the costs of sewerage collection and transport (e.g. [13]). Among the decentralized applications of wastewater management numerous possibilities are available including, from the simplest septic tanks and drainage fields, through bio-toilets, household wastewater treatment facilities allowing separation of grey and black water etc. [25]. Moreover, decentralized sanitation may reduce the problems related to operation and management of sanitation in low-density population areas, where insignificant amount of wastewater results in limited flow rate and low values of flow velocity increasing the risk of sediments deposition (e.g. [26]).

In our opinion, the sustainability of rural wastewater management systems is strongly related to economic aspects of construction, operation and maintenance of these systems, so the analyses of economy-related circle of sustainability are crucial. Thus, sustainable rural sanitation system should be affordable and cost-effective during the extended time duration of its operation and the choice of technology should be based on the extensive decision-making process.

Usually, assessment of sustainability in water and wastewater management is based on measurable sustainable development indicators (SDIs) used on various levels, from local to institutional and governmental. The applied broad range of SDI usually cover not only the environmental or ecological aspects of sustainability but also technical, social, legal and economic [27, 11]. The exemplary indicators applied to monitoring and reporting of wastewater systems may cover: i) environmental SDIs: emissions to air, water and soil, biodiversity, system stability, amount of collected and treated wastewater; ii) economy SDIs: capital costs, operation and maintenance costs, financial risk, affordability; iii) social and legal SDIs: acceptance, public health, institutional readiness, coordination, social involvement/community participation, community benefits, working conditions; iv) technical SDIs: reliability, durability, resources and energy use and recycling (e.g. [28, 27, 14, 15]). Then, after selection of the sound SDIs, the proper sustainability assessment should be based on the further multicriteria analyses utilizing e.g. weighed sum model and covering all circles of sustainability [28, 27, 9]. In our opinion, as it was stated earlier, the recent knowledge and available technology, utilized in several possible, up-to-date, acceptable in conditions of European, or precisely Polish, designs of rural sanitation systems, allow to achieve the similar, comparable values of environmental, technical, social and legal indicators of sustainability. It may appear however, that the significant investment capital costs and limited long term cost efficiency of rural sanitary sewerage would prevent the economic sustainability of the proposed designs because of their low affordability for the local rural communes. It was already reported, that no matter which proposed type of modern centralized sanitation was tested, the applied multicriteria economy analyses performed to improve financial decision-making process, showed the unprofitability of proposed concepts of sanitation for Polish rural settlements [29, 30, 23, 31]. So, analysis of economic sustainability seems to be crucial in case of decision making and conceptual designing of sustainable rural sanitary wastewater systems.

Thus, among the numerous reported detailed SDIs related to economy of the sustainable sewerage, including e.g. design, capital, operation and maintenance costs, cost-benefits analysis, investment loss risk, adoption and liability coverage, economic add-on value, income and long term management provision and costs [28], in our opinion the economic aspects of rural sanitary sewerage should be considered based on the cost-effective analysis, based on several indicators of profitability allowing to assess its cost efficiency already during the decision making process [32].

This paper presents the attempt of practical assessment of multivariate cost efficient analysis in assessment of several proposed centralized and decentralized systems of sustainable sanitation for the selected rural settlement located in SE part of Poland.

2. MATERIALS AND METHODS

The presented studies were performed for the selected settlements of rural commune located in SE part of Poland, in Lublin Voivodeship, approx. 50 km S from Lublin. The area of our study covered three settlements with 343 farms, of population equal to 1372 people. The terrain for designed rural sanitary wastewater system has a complex morphology, the elevation varies between 216 and 250 m above the sea level, with several hills and deep valleys, significantly constricting design of the conventional sewerage. The 79.8% of study commune's area is covered by arable land. About 100 of small-scale economic enterprises, including 11 public, are located in the studied commune. The actual technical infrastructure of the studied area is undeveloped. Only 30% of all residents of the commune has access to centralized water network (length of network 31.3 km) supplied from one water uptake station ($Q=50$ m^3/h). No centralized sanitary wastewater removal and management system is available in the study area. Actually sanitation is based on septic tanks of uncontrolled and unknown sealing capabilities and truck transport of sewage to the wastewater treatment plant. Additionally, no centralized heating and gas systems are available. There are available on the study area the typical for rural settlements public facilities, besides housing: primary and secondary school, communal office, health center, library, bank, several shops and post office.

Our study was based on four variants of sanitary wastewater handling in the three selected rural settlements, including three various centralized sanitation system using different technologies of sewerage transport and one proposed way of on-site decentralized sanitation.

Variant I assumed centralized sanitary wastewater system based on gravitation transport combined with 2 network and 4 domestic pumping stations allowing the pressure flow in unfavorable locations. The total length of applied gravitation pipelines PVC-U SDR 34, SN8 was equal to 8918 m, while the pressure pipes PE 100 PN 10 SDR 17 had length of 2976 m.

Variant II covered combination of two types of network, conventional (gravity) and unconventional (pressurized transport). The gravity sewer system based on PVC-U SDR 34, SN8 pipelines was designed in two of the studied settlements of the favorable landform. The pressure sewer utilizing PE 100 PN 10 SDR 17 pipelines was designed in the third settlement, where 145 buildings were connected to pressure pipelines by domestic pumping stations, the system was equipped in 3 network pumping stations. The total length of assumed gravity sewers was equal to 5323 m while pressure pipelines had length of 5050 m.

Variant III covered also combined sanitary sewer layout, consisting of conventional and unconventional sanitary sewage systems. For greater part of the three tested settlements the standard gravity sewer PVC-U

SDR 34, SN8 pipelines were designed. But in the less favorable location, the pressure wastewater network was assumed, using PE 100 SDR 17 PN 10 pipelines and equipped in three network and one intermediate pumping stations. The designed length of gravity sewers was equal to 7253 m and pressure pipelines had length of 1704 m.

For all centralized variants the container biological wastewater treatment plant Bioblok, allowing further extension of the network, of capacity equal to 350 m^3 of sewage per day was assumed. The treated sanitary wastewater are going to be discharged to the closest river. The mean assumed daily sanitary sewerage outflow, treated as the ecological effect of the studied sanitation systems, was equal to 143.1 m^3 per day.

Variant IV covered the proposal of decentralized on-site sanitary wastewater management without the pipelines transport system and central wastewater treatment plant. The sanitation in the fourth decentralized variant was based on: i) 355 biological domestic wastewater treatment plants for 1-6 persons, VH8P type, meeting requirements of EN 12566-3:2016-10 [33] combined with the drainage field of 40 m length, assumed for individual stakeholders, including residents and small services (shops, pharmacy, bank, post office etc.); ii) hybrid biological wastewater treatment plant BIO 4000 OB3K based on 4.5 m^3 septic tank and 80 meters of drainage for the local commune office; iii) BIO-HYBRYDA 16000 hybrid, two-tank, on-site biological wastewater treatment device of capacity 16 m^3, equipped with 120 m of drainage field assumed for both schools, primary and secondary, residing in one building.

For all the proposed variants of sustainable sanitary sewer system for studied rural settlements the preliminary cost estimation and operation costs assumption, required for cost efficiency assessment, were performed. The preliminary cost assessment was based on the unit capital investment costs for each element of the designed system, i.e. realization of each pipeline diameter, manholes, pumping stations with the necessary equipment. The assumption of future operation and maintenance cost was based on several sources, including publically available financial reports for the similar objects (covering conservation, repairs, spare parts, maintenance, staff salary etc.), technical documentation of pumping stations, manuals, exploitation guidelines, energy prices etc.

The necessary cost estimation for decentralized variant was based on available investment and operation and maintenance costs presented in the numerous equipment offers. The assumed investment costs covered devices, drainage pipelines and gravel as well as workload, while the operation and maintenance costs were consisting of required electric power consumption costs, removal and transport of solid wastes and/or waste sludge as well as rehabilitation and flushing of drainage field after every 10 years of usage.

The presentation of assumed investment and exploitation costs (recalculated for actual market prices from PLN to Euro) for each applied variant of the study was included in Tab. 1. In case of decentralized variant IV the financial costs were presented as total costs of the whole system and separately, for individual user, commune office and school, respectively. The operation and maintenance cost shown in Tab. 1 express values for standard year as well as for year during which (each 10 years of usage) rehabilitation and flushing of the drainage field were planned.

Table 1.
Assumed investment and operation costs of tested rural sanitation variants

Variant	Investment costs [Euro]	Annual operation and maintenance costs [Euro]
I	1211048	26694/30332
II	122410	33150/36487
III	1205324	29147/32577
IV	Total 692977 Individual user 1907 School 13861 Commune office 2140	25980/92957 72/256 249/947 128/361

The assessment of economic aspects of sustainable sanitation designed for selected rural settlements was based on three popular dynamic indicators of investments profitability, expressing the discounted value of money in time, usually used in multivariate analysis during conceptual stage of design. The applied indicators were Net Present Value (NPV), Benefit-Cost Rate (BCR) and Dynamic Generation Cost (DGC).

Net Present Value indicator collects sum of discounted cash flows, inflows and outflows (benefits and costs) reduced by the investment capital costs [34]. NPV, including variable value of money and presented in monetary units, in our case in Euro, for time duration of investment (n) may be calculated as follows [e.g. 35]:

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

Where: R_t – net cash flow for a year of investment operation (Euro), i – discount rate (%), t – year.

The net cash flow, R_t, covers sum of all financial effects, including investment and exploitation costs, for a given year. The NPV for a positive assess undertaking should have value even to, or greater than zero (NPV ≥ 0).

Benefit-Cost Rate shows dimensionless relation of investments' benefits to their costs in studied year. BCR may be calculated using the below formula:

$$BCR = \frac{PV_b}{PV_c} \tag{2}$$

Where: PV_b – present value of benefits (Euro), PV_c – present value of costs (Euro).

The value of BCR indicator for profitable investment should be BCR ≥ 1.

To allow calculations of net cash flow and present value of benefits required as input data to NPV and BCR the value of sanitary wastewater fee was assumed as 1.38 Euro (1.49 Euro with VAT included). Calculations of the assumed sewerage fee was based on mean prices of fees publicly reported (and available at [36]) by all rural communes of the region of Lublin Voivodeship, with existing centralized sanitation and wastewater plants. The reported fees for rural sanitation systems of the region varied significantly, between 0.86 and 2.84 Euro per 1 cubic meter.

In the performed costs and benefits analyses for decentralized variant IV, 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.

The last remaining proposed economic indicator, the Dynamic Generation Cost (DGC) expresses the value allowing to obtain the discounted revenues equal to discounted costs. Thus, DGC in our case presents the price of ecological effect of the investment, i.e. discounted value, in Euro, of 1 m^3 of collected, transported and treated sanitary sewerage, so this method is rather easily intelligible for designers, decision makers and authorities or representatives of local societies/governments. It presents the costs of investment in the popular, easily understandable values and units and the rule of DGC application is very simple: the lower value of DGC, the more acceptable economically investment is. The DGC may be calculated using the formula [e.g. 37]:

$$DGC = p_{EE} = \frac{\sum_{0}^{t=n} \frac{IC_t - EC_t}{(1+i)^t}}{\sum_{0}^{t=n} \frac{EE_t}{(1+i)^t}} \tag{3}$$

Where: IC_t – investment costs in given year (Euro), EC_t – exploitation 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 – ecological unit in given year (m^3).

For all presented economic sustainability indicators there were assumed the minimal time duration of investment activity equal to 30 years and discount rate on the level of i = 6%.

In our opinion these three simple economic indicators may be successfully applied in sustainability assessment for rural sanitation. They meet the basic requirements of SDIs – they are representative, conceptually sound, understandable, clear and unambiguous [38].

Finally, to directly compare all the proposed conceptual variants of rural sanitation from the point of view of economic sustainability the weighed sum model (WSM) was applied, due to its clarity and simplicity [9, 23]:

$$PC_j = \sum_{i=1}^{n} PI_{ji} w_{ji} \tag{4}$$

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_{ij} – weight factor of the indicator in the criterion.

To include the negative values of obtained NPV indicators to WSM analysis, the inversed positive values of the tested indicator expressed in 1000 of Euro were introduced. Similarly, the inversed value of DGC (expressed as Euro per cubic meter of sewage) representing the inverse proportionality between cost of ecologic effect and profitability of the investment, was assumed. The obtained values of BCR were introduced directly as PIs due to positive correlation between indictors value and increased profitability of the investment.

The wages were adopted as follows: NPV and BCR, had 30% of influence of WSM results as affordability and profitability seem to present significant value for rural communities. The remaining 40% was assigned to cost of the assumed ecological effect represented by DGC analyses.

3. RESULTS AND DISCUSSION

Table 2 presents comparison of obtained economic indicators of investment financial efficiency calculated for all tested variants of sanitary wastewater systems for rural settlements.

Table 2.
Determined cost-efficiency indicators for tested variants of rural sanitation

Variant	NPV [Euro]	BCR [-]	DGC [Euro m^{-3}]
I	-499920	0.693	2.15
II	-605468	0.651	2.29
III	-528944	0.681	2.19
IV	-531	1.000	1.49

It is visible that three different optional concepts of technically developed centralized sanitary sewerage systems, meeting all technological and environmental requirements and based on actual and up-to-date technologies and materials, showed limited financial profitability in conditions of the studied rural settlements. Which in turn, in our opinion, may significantly affect financial sustainability of the system. All of the tested different variants of centralized sanitation showed economic indicators on the similar level, NPV between approx. -50 000 and -60 000 Euro and BCR from range 0.65-0.69. The determined cost of ecological effect measured by DGC indicator was also similar in all cases, in the range of 2.15-2.29 Euro per m^3. Thus, construction and operation of such systems may pose a huge financial burden for local communities and their statutory representatives. On the contrary, the proposed decentralized system, utilizing on-site sanitary sewage collection and treatment seems to be the attractive option. Despite the fact, that this system as whole, presents no profitability (in relation to possible savings due to avoiding sewage fee payments), low but still negative value of NPV and BCR=1.0, but the determined cost of the unit environment effect is significantly lower (1.49 Euro per m^3) than in case of centralized systems. Thus, the financial sustainability of the proposed decentralized system is possible due to social acceptance and willingness to pay, the rural residents may see this proposal as attractive.

Additionally, to fully understand the possible effects of the proposed investments on the economic sustainability it is worth to analyze the separate values of economic sustainability indicators for three main groups of stakeholders in the fourth variant of decentralized rural sanitation. Because, in case of lacking governmental financial support and covering the capital and operation costs by the residents and stakeholders, the profitability of proposed solution may be decisive. The determined indicators of cost-efficiency for separate groups of users in Variant IV are presented in Table 3.

Table 3.
Determined cost-efficiency indicators for separate users of decentralized system

Variant	NPV [Euro]	BCR [-]	DGC [Euro m^{-3}]
Individual user (farm or small service)	92	1.029	1.45
School	2379	1.131	1.32
Commune office	-1566	0.629	2.37

It is also clearly visible that the mere application of decentralized sanitation may not solve the problems related to low profitability and financial attractiveness of the proposed systems, simultaneously affecting the sanitation acceptance by the rural residents or stakeholders. In our tested case, the proposed technical solution, meeting all legal requirements, showed some profitability for two of the tested subjects – individual users and primary and secondary school. In these cases, NPV for the period of 30 years showed positive values of cash inflow, while the obtained BCR also reached values BCR>1.0. The determined cost of ecological effect, covering treatment of 1 cubic meter of sanitary wastewater was also relatively low. However, in case of the local community office the proposed selection of sanitation treatment, related to specific number of users, working hours and volume of the sanitary sewage discharged, showed similar financial indicators as the three tested centralized sanitation. Thus, we may state that even the decentralized sanitation, from the sustainability point of view, should be, in several specific cases, treated as choice sensitive because it does not always automatically guarantee the proper cost efficiency of the investment and the resultant financial sustainability of the system may be questioned.

Figure 2 presents the results of weighed sum model obtained for all four applied variants of centralized and decentralized rural sanitation systems. It is visible, as related to values of economic indicators calculated and presented in Tab. 2, that the fourth, decentralized variant of rural sanitation system showed the highest performance value, reaching 1.28, according to assumed methodology. The three remaining centralized variants obtained significantly lower sum of waged performance points, between 0.40 and 0.43.

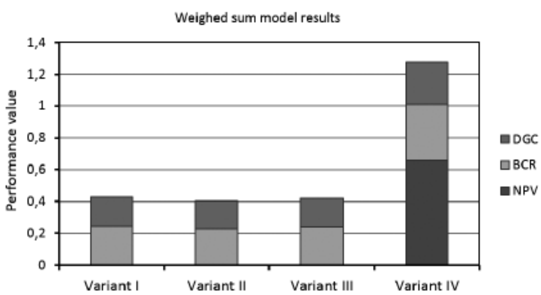

Figure 2.
Results of WSM calculations for tested variants of rural sanitation

The observed significant difference in performance value points obtained for decentralized and centralize variants was a result of significant differences in applied indicators of economic efficiency of the tested variants of investment. As it may be visible in Fig. 2 the differences in calculated performance points were mainly caused by significant disparities in probability of the studied concepts measured by cost-benefits indicators, i.e. NPV and BCR. Thus, in our opinion, difficulties in application of centralized sanitation as a sustainable solution assessed by its economic/financial aspects, even after meeting the technical, technological, ecological, environmental principles of sustainable development, should be underlined.

On the other hand it should be clearly underlined that all the presented analyses were based on the assumption that the designed systems, centralized and decentralized, are operated according to the standards, technical guidelines etc. This may present the significant meaning especially in case of decentralized systems, where the proper technical management, covering regular removal and transport of solid wastes and excessive waste sludge as well as rehabilitation and flushing of drainage field, according to the technical guidelines, is required. Thus, the awareness and responsibility of the individual users of on-site decentralized sanitation devices for their proper operation and regular servicing is necessary. Negligence of the usually simple technical and operational requirements may in relatively short time result in decrease in environmental efficiency or even in failure of the studied devices, leading directly to environmental threats as well as to increase in operational and maintenance costs, decreasing financial efficiency of the investments and possibly limiting the public acceptance.

4. SUMMARY

The performed sustainable economic analyses of four proposed variants of system of rural sanitary sewerage, covering different available centralized and decentralized manners of sewage collection, management and treatment allowed the following conclusions:

1. The applied simple and understandable indicators of cost efficiency assessment, usually used in the decision making process during the design stage of the technical infrastructural investment allowed also assessment of economic sustainability of the proposed concepts.
2. Our studies showed that, despite meeting all legal environmental requirements and utilizing up-to-date technologies, the proposed centralized variants of rural sanitation presented significantly lower profitability and higher costs of the ecologic effect, highly affecting their acceptance by rural population and the resultant economic sustainability.
3. According to the economic aspects of sustainability, measured by values of determined economic profitability indicators and MSW calculations, variant of the decentralized sanitary sewerage was found as the most suitable concept of rural saturation for the discussed settlements.
4. Limited profitability of the tested technically sophisticated centralized rural sanitation systems combined with higher costs of ecological effect, related to significant capital and operation costs may discourage the local communities, thus may limit their acceptance and undermine their sustainability.
5. On the other hand, decentralized sanitation, presenting significantly higher indicators of profitability and lower costs of ecologic effect, may be attractive for rural communities and even single users, as a result increasing economic and legal sustainability of rural sanitary wastewater systems by acceptance, affordability and willing to pay.
6. However, even in case of decentralized on-site systems, the design of treatment devices should be very careful, because sole selection of system does not guarantee the profitability and affordability of investment, which in turn, influence the sustainability.

7. Assuring sustainability of sanitation for rural settlements, in conditions of Poland, especially for centralized systems, may be a hard task, without any outside, governmental of EU community, financial support.

REFERENCES

[1] WCED. (1987). Our Common Future. Oxford: Oxford University Press.

[2] Kärrman E. (2001). Strategies towards sustainable wastewater management. *Urban Water, 3*, 63–72.

[3] Mihelcic J., Crittenden J., Small M., Shonnard D., Hokanson D., Zhang Q., Chen H., Sorby S., James V., Sutherland J. & Schnoor J. (2003). Sustainability science and engineering: the emergence of a new metadiscipline, *Environ. Sci. Technol., 37*(23), 5314–5324.

[4] Harding R. (2006). Ecologically sustainable development: origins, implementation and challenge. *Desalination, 187*, 229–239.

[5] Harris J.M., Wise T.A., Gallagher K.P. & Goodwin N.R. (2001). A Survey of Sustainable Development, Social and Economic Dimensions. Washington, Covelo, London: Island Press.

[6] Pawłowski A. (2009). Rewolucja rozwoju zrównoważonego. *Problemy ekorozwoju/Problems of Sustainable Development, 4*(1), 65–76.

[7] Chinyama A., Chipato P.T. & Mangore E. (2012). Sustainable sanitation systems for low income urban areas – A case of city of Bulawayo, Zimbabwe. *Physics and Chemistry of the Earth*, 50–52, 233–238.

[8] Boubadid A. & Louis G.E. (2015). Capacity factor analysis for evaluating water and sanitation infrastructure choices for developing countries. *Journal of Environmental Management, 161*, 335–343.

[9] Benzerra A., Cherrared M., Chocat B., Cherqui F. & Zekiok T. (2012). Decision support for sustainable urban drainage system management: A case study of Jijel, Algieria. *Journal of Environmental Management, 101*, 46–53.

[10] Mariolakos I. (2007). Water resources management in the framework of sustainable development. *Desalination, 203*, 147–151.

[11] Palme U. & Tillman A.M. (2008). Sustainable development indicators: how are they used in Swedish water utilities. *Journal of Cleaner Production, 16*, 1346–1357.

[12] Hu M., Fan B., Wang H., Qu B. & Zhu S. (2016). Constructing the ecological sanitation: a review on technology and methods. *Journal of Cleaner Production, 125*, 1–21.

[13] Massoud M.A., Tarhii A. & Nasr J.A. (2009). Decentralized approaches to wastewater treatment and management: applicability in developing countries. *Journal of Environmental Management, 90*, 652–659.

[14] Peter G. & Nkambule S.E. (2012). Factors affecting sustainability of rural water schemes in Swaziland. *Physics and Chemistry of the Earth*, 50–52, 196–204.

[15] Widomski M.K., Gleń P., Łagód G. & Jaromin-Gleń K.M. (2015). Sustainable development of one of the poorest province of the European Union: Lublin Voivodeship, Poland – attempt of assessment. *Problemy Ekorozwoju/Problems of Sustainable Development, 10*(2), 137–149.

[16] US EPA. (1988). National Water Quality Inventory: Report to congress. EPA 305(b) Report, Washington DC.

[17] Engin G.O. & Demir I. (2006). Cost analysis of alternative methods for wastewater handling in small communities. *Journal of Environmental Management, 79*, 357–363.

[18] Mara D., Drangert J., Anh N., Tonderski A., Gulyas H. & Tonderski K. (207) Selection of sustainable sanitation arrangements. *Water Policy*, 305–318.

[19] Seleman A. & Bhat M.V. (2016). Multi-criteria assessment of sanitation technologies in rural Tanzania: Implications for program implementation, health and socio economic improvements. T*echnology is Society, 46*, 70–79.

[20] Kwangware J., Mayo A. & Hoko Z. (2014). Sustainability of donor-founded rural water supply and sanitation projects in Mbire district, Zimbabwe. *Physics and Chemistry of the Earth*, 76–78, 134–139.

[21] Frone S. & Frone D.F. (2015). Emerging markets Queries in Finance and Business. Economic risk to a regional water supply and sanitation project in Romania. *Procedia Economics and Finance, 32*, 550–557.

[22] Widomski M.K., Iwanek M., Krukowski I. & Lokwinc I. (2011). Application of dynamic generation cost financial analysis to designing of sanitary sanitation systems in rural settlements. Zeszyty Naukowe Politechniki Rzeszowskiej, *Budownictwo i Inżynieria Środowiska, 4, z. 58*(276), 345–354.

[23] Lewicka A., Widmski M.K. and Łagód G. (2016). Economic analyses in sewage system designing for rural settlements – case study. *Architecture Civil Engineering Environment, 2*(9), 145–152.

[24] Harding R. (2006). Ecologically sustainable development: origins, implementation and challenges. *Desalination, 187*, 229–239.

[25] Nakagawa N., Otaki M., Miura S., Hamasuna H. and Ishizaki K. (2006). Field survey of sustainable sanitation system in a residential house. *Journal of Environmental Sciences, 18*(6), 1088–1093.

[26] Jlilati A., Widomski M.K. & Lagód, G. (2011). Materials, exploitation manners and roughness coefficient in gravitational sanitation conduits. *Ecological Chemistry and Engineering A, 7*(18), 853–863.

[27] Palme U., Lundin M., Tillman A.M. & Molander S. (2005). Sustainable development indicators for wastewater systems – researchers and indicator users in a co-operative case study. Resources, *Conservation and Recycling, 43*(3), 293–311.

[28] Ellis J.B., Deutch J.C., Mouchel J.M., Scholes L. & Revitt M.D. (2004). Multicriteria decision approaches to support sustainable drainage options for the treatment of highway and urban runoff. *Science of the total Environment*, 334–335, 251–260.

[29] Ścibior A., Widomski M.K., Iwanek M. & Musza A. (2012). Metody oceny efektywności ekonomicznej inwestycji w projektowaniu gminnej sieci kanalizacji sanitarnej (Methods of investment economic efficency assessment in designing rural sanitary sewerage). In M.R. Dudzińska, & A. Pawłowski (Eds.), Lublin: Polska Inżynieria Środowiska: prace, tom 1, monografia 99, 289–298.

[30] Suchorab P., Iwanek M. & Głowacka A. (2015). Ocena efektywności ekonomicznej wybranych systemów kanalizacji sanitarnej (Economic efficiency assessment of selected sanitary sewerage systems). *Czasopismo Inżynierii Lądowej, Środowiska i Architektury, XXXII*(62).

[31] Karolińczak B. & Miłaszewski R. (2016). Zastosowanie metod oceny ekonomicznej efektywności obiektów wodociągowych i kanalizacyjnych (Application of methods of water supply and sanitation economic efficiency assessment). *Rocznik Ochrona Środowiska, 18*, 770–782.

[32] Becla A., Czaja S. & Zielińska A. (2012). Analiza kosztów-korzyści w wycenie środowiska naturalnego (Cost-benefits analysis in valuation of natural environment). Warszawa: Difin.

[33] BS EN 12566-3:2016-10 - Small wastewater treatment systems for up to 50 PT. Packaged and/or site assembled domestic wastewater treatment plants.

[34] Berry K., Charnley G., Eberstadt N., Glantz M., Loewen E., Moore T., Opie J., Rutherford F., Seitz F., Sedjo R., Shabman L., Shugard H., Sproull R., Teta M., Trivelpiece A. & Vidaver A. (2007). Environmental Economics Volume 1: The Essentials. Washington: Environmental Literacy Council.

[35] Miłaszewski R. (2003). Ekonomika ochrony wód powierzchniowych (Economics of surface water protection), Białystok: Wydawnictwo Ekonomia i Środowisko.

[36] www.ceny-wody.pl

[37] Rączka J. (2002). Analiza efektywności kosztowej w oparciu o wskaźnik dynamicznego kosztu jednostkowego (Analysis of cost efficiency based on dynamic generation cost indicator), Warszawa: Transform Advice Program.

[38] UNITED NATIONS (2007). Indicators of Sustainable Development: Guidelines and Methodologies. New York: United Nations, Department of Economic and Social Affairs.