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Marcin K. WIDOMSKI
Małgorzata IWANEK
Ireneusz KRUKOWSKI
Iwona LONKWIC
Lublin University of Technology

APPLICATION OF DYNAMIC GENERATION COST FINANCIAL ANALYSIS METHOD TO DESIGNING OF SANITARY SANITATION SYSTEMS IN RURAL SETTLEMENTS

Several problems encountered during rural sanitation designing are caused by: low population density, spatially dispersed development, low volume of discharged sewage, high inequality of outflow and limited financial resources of rural communities. Thus, the financial and technical analysis conducted during concept designing becomes required. Recently, in connection to investments co-financing by EU founds, the method of financial analysis, Dynamic Generation Cost (DGC) has gained the growing popularity. This paper presents the DGC method as a manner of investments financial assessment, its advantages and disadvantages as well as the attempt of its practical application in obtaining the optimal environmental effect.

1. Introduction

Sustainable development as a multidimensional concept presents three major priorities: ecological sustainability, economic development and social justice, both among the subsequential generations and inside one generation [19]. The social justice among subsequential generations means meeting the needs of the present generation without the compromising the ability of future generations to meet their own needs [22]. The above means first of all: production and delivery of drinking water and conduction of treatment of sewage, thus ensuring the basic needs of population as vital needs of a biological society, and limiting the degeneration of environment as securing the societies form the current and future risks [10, 11]. The degradation of environment leading to pollution of available aquifers reflects in limiting the accessibility of water sources for current and future generations. The limited water resources are not only dependant to natural precipitation or surface and ground retention but also to the pollution by products of human domestic, agrarian or industrial activities [6].

Meanwhile, the current data presented by Polish Central Statistical Office concerning the development of centralized sanitation in rural parts of Poland show that only 24.4% of rural communities populations, by the end of 2008, had access to centralized sanitation systems. The total length of sanitation systems constructed in Polish countryside was at the end of 2008 equal to 37 011.1 km and transporting 114 154.4 dam^3 $year^{-1}$ of wastewater generated by population of 3 047 160 people. The sewages were transferred to 1815 municipal wastewater treatment plants of total capacity 4 302 516 RLM. The density of sanitation network in countryside, equal to 18.6 km versus 100km^2, in comparison to water supply network density 74.3 km vs. 100 km^2 may be described as insufficient, however one may note the positive changes since 1990 [2].

The rest of Poland's rural population uses decentralized methods of wastewater transport and treatment covering individual drainage sewage treatment plants, septic tanks of uncontrolled sealing quality and ordinary infiltration tanks. The risk for local surface water, groundwater and soil environment is obvious – e.g. values of well water pollution indicators reported by Jaszczynski et al. (2006) [3]. Thus, sustainable development of rural areas requires sustainable wastewater management [5, 24]. Development of centralized sanitation systems may also improve the economic situation and quality of life of rural populations by increased productivity, development of local trade and services, tourism or industry – the basic Sustainable Development Indicators (SDI) [4, 8, 10, 11].

Yet, development of sanitary wastewater systems in rural settlements encounters many problems resulting from: low population density, spatially dispersed development and, finally, limited financial resources of rural communities. According to the limited financial resources of Polish countryside its modernization should be supported by EU co-financing founds [4]. Then, economic analyses of conceptual designs required by the implementing institutions of EU's grants become necessary. Economic assessment was also described as one of main factors of sustainable water and wastewater management [10, 11].

There are several different methods of financial analyses applied to designing of water and wastewater systems, the most popular groups of methods are [21, 23]: Cost – Effectiveness Analyses (CEA), Cost – Benefits Analysis (CBA) and Multigoal Analysis.

The Dynamic Generation Cost is a method concerning costs and effectiveness of the investments (CEA). It was developed and applied in co-financing of environmental investments by German Bank KfW [9, 15]. It was also used by Länderarbeitsgemeinschaft Wasser (LAWA) founds as a standard tool. Then, the DGC method was adopted in Poland and advised as a main tool of economic effectiveness analyses by Polish Ministry of Regional Development [9]. Nowadays its application to feasibility studies is required by most of Polish implementing institutions of EU founds (e.g. [7, 13, 14, 16, 25]).

The DGC method is based on comparison of total discounted costs (*DCT*) of investment and its discounted revenues (incomes – *DR*). This means that total discounted value of incomes higher, or at least equal, to the discounted costs of the investments is required to ensure profitability of the investment.

$$DR = DTC \tag{1}$$

The total discounted costs of investment may be calculated as follows:

$$DTC = \sum_{t=0}^{t=n} \frac{IC_t + EC_t}{(1+i)^t} \tag{2}$$

where: IC_t – investment cost in given year, EC_t – exploitation cost in given year, t – year of investment operational time from 0 to n, the last year of investment activity, i – discount rate.

The discounted revenues of the investments cover profits obtained by the ecological effect. Its price needs to be assumed as constant during the whole period of analysis:

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

where: p_{EE} – price of ecological effect unit, EE_t – ecological effect in given year.

Thus, the following equation (2) and (3):

$$\sum_{t=0}^{t=n} \frac{IC_t + EC_t}{(1+i)^t} = p_{EE} \sum_{t=0}^{t=n} \frac{EE_t}{(1+i)^t} \tag{4}$$

makes possible the definition of Dynamic Generation Cost (DGC):

$$DGC = p_{EE} = \frac{\sum_{t=0}^{t=n} \frac{IC_t + EC_t}{(1+i)^t}}{\sum_{t=0}^{t=n} \frac{EE_t}{(1+i)^t}} \tag{5}$$

The above formula (5) is true when the time of analysis is equal to the time of investment operation. In the other case, the sum of discounted costs should be decreased or increased by the discounted remaining value.

The DGC is thus equal to the price allowing to obtain the discounted revenues equal to the discounted costs so DGC reflects the technical cost of ecological effect unit. In case of our studies covering sewerage networks the considered ecologic effect may be applied as volume of transported/treated sewage, thus the unit of DGC will be PLN m^{-3}. Implementation of DGC to investment assessment is rather easy. The rule is simple: the investment is more acceptable economically when we get the lower value of DGC [7, 13, 14, 16, 25].

Calculation of DGC requires the following data: investment and exploitation costs, ecological effect (e.g. volume of supplied drinking water, transported wastewater, deposited municipal solid wastes), investment's time horizon and discount rate.

The cost analysis based on DGC method covers the whole period of investment operation so application of the different values of investment and exploitation costs as well as ecological effect and generated incomes, in following years are possible. The method is based on discounted costs so, the changes in "money value" is reflected in the analysis. Thus, DGC method is easily intelligible for designers, decision makers and authorities or representatives of local societies because it shows the technical costs of investments presented in the popular, easily understandable units which may be applied to decision making during the conceptual stage of technical designing.

But one need to remember that DGC does not reflect the actual price of service (water supply, sewage treatment, solid waste disposal) and should not be used in assessment of investments' productivity. Moreover DGC method does not reflect many technical and technological characteristics of investments assuring the required ecological effect, e.g. the hydraulic conditions of transported media flow and the reliability characteristics of designed systems.

This paper presents the attempt of practical application of DGC method to designing process of sanitary system for rural settlement in Poland. Four variants of possible technical solutions of sanitation development resulting in achieving the same ecological effect were considered.

2. Materials and methods

Object description

The rural settlement Tereszyn, Konopnica, Lubelskie voivodeship, deprived of any type of sanitation system was selected as a subject of our study. Tereszyn is located at Równina Bełżycka (Bełżyce Plain). The ground elevation along the trace of studied sanitation variants was between 223,00 m and 236,00 m above sea level. Groundwater surface was observed between 5,1 m and 7,5 m below the ground level and freezing depth was assumed as 1.0 m (3rd climatic zone)

[12]. Soil cover in the region is consisting of sandy clay and sand of different composition, thus appropriate to engineering investments.

Our study covered 48 households and one stone – cutting facility. The total population of rural settlement considered in our study was equal to 200 people.

Designing and economic analysis assumptions

The following assumptions were adopted in our study [17]: population: 200; number of employees in stone facility: 20; unit volume of household sanitary sewage: 160 dm^3 day^{-1} $person^{-1}$; unit volume of stone-cutting facility sanitary sewage: 60 dm^3 day^{-1} $person^{-1}$; daily inequality factor N_d – 2.0; and hourly inequality factor N_h – 4.0.

The maximum daily and hourly volume of sanitary sewage generated in the region covered by our project was equal to, respectively, 64 m^3 day^{-1} and 3,69 dm^3 s^{-1} (including sewage generated in services facility and accidental water).

Four different exemplary variants of centralized and decentralized sanitary wastewater system in Tereszyn were developed (see also Tab. 1):

- variant I – gravitational sanitation system equipped with pumping station transporting wastewater to existing sanitation system and wastewater treatment plant in Marynin capable enough to treat sewages inflowing through new system of sanitation,
- variant II – mixed, gravitational and pressured sanitary wastewater system, equipped with 5 household pumping stations and two stations directing sewage to existing sanitation system and wastewater treatment plant in Marynin,
- variant III – mixed, gravitational and pressured sanitary wastewater system, equipped with 5 household and one network pumping stations, additionally supported by local container WWTP of capacity RLM = 250 – treated wastewater are to be discharged to soil through infiltration drainage,
- variant IV – 48 local infiltrational wastewater treatment plants based on 2 m^3 volume of septic reactor-tank and 48 m of drainage pipes length, supplied by household pumping systems required by spatial layout of the settlement (distances of drainage to buildings, wells, septic tankst etc.) under Polish standards [18, 20]; according to the limited time of operation and domestic WWTPs sellers' suggestions, drainage pipelines and gravel bed renovation were assumed after each 10 years (the lifespan of all variants needs to be the same to successful application of DGC method), sanitary waste management in stone-cutting facility was obtained by a single septic tank.

Local terrain configuration excluded traditional, conventional system of sanitary wastewater network, based solely on gravitational movement of transported media. In development of all considered variants the actual and up-to-date materials and technological solutions were adopted – polymer materials were selected for designed sanitary sewage and drainage pipes, revision and junction chambers, septic tanks etc.; automatic control of any pumping devices etc. The precise details of assumed conceptual variants of sanitation system in Tereszyn are presented in Tab. 1.

Table 1. Characteristics of studied variants of rural sanitation

Variant	**Gravitational pipes**	**Pressure pipes**	**Network pumping stations**	**Household pumping stations**	**Capacity of WWTPs**	**Drainage pipes**
I	2100 m PVC-U DN200 and DN250	220 m PE100 DN125	1	0	0	0
II	1800 m PVC-U DN200 and DN250	550 m PE100 DN40 and DN50	2	5	0	0
III	1800 m PVC-U DN200 and DN250	330 m PE100 DN40 and DN50	2	5	1 RLM = 250	2200 m
IV	849 m PVC-U DN110 and DN160	2666 m PE100 DN 50	–	48	48 RLM=192	2304 m

The economic factors, necessary to conduct the DGC analyses for all studied variants covered: investments costs (materials, equipments and manpower – investments in all variants are assumed to be constructed during the same duration of time, except required regular renovation of wastewater drainage pipes in Variant IV), yearly exploitation costs (electric energy, renovation services, technical management and control, screenings removal and environmental fee), operational period of the investment and discount rate. The economic data concerning exploitation costs were estimated according to public financial information published by rural communities of Lubelskie voivodeship. The assumed data applied to our studies are presented in Tab. 2.

Table 2. Assumed values for economic calculations

Economic factor	**Variant I**	**Variant II**	**Variant III**	**Variant IV**
Total investment costs [PLN]	936420	952114	1580421	2708546
Average exploitation cost per year [PLN]	22821	28183	48483	25178
Lifespan of the investment [yr]	30			
Discount rate [%]	5			
Ecological effect [$m^3 \cdot yr^{-1}$]	68 640			

3. Results and discussion

The results of calculations, presented in Tab. 3 show that, according to recent guidelines (e.g. [7, 13, 14, 16, 25]), Variant I should be selected because of its lowest value of DGC factor.

Table 3. Results of DGC calculation for each studied variant

Variant	**DGC [PLN m^{-3}]**
I	18,42
II	20,11
III	28,16
IV	34,44

The strict application of the DGC lowest value may in some cases support the simplest systems of wastewater management in rural conditions. The lowest value of DGC in our studies was observed for the simplest gravitational sanitation system equipped in one sewage pumping station. However, we also observed the high DGC value for the decentralized system based on individual treatment tanks and sewage drainage. In this case, the achieved level of DGC value depends on increased investment costs caused by the necessity to sustain the investment in operation – the renovation of drainage pipes and gravel bed were required after at least each 10 years and energy costs of pumping sewage [1].

It's visible that the more sophisticated proposed system is, the highest investment and operation costs are (resulting from materials, equipment, workload and power consumption). Thus, the obtained value of DGC for the constant value of ecological effect and life span of the investment, in comparison to conventional sanitation systems or local decentralized investments, according to actual EU co-financing standards and requirements would not favor unconventional sanitation system or decentralized location of WWTPs. DGC based analyses, unsupported by technical and reliability studies, prefer the cheapest solutions giving the same ecological effect regardless of technologies applied and reliability assured. One may easily state, basing on our studies, that the gravitational system will always obtain lower value of DGC than unconventional designs, modern, sophisticated systems offering higher flexibility, clear and proven resilience to daily and hourly variations of generated sewage inflow and strongly better hydraulic conditions of sewage flow.

4. Summary

The Dynamic Generation Cost was presented in our study. According to strict requirements of feasibility studies composition for EU's FP7 co-financing of investments in Poland, DGC method is being more and more popular. Its main advantages are reflecting the whole period of investment operation life-span, investment and exploitation costs for the whole period of analysis and presenting the easily understandable discounted cost of investment's ecological effect. These make it easily adopted for governmental and non-governmental decision makers, representatives and authorities even at the lowest level (i.e. rural community). On the other side, this method shows some serious disadvantages – the method considers only the cost efficiency of the investments except for any other important technical feature applied to achieve the given ecological effect. For instance our case study showed that the hydraulic conditions of sewage flow, self-purification velocity and system reliability are not considered in case of sanitary sanitation systems. The DCG method applied into the feasibility studies of investments co-financed by EU grants may, in certain situations [7, 13, 14, 16, 25], favors the simplest and cheapest solutions without any reference to their technological and technical abilities and characteristics. In our opinion application of DGC method to financial analyses in designing process and feasibility studies of co-financing applications should be included into multi variant analyses covering also, at least, reliability and technical studies. Otherwise, the implementation of technical progress and advanced technical solutions may be difficult as not supported by the decisional process.

Bibliography

1. Dawidowicz J., Szeroki A.: Poradnik Kanalizacja ciśnieniowa w systemie Wilo-Emu, 2008.
2. Górz B., Kurek W.: Variations in technical infrastructure and private economic activity in the rural areas of Southern Poland, GeoJournal, vol. 46, 1999, s. 231-242.
3. Jaszczyński J., Sapek A., Chrzanowski S.: Wskaźniki chemiczne wody do picia z ujęć własnych w gospodarstwach wiejskich w otulinie Biebrzańskiego Parku Narodowego, Woda – Środowisko – Obszary Wiejskie, vol. 18, nr 6, z. 2, 2006, s. 129-142.
4. Kärrman E.: Strategies towards sustainable wastewater management, Urban Water, vol. 3, 2001, s. 63-72.
5. Kłodziński M.: Czynniki i bariery dywersyfikacji gospodarczej obszarów wiejskich w Polsce, Woda – Środowisko – Obszary Wiejskie, vol. 12, nr 4, z. 2b, 2004, s. 21-36.
6. Mariolakos I.: Water resources management in the framework of sustainable development, Desalination, vol. 213, 2007, s. 147-151.
7. Metodologia opracowania studium wykonalności – analiza ekonomiczno-finansowa na potrzeby Regionalnego Programu Operacyjnego Województwa Dolnoślą-

skiego 2007-2013, Departament Regionalnego Programu Operacyjnego, Urząd Marszałkowski Województwa Dolnośląskiego, Wrocław 2008.
8. Munitlak Ivanovic O.D., Golusin M.T., Dodic S.N., Dodic J.M.: Perspectives of sustainable development in countries of Southeastern Europe, Renewable and Sustainable Energy Reviews, vol. 13, 2009, s. 2079-2087.
9. Narodowe Strategiczne Ramy Odniesienia 2007-2013. Wytyczne w zakresie wybranych zagadnień związanych z przygotowaniem projektów inwestycyjnych, w tym projektów generujących dochód, Minister Rozwoju Regionalnego, MRR/H/14(1)09/2007.
10. Palme U., Lundin M., Tillman A.M., Molander S.: Sustainable development indicators for wastewater systems – researchers and indicator users in a co-operative case study, Resources, Conservation and Recycling, vol. 43, 2005, s. 293-311.
11. Palme U., Tillman A.M.: Sustainable development indicators: how are they used in Swedish water utilities, Journal of Cleaner Production, vol. 16, 2008, s. 1346-1357.
12. PN-EN 1997-1:2008: Projektowanie geotechniczne. Część 1: Zasady ogólne.
13. Program Regionalny Narodowa Strategia Spójności. Wytyczne do sporządzenia Studium Wykonalności dla projektów realizowanych w ramach Wielkopolskiego Regionalnego Programu Operacyjnego na lata 2007-2013: Priorytet III Środowisko przyrodnicze – Działanie, Gospodarka wodno-ściekowa, Zarząd Województwa Wielkopolskiego, Poznań 2008.
14. Program Regionalny Narodowa Strategia Spójności. Wytyczne. Projekty dotyczące infrastruktury wodno-ściekowej, Urząd Marszałkowski Województwa Podkarpackiego, Rzeszów 2008.
15. Rączka J.: Analiza efektywności kosztowej w oparciu o wskaźnik dynamicznego kosztu jednostkowego. Transform advice programme – Investment in environmental infrastructure in Poland, Warszawa 2002.
16. Regionalny Program Operacyjny Województwa Lubelskiego 2007-2013. Wytyczne tematyczne do studiów wykonalności dla projektów w ramach RPO województwa lubelskiego w zakresie ochrony przyrody, Urząd Marszałkowski Województwa Lubelskiego w Lublinie, Departament Strategii i Rozwoju Regionalnego, Lublin 2007.
17. Rozporządzenie Ministra Infrastruktury z dnia 14 stycznia 2002 r. w sprawie określenia przeciętnych norm zużycia wody, (Dz.U. Nr 72, poz. 747 z dnia 31 stycznia 2002 r.).
18. Rozporządzenie Ministra Infrastruktury z dnia 12 kwietnia 2002 r. w sprawie warunków technicznych, jakim powinny odpowiadać budynki i ich usytuowanie (Dz.U. Nr 75, poz. 690 z dnia 15 czerwca 2002 r.).
19. Sarzała D.: Sustainable development jako alternatywa koncepcyjna rozwoju cywilizacyjnego, [w:] Filozoficzne i społeczne uwarunkowania zrównoważonego rozwoju, A. Pawłowski (ed.), Monografie Komitetu Inżynierii Środowiska PAN, vol. 16, 2003, s. 83-98.
20. Ustawa z dnia 7 lipca 1994 Prawo budowlane (tekst jednolity), (Dz.U. z 2003 r. Nr 207, poz. 2016 z późn. zm.).
21. Ward F.A.: Economics in integrated water management, Environmental Modelling & Software, vol. 24, 2009, s. 948-958.
22. WCED our common future, World Commission of Environment and Development Oxford University Press, Oxford 1987.

23. Weimer D., Vinning A.: Policy analysis: concepts and practice, Prentice Hall, Englewood Cliffs 1989.
24. Wierzbicki K., Krajweski K.: Kierunki rozwoju infrastruktury technicznej obszarów wiejskich w Polsce, Woda – Środowisko – Obszary Wiejskie, vol. 12, nr 4, z. 2b, 2004, s. 9-20.
25. Wytyczne do przygotowania inwestycji w zakresie środowiska współfinansowanych przez Fundusz Spójności i Europejski Fundusz Rozwoju Regionalnego w latach 2007-2013, Ministerstwo Rozwoju Regionalnego, Warszawa 2009.

ZASTOSOWANIE METODY ANALIZY FINANSOWEJ DYNAMIC GENERATION COST W PROJEKTOWANIU KANALIZACJI SANITARNEJ DLA WIEJSKICH JEDNOSTEK OSADNICZYCH

S t r e s z c z e n i e

Podstawowe problemy pojawiające się na etapie projektowania kanalizacji sanitarnej w wiejskich jednostkach osadniczych związane są z małą gęstością zaludnienia, dużymi odległościami pomiędzy obsługiwanymi obiektami, niewielką ilością odprowadzanych ścieków i dużą nierównomiernością ich dopływu oraz ograniczonymi środkami finansowymi gmin będących inwestorami. Dlatego też uzasadnione jest przeprowadzenie analizy techniczno-ekonomicznej poszczególnych rozwiązań na etapie projektowania. Obecnie, w związku ze współfinansowaniem inwestycji przez UE, coraz częstsze zastosowanie w przeprowadzaniu tego typu analiz ma metoda Dynamic Generation Cost (DGC). W niniejszej pracy przedstawiono metodę DGC jako sposób finansowego oszacowania kosztów inwestycji, zaprezentowano wady i zalety tej metody oraz podjęto próbę praktycznego jej wykorzystania w projektowaniu kanalizacji sanitarnej w wiejskiej jednostce osadniczej w celu uzyskania optymalnego pod względem środowiskowym rozwiązania.

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