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CONVENTIONAL *vs.* VACUUM SEWERAGE SYSTEM IN RURAL AREAS - AN ECONOMIC AND ENVIRONMENTAL APPROACH

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Abstract

The aim of this study is to investigate new perspectives with respect to the greening of the wastewater collection, subsequently assessing the value of the vacuum over the conventional wastewater collecting system in rural areas. The research was framed from the perspective of policy makers to aid in making decisions about benefits on long term horizon in implementing eco-innovative infrastructure technologies. The study postulates the hypothesis that the vacuum sewerage system is technologically, environmentally, economically and socially more sustainable in comparison with the classical solutions for the wastewater collection. Economics provides a powerful tool for helping solve environmental problems. A comparative analysis between two variants of the same project considering vacuum and conventional sewerage technologies was performed, by using as input for current research the Cost-Benefit Analysis. Tracing costs and benefits sheds new light on the innovative technologies for wastewater collection. The analysis of the case study provides evidence to support the hypothesis that the vacuum technology can succeed in overcoming the environmental crises by internalizing the externalities, having the capacity to improve environmental factors, reduce energy and maintenance costs. Besides, this research shows the need to provide a framework for further analysis that is essential for the promotion of eco-innovation and reflexive institutions.

Key words: cost-benefit analysis, eco-innovation, rural area, vacuum sewerage system, wastewater collection

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1. Introduction

In spite of the literature on eco-innovation and its economic analysis there are some unexplored areas such as wastewater collection and the environmental impact of eco-innovation (Abernathy and Utterback 1978; Beise 2001; Beise and Rennings 2004; Damanpour and Wischnevsky 2006; Duncan 1996; Frondel, Horbach, and Rennings 2007; Gouldson and Murphy 2000; Hegger et al. 2010; Horbach 2008; Horbach 2012; Huber 2008a, 2008b; Johnstone 2005). Eco-innovation brings about increased eco-efficiency and improved metabolic consistency, in line with reducing energy demand, etc. (Huber 2008a), therefore internalizing externalities. Some authors insist on the positive role played by costs reductions as a motivation of clean technologies (Foxon and Pearson 2008).

Collection and wastewater treatment have a huge impact on the environment and economy, considering that each community needs access to basic utilities in sanitation sector. In this respect increased attention has to be paid to the adoption of eco-innovation for the reduction of the environmental impact correlated with the reduction of the construction, functioning and maintenance costs.

There are three major challenges the local councils in rural areas are facing nowadays: obsolete or lack of sewerage systems, limited access to innovative technologies due to reduced transfer of know-how and scarce financial resources for wastewater infrastructure. Therefore, the investing authorities, instead of investing in eco-innovative technologies, are being forced to invest in less efficient and sustainable technologies, focusing on

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short-term social benefits related to the number of connections.

In the context of social and economic evolution of rural space correlated with infrastructure development, an important place is represented by the preoccupation for the management of financial funds. They must meet the requirements of satisfying the individual and collective needs, of public and private entities' functioning in accordance with the economic and social objectives, consistent with the principles of sustainable development (Bulgariu et al. 2013).

The relation between the environment and economic development has always been at odds, thus, the development of vacuum sewerage as an eco-innovative system or wastewater pumping stations with solids separation is seen as a window of opportunity for overcoming the environmental crisis. Even if the need and urgency of sewerage are recognized, adequate resources are not always available to provide sewerage immediately in all populated areas, therefore selecting the best option is of paramount importance. Sewerage projects should be prioritized by weighting costs and benefits for each alternative (Rashid and Hayes 2011).

As environmental quality is acknowledged as a social need, in the process of decision making both direct regulation instruments and market principles are being used as a decision support tool in selecting the best alternatives in wastewater planning. Economics provides a powerful tool for helping solve environmental problems.

The European Union Water Framework Directive (WFD) and Urban Waste Water Directive (WWD) pay considerable attention to economic analysis to water planning. In this respect, WFD requires that cost-benefit analyses (CBA) are made with the aim of identifying cases in which the adoption of measures to achieve a good ecological status for water bodies implies disproportionate costs (Molinos-Senate, Hernandez-Sancho, and Sala-Garrido 2010). Cost- benefit analysis has been used as an evaluation tool in private and public sectors projects (Rashid and Hayes 2011; Molinos-Senate, Hernandez-Sancho, and Sala-Garrido 2010; Pickin 2008; Van der Bruggen et al. 2009; Godfrey, Labhasetwar, and Wate 2009; Papa, Casper, and Moore 2013), whenever its application in sewerage sector is limited.

The aim of this paper is twofold. First, a comparative financial cost-benefit analysis is carried out in order to quantify the range of costs and benefits associated with investment in two variants of modern wastewater collecting systems. The paper aims to obtain useful information of the financial feasibility of the construction, operation and maintenance of alternative wastewater collection systems.

The main proxy for the two variants of projects is the energy consumption. Secondly, a new method is developed to quantify environmental benefits, associated in economic terms with avoiding the discharge of pollutants into the environment. In this regard, the main criterion of comparison is the security of the system in what concerns the leakage of wastewater into soil and groundwater. In this regard, the research seeks to highlight areas for improving the comprehensiveness and adequacy of assessing the externalities in the frame of CBAs of infrastructure development projects.

The research postulates the hypothesis that on long term the vacuum sewerage system is technologically, environmentally, economically and socially more sustainable and feasible in comparison with the classical solutions for the wastewater collection pumping stations with solids separation. The analysis focuses on a simulation of a particular territorial context, the case of flat land rural area in Romania. It is expected that the results of the study will provide the decision makers with recommendations in making decisions about benefits on long term horizon in implementing eco-innovative infrastructure technologies in what concerns the economic viability and sustainability.

2. Material and methods

2.1. Methodology

This section presents the analytical model of data analysis and the arguments behind the hypothesis that is tested in this work. Due to the exploratory character of the study, a qualitative and quantitative research was used. A desk study was conducted in order to make an inventory of the main innovations in wastewater collection technologies.

The cost-benefit analysis is a tool for assessing the efficiency of alternative public choices within set budgetary limitations. The present study demonstrates how to tackle the decision making questions regarding the disposal of wastewater from an economic stand-point. It compares two different wastewater collecting systems by computing in Microsoft Excel the costs and benefits applied to a specific case study in Romania. A financial cost-benefit analysis was carried out to analyze the effect of implementing the vacuum sewerage system vs. classical solution alternative with pumping stations with solid separation for wastewater collection. The question in place is whether it is financially and also environmentally beneficial to construct a vacuum sewerage system in comparison with the classical solution.

2.1.1. Stages of CBA

In any CBA, several stages must be conducted: defining the project, identifying impacts which are economically relevant (estimating costs and benefits), physically quantifying impacts, calculating a monetary valuation, discounting, weighting and sensitivity analysis (Hanley and Splash 2003).

The economic evaluation compared the value of all quantifiable benefits gained due to a specific project variant with the costs of implementing the same intervention.

2.1.1.1. Estimated costs and benefits

Data on costs and benefits came from primary data collected from feasibility studies, from other published studies, catalogues of products, statistics, and from expert opinion. The analysis considers resources costs and benefits associated with two project alternatives. The study makes the proviso that the analysis does not attempt to monetize all costs and benefits, focusing on the competitive advantages of both sewerage collecting technologies.

All different economic, social and environmental costs for the target group of the project were taken into account including local inhabitants, socio-economic activities, as well as impact on employment, health, tourism, and environment. The study reflects mainly on two categories of costs. Information on the first category of costs that concerns the wastewater collection and treatment is the most precise. Information on the second category regarding prevention and environmental management costs are more difficult to determine, because it can overlap with the first category. Estimated costs (financial outputs) include those of investment/capital costs (planning, supervision, hardware, machinery and equipment, civil works), recurrent or operating costs (energy consumption, materials, services, technical and administrative personnel, maintenance costs).

Benefits include financial benefits (financial inflows) that comprise the taxes applied for wastewater connection and revenue earned from sewer bill, quantifiable socio-economic benefits associated with direct benefits of avoiding water-borne infections, benefits from collateral activities as new economic activities that will generate employment, benefits from tourism development, benefits from the increased value of properties and land etc. Regarding the benefits, the environmental ones are more difficult to quantify from a financial point of view. All costs and benefits were evaluated by converting them into financial impacts.

Cost-benefit analysis starts from the premise that a project is feasible only when the aggregated benefits exceed all costs. Whenever, it is well known that wastewater collection and treatment it is a feasible process mainly from the point of view of positive environmental externalities as we deal with proving a public good. We pose that the most efficient wastewater collection process is the one that minimizes input consumption (energy) and undesirable output generation (smell and pollution generation, leakage) while minimizing the operating and maintenance costs.

2.1.1.2. Financial quantification of environmental externalities

CBA has few recognized limitations as concerns the valuation of environmental and social issues. Wastewater collection and treatment has important environmental and public health benefits that are defined in economic terms as positive externalities. Externalities as a whole are made up of positive and negative impacts derived from the project alternatives.

For small scale projects, these positive externalities are not quantified according to the Guide for cost-benefit analysis of investment projects because they do not have a market value. In order to capture the total economic value of environmental risks associated with each project variant, the monetary valuation of positive externalities is important in order to justify the economic feasibility of the projects in wastewater collection.

Environmental benefits result from avoiding external environmental effects. They reflect the value of environmental damage avoided derived from wastewater collection. In this regard, it was considered the probability of sewer seepage occurrence in both alternatives.

In financial terms, it was assessed the value of the externalities generated by the wastewater seepage into the soil and groundwater as the aggregated amount of pollutant emission discharged into environment without treatment with a direct effect on groundwater. The method proposed consists in quantifying the cost of the damage avoided as a result of each project variant implementation. The difference between the parameters of NTPA 002 (Romanian Government 2005b) (Normative concerning the conditions for wastewater discharge into urban collecting systems or directly into waste water treatment plants) and NTPA 001 (Romanian Government 2005a) (Normative establishing the pollutants limits for urban and industrial waste water when discharged into natural receivers) and the probability of leakage occurrence was used in calculating the amount of each individual pollutant discharged into the environment that makes the difference between the two design variants of the sewerage system. Both regulations transpose the requirement of the Council Directive 91/271/EEC (1991) concerning the urban waste water treatment.

2.1.1.3. Time horizon and residual value

The time horizon for wastewater collection and treatment projects is of 30 years and represent the maximum number of years for which forecasts are provided. The time horizon included the time for design, construction, start-up and operation of the sewerage system and wastewater treatment plant. The residual value of the investment is a liquidation value calculated by considering the residual market value of fixed capital (assets and liabilities) at the end of considered time horizon. The residual value (set at 39.58%) is expressed at constant prices and not distorted, and it is allocated in the last year of the time horizon of the investment project.

2.1.1.4. Decision rule and discounting

The international methodology of financial analysis of the project on a cash flow forecast basis suggests conducting the financial analysis and the calculation of the investment returns using the total cost of the investment. In order to evaluate the financial attractiveness of a project alternative against the other, the Net Present Value (NPV) and Internal Rate of Return (IRR) techniques were used. Both techniques emphasize the importance of the concept of the time value of money.

The discount rate recommended by the European Union and applied within the two projects is 5%, and it is used to discount the financial flows to the present and calculate the NPV. It represents the rate at which future values are discounted to present, and it is, in fact, the opportunity cost of the capital. In order to calculate the NPV it was necessary to use a discounted cash flow, including the annual inflows and outflows over the 30 year time horizon, considered the time of investment.

The IRR describes by how much the cash inflows exceed the cash outflows on an annualized percentage basis, taking into account the timing of those cash flows (Parissis et al. 2011). The IRR of the investment is calculated considering the total investment costs as an outflow, together with the operating costs and revenues as an inflow and measures then capacity of operating revenues to sustain the investment costs.

Finally, we calculated the benefit-cost ratio, an important indicator of the relative efficiency of a project defined as total benefits divided by the total costs of the project. The time value of money it is incorporated, therefore, the present values of the benefits and costs are incorporated. All calculations were made on a yearly basis.

2.1.1.5. Sensitivity analysis

The impact of the most significant parameters was estimated. It allowed the determination of the 'critical' parameters of the model. Such parameters are those whose variations, positive or negative, have the greatest impact on the project's financial performance. The analysis was carried out by varying one element at a time and determining the effect of that change on IRR or NPV. We considered those parameters (discount rate, investment value and electricity costs) for which an absolute variation of 1% around the best estimate gives rise to a corresponding variation of not more than 5% in the NPV and 1% of RIR (i.e. elasticity is unity or greater).

2.2. Area of the study

The case study presented herein is that of a small community in Romania. The villages Siretu and Rusi Ciutea (Letea Veche commune, Bacau County, Romania) count together 1996 residents, communities with no major economic activities. The population is connected to the water supply system with an average of 3.4 inhabitants per family and nowadays does not dispose of a sewage system and wastewater treatment plant, the wastewater being collected in septic tanks, privies or discharged untreated directly into soil. The role of the local authorities is to provide the best alternative in what concerns the financial and environmental concerns on long term that is why a cost-benefit analysis helps in the process of decision making. The topography of the studied area is flat, allowing for the design of vacuum sewerage system, but also for the classical solution for wastewater collection with pumping stations with solids separation.

The study includes the analysis of two alternative projects for the construction of a sewerage system for two small sized suburban, rural communities. The project includes in the first stage the development of a sewerage system for Siretu Village and a wastewater treatment plant placed in Rusi Ciutea village dimensioned for the entire volume of wastewater for the two communities. The meaning of the study is to offer a comparative analysis of two alternate wastewater collection systems keeping the wastewater treatment plant as a constant for the two alternatives. The objective of the paper is not to get into details concerning the wastewater treatment plant, even though the financial costs were included for both variants, but to look at the competitive advantages of the two wastewater collecting systems.

3. Options analysis: Vacuum sewerage system *vs.* classical solution alternative with pumping stations with solid separation

3.1. Vacuum sewerage system scenario

Vacuum sewage system is an eco-innovative solution for wastewater collection because it deals mainly with environmental and health protection, reduced seepage and odors, economies in energy consumption in the operational phase, therefore internalizing the externalities (extra non- monetary costs of pollution generation). The general conditions conducting to the use of the vacuum system include especially terrain conditions as unstable soil, flat terrain, rolling land with small elevations, high water table, sensitive eco-systems, and developed rural areas (Airvac Inc. 2013; Deutsches Institut für Normung (DIN) 1996; Roediger 2013).

The system is based on the principle of using the differential pressure in vacuum pipelines to collect the wastewater and transport it to a vacuum station, then gradually to a centralized wastewater treatment plant (Airvac Inc. 2013; Deutsches Institut für Normung (DIN) 1996; Roediger 2013; Buchanan et al. 2010). Regarding the functioning principle, a vacuum is generated at a single point in the sewerage system, thus requiring only one point of energy consumption, simplifying power sourcing and reducing construction and ongoing operational costs. The energy is used for the vacuum generators to evacuate the vacuum pumps and pipelines and for the discharge pumps to discharge wastewater out of the vacuum system in an existing sewage system or a wastewater treatment plant.

In the construction phase, the vacuum sewerage brings savings by avoiding deep and large excavations, a smaller diameter of the pipes, elimination of pumping stations etc. A number of minimum 200 connections or more is necessary. Thus, the entire investment including the vacuum station, connection chambers and monitoring system justify the investment, and the investment costs are recovered. It is reported that monthly power costs range from \$1.66 to \$3.34 per month per connection. Larger stations typically have lower power consumption per connection (Buchanan et al. 2010). The vacuum sewer system proved to be with 23.91% cheaper than the gravity sewer system, from the economical point of view while the pumping sewer system is only with 1.7% cheaper than the gravity system (Panfil et al. 2013).

The solution proposed as a first alternative for wastewater collection consists in dimensioning a vacuum sewage system and of a wastewater treatment plant to treat the wastewater from Rusi Ciutea and Siretu villages. The vacuum sewerage system is represented by the pressure sewers, collecting chambers, vacuum station, bio-filter, gravitational sewer from the vacuum station to a pumping station, a pumping station that pumps the water into the wastewater treatment plant.

Vacuum mains are slightly sloped towards the vacuum station (min 0.2%), excepting the lifts in the saw tooth profile that help in keeping the sewer lines shallow. Diameters in vacuum sewers are in the range of DN 90 and DN 250 mm (inner diameter) as can be seen in Table 1. HDPE pipes are applied in vacuum systems due to their low costs of installation and flexibility. DIN EN 1091 requires a thickness of at least PN 10; within the project the chosen thickness is PN16. Leakages do not appear in vacuum systems due to an absolute tightness of installations. The pipes are aligned on both sides of the road, in comparison with the classical solution when the sewers were planned to be aligned on the axis of the road. Advantages of the solution arise from the fact that the road infrastructure is not damaged during the works, also for further interventions for maintenance and repairing.

The vacuum sewers are connected to a vacuum station equipped with hydraulic, electrical, ventilation and control unit installations. The vacuum station consists of three rotary vane vacuum pumps that generate vacuum in the sewer lines (3 x 5.5 kW), a collection tank made of steel dimensioned according to the flow rate and vacuum suction capacity to 10 cubic meters (4.17 l/sec), and two sewage pumps that discharge sewage away from the collection tanks to a gravitational sewer (2 x 11 kW).

The vacuum pumps maintain a negative pressure between -0.4 and -0.6 bar in the collection tank. When the tank pressure falls under a preset limit, the vacuum pumps start working to restore the pressure. As such, vacuum pumps run only for 2-3 hours a day. A monitoring system was designed to indicate the status of the vacuum valves and collection chambers.

For a better functioning of the vacuum station and for reducing air emissions from vacuum generators, a bio-filter was planned (2.5 square meters). The filter media absorb odors and volatile compounds from the airstream by oxidation to carbon, inorganic salts and water with the support of micro-organisms in the filter media. Bio-filter achieves a reduction of sulfuric acid of greater than 95%.

3.2. Conventional sewerage system with solid separation wastewater pumps scenario

Conventional gravity sewers convey sewage through pipelines to the wastewater treatment plant with means of five pumping stations. The sewer lines are installed on a specific alignment, with interspaced manholes placed at set intervals, at pipe intersections and changes in pipeline direction. Construction of the system on flat terrain requires deep excavations (1.2 to 5 m below ground level) and proper preparation and bedding materials are required in the pipeline trenches. Installation of pipe, manholes, pumping stations, building connections, junction chambers or boxes and terminal cleanouts, requires large amounts of excavation.

Due to efficiency reasons and environmental aspects and in order to keep a balance between the two sewerage options, five pumping stations with solids separation were selected to transport the sewage by collecting pipes and send it further in a wastewater treatment station.

The wastewater treatment plant keeps the same characteristics as in the previous analysis. The sewers are designed to be installed on the axis of the road due to configuration of the land and impossibility to dig large trenches on the sides of the road. According to the producers (KSB Group 2013), the solid separation wastewater pumping stations bring few benefits:

- energy saving due to pumps with narrow ball passage, which produces better efficiency than with conventional sewage pumping stations;
- considerably less susceptible to plugging as the pumps do not come into contact with the solids in the wastewater;
- uninterrupted operation during maintenance or repair work due to the station's double-pump design and individual shut-off of the solids separation reservoirs;
- all parts are accessible from outside, so very easy to maintain and hygienic;
- resistance to corrosion and long life due to construction from PE-HD material.

This innovative technology separates the solids from sewage and guides it into separate solids separation tanks. Only pre-purified sewage is able to continue through the pump into the large, combined collection tank. The coarse solids are eliminated from the sewage, and in the next step the sewage is transported by the dry sump pumps and pumped downward into the collection tank.

On the way to the outgoing pipeline, the sewage flows through the solids separation tank, pressing the solids out. The pumps function with higher efficiency since only purified sewage without coarse solids flows through the pumps, leading to significant saving on energy and thus on operating costs. Moreover, blockages are no longer a problem. One outline of the classical sewerage system investment with solid separation pumping stations is presented in Table 2.

4. Results and discussions

This section discusses the main findings and implications obtained from the analysis with respect to the selection of the best alternative in wastewater collection in terms of financial implications, environmental and social benefits.

As the average water consumption in Romania in the rural areas is about 100 l per person per day, the total demand for domestic use for selected case study is 451.24 cubic meters a day. The volume of wastewater to be collected and treated has been estimated at 375.62 cubic meters on the basis of average daily water consumption, taking into account the reduction of volume of water for farms (livestock consumption). The estimation of wastewater demand for new connections is based on data gained from previous experience in the area based on the concept of the consumer willingness to pay. The maximum requirement for wastewater collection is taken into account for the investment.

We presume that 100% of households in the selected area will be connected to the sewerage until the 20th year of the time horizon. Our assumption is that the biggest connection rate will take place in the first three years after the project implementation (around 80%), then the connection rate will decrease gradually until the 20th year, when the potential development of new houses will end due to construction land limitations. The investment cost for vacuum sewerage system is 1,392,259.13 euro, while for the conventional system is 1,358,797.06 euro.

Costs and benefits are presented assuming that all the investment interventions are implemented within the first two years. The costs associated with wastewater collection and treatment has been grouped in five groups: staff, energy for wastewater collection, and energy for wastewater treatment, costs for wastewater treatment (reagents, waste management etc.), administrative costs and maintenance.

Considering the two wastewater collection technologies, the energy consumption for both project variants represented a proxy for selecting the alternative with less energy consumption. The major cost is the investment cost, whereas the most important operating cost is energy cost for wastewater treatment. Staff costs reflect wages, social security charges, taxes, etc. The staff costs were considered similar for the two projects, the implementation of the projects employing a number of two persons for the exploitation and maintenance of the investment.

Table 1. Outline of the vacuum sewerage system investment

Sewers	*L (m)*	*Collecting Chambers (number)*	*Vacuum station + bio-filter*	*Pumping stations (pcs.)*	*River crossing*
Vacuum sewers HDPE, PE100, SDR11, PN16, DN 90 x 8.2 mm	1268	50 (PVC)	*-3 rotary vane vacuum pumps (3* x *5.5 kW), -a collection tank made of steel (10 cubic meters-4.17 l/sec), -2 sewage pumps (2* x *11 kW)*		
Vacuum sewers HDPE, PE100, SDR11, PN16, DN 110 x10 mm	24				
Vacuum sewers HDPE, PE100, SDR11, PN16, DN e 125 x 11.4 mm	17				
Vacuum sewers HDPE, PE100,SDR11, PN16, DN 140 x 12.7 mm	0				
Vacuum sewers HDPE, PE100, SDR11, PN16, DN 160 x 14.6 mm	450				
Vacuum sewers HDPE, PE100, SDR11, PN16, DN 200 x 18.2 mm	50				
Vacuum sewers HDPE, PE100, SDR11, PN16, DN 250 x 22.7 mm	400				
Gravitational sewers HDPE, PE80, SDR17.6, PN6, DN 125 x 7.1 mm (from the vacuum station to pumping station)	2450			*1 pcs*	*Pipe bridge over UHE OL125mm (133* x *5.0 mm)*
Gravitational sewers HDPE, PE80, SDR17.6, Pn6, DN 160 x 9.1 mm (from the pumping station to WWTP)	1350				
PVC, SN2, Ø 200 x 3.9 mm (from WWTP to emissary)	690				
Connections to the connecting chambers- PVC, SN2, Ø 200 x 3.9 mm	300				
Sewers	***6.999***	***50***	***1***	***1***	

Table 2. Outline of the classical sewerage system investment with solid separation pumping stations

<table>
<tr><th>Sewers</th><th>L
(m)</th><th>Collecting Chambers</th><th>Pumping stations</th><th>Manholes</th><th>River crossing</th></tr>
<tr><td>Sewers PVC, SN4, DN 200 x 4.9 mm</td><td>120</td><td rowspan="6">(including connection chamber, PVC pipes, SN2, DN 200 x 3.9 mm and DN 400 x 28.5 mm</td><td rowspan="6">5 pcs.
1. Q=6 m^3/h, P = 2 kW.
2. Q=9 m^3/h, P = 2 kW.
3. Q=13 m^3/h, P = 2 kW.
4. Q =16 m^3/h, P = 2 kW.
5. Q = 23 m^3/h, P = 2 kW.</td><td rowspan="6">48pcs.</td><td rowspan="6">Pipe bridge over UHE OL125 mm (133 x 5.0 mm)</td></tr>
<tr><td>Sewers PVC, SN4, DN 250 x 6.2 mm</td><td>1540</td></tr>
<tr><td>Pressure pipe HDPE, PE80, SDR17,6, PN6, DN 110 x 6.3 mm</td><td>1092</td></tr>
<tr><td>Pressure pipe HDPE, PE80, SDR17.6, PN6, DN 140 x 8.0 mm</td><td>1967</td></tr>
<tr><td>PVC, SN2, Ø 200 x 3.9 mm (from WWTP to emissary)</td><td>690</td></tr>
<tr><td>Connections (including connection chamber, PVC pipes, SN2, DN 200 x 3.9 mm and DN 400 x 28.5 mm</td><td>300</td></tr>
<tr><td>Sewers</td><td>5.709</td><td>200</td><td>5</td><td>48</td><td>1</td></tr>
</table>

Table 3. Costs for wastewater collection and treatment

Costs	*Vacuum system (euro/m^3)*	*Classical system (euro/m^3)*
Staff	0.044	0.044
Energy for wastewater collection	*0.020*	0.036
Energy for WWTP	0.146	0.146
Reagents for WWTP	0.023	0.023
Administrative costs and maintenance	0.004	0.005
Total	**0.237**	**0.254**

In the case study, the energy costs for the classical solution exceed with 0.016 euro/m^3 the vacuum sewage solution; also the administrative and maintenance costs are higher for the classical wastewater system (Table 3). The reason is the high efficiency of the vacuum station and the reduced hours of functioning (2.5 hours/day). Our point is that efficient technologies are less intensive in energy and environmental pollution. Energy saving and significant carbon reduction are achieved within the vacuum sewerage solution. As the same model of wastewater treatment plant was considered, the energy consumption for the wastewater treatment plant (WWTP) for both alternatives is constant.

Based on the energy cost saving alone, the payback time for vacuum sewerage is smaller than payback time for classical sewerage project. The reagents include chemicals utilized for the wastewater and sludge treatment. The cost of reagents was considered 0.023 euro/m^3 wastewater, based on similar projects.

The maintenance costs include costs that incur for the maintenance and replacement of sewerage system and components of wastewater treatment plant. The average operating costs were considered as representing 2 % from energy and staff costs, showing a smaller cost for the vacuum alternative. Quantification of benefits, in monetary terms, poses certain difficulties as time as benefits split in three categories: financial, social and environmental benefits. The last two categories are non-market benefits. In both cases, according to the number of connections and therefore, the willingness to pay, the financial or market benefits include the total income from the tariffs for wastewater collection and treatment and vary from 21,921 €/year after the implementation of the project to 40,233 €/year at the end of the time horizon.

Assigning a value in willingness to pay is one potential approach to value the benefits derived from the implementation of the project. Whenever, no matter what technology is implemented, it was considered that each variant has the same value concerning the willingness to pay for the sewerage infrastructure to avoid waterborne diseases, supplementary costs for emptying the septic tanks, etc. The project generates its own revenues from the tariffs of the wastewater collection and treatment, determined by the forecasts of the number of connections to the wastewater network and relative tariffs. The revenues generated by both alternatives are equal, namely 11.28 € for a connection permit and 0.29 € for the collection and treatment of 1 m^3 of wastewater.

Non-quantifiable socio-economic benefits imply avoiding evacuating wastewater on the soil with effects on the soil quality and agriculture use, improved recreational opportunities, etc. The benefits primarily include mitigation of the environmental pollution by reduction of raw wastewater discharge and seepage, improved health conditions due to pollution abatement and other tangible and intangible benefits that will be presented below. Moreover, water-borne and water-washed diseases are responsible for the greatest proportion of the direct-effect water and sanitation-related disease burden. Costs savings in health care are associated mainly with a reduced number of treatments for diarrheal cases (Hutton and Haller 2004).

The benefits of environmental improvement from pollution reduction contribute to environmental quality, public health quality and affects society welfare of the local communities (Rashid and Hayes 2011).

According to the Guide for Cost-Benefit Analysis of Investment Projects of the European Commission (2008), these types of socio-economic benefits are defined as externalities incurring any cost or benefit that spills over from the project towards other parties without monetary compensation. Even though a second step of the cost-benefit analysis is the economic cost-benefit analysis, for projects whose investment value is under 50,000,000 € only financial cost-benefit analysis is required, which measures only the direct financial implications of the intervention.

Even not a component of financial cost-benefit analysis, the evaluation of the socio-economic benefits was financially quantified in order to emphasize important economic benefits on estimating the health effects associated with groundwater quality improvement, budget revenues due to income tax, corporate tax generated by the increased economic activity and tourism development, and value generated by the land and property markets. The appraisal of the impacts mentioned above is relevant for society, but for which a market value is not available. These effects have been identified, quantified and given a realistic monetary value based on average current prices. The method of appraisal is either the number of infectious diseases avoided or costs generated by hospitalization, either the number of new companies in the area of project and income generated, and willingness to pay approach which allows for the estimation of a money value through user revealed preferences in similar cases.

In the cost-benefit analysis, benefits were converted into monetary amounts using assumptions about the value of identified benefits such as number of cases avoided. The value of financial costs gained is due to less diarrhea or Hepatitis A illness, using the minimum treatment costs as the measure of value. Given the number of inhabitants and similar projects, a number of two cases of Hepatitis A avoided were considered, with a total number of hospitalization of 30 days and 34.76 €/day, according to the average tariffs at national level charged by hospitals within the Infectious Diseases Division. These prices include the price of medication and hospitalization. The estimated cost for a diarrheal case in Romania, considering the cost of medication and the cost of lost work productivity due to live of absence is 67.43 €/2 days, with a maximum occurrence probability of 7 cases a year in the case study considering the target group and similar projects.

Due to the huge marginal health impact of collecting wastewater at the point of use, the annual global value of costs avoided is 2,557.76 €, representing the number of cases avoided of Hepatitis A and diarrheal illness multiplied with the number of cases and cost of medication and hospitalization as specified previously.

Any variant of the project implementation will have a significant social and economic impact on the local community. The assumption was that ten new small companies with four employees each of them, will start a business until the last year of the time horizon. The minimum gross basic salary guaranteed to be paid was set at 190 € per month. The income tax payable by the employee (47.72 €/person/month) generated by the increased economic activity will bring contribution to the budget of the local council, therefore, more resources for further development of infrastructure. The additional income to the state budget from the income tax is set at 19.80 €/person/month and minimum profit was approximated according to previous projects in the rural areas at 352.27 €/month per each new company and the corporate tax (84.57 €/person/month). Maximum socio-economic benefits derived from the further economic development as a result of wastewater infrastructure project implementation is estimated in monetary terms at 148,738 €/year at the end of the projection period and represents the sum of net salary, net profit, the income tax payable by the employee and corporation tax, according to the maximum number of settled companies.

The benefits generated by new sewerage infrastructure, have the potential to contribute to the tourism development, increased tourism infrastructure and number of tourists staying overnight (varying from 3-12 days). It is also forecasted that the amount spent by tourist would increase. A minimum number of 40 tourists/year were considered with a minimum cost for B&B of 34 €/day. The estimation of maximum benefits from tourism development in monetary terms counts 16,253 €/year. On the other hand, the value generated by the land and property markets would increase. A price of 10.9 €/square meter was considered, according to the average price of land in the region. Thus, an increase with 20% of the value of land determines a supplementary income of 2.16 €/square meter. According to the estimations, within a year the transactions will consist in 12 acres of land, resulting in a supplementary income of 26,004 €/year. Land use is in terms of arable land, permanent cropland and construction land, and it plays an important role in the progress of economic development from an agricultural economy to an industrialized economy.

Environmental benefits from a wastewater project when compare the two types of wastewater collecting technologies include mainly the reduction of raw sewage discharges because of seepage risks in the wastewater network, the pollutants damaging the environment, quality of drinking water in private wells and public health. These benefits represent, in fact, the avoided monetary losses expected to accrue as a result of the implementation of one project, or another. Moreover, the reduction in the energy consumption of the sewerage system can be seen as an environmental benefit as time as production of energy contributes to the climate change. However, in order to avoid double counting the energy is considered an operating cost.

The environmental benefits, expressed in monetary terms, have been calculated. They reflect the value of environmental damage avoided derived from wastewater collection or an environmental benefit. In this regard, we considered the probability of sewer seepage occurrence in both alternatives. According to the expert opinion, in the classical wastewater system the sewer leakage can reach 5% or more of the total volume of raw wastewater, with difficulties in decelerating the sewer line break, manholes or pumping stations which allows wastewater seepage. In the vacuum system, this probability is much reduced due to negative pressure in the system and possibility of detecting the leakage because of monitoring system, reaching 1% of the total wastewater running into the system with rapid intervention on the specific sector with sewer line break.

The occurrence of a sewer leakage event was quantified at 3 times a year counting a volume of 180.76 m^3 a year for the classical system and 11.25 m^3 for the vacuum system in relation with the entire volume of wastewater and security of the system. The quantity of biologic oxygen consumption (BOD_5) and total suspended solids (SS) were calculated and multiplied with the financial value of the penalties for exceeding the maximum allowed concentration according to NTPA, when considered the entire volume of wastewater had to be treated. The total volume of sewer leakage can be easily calculated by making the difference between the volumes of wastewater calculated as a result of metered water consumption and metered wastewater entering the wastewater treatment plant.

In financial terms, we value the externalities generated by the wastewater seepage into the soil and groundwater as the aggregated amount of pollutant emission discharged into the environment without treatment with a direct effect on groundwater. The cost of the damage avoided as a result of two projects variant implementation was taken as a proxy.

Water quality is measured mainly in terms of biochemical oxygen demand (BOD_5). Having a low level of BOD_5 in wastewater is essential to avoiding penalties and producing high-quality effluent. If the amount of pollutants leaving a wastewater collecting system is too high, or the discharge endangers public health or the environment, the facility may violate its permit and can be fined or required to upgrade. Due to relatively reduced volume of wastewater to be collected and the low financial value of penalties, the level of penalties is reduced both for classical and vacuum system.

According to the Government Decision no. 328 (Romanian Government 2010), the level of penalty for exceeding the BOD_5 is 46.165 €/tons and 5.77 €/tons for SS.

The damage costs are based on the willingness to pay for environmental quality, smaller in our case on the vacuum sewerage alternative. The financial value of avoiding further pollution is emphasized in Table 4. In conditions in which the level of penalties would increase and the leakage at the classical system would keep a minimum level of 5% of the entire volume of collected wastewater, it is evident that the level of penalties for classical system is 17 times higher in what concerns the BOD_5 and 14 times for SS. Based on the damage costs the vacuum sewer system is more efficient when analyze only two quality parameters of wastewater.

The water and wastewater projects represent the case of natural monopoly and that is why market prices suffer considerable distortions focusing on the principle of total costs recovery, including financial costs for providing wastewater services, operating and maintenance costs, environmental costs related to damage to environment.

Due to its character of public good, the consumers cannot renounce in consuming water (Budds and McGranahan 2003) or produce wastewater. This is one reason of the financial intervention of the European Union. In this regard, water supply and sanitation represent natural monopolies, case in which the costs of infrastructure are so high that they are not profitable for a private company to provide them. In order to evaluate the financial attractiveness of a project against the other, the Net Present Value and Internet Rate of Return techniques were used. The most important indicators for the two sewerage systems are presented in Tables 5 and 6. In the absence of funding constraints, the best value for money projects is that with the highest NPV (vacuum system). For infrastructure projects, financial rates of return are usually negative because of the tariff structure and public good character, non-exclusive and non-rivalry, where the main aim is to satisfy social and environmental requirements. Negative IRR is accepted for social projects due to the fact that this kind of investments represents a priority, without having the capacity to generate revenues.

The negative values of NPV within the two alternatives of sanitation projects draws on the necessity the project is co-financed. The IRR is smaller than 5% (the recommended discount rate).

The benefit-cost ratio (BCR) is higher than 1, meaning both projects are viable. For each Euro invested in the vacuum sewerage project, 1.36 € is saved (BCR = 1.36). Whenever, for each Euro invested in the classical sewerage project, 1.28 € is saved (BCR = 1.28). On the other hand, as was discussed before, when looking at externalities, the vacuum sewerage system brings more savings due to the reduction of raw sewage discharges because of spillage in the wastewater network. These benefits represent, in fact, the avoided monetary losses expected to accrue as a result of the implementation of one project, or another. Having estimated the summary measures, we then studied the impact of different input variables on the results of our analyses by conducting a sensitivity analysis.

Sensitivity analysis takes into account the uncertainty associated with the assumptions and parameters of CBA by studying how changes in variable values impact the results. We take the uncertainty into account by conducting a *sensitivity* *analysis (SA)* and examining how "sensitive" the analysis results are to a change in base-case parameters (discount rate, increasing investment value and energy price).

The results are presented in Tables 7 and 8. The sensitivity analysis for the vacuum sewerage project exposed to the risk factors shows that the variation with 1% of the discount rate, cost of investment or energy price generates a modification of NPV smaller than 5%, and the reduction of IRR is under the limit of 1% indicated by the European Union.

For a variation with 5% of the investment costs, the vacuum sewerage alternative is exposed to risks resulting in a variation with 5.36% of NPV.

The sensitivity analysis for the classical sewerage project shows that the variation of selected risk factors with 1% generates a variation of NPV smaller than 5% while the reduction of IRR is under the limit of 1% indicated by the European Union.

Table 4. Quantification of the wastewater seepage from the wastewater network

Parameter	***Quantity (tone/year) x value of penalty (€/tons)***	
	Vacuum system	***Classical system***
BOD_5	0.003 x 46.165 = 0.138 €	0.050 x 46.165= 2.308 €
SS	0.004 x 5.77= 0.024 €	0.060 x 5.77 =0.346 €

Table 5. Key performance indicators for the vacuum sewerage alternative

Key performance indicators	***Value***	***Permissible value***
Investment costs	1,392,259.13	
NPV	-1,134,321.32	≤0
IRR	-6.90 %	≤5%
Cost-benefit ratio	0.73	<1
Cumulative cash flow	Positive every year	Positive every year

Table 6. Key performance indicators for the classical sewerage alternative

Key performance indicators	***Value***	***Permissible value***
Investment costs	1,358,797.06	
NPV	-1,114,957.86	≤0
IRR	-7.07 %	≤5%
Cost-benefit ratio	0.78	<1
Cumulative cash flow	Positive every year	Positive every year

Table 7. Sensitivity analysis for vacuum sewerage project

		Increase with 1% of the discount rate		***Increase with 5% of the discount rate***	
	Initial	Adjusted	Variation (%)	Adjusted	Variation (%)
NPV	-1,134, 321.43	-1,134,592.32	0.02	-1,135,369.31	-0.09
RIR	-6.90%	-6.95%	0.05	-7.13%	-0.23
		Increase with 1% of the investment costs		***Increase with 5% of the investment cost***	
	Initial	Adjusted	Variation (%)	Adjusted	Variation (%)
NPV	-1,134,321.32	-1,146,471.30	1.07	-1,195,070.78	**-5,36**
RIR	-6.90%	-6.91%	-0.01	-6.95%	-0.05
		Increase with 1% of the energy cost		***Increase with 5% of the energy cost***	
	Initial	Adjusted	Variation (%)	Adjusted	Variation (%)
NPV	-1,134,321.32	-1,135,710.92	0.12	-1,141,269.60	-0.61
RIR	-6.90%	-6.92%	-0.02	-7,01%	-0.11

Table 8. Sensitivity analysis for classical sewerage system

		Increase with 1% of the discount rate		***Increase with 5% of the discount rate***	
	Initial	Adjusted	Variation (%)	Adjusted	Variation (%)
NPV	-1,114,957.86	-1,115,089.31	0.01	-1,115,334,56	0.03
RIR	-7.07%	-7.12%	-0.05	-7.30%	-0.23
		Increase with 1% of the investment costs		***Increase with 5% of the investment cost***	
	Initial	Adjusted	Variation (%)	Adjusted	Variation (%)
NPV	-1,114,957.86	-1,126,796.14	1.06	-1,174,149.23	**5.31**
RIR	-7.07%	-7.08%	-0.01	-7.11%	-0.04
		Increase with 1% of the energy cost		***Increase with 5% of the energy cost***	
	Initial	Adjusted	Variation (%)	Adjusted	Variation (%)
NPV	-1,114,957.86	-1,116,231.70	0.11	-1,122,252.83	0. 65
RIR	-7.07%	-7.09%	-0.02	-7.19%	-0.12

For a variation with 5% of the investment costs the classical variant of the projects is sensitive, resulting in a variation with 5.31% of the NPV. Moreover, the classical sewerage system is more exposed to the risks in what concerns the variation in the price of electricity that has the greatest chance to increase.

The research shows the difference between vacuum sewerage technology and conventional technology, in terms of costs, environmental and social benefits. Even though there is a shortage of published articles on the wastewater collection technologies and their environmental impact, the analysis of the case study provides evidence to support the hypothesis that the vacuum technology can succeed in overcoming the environmental crises by internalizing the externalities, having the capacity to improve environmental factors, reduce energy and maintenance costs.

On the one hand, the results showed in this paper are based upon a technical analysis of energy consumption. Despite the higher overall energy efficiency of both wastewater collection solutions, the vacuum technology brings more energy savings (see Table 3) and consequently reduced greenhouse emissions. On the other hand, the environmental externalities were estimated, and wastewater leakage occurrence was used in calculating the amount of main individual pollutants discharged into the environment that makes the difference between the two design variants of the sewerage system, showing greater benefits in implementing the vacuum technology. Besides analyzing the current and potential developments and creating knowledge about the environmental costs and benefits of a sewage system construction and operation, this research shows the need to provide a framework for further analysis to quantify the level of greenhouse gases released as a result of functioning of alternative wastewater collecting system, that together with the quantification of wastewater seepage into the soil and groundwater, is essential for the promotion of eco-innovation and reflexive institutions.

In order to overcome some recognized CBA limitations, a method to quantify the environmental impacts was developed. In our specific case, despite commonly relied upon metrics to communicate benefits to decision making, the CBA was used to formulate economic arguments for investing in risk reduction, rather than responding to the future impacts. The positive externalities associated with avoiding the discharge of pollution into the environment made the subject of the study. Moreover, life cycle assessment would help together with cost-benefit analysis in delimitating the best solution of investment.

By adopting more stringent and innovation oriented regulations, environmentally proactive bodies will be more capable of facing the challenge of an accurate internalization of environmental effects and reduce negative environmental impacts (Ferrón-Vílchez, de la Torre-Ruiz, and de Mandojana 2013). It may also be worthwhile to take the societal perspective, which would include benefits to tax payers for wastewater collection and improved quality of life. Unfortunately, the problem of tariff setting for sanitation deviates from the optimum economic, that is why the opportunity costs of the service are not visible, being very small in relation with the financial costs (Rogers, de Silva, and Bhatia 2002). Due to the public good character of sanitation this aspect creates inefficiencies in providing the sanitation services.

A possible way of reaching the sustainable development of wastewater collection is by using shadow networks to inspire innovation, encourage institutional learning, and improve governance rules. This creates a new social reality that is more future-responsive to problems and more hospitable to new ways of thinking about water management (Medema et al., 2013).

5. Conclusions

The approach described herein provides a framework for deciding if the supplementary investment costs for vacuum technology is commensurate with the potential benefits. While the analysis is based on a simple methodology for cost-benefit analysis, and somewhat uncertain data concerning the willingness to pay, it is clear that some more benefits accrue when look from an environmental perspective.

Research shows that the increase of the additional benefits accruing from additional provisions in the design and operation of infrastructure is directly proportional with the technological improvements being brought to the system.

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