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Cost-benefit analysis of integrated approach of waste and energy management

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Abstract

The current needs of sustainable urban development give an effort to focus on environmental issues during decision making. In urban areas major environmental concerns are usually related to air quality problems caused by transport activity. Another crucial issue concerns increasing amounts of waste and inefficient waste management. The aim of the paper is to provide a methodology for the decision making process to assess integrated waste and energy management in urban areas. The methodology is based on the application of cost-benefit analysis including an impact pathway approach to evaluate the economic value of environmental aspects of the waste-to-energy process route. The study covers the whole waste-to-energy system including waste management, energy production and energy end-consumption alternatives. Cost-benefit analysis integrated with impact pathway approach was chosen for this analysis as an effective tool that is used to guide decisions about the prioritization of different investment options. This approach allows including not only the investment costs and the economic value of the outcomes but it also provides a wide range of environmental aspects that have economic valuation. The cost-benefit analysis of the integrated waste-to-energy concept is demonstrated on a case study of Valmiera city in Latvia. The results show that operating costs of fossil fuel buses are higher than biomethane fuel buses if the external operating costs and benefits are taken into account. The results from the Valmiera case study show that the total operating costs, including externalities can be reduced.

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Keywords: cost-benefit analysis; waste to biomethane; urban development; impact pathway approcach

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1. Introduction

Policy makers play a major role to ensure common benefits of society. To ensure such common benefits, socio-economic aspects and impacts need to be considered during the process of policy making. Economic analysis, for example, cost-benefit analysis of alternative options and use of funds are important for further development [1]. As it is defined in the Green Book [2] cost-benefit analysis is "analysis which quantifies in monetary terms as many of the costs and benefits of a proposal as feasible, including items for which the market does not provide a satisfactory measure of economic value". In practice, cost-benefit analysis plays a limited role in the decision-making process and the results of this kind of economic analysis are not always taken into account in actual policy-making [1]. Nyborg [1] points out that one of the reasons why there is a lack of influence of cost-benefit analysis during policy-making is due to the lack of understanding of the cost-benefit methodology by policy makers. Another reason is that policy-makers are not really interested to know the costs and benefits of proposed policies at all. Hahn and Tetlock [3] highlight that politicians sometimes choose to disregard basic economic principles despite the fact that analysis are economically justified and the real benefits of the system are shown. Previous studies show that alternative projects, like waste-to-energy projects require high investments. It is also rare that decisions in municipalities are based on complete cost-benefit analysis which includes environmental externalities. Waste-to-energy approach projects have several advantages that should be considered and taken into account during the project evaluation process. This study focuses on the biologic waste treatment and subsequent energy applications. Waste-to-energy is used to describe the utilization of organic waste for biogas production in the anaerobic digestion process and further upgrading of biogas to biomethane for transport/energy applications [4].

The aim of this paper is to provide a methodology for the decision making process to assess integrated waste-to-energy solutions in urban areas. The methodology is based on the application of cost-benefit analysis including an impact pathway approach to evaluate the economic value of environmental aspects. Cost-benefit methodology can be approbated to evaluate waste to biomethane projects in municipalities. The significance of introducing the cost-benefit is to evaluate the monetary value of environmental benefits of the projects, which usually are excluded. This could be one of the ways to improve decision-making at the municipal level in the future. The methodology presented in this paper is demonstrated on a case study of Valmiera city in Latvia.

2. Waste-to-biometane process route

Recent studies on biodegradable waste conclude that "one third of all food produced for human consumption each year goes to waste totalling 1.3 billion tonnes" [5]. One of the solutions to reduce inefficient waste management is to introduce anaerobic digestion and produce biogas (called raw biogas) [6]. It has been estimated that currently landfilled food waste (annually 1.3 billion tonnes) has a potential of 367 m^3 of biogas per dry tonne at about 65 % methane. Assuming that the energy content of biogas is 6.25 kWh/m^3, estimated energy potential is 894 TWh/year [5]. Anaerobic food waste digestion instead of landfilling could reduce the costs and also GHG emissions from both the waste and transport sectors [5]. The anaerobic digestion of food waste can be processed in different systems. It is common to install a single continuously stirred tank or a two-phase system. The process can be run „wet" (less than 15 % of total solids) or „dry" (15–40 % of total solids) single or two-phase systems [5]. For each system there are advantages and disadvantages and these mainly depend on substrate, system size and configuration.

Biogas production from biodegradable waste is one of the opportunities to reach the EU waste and renewable energy targets [7–9]. Biogas can be used in cogeneration plants and used for biomethane production. Biogas upgrading to biomethane is defined as "production of biomethane by microbiological processes. The initial product is raw biogas which must be cleaned (normally called upgrading) to reach the high methane content" [6]. The biomethane after upgrading further can be injected into the natural gas grid or used as a biocombustable fuel in the transport sector [6].

3. Methodology

The cost-benefit analysis consists of multiple stages. For successful cost-benefit analysis it is required to follow a logical sequence of steps [10]:

- First step: define what will be evaluated: what policy or project is being evaluated? What are the objectives? What alternatives are there? What time period is considered? Whose welfare is considered?;
- Second step: identification of the physical impacts of each project. For the projects or policies related to environment, an environmental impact analysis is performed;
- Third step: valuation of the impacts. The monetary valuation of environmental impacts is critical for the reliability and success of the whole cost-benefit analysis;
- Fourth and fifth steps: discounting flows of costs and benefits and sensitivity analysis.

Focusing on the environmental (social) costs – the practice shows that social costs usually are not included in the project evaluation. Analysis confirms that through policy interventions such as taxes, regulations, subsidies and other measures, social costs are integrated in the projects. In the perfect market situation where the social costs (social welfare) are considered, the private costs would be equal to social costs – "all the costs and benefits to society of economic activity reflected in the market price" [11].

The aim of the methodology is to assess the economic and environmental aspects of waste management options focusing on waste-to-energy concept. In this case the end energy output is biogas (if upgraded – biomethane). The presented methodology of cost-benefit analysis is an approach to compare a typical waste management system (waste disposal in landfills) with energy recovery of waste and different energy usage scenarios. The provided cost-benefit analysis is focusses more on welfare economics to assess the costs and benefits of alternative policies and scenarios. The cost-benefit analysis framework provides a useful tool for policy-makers as it provides a comparison of alternative options [12]. The used methodology is an integrated cost-benefit analysis that includes economic, environmental and social aspects. The core of cost-benefit analysis is to provide costs and benefits of goods and services, not excluding environmental goods, by giving a common monetary value [12].

The first step is the definition of the project which is linked to waste management and the efficient use of resources to produce and use energy in an urban area. The system consists of two integrated parts: waste management and energy use. The objective of the analysis is to find the best solution for biodegradable waste treatment and energy use. In order to perform the analysis, two scenarios are developed: base (reference) and alternative scenario (see Fig. 1).

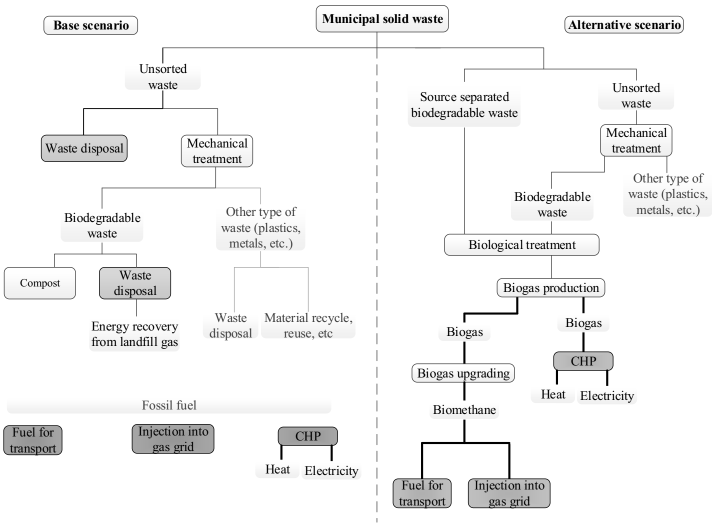

Fig. 1. Base and alternative scenarios.

There are private and social costs and benefits when welfare is considered. Private costs are usually associated with costs that are related to capital investment, construction, operating and maintenance. Benefits are the incomes from provided services, e.g. collected and treated waste, produced and sold energy, transport services, etc. Social (public) costs are related to the externalities that rise directly and indirectly from the introduced project. The main externalities concern changes in air, water, noise, resource use, etc., which cause effects to human health (mortality, morbidity), climate change [12]. The social benefits are the positive effects if the damage costs are reduced, e.g., the result of "cleaner" fuel changes in energy production, transport sector, etc. The environmental and social externalities depend on geographic location and the results will vary widely according to this aspect. External benefits or costs can be defined as positive or negative (any loss of human wellbeing associated with a process) side effects. The second step is the definition of the physical impacts for the reference and alternative scenarios. For each scenario, impacts in physical value are defined. These values are later used for monetary calculations. For example, the externalities that are related to climate damage should be represented in terms of carbon savings – measured in tonnes of carbon-dioxide equivalent (tCO_2) [13]. During the analysis the amount of CO_2 are compared and the effect to climate change of the project can be estimated – whether the emissions are increased or decreased. The third step is linked to valuation of the impacts. The most challenging part is monetary valuation of environmental impacts. According to the proposed scenarios, the main environmental impacts that should be monetarized are emissions of disposed waste in landfill, emissions from transport services and emissions from energy production. One of the most common approaches to estimate externalities is the impact pathway approach which is part of the ExternE methodology, developed by the European Commission [12].

The impact pathway approach consists of several basic steps [13]:

- Estimation of emissions according to chosen technology, e.g. kg of oxides of nitrogen (NO_x) per GWh emitted by a power plant, kg of particular matters per GJ emitted by public bus, etc.;
- Calculation of dispersion of increased pollutant concentrations in affected regions. The estimation is carried out by using models of atmospheric dispersion;
- Calculation of impact of the cumulated exposure from the increased concentration. During this step the impact is calculated in physical units and uses an exposure-response function, e.g. cases of asthma due to this increase in O_3;
- Valuation of costs of the determined impacts in monetary terms, e.g., multiplication by the monetary value of a case of asthma.

The impact pathway approach is used to determine health damage costs which are strongly linked with the population that is affected. Climate damage costs caused by GHG emissions can be evaluated similarly in all places. It is not important where the GHG emissions take place, because of a long half-life period – the effects are on a global scale [13].

According to the cost-benefit principles, further steps are discounting of cost and benefit flows. After fulfilling all the steps presented, the results can be analysed and the best alternative can be selected.

4. Application of the methodology in the case study of Valmiera municipality

The approbation of the methodology is carried out for Valmiera municipality. Valmiera is considered to be one of the industrial centres in North Eastern Latvia and belongs to the historical Vidzeme Region. Valmiera is a mid-sized city with 24 796 inhabitants (1.2 % of the total population of Latvia) [14] and the area of the city is 18.18 km^2 [15].

Valmiera is one of the cities in the North Vidzeme Waste Management Region. Only one municipal waste company "North Vidzeme Waste Management Company" (ZAAO) operates in this region. Currently all unsorted and sorted municipal solid waste in the region is collected and transported to the landfill site Daibe; located around 35 km from the city of Valmiera. During the mechanical treatment process, the waste is sorted into several fractions. Around 35 % of the total waste amount is processed into fine fraction and 70 % of it is made of biologically degradable material [16]. The emission concentration in Valmiera city is approximately 25 % of the whole emission concentration in the region. According to the Environmental Review of Valmiera city [15] it is forecasted that the main factor causing air quality deterioration in the future will be road transport emissions.

4.1. Defining reference and alternative scenarios for the case study

The base scenario and two alternatives (dry fermentation; wet fermentation) were evaluated. The described alternative in previous sections - biomethane injection into natural gas grid - was not evaluated in the case study due to the small amount of produced biomethane and too long distance to natural gas pipeline. Other two alternatives (Biogas usage in CHP; Biomethane fuelled public transport) are described in this study.

The reference scenario includes figures from the existing waste management system (landfill Daibe), public transport in the city of Valmiera and CHP plant (JSC "Valmiera Energija", Rigas street 25, Valmiera). The estimated costs of the landfill are considered till 2032 which is the official closedown of the landfill. It is considered that the biogas production plant will be installed next to the landfill Daibe, according to the existing infrastructure.

4.2. Estimation of externalities

The main costs considered in the calculations where climate damage costs (caused by CO_2 emissions) and health damage costs (caused from emissions from transport, e.g. NO_x). Climate damage costs were calculated based on the CO_2 value that was defined in European Commission [11] report (50 EUR/tCO_2). Health damage costs caused from transport were calculated based on the European Commission report [11].

4.2.1. Landfill

The main external costs are emissions from landfill that cause climate damage. The external costs for CO_2 and CH_4 emissions were calculated. In order to calculate the amount of landfill gas, LandGEM model was used. The landfill gas efficiency was assumed to be 30 %. From this assumption, 70 % of the landfill gas is emitted to air and these are the externalities that cause climate damage. The average calculated external costs per disposed tonne of waste were 29.8 EUR/t_{waste}. Another climate damage causing factor is transportation of the waste. The following parameters were used for these calculations: average distance waste collection trucks travelled per year and average fuel consumption. Emissions from waste collection transport were estimated based on distance travelled (km). To calculate health damage costs, impact from waste collection trucks was assessed by introducing emission factors from the UK National Atmospheric Emission Inventory database [17]. The external costs (climate damage and health damage costs) of waste collection km are 0.09 EUR/km. External benefits depend on avoided emissions from landfill. As it was defined previously, the gas collection efficiency is 30 %. GHG emissions from landfill were calculated and expressed as tCO_2 equivalent. The average calculated external benefits per disposed tonne of waste are 12 EUR/t_{waste}.

4.2.2. Alternatives - dry and wet fermentation

The main social benefit is avoided landfill emissions. Assuming that biodegradable waste is not disposed, the external costs calculated in the reference scenario are the external benefits in the alternative scenario. Assuming that from 2015 biodegradable waste is not landfilled, the external benefits per tonne of processed biodegradable waste are 20 EUR/$t_{processed}$. In case of dry fermentation scenario, the waste collection system and also emitted emissions from waste collection trucks remain the same as in the reference scenario. The opposite situation is in case of wet fermentation scenario - the waste collection system has been modified (longer distance travelled to collect sorted waste) and the emissions from the waste trucks are increased (see Fig. 2 (a)).

4.2.3. Public transport

The parameters that were taken into account to calculate the impact from public transport are the following: amount of public buses; average distance travelled for one bus per year; fuel consumption; maintenance costs. Public transport operation include climate and health damage costs. The same emission factors [17] and monetary values [11] were used as previously described. The climate damage costs were indicated as 0.06 EUR/km and health damage costs were 0.07 EUR/km. The noise impact of public transport was estimated and an indicative value of 0.03 EUR/km was used in the study [18]. For alternative scenarios of public transport, climate damage costs are considered neutral due to the fact that CO_2 emissions from combusted biomethane do not contribute any net GHG into the atmosphere [19]. The reduced emissions from fossil fuel transport are the benefits. This result in that climate damage costs are reduced by 0.06 EUR/km. Heath damage costs are reduced as well. The estimated health damage costs are 0.03 EUR/km. Noise impact costs are reduced by 10 % compared to reference scenario [18].

4.2.4. CHP

The fuel used in the CHP is natural gas. The total capacity of the plant is 41.78 MW and annual maximum natural gas consumption is 10.44 mill. m^3/year [20]. Climate damage costs are calculated based on the fuel consumption and emission factor of natural gas. The total CO_2 emissions from the boiler house are 15 387 tCO_2/year [20]. According to the amount of emissions, the estimated climate damage costs are 0.09 EUR/m^3. The amount of produced biogas can replace natural gas and reduce the CO_2 emissions in the alternative scenarios. The estimated production of biogas is between 0.94–1.53 mill. Nm^3/year in the 2015–2032 period. The replaced biogas can reduce climate damage resulting from usage of natural gas (0.09 EUR/m^3).

5. Results

The capital costs of waste processing are represented as total capital costs per total landfilled waste. Operating costs are represented as annual operating costs per annually collected waste (EUR/t) (see Table 1). The climate damage costs for landfill operations are the total damage costs from the GHG emissions per total amount of landfilled waste. For alternative I (dry fermentation) and II (wet fermentation) the damage costs are reduced due to the avoided emissions from landfill gas, i.e. biodegradable waste is separated and not landfilled and the emissions are reduced (see Fig. 2 a). The avoided emissions were calculated assuming that the waste is not landfilled from the year 2015. Alternatives for final energy use were compared in a similar manner as was done for waste processing. Table 1 presents the indicative values of public transport operations (capital and operating costs). Alternatives I and II have much higher capital costs due to investments for a new filling station and upgrading plant. The price of a gas fuelled bus is around 20 % higher than for a diesel fuel bus and also maintenance costs are higher. Based on the current operational and maintenance costs of the CHP plant, operational costs for both alternatives were calculated. The existing plant does not require significant investments to use biogas for energy production. The operating costs include the price of used fuel. The price of natural gas was assumed 0.365 EUR/m^3 and for biogas 0.18 EUR/m^3.

Table 1. Comparable values of waste processing options and public transport.

	Capital	Operating		Capital	Extra capital: Upgrading	Extra capital: Filling station	Operation and maintenance	Operating, fuel
	Reference scenario			Reference scenario				
	EUR/$t_{landfilled}$	EUR/$t_{operated}$		EUR/bus; EUR/km	-	-	EUR/km	EUR/l
Waste processing	16.07	30.2	Public transport	164400; 0.22	-	-	0.18	1.087
	Alternative I - dry fermentation			Alternative I - dry fermentation				
	EUR/$t_{processed}$	EUR/$t_{operated}$		EUR/bus; EUR/km	EUR/m^3/h	EUR/station	EUR/km	EUR/m^3
	9.49	6.04		205500; 0.27	4036.7	600000	0.23	0.75
	Alternative II - wet fermentation			Alternative II - wet fermentation				
	EUR/$t_{processed}$	EUR/$t_{operated}$		EUR/bus; EUR/km	EUR/m^3/h	EUR/station	EUR/km	EUR/m^3
	13.95	19.5		205500; 0.27	3865.5	600000	0.23	0.75

The annual external costs for all scenarios are presented in Fig. 2 (a; b). The largest share of the total external costs is externalities from landfill. In both energy use alternatives ~80 % of the total external benefits are from avoided emissions from landfill. This shows the significance of "moving away from landfills". Health impacts might vary according to population density and in other cities can produce a completely different outcome. For this reason, calculations of CO_2 (climate damage) and monetary value can be used worldwide due to the global and long term impact.

The alternative II with biomethane use in public transport has the greatest biogas/biomethane production and the number of buses running with biomethane. According to the indicative comparable values of benefits and costs for public transport (climate damage benefit 0.06 EUR/km and health damage costs 0.03 EUR/km; see Table 1), in case of Valmiera city both biogas production alternatives have a similar outcome, i.e. by higher share of the replace fossil fuel, higher environmental benefits will be obtained. From the investment point of view (see Table 1), the wet fermentation plant is more suitable for greater amount of waste input – generated biogas. Increasing the biogas plant capacity will decrease the price of generated biogas. If the current waste management system in Valmiera will be improved and the rate of the separated biodegradable waste will increase, a wet fermentation plant is the best alternative. Depending on the investor, capital costs can be calculated. It should be mentioned that in analysis of CHP plant human health damage costs were not calculated due to the lack of suitable external cost data. Calculation of such costs might change the external benefits of the CHP plant due to the fact that the plant might influence on health on the population of Valmiera city.

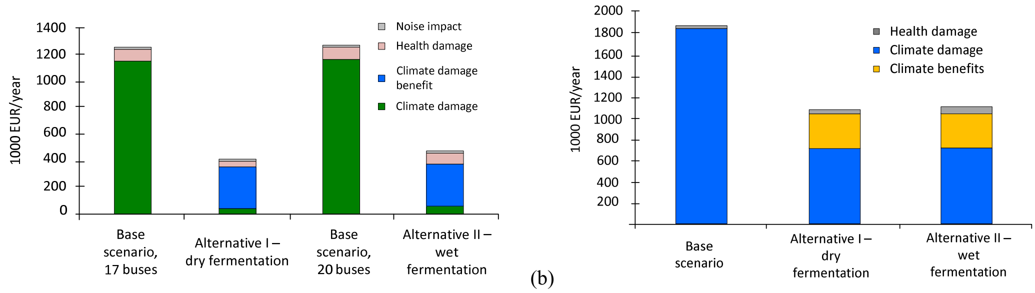

Fig. 2. Total annual external costs (benefits): (a) landfill operating and public transport; (b) landfill operating and CHP plant.

The external costs in this study were calculated for three services that citizens of Valmiera city receive: waste collection, public transport and heat and electricity generation. The market price of waste tariff, public transport ticket and heat tariff accepts the externalities from landfill and public transport or CHP plant. For example, external human health damage costs of an average trip by public transport in Valmiera is ~0.25 EUR/trip (caused from NO_x and $PM_{2.5}$). Improving infrastructure for biomethane usage in public transport might influence the price.

6. Conclusion

Policy improvements need to be introduced to support effective waste collection by ensuring cooperation with different stakeholders (municipal waste collection company, public transport operator, waste treatment management, energy producer, etc.). The cooperation opportunities have already showed good results in achieving environmental benefits as well. Improvement of municipal, commercial and industrial waste collection will significantly increase the produced amount of biogas and biomethane according to the chosen technology, as it was confirmed also with the case study of Valmiera.

Cost-benefit analysis can be used as a tool to show the environmental benefits and costs that usually are not included in typical project analysis. Impact pathway approach is one of the efficient ways to determine the monetary value of environmental externalities. Integrated cost-benefit analysis with impact pathway approach is a powerful tool that is suggested to be used to guide decisions about the prioritization of different investment options in municipalities. During the evaluation of environmental externalities important aspects to be considered are elements such as population density, meteorological data, geographical location, etc. These parameters describe the certain area where the planned activities will take place. The climate damage costs are very significant during the impact of monetization and evaluation. Usually the greatest amount of avoided emissions is due to the reduction of GHG emissions by replacing, e.g., fossil fuels. Based on the latest available information about European countries, CO_2 climate damage costs at 50 EUR/tCO_2 were used in the study.

The existing situation in Valmiera shows the typical social example of willingness to accept. The market price of waste tariff, public transport ticket and heat tariff accepts the externalities from landfill and public transport or CHP plant. For example, previous investigations shows that ~70 % of inhabitants of Valmiera do not support separate collection system of biodegradable waste if the price of waste tariff is increased.

Results show that the potential of the processed biodegradable waste in Valmiera can ensure not only 10 intercity buses but at least 17 biomethane fuel buses if dry fermentation is selected and 20 if wet fermentation is introduced. The operational and maintenance costs of diesel public buses are ~20 % lower than the operational costs of biomethane buses. However, considering also external costs and benefits, the results show the opposite – the costs of biomethane buses are lower. The results from Valmiera case study show that the total operational costs, including externalities can be reduced by 12 % for the wet fermentation scenario. The alternative with wet fermentation and biomethane use in public transport in Valmiera showed the greatest environmental benefit - major reduced external costs. If the external avoided emissions from landfill are included to evaluate biomethane use in transport sector, the avoided GHG emissions can be up to 80 % of the total external benefits. Besides the fact that the wet fermentation with biomethane use in public transport provides the greatest environmental benefit, the set indicative values for Valmiera show similar external benefits from dry fermentation and public transport use as well. According to financial aspects, wet fermentation requires higher capital and operational costs. If the amount of produced biogas is increased, profitability will also increase.

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