The first municipal solid waste incinerator project in Southeast Europe

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Abstract

Purpose

The City of Belgrade, the capital of Serbia, is in the project preparation phase for a public-private partnership (PPP) project for the provision of services of treatment and disposal of residual municipal solid waste (MSW), including the construction and operation of a waste to energy (WtE) facility. The objective of this work was to perform a social cost-benefit analysis (CBA) for a combined heat and power municipal solid waste mass burn incineration facility in Belgrade.

Methods

A financial and an economic analysis were conducted for the proposed WtE facility. The contributions of energy derived from waste incineration to the total energy consumption in Belgrade were also evaluated.

Results

Belgrade has a developed district heating system and locating the WtE facility next to an existing thermal power plant would enable the utilization of the heat energy produced by incineration. It was estimated that in its first year of operation, the incinerator would produce electrical energy and heat in the equivalent of 6% of the electrical household demand in 2014 and 26% of the thermal energy delivered during the 2014/2015 heating season in Belgrade. The financial and economic analyses, done in the form of a CBA, showed that the project would be financially and economically positive and viable.

Results

The Belgrade WtE facility project is a first-of-its-kind in the region. The presented work could serve as a primer on conducting a WtE project sustainability analysis for other cities and urban areas in the region that do not have developed WtE systems.

Keywords: waste to energy (WtE); mass burn incineration; combined heat and power (CHP) system; cost benefit analysis (CBA)

1. Introduction

The City of Belgrade, the capital of Serbia, has expressed interest in procuring a waste to energy (WtE) facility through a public-private partnership (PPP) [1][2]. The objective of this work was to perform a sustainability analysis, done in the form of a social cost-benefit analysis (CBA), to assess the financial as well as the environmental and social effects of a WtE project in Belgrade. As explained in the book “Cost-benefit analysis and the environment” [3], the essential theoretical foundations of CBA are defining benefits as increases in human wellbeing and costs as reductions in human wellbeing. For a project to qualify on cost-benefit grounds, its social benefits must exceed its social costs. All costs and benefits are converted to monetary units. CBA has previously been applied to evaluate the positive and negative effects of waste management scenarios [4][5][6].

The chosen WtE combustion technology was mass burn grate incineration with energy recovered in the form of electricity and heat. Mass burn incinerators are used widely in Europe and worldwide and are designed with sufficient flexibility to cope with the wide range of waste compositions that they may receive [7][8]. Waste incinerators that produce steam for both electricity generation and district heating as combined heat and power (CHP) systems have an overall higher energy conversion that when only electricity is generated [7]. The option of producing both electricity and heat is applicable as the City of Belgrade has a developed district heating system with an overall length of the heating route of 1420 km that services about half of the population in Belgrade [9]. When incineration is considered as a waste management option, the Waste Management Strategy for the period 2010-2019 [10] prescribes that energy recovery in the form of electricity and heat should be considered with the goal of increased energy efficiency.

2. Materials and methods

2.1. Current MSW management practices

Waste in Belgrade is collected by seven different public utility companies (PUC) and is disposed of at five unsanitary landfills. The largest PUC is called "Gradska cistoca" ("City Sanitation") and services eleven municipalities that generate about 85% of the municipal solid waste in Belgrade. Current municipal waste management practices conducted by City Sanitation include limited recycling and waste disposal at the Vinca unsanitary landfill located 15 km from Belgrade, on the right bank of the River Danube. The landfill site has been in operation since 1977, it occupies an area of about 70 ha where the landfill body has an area of 45 ha and a height of 5 to 50 meters. There is no collection of landfill gas and leachate drains though a canal into a natural swamp within the Danube riverbed. The City of Belgrade is planning to perform remediation works with landfill gas capture at the existing unsanitary landfill site in Vinca and construct a new sanitary landfill for the disposal of WtE treatment process residues, also through the PPP project [1].

2.2. MSW characterisation

It is planned that residual MSW (waste after source-separation of recyclable materials has been carried out) from 13 municipalities that generate up to 90% of the total waste in the City of Belgrade will be treated in the incinerator facility. MSW from these municipalities is made up of approximately 80% household waste (HHW) and 20% commercial waste (CW). Projected municipal waste quantities from the 13 participating municipalities are given in Figure 1 from the expected year of start of commercial operations at the incinerator facility up to the end of the operational period. Recycling rates were projected to increase until they reach a steady rate of 23% for HHW and 55% for CW, resulting in an overall MSW recycling rate of 32% [1]. Total MSW waste generation, combined recycling forecasts and composition data were provided by the City of Belgrade, while the composition and heating value of residual MSW were calculated by the authors.

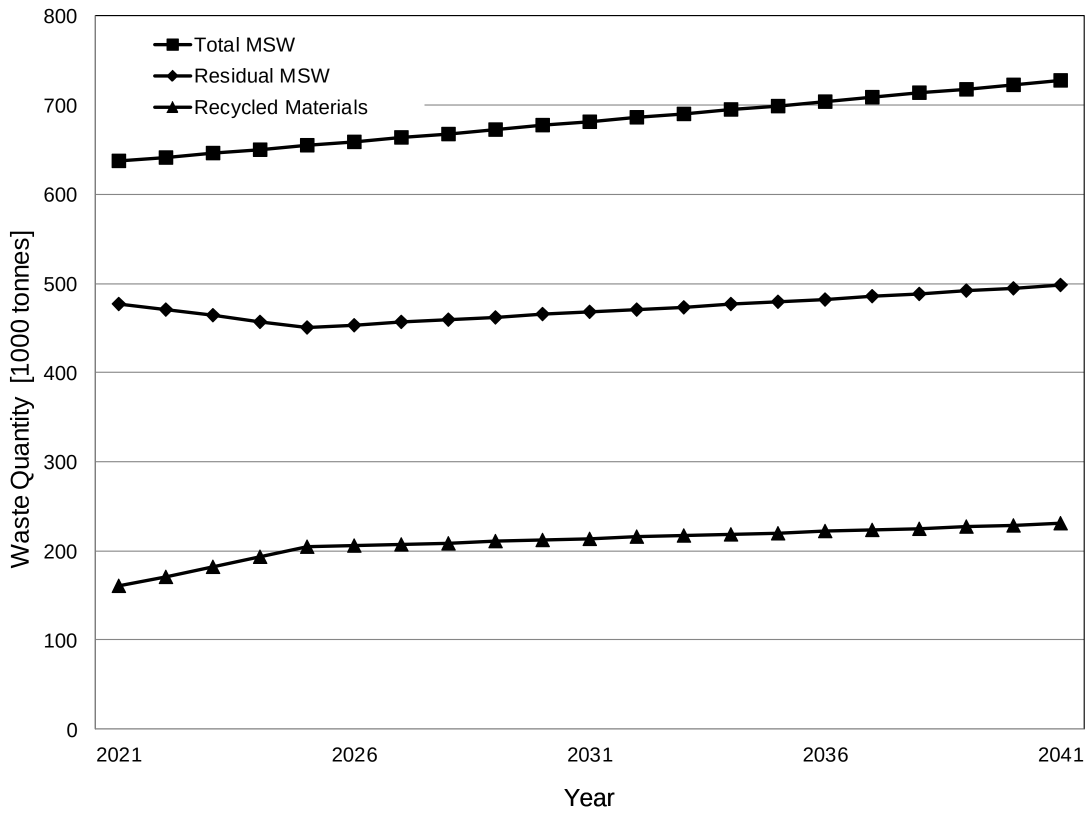

Figure 1. Projected municipal waste quantities

Table 1 presents total and residual MSW composition data and the calculated lower heating values for individual waste components. The estimation of the composition of residual MSW was based on the recycling rates of packaging waste components prescribed in the adopted Proposal for a Directive of the European Parliament and of the Council amending Directive 94/62/EC on packaging and packaging waste [11]. This proposal is a part of the adopted EU Circular Economy package and it sets out the following targets for the reduction of the waste components specified herein by 2025: 75% for paper and cardboard; 55% for plastics; 75% for glass; 75% for metals; and 60% for wood. Serbia is achieving the recycling goals defined in the national Plan for the reduction of packaging waste [12], mostly by recycling waste from the commercial sector [13]. There is sufficient processing capacity in Serbia for all types of packaging waste recyclables.

For the purposes of calculating the heating value of residual MSW, it was assumed that the stated recycling goals would be fulfilled and that hazardous waste would be source-separated and not incinerated. The lower heating values (LHV) for food waste, paper, cardboard and plastics were adopted from Athanasiou et al. [14], who used data from Komilis at al. [15]. The LHV for other MSW components were taken from the work conducted by Riber et al. [16] and presented in detail in Christensen [17]. The LHV of MSW prior to recycling and residual MSW were calculated to be 10.6 MJ kg^{-1} and 8.5 MJ kg^{-1}, respectively.

Table 1. MSW composition and lower heating values

Waste Fraction [%]	MSW	Residual MSW	LHV (wet basis) [MJ kg^{-1}]
Food waste	26.3	38.8	3.8
Paper/ Cardboard	22.2	8.2	12.2
Plastics	13.9	9.2	35.3
Textile	3.9	5.8	18.5
Diapers	4.0	5.9	11.1
Leather	1.1	1.6	22.9
Yard waste	6.7	9.9	5.9
Wood	1.1	0.6	15.6
Glass	5.5	2.0	0
Metals	3.6	1.3	0
Inert	11.2	16.5	0
Hazardous waste	0.5	0	
Total	100	100	

2.3. Energy generation

The energy yield from a CHP incinerator facility was calculated based on recommendations from Rand et al. [18] where residual MSW with a LVH of 8.5 MJ kg^{-1} yields 0.47 MWh of electrical energy and 1.53 MWh of heat per tonne of residual MSW. Calculations of the annual quantities of electricity and heat produced were based on these yields and the annual forecasts of residual MSW quantities. For example, in its first year of operation, the incinerator produces 224 GWh of electrical energy and 729 GWh of heat or the equivalent of 6% of the electrical household demand in 2014 and 26% of the thermal energy delivered during the 2014/2015 heating season in Belgrade [9]. These new capacities would fulfil the goals for obtaining energy from waste set in the National Renewable Energy Action Plan for Serbia [19].

2.4. Financial and economic analysis

The main purpose of the financial analysis is to use the project cash flow forecast to calculate suitable net return indicators. The Discounted Cash Flow (DCF) approach [20] was taken and a particular emphasis was placed on the following two financial indicators:

- the Financial Net Present Value (FNPV(C)) of the project, expressed in monetary terms (Euro); and
- the Financial Internal Rate of Return (FRR(C)), expressed as a numeric value.

Both of the indicators were expressed in terms of financial return on the total investment cost. These two indicators measure project performance, independently of the sources or methods of financing, and contribute to deciding whether the project requires external financial support (when FNPV(C) is negative or FRR(C) is lower than the applied financial discount rate).

Within the economic analysis a CBA requires an investigation of a project's net impact on economic welfare of a region or a country [20]. The economic analysis is made on the behalf of the whole society instead of solely the owner of the infrastructure, as is done in the financial analysis. The standard approach, consistent with international practice, consists of four steps: conversion of market to shadow prices, monetarisation of non-market impacts, discounting of net cash flow and calculation of economic performance indicators.

3. Results and discussion

3.1. Financial analysis

The tender documents for dialogue phase for the PPP project issued by the City of Belgrade state that the term of contract is up to 25 years from the effective date of the contact [2]. The PPP contract is expected to be signed in early 2017 which was taken as the start of a 25-year life cycle that includes four years for project implementation and a 21-year operation period starting in 2021. The chosen reference periods are in line with European Commission and World Bank recommendations [18][20]. The financial discount rate (FDR) was adopted as 4.5% [21].

The maximum amount of residual MSW is generated at the end of the project life cycle in 2041 and is equal to 498,000 tonnes (Figure 1). The adopted nominal capacity (NC) of the incinerator facility was 550,000 tonnes per year to include a safety factor of 10%. The initial capital investment (I) and annual operational cost (OC) were calculated using the cost functions developed by Tsilemou and Panagiotakopoulos [22] that are based on a survey of 32 mass burn MSW incinerator facilities across Europe:

$$I = 5000 \cdot NC^{0.8} \text{ [€]}$$

$$OC = 700 \cdot NC^{-0.3} \text{ [€}t^{-1}\text{]}$$

All monetary values were adjusted to November 2015 with the average inflation rate of 2.03% [23]. As the City of Belgrade will provide the land for the incinerator facility within the PPP [1], the capital investment cost was decreased by 2% to account for the value of land acquisition. The investment capital cost was calculated to be €239 million.

The operating costs were calculated to be €16.5 per tonne of residual MSW or €7.9 million and €8.2 million in the first and last year of operation, respectively. The additional financial outflows included:

- the replacement costs (RC) of short life facility components in the 19th year of project life cycle (adopted as a 75% of the facility and equipment costs); and

- the clearance and decontamination cost (CDC) of the project site at the end of the operational period (assumed to be 4% of the initial capital investment or €9.5 million).

The financial inflow consisted of the waste treatment and recovered energy revenues. The monthly MSW collection and disposal fee in 2014 was €0.89 per resident with a payment rate of 95% [24]. For purposes of this analysis, the assumed monthly incinerator gate fee was €1 per resident. The total monthly waste management fee (collection, disposal and treatment) was €1.89 per resident or €5.2 per household, which equates to 0.9% of the average household income in Belgrade [9]. In Wilson et al. [25] it is stated that if the cost per household for the entire waste management system is less than 1% of household income in low-income countries or 2% in middle-income countries, the cost will likely be affordable. The annual waste treatment revenue was calculated with respect to the expected population growth for Belgrade from the publication “Population Projections of the Republic of Serbia 2011-2041” [26]. The annual residual MSW incineration fees were calculated by multiplying the annual population projections by the incinerator gate fee and resulted in annual revenues in the range of €19.4 to €20.7 million.

The recovered energy revenues were based on the sale of electricity and heat. A feed-in tariff for electricity generated from WtE facilities was prescribed in 2013 as €85.7 per MWh [27]. The monetary value was adjusted using an inflation rate of 1.99% (February 2013 - November 2015) to €87.4 per MWh. The annual electricity revenues were calculated to be from €18.8 to €19.5 million during the project cycle, assuming the payment rate would remain at the current level of 96%.

The current retail price of heat energy delivered via the district heating system in Belgrade is €56.3 per MWh [28]. The production price of thermal energy as provided by the Cerak thermal power plant is €42 per MWh. The heat production price is relatively high due to the high cost of imported natural gas that is used as fuel, which is currently about €0.3 per cubic meter [29]. It was assumed that the heat generated by the MSW incinerator could be sold to the City of Belgrade at the current natural gas based heat production price of €42 per MWh per the substitution principle. The recovered heat annual revenue was between €26.6 and €27.6 million, with the current payment rate of 87% [30].

The residual value of the investment was conservatively set to zero [20].

The allocation of financial outflows and inflows within the project life cycle and the resulting indicators are shown in Table 2.

Table 2. Financial analysis (in millions of €, zero values are not shown)

FDR	4.5%													
Year	1	2	3	4	5	6	7	8	9	10	15	19	20	25
I	8.9	10.6	105.9	113.2										
OC					7.9	7.8	7.7	7.6	7.4	7.5	7.7	7.9	8.0	8.2
RC												164.3		
CDC														9.5
Total Outflow (TO)	8.9	10.6	105.9	113.2	7.9	7.8	7.7	7.6	7.4	7.5	7.7	172.3	8.0	17.8
Treatment revenue					19.4	19.5	19.6	19.6	19.7	19.8	20.1	20.3	20.3	20.7
Electricity revenue					18.8	18.8	18.5	18.3	18.0	17.8	18.3	18.8	18.9	19.5
Heat revenue					26.6	26.6	26.3	25.9	25.6	25.2	26.0	26.6	26.8	27.6
Total Inflow (TI)					64.9	64.9	64.4	63.9	63.3	62.7	64.4	65.7	66.0	67.8
TI – TO	-8.9	-10.6	-105.9	-113.2	57.0	57.2	56.7	56.3	55.9	55.2	56.7	-106.6	58.0	50.1
FNPV(C)	360													
FRR(C)	19.6%													

In this analysis, the FNPV(C) proved to be positive and very high (€360 million) and the FRR(C) is significantly higher than the applied financial discount rate (19.6% compared to 4.5%), implying that the generated revenues are considerably higher than the investment costs and that the project does not require any external financial support. The received financial benefit per tonne of MSW is €36.3. The results obtained from the financial analysis show that the project is a good candidate for a PPP. However, the question of project social and environmental acceptability remained to be assessed by an economic analysis.

3.2. Economic analysis

As stated in the Introduction, the first step of an economic analysis is to convert market to shadow prices. Shadow prices reflect the social opportunity cost of goods and services, instead of prices observed in the market, which may be distorted [20]. A discount rate, termed the Social Discount Rate (SDR), is also used in the economic analysis. The SDR reflects the social view on how future benefits and costs should be valued against present ones. The recommended SDR for infrastructure projects in Serbia is 5.5% [31].

Shadow prices were obtained by multiplying the inputs and outputs of the financial analysis by calculated conversion factors (CF) that account for the market price distortion of goods and services. Conversion factors were calculated based on the following principles [20]:

- when project inputs were tradable goods, border prices were used;
- a standard conversion factor (SCF) was used for non-tradable goods;
- a shadow wage (SWR) was calculated for manpower wages.

A SCF measures the average difference between world and domestic prices and can be calculated with the following formula [20]:

$$SCF = \frac{M + X}{M + X + TM}$$

where M is the total value of import at shadow prices; X is the total value of export at shadow prices; and TM is the total value of duties on import. The SCF for Serbia was calculated as 0.98, where values for M, X and TM were taken from the Statistical yearbook of Belgrade 2014 [9] and the Customs Administration of the Ministry of Finance [32].

Shadow wages for manpower were calculated for skilled and non-skilled manpower separately according to the following formula:

$$SWR = W(1 - T)(1 - u)$$

where W is market wage, T is the income taxation and u is unemployment rate. In Serbia, T is 47.8% [33] and u is 15.4% and 2.45% for skilled and non-skilled manpower, respectively [34]. The resulting value of skilled and non-skilled manpower conversion factors were 0.44 and 0.51 respectively. Other conversion factors for outflows and inflows were calculated based on the percentage of costs for skilled and non-skilled manpower, materials and equipment. All conversion factor values are shown in Table 3.

Table 3. Conversion factors for the economic analysis

Type of cost	**CF**	**Comment**
Design	0.44	100% skilled labour
Construction	0.64	40% construction materials (CF=SCF), 5% skilled labour, 45% non-skilled labour, 10% profit
Equipment	1.00	Imported without taxes and tariffs
Investment (weighted)	0.88	7% design, 23% construction, 70% equipment
Labour and administration	0.56	54% non-skilled labour, 31% skilled labour, 15% materials
Materials	0.98	traded good; CF=SCF
Energy and water services	0.98	SCF
Maintenance	0.92	5% skilled labour, 10% non-skilled labour, 85% equipment
Operation and maintenance (weighted)	0.86	25% labour and administration, 40% energy and materials, 35% maintenance
Residual value	0.88	100% investment (weighted)
Treatment services	0.98	SCF
Clearance and decontamination	0.60	10% skilled labour, 70% non-skilled labour, 20% materials

The next step was the monetisation of non-market impacts or externalities. The externality that most importantly contributes to climate change mitigation and is the most significant in monetary terms is the reduction of greenhouse gas (GHG) emissions due to: the diversion of biodegradable waste from the landfill where it decomposes under anaerobic conditions and creates methane; and partial replacement of fossil fuels used for the generation of heat and electricity. The economic value of the reduction of GHG emissions emitted to the atmosphere was conducted by multiplying the amount of emissions avoided (CO_2-equivalents per year) by their unit cost expressed in Euro per tonne. The unit cost of GHG emissions was €32 and €50.5 per tonne of CO_2-eq at the start and end of the project cycle, respectively, as recommended by European Investment Bank [35].

The avoided GHG emissions due to diversion of biodegradable waste from landfills were quantified by calculating the difference between the GHG emissions that emanate from landfills and the WtE facility based on data from the Guide to CBA of investment projects [20]. The GHG landfill emissions were 0.67 tonnes CO_2-eq per tonne of landfilled waste at the start of the project cycle and decreased to 0.62 t CO_2-eq per tonne of waste at the end of the project cycle, due the assumed changes in the composition of residual MSW where the organic and plastic waste contents will decrease and increase, respectively. The GHG emission from the WtE facility ranged from 0.47 to 0.55 t CO_2-eq per tonne of incinerated waste. The calculated difference between the GHG emissions that emanate from landfills and the WtE facility ranged from 0.2 to 0.07 t CO_2-eq per tonne of waste during the project life cycle.

The avoided GHG emissions for energy recovered in the form of heat were based on the GHG emission factor for natural gas based district heating systems of 0.26 kg CO_2-eq per kWh [36]. The GHG emission factor of 1.7 kg CO_2-eq per kWh for lignite was taken from the same source for calculation of avoided GHG emissions through energy recovery in the form of electricity.

The calculation of economic performance indicators is shown in Table 4. The economic net present value (ENPV) is the difference between the discounted total social benefits and costs. The calculated ENPV is higher than zero (€611.4 million), meaning that the project is desirable from a socio-economic perspective and that society is better off with the project. The economic rate of return (ERR) is the rate that produces a zero value for the ENVP; ERR is significantly higher than adopted SDR (31.8% compared to 5.5%). The received net economic benefit per tonne of MSW is €61.6. This positive result shows that the project is social and environmental acceptable and beneficial.

Table 4. Economic analysis (in millions of €, zero values are not shown)

SDR	5.5%													
Year	1	2	3	4	5	6	7	8	9	10	15	19	20	25
I	7.8	9.3	93.1	99.5										
OC					6.7	6.6	6.6	6.5	6.4	6.4	6.6	6.8	6.8	7.0
RC												144.4		
CDC														5.7
Total economic cost (TEC)	7.8	9.3	93.1	99.5	6.7	6.6	6.6	6.5	6.4	6.4	6.6	151.2	6.8	12.7
Treatment revenue					19.1	19.1	19.2	19.2	19.3	19.4	19.7	19.9	19.9	20.3
Electricity revenue					18.8	18.8	18.5	18.3	18.0	17.8	18.3	18.8	18.9	19.5
Heat revenue					26.6	26.6	26.3	25.9	25.6	25.2	26.0	26.6	26.8	27.6
Avoided GHG emissions due to diversion of biodegradable waste from landfill					3.4	3.4	3.3	3.2	3.2	3.2	3.0	2.7	2.6	1.8
Avoided GHG emissions from partial replacement of fossil fuels used for generation of heat					6.8	6.9	7.0	7.1	7.2	7.4	8.5	9.1	9.2	10.0
Avoided GHG emissions from partial replacement of fossil fuels used for generation of electricity					13.7	13.9	14.1	14.3	14.4	14.9	17.0	18.2	18.5	20.1
Total economic benefit (TEB)					88.5	88.8	88.4	88.1	87.7	87.8	92.4	95.2	95.9	99.3
TEB-TEC	-7.8	-9.3	-93.1	-99.5	81.7	82.1	81.9	81.6	81.3	81.4	85.8	-56.0	89.0	86.5
ENPV	611.4													
ERR	31.8%													

4. Conclusions

A comprehensive project sustainability analysis was performed for a CHP mass burn incineration facility for the City of Belgrade in Serbia. MSW characterisation showed that the LHV of the residual MSW fraction was 8.5 MJ kg^{-1} and that the energy generation potential was 0.47 MWh of electrical energy and 1.53 MWh of heat per tonne of residual MSW. The City of Belgrade has a developed district heating system and locating the WtE facility next to an existing thermal power plant would enable the utilization of the heat energy produced by incineration and substitution of a portion of the imported natural gas currently used for district heating. Electrical energy produced by incineration will reduce the amount of coal burned in power plants that currently supply Belgrade with electricity. The financial and economic analyses, done in the form of a CBA, showed that the project was financially and economically positive.

The Belgrade WtE facility project is a first-of-its-kind in the region. The presented work could serve as a primer on conducting a WtE project sustainability analysis for other cities and urban areas in the region that do not have developed WtE systems.

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