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Solid Waste Management Baling Scheme Economics Methodology

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Abstract: A cost structure is proposed for evaluating and improving the ecological-economic efficiency of baling sub-scheme units within solid waste management schemes that end with, for example, incineration for heat and power production. The methodology proposed employs the previously introduced WAste Managements' Efficient Decision model (WAMED) and the COmpany STatistical BUSiness Tool for Environmental Recovery indicator (COSTBUSTER). The previously introduced *equality principle* and the Efficient Use of Resources for Optimal Production Economy (EUROPE) model are applied so to in monetary terms express the emissions in case of bale related fire (sol), pollutions from leachate (liq) and odour (g) at a scheme. Previously, the EUROPE model has been applied to residuals from producing industry, the construction sector and whole landfills. A case study presents the practical application of the proposed methodology. It is concluded that the presented novel methodology for evaluation and improvement of the ecological-economic efficiency of solid waste baling management schemes simultaneously decreases the negative impact on the environment and the health of the population, provides the foundation of an investment appraisal support tool for the implementation of solid waste management projects and enables comparative analysis of estimated, actual and prevented monetary damages from the implementation of baling plant units.

Key words: Solid waste management baling plants % Pollutions % COSTBUSTER model % The equality principle % The EUROPE model

INTRODUCTION

The baling technique has been shown to be the most promising method for the storage of waste intended for use as a fuel [1]. In Sweden, the storage of baled waste fuels has recently increased and a substantial increase in the national incineration capacity has been observed. This had been predicted [2] based on the implementation of the EU Council Directive [3] on the landfilling of waste. Thus, in this study the baling technique is mainly related to incineration due to reasons of economic relevance.

Previously, at the beginning of the 1990s, waste was stored and compacted in landfill sites or stored in loose heaps. Occasionally, this method caused self-ignition. Therefore, baling was introduced as a cleaner, risk-free and tidy method [4]. Generally, one of the main emission problems related to the storage of waste is accidental *fire*. Fires also occur in landfilled waste.

Open burning is defined as the unenclosed combustion of materials in an ambient environment. It has similarities with fires in stored waste fuels, particularly as regards the emissions. A single fire of this type might give an emission higher than the annual emission from all the waste incinerator plants in Sweden [5]. This represents emissions in a solid (sol) form.

Leachate is defined as: "liquid which seeps through a landfill and, by so doing, extracts substances, including contaminants, from the deposited waste and may result in hazardous substances entering surface water, groundwater, or soil" [6]. Leachate might gather at certain baling machines and storm water might also occasionally occur, this occasionally causing a mild odour. This represents emissions in a liquid (liq) form.

Odour creates socio-economic problems for people living or working in and around a solid waste management (SWM) plant. In the case of excessive disturbance of citizens, for example, in the form of noise and odours, in combination with insufficient dialogue and public information, public opinion may force factory close-downs. In particular, this is possible when information

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regarding the relevant emissions is obsolete. This represents emissions in a gaseous (g) form.

Environmental and safety aspects of seasonal and long-term storage of baled municipal solid waste (MSW) to be used as fuel for energy production (waste fuel) in the cold season have been investigated. Experiments have also been carried out on the burning of bales [7, 8].

Literature search performed shows that earlier studies within the current field have dealt with, for example, the problem of translating polluting emissions into monetary units. Thereby, *shadow prices*, defined as: “the marginal reduction cost at the emission target level”, are elaborated and quantified for various environmental impact categories characterised by equivalents for certain substances [9].

Also emission externalities, defined as: “the costs and benefits that arise when the social or economic activities of one group of actors (people/firms) affect another group of actors and the effects are outside (‘external’) the pricing system”, are estimated in economic unit values per-kg-of-pollutant for both landfill and incinerator. Thereby, the final phase of the life cycle of a product - the disposal - is addressed since all alternative strategies of waste disposal result in externalities in various forms and levels [10].

In particular the baling-wrapping technology is studied as regards the physical, chemical and biological processes of a MSW landfill with respect to mainly the environmental impact of the emission of gases and leachate. Up to a certain maximal size, plastic-wrapped bales are found to be a promising option from an environmental point of view which resolves the problems of leachate and biogas generation [11].

Tsilemou and Panagiotakopoulos [12] have studied the general problems of cost estimation for planning MSW management systems, in particular in the light of only fragmented data available. Thereby, initial capital cost and operating cost functions are generated relevant for the following types of MSW treatment facilities: (i) waste-to-energy; (ii) composting; (iii) anaerobic digestion and; (iv) landfilling.

Cost-benefit analysis (CBA) is defined as a technique which attempts to set out and evaluate the social cost and social benefits of investment projects to help to decide whether or not the projects should be undertaken. Thus, CBA has been used to estimate the *social* cost of certain MSW disposal systems.

For example, the Danish deposit system for single use drink containers has been studied by Vigsø [13]. Thereby, the cans are suggested to be incinerated instead of recycled, this policy implying substantial social cost savings even though certain uncertainties exist, however being of minor importance.

This review of the state of the art of the field of research in question points at a substantial need to combine economic tools related to the daily use in a business administration context, with waste management matters. In particular, the prospect looks beneficial for studying possibilities to improve the financial situation from an environmental point of view with emphasis on the practical MSW baling reality.

Therefore, the main objective of *this* sub-scheme study is to apply the WAMED and COSTBUSTER models [14, 15] specifically to baling units, being a component in SWM schemes which end with, for example, incineration in general, to evaluate and improve their ecological-economic efficiency (ECO-EE) related to the impact of the expected emissions of the baling units on the SWM companies’ corporate economy regardless of the current extent of the emissions from the object of study. In particular, a decision-making tool is developed for appraisal of the costs of potential investments in baling facilities within a SWM scheme ending with, for example, incineration the main ambition being to study a baling sub-system within a major plant, such as a landfill that provides the baling machinery with the necessary raw material that also may be delivered from far away.

This study is constricted to accidental and unwanted pollution phenomena that sometimes in an exceptional way interfere with the operation of a baling scheme and have impact on the decision to invest in the scheme or not according to the principle of *management by exception.* The system-boundary encompasses the rather small baling-plant unit of interest only, not a whole landfill and possibly situated next to a power plant for production of heat and electricity. Thus, the methodology is not applied on the emissions from the final burning of the bales within a scheme ending with incineration since this stage represents the final phase of a regular, industrial process that can be controlled by, for example, commonly used smoke-absorbing devices to comply with the current laws and regulations. Also, if the monetary value of the emissions from the incineration of the bale-fuel in a combined heat and power plant is calculated and then compared with the emissions from the baling equipment and the very process for just producing the bales, then the latter emissions will be neglect able from an environmental point of view and not worth studying.

This effort promotes the energy supply in the form of electricity production from incineration of solid waste in combined heat and power (CHP) plants of 30 MW or above and an interest of 6% or below, this way of producing electricity being outstanding from a cost per kWh point of view if all taxes and other fees are deducted [16]. In doing so, the EUROPE model [17], based on *the equality* principle [18], is applied to common and unusual emissions and pollutions from such a baling plant in order to develop methods, based on financial incentives, to reduce the unwanted and sometimes harmful substances and to provide a tool for investment appraisal. In this context, the main question to be answered is what the potential investor should do with surplus money if the opportunity occurs to buy a baling-plant to be built, for example, within a landfill; what are all the different costs, including the environmental ones, in order to obtain a proper decision-basis to enable deciding to invest in sub-scheme baling-equipment or not? Previously, the EUROPE model has been applied to residuals from producing industry [18], the construction sector [17] and whole landfills [14] the general theory for the latter being outlined in co-operation with Moutavtchi *et al* [15]. As regards the process of development of models for waste management purposes, the foundation was presented by Stenis [17] and later combined with the works of Moutavtchi *et al*, in particular the WAMED model [15], so to analyze the applicability of these two models on landfilling in general [14] and finally, in the present paper, to the emissions from baling-units.

METHODOLOGY

In this article, a cost structure is proposed for evaluating and improving the ECO-EE of SWM baling-units, for example, with emphasis on the sub-scheme emissions from fires in bales (sol), from the leachate (liq) and from the odour (g). The system-limit of the study is set to the baling-plant itself only and not the whole integrated SWM scheme wherein it possibly is located. An introduction touches upon mainly practical difficulties in decision-making when implementing such a plant-unit. Relevant cost structures are then explored to enable evaluation and improvement of the ECO-EE of investing in complementary production of baled solid waste fuel at a SWM baling plant employing the previously introduced WAMED and COSTBUSTER models which are compatible with the developed theories of *the equality principle* and the EUROPE model which hence are introduced and applied in this context. Thereafter, the monetary consequences, i.e. the impact on the corporate economy of the emissions (sol) from the accidental burning of bales, pollutions (liq) from the leachate and annoyances (g) from the odour at a SWM baling plant are explored after a description of the used method. The case study that follows concerns a cost-based evaluation approach exemplified by data taken primarily from a power and district heating plant in Sweden and a baling-machine manufacturer, also in Sweden. Thereby, the environmental costs, the future remediation costs and the social costs are quantified in practice by the use of the accounting system of the company in question, its budgeting system and CBA respectively. The external monetary damages of various environmental loads are calculated for gaseous emissions by using the concept of Emission Factors (EF), for the leachate and stormwater from plants by data from the operation of real world plants and for the impact of odour by estimations based on the authors' professional experience. More precisely, in practice the damage stemming from baling plants are shown for gaseous emissions by the use of the profit and loss account of the company in question, for the impact of leachate and stormwater by data from relevant literature based on the study of real world plants during operation and for the expected impact of odour by the study of corporate forecasts, the realistic outcome when applying the models in the case study pointing on the favourable generality of this approach. After a discussion section, the theoretical provisions of evaluation of the ECO-EE are summarized in a conclusions and recommendations section. The evaluation of the ECO-EE of SWM schemes is based on CBA that employs the cost structure developed here and takes into consideration the recommendations of the full cost accounting (FCA) methodology.

EVALUATION OF THE COST STRUCTURE

Due to its rationality and flexibility, the FCA method is considered suitable as the basis for the cost structure theory build-up in the present work and as a part of an ECO-EE tool [14]. In this context, the FCA method is applied to integrated SWM plants considering the whole life cycle of solid waste by offering a certain set of elements.

The Waste Management Efficient Decision model - the WAMED model [14, 15] - for evaluation of the ECO-EE of a SWM scheme is a single-purpose, complex and short-period model for use on municipal and regional levels. The WAMED model evaluation procedure of the ECO-EE of such a SWM scheme as presented in Figure 1 takes into consideration the recommendations of the FCA method for SWM [19, 20] and could be presented according to Equation (1) that is modified after Moutavtchi *et al*. [15].

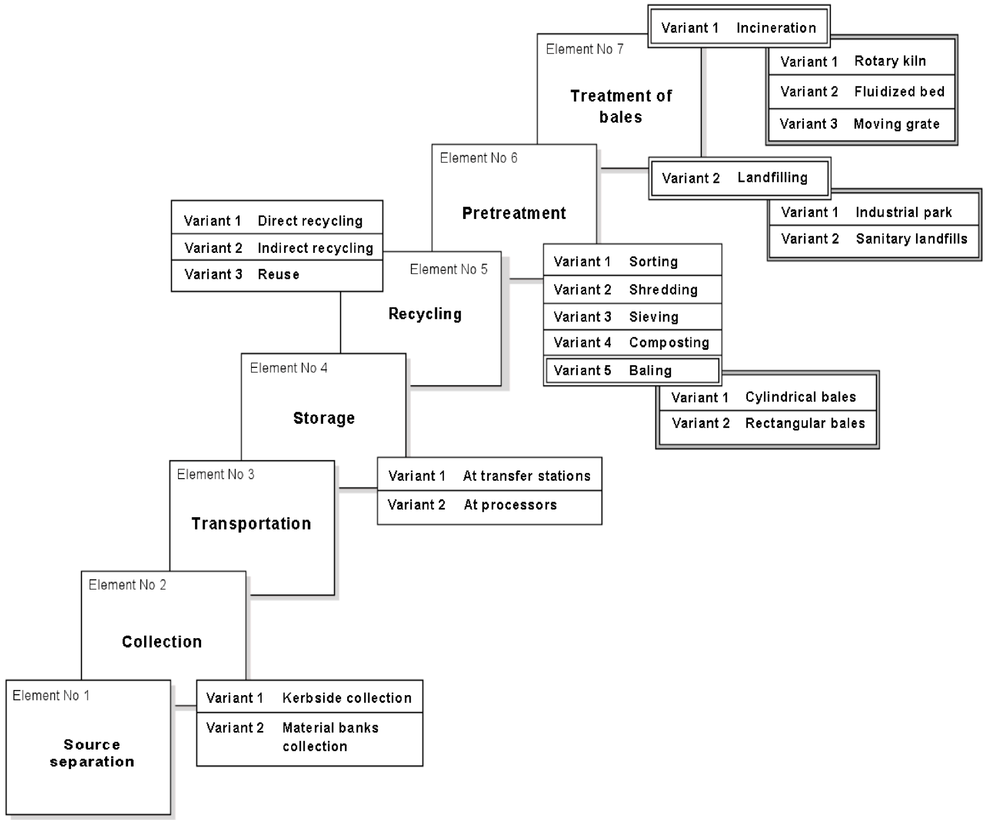

Fig.1: Elements of an integrated solid waste management scheme

The WAMED model is based on CBA theory, the essential difference between CBA and ordinary investment appraisal methods used by firms being the stress on the social costs and benefits. Thereby, the aim is to identify and measure the losses and gains in economic welfare which are incurred by society as a whole if the particular project in question is undertaken. Thus, CBA is considered to be suitable for encapsulating the majority of the different cost items, also intangibles, that is relevant to consider when evaluating the ECO-EE of a SWM plant.

$$C = GC_j = C_c + C_{tax} + C_{op} + C_r + C_{en} + C_t + C_i + C_{ec} + C_{fee} + C_{rem} + C_o, \quad (1)$$

Where
C =costs for implementation of a SWM plant;

Fixed Costs (FC)

C_c = capital outlays;
C_{tax} = costs for general, standardized and fixed, external, environmental taxes; and

Variable Costs (VC)

C_{op} = Operating costs;
C_r = Costs for extensive and routine repairs;
C_{en} = Costs for creating engineering networks (infrastructure);
C_t = Costs for creating the transport scheme servicing a SWM plant;
C_i = Costs for investment project services;
C_{ec} = Costs for actual monetary damage, including external and relative ad hoc taxes specifically based on actually occurring damage, caused by pollution of the environment;
C_{fee} = Costs for environmental punishment fees for prohibited actions;
C_{rem} = costs for remuneration of the public to make them accept pollution, e.g. lawsuits;
C_o = Other costs [14]
j = c, op, … , o

For most countries, the cost structure presented in (1) is regarded as normal and convenient in the practical implementation of SWM schemes.

The total cost, C, can be deducted from the current or estimated total plant revenue giving the gross profit. A plant for incineration of waste directly at the reception of the waste is the main technical alternative to a baling plant. The gross profits of these main alternatives may then be compared in order to estimate the relative profit abilities for the investment alternatives to facilitate investment appraisal.

The size and extent of the current SWM plant can be expressed in relative terms by Equation (2). Such an indicator compares the size and extent of the current SWM with the total size of the average budget of a SWM actor of a certain kind and is based on generally applicable statistical facts for the size and extent of "C". Thus, for purposes of facilitating SWM project appraisal, the additional information obtained about the relative size of the costs of the studied plant could be useful in order to obtain an adequate basis of information for enabling reliable decision-making.

$$R = C / Tc_{avg} \quad (2)$$

where

R = Relative size and extent of the current baling plant of a certain kind;

C = GC_j = sum of the sub-costs of the studied baling actor of a certain kind and;

TC_{avg} = Total cost of the average baling actor of a certain kind chosen, if possible including its monetary value of damage, according to the needs of comparison of the current task [14];

j = c, op, … , o

Equation (2) is termed the COmpany STatistical BUSiness Tool for Environmental Recovery indicator (the COSTBUSTER indicator). This mathematical indicator model representation is based on the WAMED model and expresses its implications for SWM plant relativistic studies. The acronymic name of the indicator (COSTBUSTER) mirrors the ambition of the authors to reduce the internal costs for the company in question as well as the costs for improving the environment.

In the WAMED model, evaluation of the ECO-EE of a SWM plant expresses, in an explicit form, assessment of the monetary damage that appears by degradation of lands, pollution of surface water, groundwater and the atmosphere, spreading of diseases (among the population and the personnel) and disturbance of landscapes. The obligatory inclusion of these in the calculation is the main feature of the model [14].

An approach that is termed the "equality principle" [18] forms the basis for the forthcoming discussion. This principle induces a shift in paradigms that involves equating industrial waste with normal products in terms of the allocation of revenues and costs. Otherwise, the process of achieving an environmentally sound industry can be unacceptably slow. Thus, a new way of looking at waste is needed.

Thereby, the waste fractions studied are regarded as a company's output. This approach is mathematically considered in equation (3) and used for the *additional* allocation of revenues and fixed as well as variable costs to a certain waste fraction through multiplication by the costs or revenues in question that are to be *additionally* allocated by splitting them up in their proper proportions. Thus, equation (3) constitutes the mathematical expression of the *equality principle.* The shift in paradigms imply the allocation of also fixed costs to the residual products, this mirroring the novel attempt to enhance the status of the residuals in financial terms to the same level as regular products.

$$PF = X / (Y + Z) \quad (3)$$

where

PF = The proportionality factor;

X = The quantity of a certain waste fraction produced;

Y = The quantity of normal product output and;

Z = The sum of the quantities of all the different waste fractions produced.

A suitable production or administrative unit must be defined, depending on the circumstances, when applying equation (3) that represents the economic implications of the equality principle and is termed *the model for Efficient Use of Resources for Optimal Production Economy* (EUROPE) [17]. In this context, the term optimal refers to a simultaneous optimization of the production economy, the technology used and the environmental impact of the production process in question.

Here, it is proposed that C, the costs for implementation of a SWM baling plant, is *additionally* allocated to the accidental emissions from open burning (sol), from leachate pollution (liq) and from the odours of solid waste bales (g), through the creation of additional *shadow prices* or *shadow costs*, obtained by multiplication of C with PF. By adding the *shadow costs* to the total costs of the plants, a kind of punishment is obtained for not managing the business optimally in an environmentally sense. Otherwise, if no addition had taken place, the application of the EUROPE model would just mean a common redistribution of costs within the company's total output. That would not induce the same economic incentives to improve the ecological footprint of the plant in question in particular during its operation. Thereby, the *shadow costs* are added to the original total costs of the businesses in order to increase the economic incentives to improve the environment by making the production process more efficient in terms of the baling-machinery, the logistics for handling of the bale-heaps and the environmental conditions that may be improved by, for example, additional wrapping of the bales in order to decrease the emissions [2, 5, 7, 11]. In practice, the *shadow costs* are supposed to be applied throughout the accounting system of the firms; they should occur in the estimations, in the budgets and the forecasts, yes everywhere where the unwanted pollutions show up in the internal economic system of the company.

Thus, this approach induces economic incentives for the reduction of solid, liquid and gaseous emissions, one possible case being schemes that end with incineration. Therefore, the terms according to Equation (3) here denote the following phenomena on an annual basis:

X = Monetary damage value of a certain emission produced;
Y = Monetary value of the SWM plant's regular output in normal operation; and
Z = Monetary damage value of all the different emissions produced.

The general process of evaluation of the ECO-EE in monetary terms that is applied here for baling at a SWM plant, is summarized by Moutavtchi *et al.* [14]

However, this study proposes that *weighting* can be used to adjust the costs associated with a particular type of waste to its environmental impact, based on scientific evidence and/or in terms of overall societal aims. For example, a factor of 1.2 can be used in combination with the initially obtained additional *shadow cost* if a certain emission or pollution, by the authorities or the company's management, is considered being so harmful to justify a 20% mark-up to provide an extra incentive to reduce its existence. Also, weighing may be applied in order to make certain resulting *shadow costs* comprehensible enough to be used together with *shadow cost* for other kinds of emissions and pollutions than the one having such a large *shadow cost* that the *shadow costs* of other substances are almost neglect able. However, the major point with using the concept introduced here is to provide management with a tool to improve the efficiency in the utilization of the inputs of the company in question and, at the same time, monitoring the improvement of this process, the obtained *shadow costs* being mainly a virtual, financial construction to achieve the goal of an improved ECO-EE and increased profits. Thus, what can be termed "environmental shadow prices" [17] should be used in combination with the cost allocation principle in defining environmental standards. As always, the personal judgement of managers is crucial, in the case of applying weight factors depending on the manager's ability to employ different factors that level the different *shadow costs* in order to finally obtain a set of *shadow costs* that are comparable without any major deviations. To conclude, the previous works by Stenis [17, 18] are here combined with the recent modelling-efforts by Moutavtchi *et al.* [14, 15] in order to provide the tool presented here for enabling estimation of the monetary value of the emissions and pollutions from a baling unit if such equipment is necessary to evaluate as regards cost when a decision must be made whether to invest in such equipment or not.

MEASURMENTS OF EMISSIONS AND POLLUTIONS

Accidental Open Burning (SOL): In the case of accidental fire in bale storages, open burning emission data may be applied when performing calculations on emission impacts. Emission data from open fires can be presented, for example, as emission factors (EFs) in the form of the mass of pollutant emitted per unit mass of material burned [8, 21]. The EFs are listed in Table 1 for the relevant open burning solid waste sources. Mainly, the data for costs per kg stem from the Norwegian study ECON (1995), later applied in the ORWARE model [21]. In Chapter 5, the principles are described of how to apply the EFs in combination with the EUROPE and the WAMED models.

Pollutions (liq) from Leachate: At the baling-plant level, the severity of the environmental impact of the leachate can be classified according to the treatability and the polluting impact of the leachate (Table 2). Thereby, the monetary values for a baling-unit under certain levels of environmental impact of the leachate are estimated through the use of data from the daily operation of real world plants for the treatment of waste waters.

Table 1: Criteria pollutant EFs (g/kg) and the connected monetary values (€/unit) (€1 = SEK9.2, July 2006) for the main pollutants from open burning of solid waste

Solid waste source	Particulate	SOx	CO	TOCmeth	NOx
EF (g/kg) [21]	83	0.5	42	6.5	3
€/kg[2] (mean value)	12.23	4.17	0.13	1.26	3.86
EF * €(€/kg)	97.83	2.09	5.34	8.20	11.58

Table 2: Estimated monetary values (€1 = SEK9.2, July 2006) for the environmental impact in monetary terms (€/m3) of the leachate from baling schemes [23]

Impact category:	No. 1	No. 2	No. 3	No. 4
Characteristics of the impact category level	Possible to direct the leachate and stormwater to municipal sewage treatment plants	Environmentally based methods for local treatment of the leachate and storm water	Moderate to high concentrations of polluting leachate and stormwater	Severe pollution by leachate and stormwater
Monetary value of the impact level for one solid waste baling scheme plant	€1/m3	€1.5–2.0/m3	€3–5/m3	€7–15/m3

Table 3: Estimated monetary values (€) (€1 = SEK9.2, July 2006) for the impact of the smell from baling schemes

Impact category:	No. 1	No. 2	No. 3	No. 4
Characteristics of the impact category level5	No smell at all	Reasonable smell requiring:· information meetings with advertisements work stoppage· at certain wind directions	Severe smell requiring reconstruction with filter installations	Very severe smell requiring plant closure, causing higher electricity price
Monetary value of the impact level for one solid waste baling scheme plant estimated by the authors	0	200/labour hour400/information meetings, advertisements and expert talk	50,000	2,000,000

Emissions (g) from Odours: At the baling-plant level, the severity of the environmental impact of the smell can be classified according to the strength of the public reaction (Table 3). Thereby, the presented monetary values for the impact of smell from a baling-unit are based on the extensive professional experience of the authors.

CALCULATION OF THE ENVIRONMENTAL LOAD

When the environmental load in monetary terms from gaseous (g), liquid (l) and solid (s) emissions from a sub-scheme baling unit is calculated, the following procedure is applied:

- The WAMED model provides C = the sum of the costs for implementation of the SWM baling scheme (Equation 1).
- The COSTBUSTER indicator (Equation 2) is applied on the current SWM baling scheme, so to investigate its relative size compared with the average scheme in the relevant branch and plant-category.
- The EUROPE model (Equation 3) provides the Proportionality Factor (PF) for the gaseous (g), liquid (l) and solid (s) emissions and pollutions of importance from the sub-scheme baling unit in question according to equation 4.

PF_x = (EF_x *$€_x$ * the amount of the studied substance * the risk factor) / (monetary value of the SWM plant's regular output in normal operation + monetary damage value of all the different emissions produced at the plant) (4)

- Multiplication of the different PFs with C, the sum of the costs, provided by the WAMED model gives the monetary *shadow cost* values to additionally allocate to the emissions and pollutions of different kinds from the plant in question.
- Monetary values, related to the different kinds of emissions and pollutions, are allocated per unit (C * PF_x / unit) in order to obtain the final *shadow costs* to additionally allocate to the current units of emissions and pollutions so to initiate extra economic incentives to reduce the existence of these unwanted substances.
- If considered necessary, weight factors (wf) are applied in order to make certain *shadow costs* comparable to the majority of the obtained *shadow costs* for enabling of its practical use.

Thus the final formula reads as follows to obtain the additionally allocated *shadow cost* per unit of the unwanted emission or pollution from the current plant.

The *shadow cost* per unit (€) = C * PF_x / unit = (C * EF_x * $€_x$ * the amount of the studied substance * the risk factor / unit * wf) / (monetary value of the SWM plant's regular output in normal operation + monetary damage value of all the different emissions produced at the plant) (5)

Where

C = The sum of the costs for implementation of the baling plant (Eq. 1).
PF = Proportionality Factor = X / (Y + Z) (Eq. 3)
EF = The Emission Factor for a certain substance
€ = The monetary value connected to the criteria pollutant (EF)
wf = The weight factor

CASE STUDY

CBA for Solid Waste Baling Schemes: The theory introduced in this paper is tested in practice by the use of information from a power and district heating plant and a baling machine manufacturer, both in Sweden. The latter supplies the former with equipment.

The theoretical basis of the "cost" approach evaluation of the ECO-EE of the MSW management plants, according to the WAMED model concept, has enabled evaluation of the cost items for the year 2006. This data is used to construct a fictional but representative example of a combined heat and power (CHP) plant of 50 MW giving approx. 20 GWh of electricity annually. Accordingly, even though the system boundary of the current study encompasses the very equipment of the baling-plant unit itself in question only, due to the emissions, this fictional plant example is assumed to be supplied by a baling plant providing the necessary fuel in the form of annual production of 20,000 round bales, each weighing 800 kg and consisting of industrial waste to be incinerated.

The calculations are performed for the fire-related emissions SO_x and NO_x, because of the big general attention in the public debate to these substances in combination with their relatively large EF and their large connected monetary value according to US EPA [21] and Sundqvist [22] pointing in the direction of SO_x and NO_x being important substances to study. Calculations based on data for two gaseous substances only (SO_x and NO_x) are considered sufficient to demonstrate the general usefulness of the approach that is introduced here and simplifies the presentation. A probability of 27% for fire accidents is applied as a most extreme and very unlikely, worst case, this figure being representative for all Swedish landfills during 2002, mainly due to self-ignition [24]. A weight factor of 1/100,000 is applied for specifically the fire-related emissions to make its allocated *shadow costs* comparable to the other studied substances.

Also, it is assumed that it is possible to direct the leachate and the stormwater to municipal sewage treatment plants. A local annual precipitation of 500 mm over the plant area of 4000 m^2 is assumed to give rise to storm water and leachate. This gives an assumed, maximal total annual storm water and leachate volume of 2000 m^3.

Furthermore, as regards emissions of odours, a state of "reasonable smell" is assumed. Finally, four weeks work stoppage is assumed annually during summertime because of this "reasonable smell". An exchange rate of €1 = SEK 9.2 (July 2006) is assumed throughout.

Application of the WAMED model, according to Equation (1), to the fictional SWM scheme, gives the following estimate (k€) on an annual basis:

C = GC_j = sum of the costs for implementation of the SWM baling scheme = $C_c + C_{tax} + C_{op} + C_r + C_{en} + C_t + C_i + C_{ec} + C_{fee} + C_{rem} + C_o$ =
= 73 + 0 + 247 + 65 +1 + 0 + 16 + 11 + 0 + 9 + 16 =438;

Fixed Costs (FC)

C_c = Capital outlays for land acquisition, construction of the main facilities, buildings and ground works, machinery and trucks and intangibles, such as software = 73;
C_{tax} = Costs for environmental, fixed, external and standardized taxes (combustion and landfill tax) = 0, as such taxes are not referable to the baling activity specifically; and

Variable Costs (VC)

C_{op} = Operating costs such as those for energy, salaries, insurances, leakage and air pollution costs, plus k€139 for annual depreciation = 247;
C_r = Costs for repairs and maintenance of baling machinery and front loaders = 65;
C_{en} = Costs for creating engineering networks such as technical installations (light, sewerage, etc.) = 1;
C_t = costs for creating the transport scheme servicing a SWM baling scheme = 0 (no lorries to be used in this specific case);

C_i = costs for project services such as research and design, local EPA permissions and certification and training of the personnel = 16;
C_{ec} = costs for actual damage, including costs for pollution and cleaning of water and leachate and plant cleaning plus insurance cost increases due to accidents = 11;
C_{fee} = costs for environmental punishment fees = 0;
C_{rem} = Costs for remuneration of the local population to make them accept pollution, e.g., lawsuits = 9;
C_o = Other costs for estimated miscellaneous expenses = 16
j = c, op, … , o

Application of the COSTBUSTER indicator to the current SWM baling scheme, to investigate its relative size, yields:

$C = \sum C_j = C_c + C_{tax} + C_{op} + C_r + C_{en} + C_t + C_i + C_{ec} + C_{fee} + C_{rem} + C_o$ = k€438 = total annual cost of the current fictional SWM baling scheme;

Tc_{avg} = current total annual cost of the average Swedish SWM baling scheme, excluding its monetary value of damage, (at a production rate of 20,000 bales / year weighing 825 kg / bale @ €20/tonne) = k€330; and
R = k€438 / k€330 = 133%.

In Equation (3), Y = k€652 (20,000 bales produced annually at a revenue of €32.6 (SEK 300) each), while Z = approx. k€39 (all the five fire-related emissions taking a 27% fire risk and a weight factor of 1/100,000 into account: k€5.4; leachate pollutions: k€2; and odour emissions: k€32). Equation (3) gives the following results for: (a) the SO_x and NO_x related emissions (sol) from a fire, (b) the pollution (liq) from leachate and (c) the emissions (g) of odours.

- a $PF_{burning}$ for the SO_x emissions, as an example (Table 1) = ((0.5 g SO_x / kg waste * €4.17 / kg waste / 1000 g / kg waste / €1000 / k€ * 20,000 bales / y * 800 kg / bale) * 27% fire risk) / (k€652 + k€39) = k€9.0 / (k€652 + k€39) = 0.013
- b $PF_{burning}$ for the NO_x emissions, as an example (Table 1) = ((3 g NO_x / kg waste *€3.86 / kg waste / 1000 g / kg waste /€1000 / k€* 20,000 bales / y * 800 kg / bale) * 27% fire risk) / (k€652 + k€39) = k€50.0 / (k€652 + k€39) = 0.072
- $PF_{leachate}$ for 2000 m^3 leachate for case No. 1 (Table 2) = (€1 /m^3 stormwater and leachate * 0.5 m precipitation / m^2 * 4000 m^2 total area) / (k€652 + k€39) = k€2 / (k€652 + k€39) = 0.003
- PF_{odours} for case No. 2 (Table 3) = (((€200 / labour hour * 4 weeks labour lay down * 5 days/week * 8 hours / day) + (€400 / information meeting, advertising and expert talk * 1 event)) / €1000 / k€) / (k€652 + k€39) = k€32 / (k€652 + k€39) = 0.046

Thus, the following *total* amounts of money are to be *additionally* allocated to the four different kinds of emissions and pollutions respectively.

- a) Amount to allocate to the SO_x fire-related emissions (sol) = $PF_{burning}$ * C = k€5.71
- b) Amount to allocate to the NO_x fire-related emissions (sol) = $PF_{burning}$ * C = k€31.69
- Amount to allocate to the pollution (liq) from stormwater and leachate = PF_{water} * C = k€1.26
- Amount to allocate to the emissions (g) of odours = PF_{odours} * C = k€20.28

Thus, the following amounts of money, related to the three different kinds of emissions and pollution, respectively, are to be allocated *per unit* to the different substances in the waste management scheme.

- a) Amount to allocate per kg SO_x for the SO_x fire emissions (sol) = ($PF_{burning}$ * C = (k€9 / k€691) * k€438 = 0.013 * k€438 = €5705 / (0.5 g SO_x (EF) / kg waste / 1000 g / kg * 20,000 bales * 800 kg / bale) = €0.71 per kg SO_x. Alternatively: the amount to allocate per tonne of waste for the SO_2 fire emissions = ($PF_{burning}$ * C) / (20,000 bales * 800 kg / bale / 1000 kg / tonne) = €0.36 per tonne waste
- b) Amount to allocate per kg NO_x for the NO_x fire emissions (sol) = ($PF_{burning}$ * C = (k€50 / k€691) * k€438 = 0.072* k€438 = €31693 / (3 g NO_x (EF) / kg waste / 1000 g / kg * 20,000 bales * 800 kg / bale) = €0.66 per kg NO_x. Alternatively: the amount to allocate per tonne of waste for the NO_x fire emissions = ($PF_{burning}$ * C) / (20,000 bales * 800 kg / bale / 1000 kg / tonne) = €1.98 per tonne waste
- Amount to allocate per m^3 leachate for the pollution (liq) from the leachate = $PF_{leachate}$ * C = (k€2 / k€691) * k€438 = 0.003 * k€438 = €1268 / (4000 m^2 total area * 0.5 m precipitation / m^2 / year) = €0.63 per m^3 leachate

- Amount to allocate per tonne waste to the emissions (g) of odours = PF_{odours} * C = (k€32 / k€691) * k€438 = 0.046 * k€438 = €20284 / (20,000 bales * 0.8 tonne/bale) =€1.27 per tonne waste

DISCUSSION

The basic thrust of this study has been to provide the foundation of a practically useful tool in economic terms when decisions are needed about whether to invest in complementary solid waste baling equipment or not. Thereby, the ECO-EE is evaluated in monetary terms in order to review the existing or expected costs to consider based on CBA that stresses social costs and benefits.

Baling, of course, is a subsystem among others in MSW management schemes. The system limit in question restricts the study to a more manageable size and enables the estimation of the environmental impact of, for example, gaseous emissions from burned material, leachate and odours also in economic terms.

In this respect, the objective of the study to apply the WAMED and COSTBUSTER models to SWM plants in general to evaluate and improve the ECO-EE is fulfilled, the strength and novelty of the methodology being its general adaptability to the circumstances at hand and the aggregation level of the current plant. Thereby, the application of weight factors on pollution-phenomena of certain need enables management to elaborate the span of shadow cost so to achieve reasonable and comparable sizes for the resulting *shadow costs*. The shortcomings of the model mainly lie in the wide span of the input data and monetary values used for estimating the environmental impact of the emissions and pollutions in monetary terms. However, the applied concept of weighting alleviates this deficit.

Earlier investigations as regards monetary evaluation of emissions in, for example, the Netherlands [9] have studied optimal levels of pollution and its corresponding *shadow price* for the major environmental impact categories. Israeli studies [10] highlight the costs of landfill and incineration externalities and the main polluting substances.

However, these attempts to express the environmental damages in monetary terms do not provide the CBA approach of this study based on the listing of all the kinds of costs encompassed in the WAMED model which provides a sufficient cost review as a decision basis when estimations for possible investment options in SWM plant schemes are made. Neither do these earlier works enable the allocation of *shadow costs* to the pollutants adapted to the corporate realities of the internal economy of a company that the application of the EUROPE model makes possible. Also, the EUROPE model constitutes a tool for monitoring the progress of the work for a better environment expressed in monetary units which in the baling plant context can be used for quantifying this development and hence enables measuring of the process.

Spanish studies [11] of the baling-wrapping process are in favour of rectangular bales compared to conventional landfills. Unit costs per tonne for plastic-wrapped bales and landfills are estimated. In Greece, the cost structure of selected types of solid waste treatment and disposal facilities, relevant to European states, have been estimated [12]. Danish studies [13] based on CBA have compared the social costs and environmental benefits of the deposit system with the municipal waste disposal system with emphasis on certain consumer facilities in order to decide whether the costs in the deposit system are justified from an environmental benefit point of view.

However, these three latter studies do not employ a framework for estimating *shadow costs* that give incentives to improve the environmental performance, nor do they provide a comprehensive cost review to base, for example, an investment decision on or to monitor the business activities which the cost allocation by application of the EUROPE model enables. Thus, the present study represents a novel and useful approach as regards evaluating and optimizing the ECO-EE of a baling plant-unit in economic terms. The case study provides realistic results when the WAMED model and the COSTBUSTER indicator are applied. The latter model gives a 133% relative size for the scheme studied, showing that this plant is rather large, however not *too* large to deter from possible investments. In case the COSTBUSTER indicator indicates an unreasonable large baling-unit to build, the manager in charge should seriously consider resizing the intended investment. As always, the personal judgement is crucial for a successful management.

When applied to the emissions and pollutions studied, the *equality principle* and the EUROPE model also produce reasonable and consistent results as regards the additional monetary amount to allocate to the emissions and pollutions studied. Therefore, if applied and integrated in practice in the companies' internal accounting, budgeting and forecasting systems etcetera, these additional *shadow costs* give management a practically useful tool to monitor their company's environmental performance over time in monetary terms. In this context, the allocation of also *fixed* costs to residuals is a novelty. It should be noted that a linear relationship exists between the sum of the costs (C) for a baling-plant and the *shadow costs* that are allocated to such plants by applying the EUROPE model in combination with the WAMED model according to the present findings.

The suggested methodology also induces *shadow cost*-based economic incentives that would act to reduce substantially the emissions and pollutions to which management, by using the EUROPE model, might attribute extra importance. In this context, the possibility of applying *weights* allows the authorities, as well as management, for example, to take into account certain concerns about reducing, in particular, the existence of certain negative phenomena by allocating even more economic incentives, hence creating *shadow costs* for these unwanted phenomena.

The possibilities of using this methodology on the regional and even global scales should be investigated and the methodology made to encompass, for example, the environmental impact on air, soil and water due to significant pollutants. This would be possible objectives for *further research*. Moreover, the developed methodology may be adapted to estimation of the economic value and environmental impact of waste management schemes in the perspective of resource economy optimisation on the societal and global levels. Also, it should be investigated if the methodology can be used for estimating the proper amounts of carbon dioxide tax and similar expressions of the human ecological footprints in the SWM context. However, carbon dioxide is mainly of importance for the climate debate, but precisely this aspect could be considered within the scope of another study, not in the context of minor baling-unit machinery plants. Thus, further research can also be performed concerning how the WAMED model, the COSTBUSTER model and the EUROPE model can be applied on the emissions from the combustion from the very bale-burning itself.

Possible *End Users* for the Methodology and the Related Major Aspect of Importance Would Be as Follows:

- Parties wanting to estimate and monitor the ECO-EE of a SWM baling plant with respect to the estimated, occurring and prevented emission and pollution levels, expressed in monetary terms;
- Local authorities, such as local EPAs, wanting to apply environmental legislation;
- National governments wanting to design new environmental legislation;
- Environmental courts that fix punishments related to the current environmental impact and;
- Plant owners wanting an investment appraisal tool about, for example, a baling plant that takes into account views of the plant neighbourhood, to avoid, for example, protest actions and mass hysteria;

CONCLUSIONS AND RECOMMENDATIONS

This paper is aimed at studying the economics of SWM baling plants and it shows utility when, in practice, focusing on economic and emission- and pollution-related aspects of SWM. The developed methodology induces a more efficient and sustainable use of natural resources through providing economic incentives that promotes waste reduction at the source. *The main features* of the research performed are as follows:

- It decreases the negative impact of solid waste on the environment and the health of the population by reflecting an integrated approach to solving these problems simultaneously.
- It provides a generally applicable investment appraisal support tool for the implementation of SWM projects through increasing the economic benefits at both the corporate, municipal and regional levels.
- It enables the carrying out of the comparative analysis, in monetary terms, of the estimated, actual and prevented monetary damages from the implementation of a sub-scheme plant unit.
- It increases the efficiency of the use of natural resources, in particular as regards the utilization, recycling and reuse of material and immaterial resources such as energy.
- It provides a performance indicator for the project in question in terms of its economy, the efficiency of the technology used and the project's environmental impact through the development by time of the current *shadow costs.*
- A linear relationship exists between the total sum of the costs (C) of a baling-scheme and the *shadow costs* that are allocated to the related emissions and pollutions from the baling-unit in question by application of the WAMED and the EUROPE models.

- The EUROPE model can, when combined with the WAMED model, be applied to landfilling in general and the emissions and pollutions from, for example, sub-scheme baling-units as well as to producing industry and the construction sector.

The case study performed, investigating the practical application of economic models on a Swedish SWM baling plant-unit, shows utility for evaluation of the ECO-EE of the studied unit. In particular, the results from the case study point in the direction of promising possibilities for the allocation of *shadow costs* to emissions and pollutions from a SWM baling plant, based on use of the EUROPE model, which in turn is based on the *equality principle*, in combination with the WAMED model.

Based on the Analysis Performed, the Following *Recommendations* Are Made:

- Application of the WAMED and COSTBUSTER models to SWM schemes as well as to sub-schemes costing is recommended in general.
- When deciding to invest in SWM sub-scheme plant units, in particular baling equipment, the EUROPE model is recommended for economic estimation of the emissions from accidental burning of bales, pollution by leachate and odour at a SWM baling scheme in order to, by induced economic incentives, reduce such unwanted and sometimes harmful substances.
- Thereby, public complaints against realization of waste management schemes should be foreseen and dismantled by taking proactive measures based on precautionary estimations of the environmental impact of the scheme in monetary terms.

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