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Assessment of economic instruments for countries with low municipal waste management performance: An approach based on the analytic hierarchy process

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Abstract

Economic instruments provide significant potential for countries with low municipal waste management performance in decreasing landfill rates and increasing recycling rates for municipal waste. In this research, strengths and weaknesses of landfill tax, pay-as-you-throw charging systems, deposit–refund systems and extended producer responsibility schemes are compared, focusing on conditions in countries with low waste management performance. In order to prioritise instruments for implementation in these countries, the analytic hierarchy process is applied using results of a literature review as input for the comparison. The assessment reveals that pay-as-you-throw is the most preferable instrument when utility-related criteria are regarded ($w_b = 0.35$; analytic hierarchy process distributive mode; absolute comparison) mainly owing to its waste prevention effect, closely followed by landfill tax ($w_b = 0.32$). Deposit–refund systems ($w_b = 0.17$) and extended producer responsibility ($w_b = 0.16$) rank third and fourth, with marginal differences owing to their similar nature. When cost-related criteria are additionally included in the comparison, landfill tax seems to provide the highest utility–cost ratio. Data from literature concerning cost (contrary to utility-related criteria) is currently not sufficiently available for a robust ranking according to the utility–cost ratio. In general, the analytic hierarchy process is seen as a suitable method for assessing economic instruments in waste management. Independent from the chosen analytic hierarchy process mode, results provide valuable indications for policy-makers on the application of economic instruments, as well as on their specific strengths and weaknesses. Nevertheless, the instruments need to be put in the country-specific context along with the results of this analytic hierarchy process application before practical decisions are made.

Keywords

Waste management, analytic hierarchy process, multi-criteria decision making, economic instruments, landfill tax, pay-as-you-throw (PAYT), extended producer responsibility, deposit–refund systems

Introduction

The key vision of the European waste legislation is to move the European Union (EU) away from linear production and consumption patterns towards a circular model. This vision is addressed in several pieces of EU legislation on waste and broken down to specific objectives such as supporting waste reduction and high-quality separate collection of waste, increasing recycling rates and eliminating landfilling of recyclable waste in order to close the loop and minimise negative environmental impacts (European Commission, 2014a). In particular, the envisaged ambitious targets to eliminate landfilling and increase recycling rates will be challenging for some EU Member States (MS) and EU candidate countries owing to their comparably low municipal waste management performance. There is a high degree of similarity in the waste management situation among these countries. According to BiPRO (2013), characteristics of the countries' low waste management performance include a high dependence on landfilling of municipal waste, a high share of biodegradable waste going to landfills, insufficient separate collection of recyclables, as well as problems with planning and practical implementation/enforcement of waste legislation. In order to overcome these obstacles, countries with good waste management performance (meaning that (EU) waste legislation is implemented and enforced for a long time and formal recycling infrastructure exist in these countries) apply a variety of policy instruments, such as planning instruments (e.g. waste management plans), regulatory instruments (e.g. restrictions and bans), administrative instruments (e.g. guidance documents) and economic instruments (e.g. taxes) (BiPRO, 2013). Economic instruments, especially compared with regulatory instruments, provide

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significant advantages to improve the waste management situation while maintaining a higher economic efficiency (Linscheidt, 1998) as involved actors can independently decide and act on how to fulfil the requirements or to benefit from the incentives set by the instrument (Rogall, 2002).

This research shall further extend the knowledge basis of applying economic instruments in waste management in countries with low municipal waste management performance. There are studies that analyse the relationship between waste management performances of EU MS and their use of economic instruments (Watkins et al., 2012), list selected policy instruments applied in the EU and their reduction possibilities for environmental impacts of waste management (Tojo et al., 2008), or compare economic instruments applied in selected Organisation for Economic Co-operation and Development (OECD) and Latin American countries (Schlegelmilch et al., 2010). These studies present information on economic instruments but did not specifically rank them. Nevertheless, a prioritisation of instruments and clear recommendations on which economic instruments bring the most benefits for countries with low municipal waste management performance is very useful considering the financial limitations in these countries. This shall be the particular research objective of this research. A ranking of economic instruments is classified as a problem of complex decision-making with multiple criteria influencing the final result and hence needs to be performed under consideration of rationality (Eisenführ et al., 2010). A suitable methodology is needed to properly assess and prioritise economic instruments in waste management. The analytic hierarchy process (AHP) is thereby an approach of multi-criteria decision-making that enables a ranking of different alternatives evaluated according several criteria (Saaty and Vargas, 2012). The AHP has proven to be useful in ranking policy instruments, but the approach of this research to apply this method on ranking economic instruments in waste management is new.

Material and methods

An assessment of economic instruments in waste management, with respect to a defined goal, can be classified as a process of complex multi-criteria decision-making. Following Bechmann (1978), a cost-utility or use-value analysis is a suitable option to prioritise several complex action alternatives based on the preferences of the decision maker and with regard to a multi-criteria system of objectives. The AHP, as developed by the economist Thomas L Saaty in the 1970s, is an extended or at least closely related form of use-value analysis, which is able to concurrently consider qualitative and quantitative comparison criteria and where a lot of baseline research literature is available. Therefore, the AHP is seen to be more suitable for this research than cost-benefit analyses and other forms of multi-criteria decision-making tools.

Modelling of hierarchy

The modelling of the decision problem in the form of a hierarchy significantly influences the outcome of the AHP. Actual conditions and relevant details concerning the decision problem have to be considered carefully while setting up the hierarchy (Meixner and Haas, 2009). The highest level of the decision hierarchy is the main goal of the decision problem. It is followed by criteria that influence the decision-making process in the second level of the hierarchy, where potential alternatives have to fulfil these criteria in order to reach the main goal. The decision hierarchy can contain quantitative and qualitative criteria. The decision maker may subjectively decide which aspects to include as relevant criteria tailored to the decision problem (Saaty and Vargas, 2012). Nevertheless, there are general requirements for 'target systems' in multi-criteria decision-making processes to be fulfilled, such as completeness, non-redundancy, measurability, preference independency and simplicity (Eisenführ et al., 2010).

Weighing of criteria

Having identified relevant criteria for the decision problem in the hierarchy, the decision maker weighs those criteria according to his/her preferences. The weighing is conducted via a pair-wise comparison between the identified criteria of a same level, with respect to the next higher level in the hierarchy. This is successively repeated, beginning at the highest level of the hierarchy, until all sub-criteria have been weighted with respect to their superior criteria. A comparison matrix A is used, with the format $n \times n$, where n is the number of criteria considered. Each entry in the matrix displays the relative importance between the compared criterion i and the criterion j (Saaty, 1980). If $a_{ij} > 1$ it is assumed that the criterion i is more important than the criterion j and vice versa. If both criteria are equally important, then $a_{ij} = 1$ applies. Furthermore the constraint $a_{ij} \times a_{ji} = 1$ has to be satisfied. Besides, the general axioms of the AHP have to be considered at this point, e.g. the horizontal independency of elements at the same hierarchy level (criteria and alternatives) (Meixner and Haas, 2009). The comparison matrix A and its formal assumptions are displayed in the following matrix (Peters and Zelewski, 2002):

$$A = \begin{bmatrix} a_{11} & \dots & a_{1j} & \dots & a_{1n} \\ \dots & \dots & \dots & \dots & \dots \\ a_{i1} & \dots & a_{ij} & \dots & a_{in} \\ \dots & \dots & \dots & \dots & \dots \\ a_{n1} & \dots & a_{nj} & \dots & a_{nn} \end{bmatrix}$$

$$\forall_i = 1,\dots,n \,\forall_j = 1,\dots,n : a_{ij} > 0$$

$$\forall_i = j : a_{ij} = 1$$

$$\forall_i = 1,\dots,n \,\forall_j = 1,\dots,n : a_{ij} = a_{ji}^{-1} \tag{1}$$

The total amount of required comparisons is $(n*(n-1))/2$. All comparisons between the same criteria $a_{11}, a_{22}, \dots, a_{ij}$ equal 1. This means that all elements of the matrix's main diagonal equal 1. Owing to the assumption that each comparison is

Table 1. The fundamental scale (Saaty and Vargas, 2012).

Intensity of importance	Definition	Explanation
1	Equal importance	Two activities contribute equally to the objective
2	Weak	
3	Moderate importance	Experience and judgement slightly favour one activity over another
4	Moderate plus	
5	Strong importance	Experience and judgement favour one activity over another
6	Strong plus	
7	Very strong or demonstrated importance	An activity is favoured very strongly over another, its dominance demonstrated in practice
8	Very, very strong	
9	Extreme importance	The evidence favouring the activity over another is of the highest possible order of affirmation
Reciprocals of above	If activity *i* has one of the above nonzero numbers assigned to it when compared with activity *j*, then *j* has the reciprocal value when compared with *i*	A reasonable assumption
Rationals	Ratios arising from the scale	If consistency were to be forced by obtaining *n* numerical values to span the matrix

reciprocal, all matrix values *beneath* the main diagonal are inverses of their corresponding values (reflected along the main diagonal) *above* the main diagonal. The scientifically most accepted scale in AHP applications is the 'fundamental scale', which was developed by Saaty (1980) and is displayed in Table 1. Usually applied values of the scale are 1, 3, 5, 7 and 9, whereas values in between may be used to make more precise judgements.

The comparison matrices have to be converted in weighing factors w_n using the eigenvector of the matrices (Saaty and Vargas, 2012). To check consistencies of the conducted comparisons, the calculation of eigenvalue and eigenvector are additionally necessary (Meixner and Haas, 2009).

Prioritisation of alternatives

One of the most useful aspects of the AHP is that complex multi-criteria decision problems can be broken down to a series of pair-wise comparisons. Uncertainties can be decreased since only fragments of the general decision problem are regarded and the overall problem is solved via an aggregation of these results. The actual procedure to compare alternatives with respect to the criteria is analogous to the procedure of the weighing of criteria. For the prioritisation of the alternatives, two different comparison modes may be chosen, a relative or an absolute one. In relative comparisons, pair-wise comparisons are conducted analogous to the process for the weighing of criteria (Peters and Zelewski, 2002). Within the absolute comparison or rating mode, categories are defined for the ranking of alternatives. The categories can be set following the decision maker's choice, e.g. very good, good, average, below average, poor. Categories (and not the alternatives) are compared pair-wise applying the Saaty scale (see Table 1), e.g. 'very good' is '9 times more preferable' than 'poor'. Finally, the alternatives are ranked following the categories for each criterion (Saaty and Vargas, 2012). No clear recommendations exist in literature of when to use which mode (Saaty and Vargas, 2012). It is mentioned by Meixner and Haas (2009) that the rating mode is recommendable when more than nine alternatives are compared, since relative pair-wise comparisons in this case are hardly feasible. In this research, both modes are conducted and possible different results are discussed. Irrespective of the comparison mode, quantitative and qualitative data can be compared for the alternatives in the Saaty scale (Meixner and Haas, 2009).

For the conversion of the pair-wise comparisons into priority factors, two possibilities exist, the distributive and the ideal mode. The distributive mode is analogously to the aggregation process for weighing factors. A clear sign for priority factors derived according the distributive mode is that they add up to 1. By contrast, the ideal mode slightly changes the described derivation and does not rely anymore on the calculation of the eigenvector for the comparison matrix (Peters and Zelewski, 2002). The consistency of the comparisons has to be checked for ideal and distributive modes (Meixner and Haas, 2009).

Research-specific adaptions of the AHP

The AHP is a method that can be conducted relatively easy and is applicable in a wide range of fields, including economy, law, business and policy (Meixner and Haas, 2009; Saaty and Forman, 1993). To ensure applicability of the AHP for the aims of this research, relevant literature in the field of environmental policy, economics and waste management is regarded with the aim to identify critical aspects and success factors in AHP applications (see overview in Table 2).

This research sets up two different decision hierarchies based on the same alternatives but with different criteria. One containing only utility-related criteria (commonly rather qualitative), and

Table 2. Overview on relevant AHP applications.

Source	Description of study	Identified relevant aspect(s)
Waste management		
Achillas et al., 2013	Collection of practical application of multi-criteria decision making (including AHP) in waste management	AHP mostly applied to define optimal locations for treatment facilities and to evaluate waste management strategies.
Antonopoulos et al., 2014	Ranking of different technical waste treatment alternatives for MSW	Weighing of criteria has a high influence on final outcome which eventually depends on the decision maker.
Kim et al., 2013	Choosing of WEEE types that shall be covered by the Korean EPR scheme	The applied AHP methodology proved to be an efficient tool, although precise objective data was missing.
Morrissey and Browne, 2004	Comparing models (e.g. the AHP) used to support decisions in waste management	The AHP decision process may be difficult if the comparability of the alternatives is questionable.
Nixon et al., 2013	Ranking different technological alternatives for generating electricity of MSW in India using AHP and ANP	Owing to uncertainties in setting priorities for alternatives, a sensitivity analysis for the results is important.
Milutinović et al., 2014	Evaluating different waste management scenarios (e.g. landfilling, incineration with energy recovery)	A sufficient amount of criteria needs to be developed. Increasing numbers of criteria may lead to increasing sensitivity of the model.
Lin et al., 2010	Determination of priorities for WEEE appliances to be recycled	Interdependencies between selected AHP criteria may occur and the results highly depend on the input information level.
Environmental policy and economics		
Blechinger and Shah, 2011	Selecting most appropriate policy instruments applying multi-criteria evaluation methods (e.g. the AHP) in order to reduce greenhouse gas emissions in small island developing states	The main problem faced is a lack of empirical work and quantitative data regarding effects of policy instruments. In addition, benefits of a combination of policy instruments cannot be assessed with the methodology.
Kablan, 2004	Prioritisation of energy conservation policy measures in Jordan	Judgements have been conducted according one decision maker. More reliable results could have been achieved with a higher number of sources as input for the pair-wise comparison.
Konidari and Mavrakis, 2007	Evaluating climate change mitigation policy instruments	Decision makers' knowledge and available data are success factors for delivering reliable results.
Turcksin et al., 2011	Recommendation of a multi-instrumentality policy package to encourage people in Belgium to choose more sustainable vehicles using a combination of the AHP and the PROMETHEE approach	The PROMETHEE approach avoids the AHP's possibly occurring trade-offs between the alternatives' different performances regarding different criteria.

AHP: analytic hierarchy process; ANP: analytic network process; EPR: extended producer responsibility; MSW: municipal solid waste; PROMETHEE: preference ranking organization method for enrichment of evaluations; WEEE: waste electrical and electronic equipment.

another containing only cost-related criteria (commonly rather quantitative). An explicit distinction between utility and cost in the application of the AHP is recommended by Saaty and Vargas (2012) and by Meixner and Haas (2009). Saaty and Vargas (2012) state that criteria for utility and cost, even if applied in different hierarchies, do not have to be opposites, but instead can be partially or totally different. Indeed, if a cost–utility ratio shall be derived, first both hierarchies need to have identical alternatives. Second, the priority factor $w_b\,(A)$ derived from the utility hierarchy (b) for the alternative A has to be put in relation to the priority factor $w_c\,(A)$ derived from the cost hierarchy (c) for the alternative A. The cost–utility ratio (bc) for alternative A is displayed here:

$$bc_A = \frac{w_b\left(A\right)}{w_c\left(A\right)} \tag{2}$$

A derivation of utility–cost ratios will only be significant if the alternatives in both hierarchies are evaluated with the same approach, namely by answering the question, which alternative creates more utility/more cost with respect to the corresponding criteria (Meixner and Haas, 2009).

Evaluating identified criteria as well as alternatives in order to receive a reliable assessment of economic instruments in waste management, requires a comprehensive and profound knowledge on the topic. In many applications of the AHP, the pair-wise comparisons with prioritised alternatives are carried out in the frame of expert interviews (multiple decision makers), which generally prove to be a reasonable method but have the disadvantage of a high subjective influence factor depending on the interviewed experts. Instead, the approach of this research is to review literature on the selected economic instruments (alternatives), in order to prioritise alternatives and to weigh the chosen criteria. For particular aspects, literature information may not be available at the same level of detail as information obtained from targeted expert interviews, but statements and opinions retrievable from

Table 3. Overview on exemplary key literature for the review.

Instrument	Key studies	Author(s)
Economic instruments in general	Global review of economic instruments for solid waste management in Latin America	Cointreau and Hornig, 2003
	Selection, design and implementation of economic instruments in the solid waste management sector in Kenya	UNEP, 2005
	Economic instruments for solid waste management in South Africa	Nahman and Godfrey, 2010
Landfill tax	Effectiveness of landfill taxation	Bartelings et al., 2005
	Landfill reduction experience in the Netherlands	Scharff, 2014
PAYT	Status and prospects of PAYT in Europe	Reichenbach, 2008
	Economic instruments in solid waste management – case study Bayawan, Phillipines	Paul, 2012
Deposit–refund systems	Deposit–refund systems in practice and theory	Walls, 2013
	Deposit return systems for packaging: applying international experience to the UK	Oakdene Hollins, 2010
EPR	Development of guidance on EPR	Monier et al., 2014
	Economic instruments in solid waste management – case study Bulgaria	Doychinov and Whiteman, 2012
	EPR for packaging waste in South Africa	Nahman, 2010

EPR: extended producer responsibility; PAYT: pay-as-you-throw.

literature, e.g. case studies on the implementation of economic instruments in certain countries, are widely available. Information from literature is usually (peer-)reviewed, more far-reaching and objective as statements from individual experts.

The carried out literature review collects information necessary to enable a prioritisation of alternatives according to utility-related and cost-related criteria in a 'research matrix'. Qualitative statements and quantitative facts are arranged according to the regarded alternatives (x-axis) and the selected comparison criteria of the AHP hierarchy (y-axis). The literature assessment includes case studies, journal articles and publications by research institutions dealing with the selected economic instruments or assessing (economic) policy measures. Table 3 only presents selected key literature. More than 50 additional sources are assessed and the excerpted information is allocated to the AHP criteria and the respective economic instruments. A complete list of references and the results of the review for each economic instrument structured alongside the comparison criteria can be made available upon request. Based on the collected information from literature, the authors carried out the pairwise comparisons (single decision maker).

The information collected for the prioritisation of alternatives already provide some indications on the weighing of criteria in the AHP hierarchy, but are not substantive to weigh the main criteria in the AHP hierarchies. Therefore, the findings are complemented with a brief review of political statements in the frame of waste policy, in terms of official published strategy articles expressing the political goals and objectives with a focus on EU waste policy (European Commission, 2011, 2014a, 2014b) at the time of the research or key pieces of EU waste legislation (e.g. Directive 2008/98/EC on waste).

The software 'Super Decisions (Version 2.6)' carries out the numerous matrices calculations to derive the eigenvector, to calculate consistencies and to conduct sensitivity analyses. This software covers all necessary functions and is based on the AHP calculations.

Figure 1 illustrates the applied research method taking into account the general AHP methodology and the research specific adaptations.

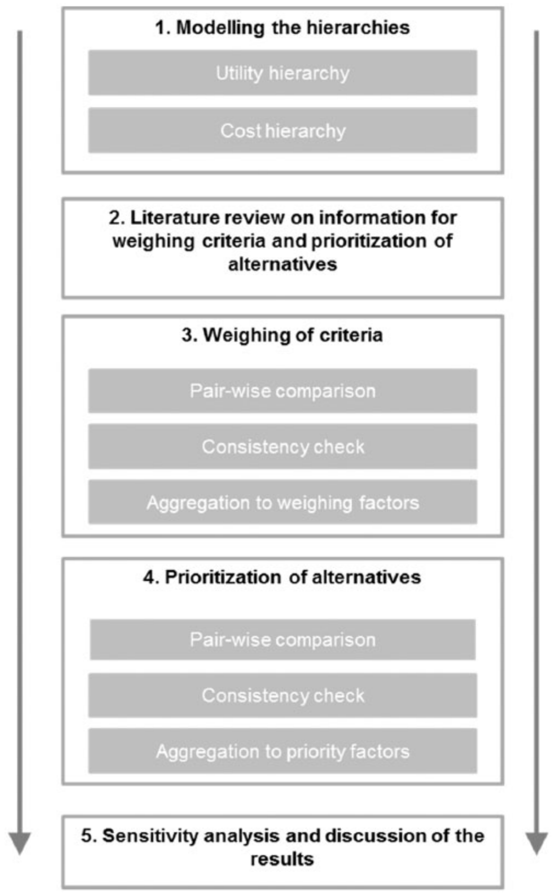


Figure 1. Flowchart of the research method.

Results and discussion

Results: Modelling of hierarchies

Table 4 displays the utility and cost AHP hierarchies set up in this research.

The overall goal within the AHP hierarchy is derived from the research objective to assess different economic instruments on their potential to improve the waste management situation in countries with low municipal waste performance. Improving is understood as moving away from predominant disposal to recycling or recovering techniques, e.g. moving up the waste hierarchy set up by Article 4 of Directive 2008/98/EC on waste as this brings most benefits owing to the avoidance of losing valuable raw materials (European Environment Agency, 2009) and a decrease in carbon emissions (Dehoust and Vogt, 2010). Reducing the landfilled amount of waste is also a primary aim of European policies related to waste and material use under the European Strategy on Resource Efficiency (European Environment Agency, 2013). Hence, the overall goal of the AHP hierarchy in this research is to achieve a better waste management performance by fostering landfill diversion (see Table 4). With this goal in focus, every alternative (economic instrument) has to be compared with respect to utility and cost criteria. The applied criteria, as displayed in Table 4, have been selected and interpreted based on an analysis of other studies comparing environmental policy instruments either using the AHP or other methods, with Achillas et al. (2013) providing a broad overview on comparison criteria used in multi-criteria decision making for waste management-related problems. The compared economic instruments form the alternatives of the AHP hierarchy. Based on the categorisation established by Cointreau and Hornig (2003), economic instruments have been selected that are considered to be most relevant and where data on their effectiveness is available, since some countries already apply those instruments (BiPRO, 2013). Besides, it must be at least partly possible to relate the impacts on waste management to the applied economic instruments (Watkins et al., 2012). In line with other studies comparing economic instruments in waste management, landfill tax, pay-as-you-throw (PAYT), deposit–refund systems and extended producer responsibility are selected as alternatives (see Table 4).

Results: Weighing of criteria

Based on the findings and results from the literature review, the pair-wise comparisons of the criteria are conducted following the described methodology and using the software ‘Super Decisions (Version 2.6)’. An exemplary matrix for the comparison of the main utility criteria is presented in Table 5. All software calculations can be made available upon request. The comparisons are conducted according to the ‘Saaty scale’ and with regard to the next higher level of the hierarchy, namely the main goal.

Referring to the collected information, the criterion ‘Reduction of landfilled amount of waste’ appears to be the most important criterion, since it is seen as substantially important by the considered EU strategy papers (European Commission, 2011, 2014a, 2014b). Hence, it is considered as ‘3 times more preferable’ (in wording of the Saaty scale: ‘moderately more important/preferable’) than the criterion ‘Coverage of waste streams’, and even as ‘9 times more preferable’ (in wording of the Saaty scale: ‘extremely more important/preferable’) than the criterion ‘Creation of revenue for investments’. The weighing of the other criteria and sub-criteria of the utility and cost hierarchies is conducted analogously.

The aforementioned comparisons need to be aggregated to weighing factors (w_n). Therefore, the used software calculated the matrices’ eigenvectors. The global weighing factors for utility criteria are displayed in Table 4. A substantial difference in the influence of the respective criteria is recognised. Weighing factors for criteria are derived independent from available modes within the AHP (same weighing of the criteria, no matter if relative or absolute comparison, distributive or ideal mode are applied). Consistencies of the pair-wise comparisons have been checked according the AHP methodology. All comparisons from absolute and relative modes lie beneath the critical threshold of 0.1.

Results: Prioritisation of alternatives

Alternatives are compared on the basis of information collected from the literature review. The comparisons are conducted according both available modes (absolute and relative) and the comparison matrices are set up reciprocal to the example in Table 5. As exemplary judgement for the relative comparison mode, the utility criterion ‘Coverage of waste streams’, is considered. Landfill tax and PAYT schemes perform equally since they, per definition, both cover the municipal waste stream as a whole. Deposit–refund systems and extended producer responsibility per definition are both just applicable to certain waste streams (e.g. glass bottles, packaging waste, waste of electrical and electronic equipment, or batteries), which lowers their relative performance regarding this criterion. A difference between the latter mentioned instruments is not clearly visible from literature. Thus, both instruments are classified ‘moderately less preferable’ as landfill tax and PAYT. Since they usually do not cover all municipal solid waste streams, but indeed are applicable to several recyclable waste streams, judgement 3 is chosen and not 5, 7 or 9 (‘strongly’, ‘very strongly’ or ‘extremely’ less preferable).

Another example is the utility sub-criterion ‘Amount diverted from landfill’, which together with ‘Amount prevented at source’ forms the utility criterion ‘Reduction of landfilled amount’. Quantitative and qualitative statements collected from literature classified both PAYT (Reichenbach, 2008; Tojo et al., 2008; Watkins et al., 2012) and landfill tax (Bartelings et al., 2005; Denne, 2005; European Environment Agency, 2009; Nicolli and Mazzanti, 2013; Watkins et al., 2012) as generally very effective in diverting waste from landfills. A further differentiation between

Table 4. Utility and cost hierarchy.

Goal	Achieving a better waste management performance by fostering landfill diversion in order to move up the EU waste hierarchy					
Utility criteria	Reduction of landfilled amount $W_1 = 0.41$	Coverage of MSW streams $W_2 = 0.16$	Creation of revenue for investments $W_3 = 0.03$	Required infrastructure $W_4 = 0.24$	Feasibility of administrative implementation $W_5 = 0.06$	Socio-political acceptance factors $W_6 = 0.10$
Sub-criteria	Amount diverted from landfill $W_{11} = 0.10$			Collection infrastructure $W_{41} = 0.15$	Time frame $W_{51} = 0.005$	Equity of burden $W_{61} = 0.04$
	Amount prevented at source $W_{12} = 0.31$			Administration infrastructure $W_{42} = 0.02$	Level of awareness/ knowledge $W_{52} = 0.04$	Loopholes for non-participation $W_{62} = 0.04$
				Treatment infrastructure $W_{43} = 0.07$	Flexibility $W_{53} = 0.015$	Transparency $W_{63} = 0.02$
Alternatives	Landfill tax		PAYT	Deposit–refund system		Extended producer responsibility
Goal	Achieving a better waste management performance by fostering landfill diversion in order to move up the EU waste hierarchy					
Cost criteria	Investment cost $W_{c1} = 0.26$		Operation cost $W_{c2} = 0.64$	Indirect cost $W_{c3} = 0.10$		
Alternatives	Landfill tax		PAYT	Deposit–refund system		Extended producer responsibility

EU: European Union; MSW: municipal solid waste; PAYT: pay-as-you-throw.

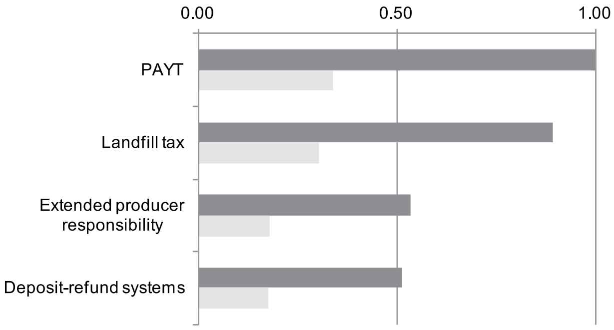
Table 5. Pair-wise comparisons of main utility criteria.

Achieving a better waste management performance by fostering landfill diversion in order to move up the EU waste hierarchy	Reduction of landfilled amount of waste	Coverage of waste streams	Creation of revenue for investments	Required infrastructure	Feasibility of administrative implementation	Socio-political acceptance factors
Reduction of landfilled amount of waste		3	9	2	7	4
Coverage of waste streams	$\frac{1}{3}$		5	$\frac{1}{2}$	3	2
Creation of revenue for investments	$\frac{1}{9}$	$\frac{1}{5}$		$\frac{1}{7}$	$\frac{1}{2}$	$\frac{1}{3}$
Required infrastructure	$\frac{1}{2}$	2	7		4	2
Feasibility of administrative implementation	$\frac{1}{7}$	$\frac{1}{3}$	2	$\frac{1}{4}$		$\frac{1}{2}$
Socio-political acceptance factors	$\frac{1}{4}$	$\frac{1}{2}$	3	$\frac{1}{2}$	2	

both instrument's effectiveness depends on the practical implementation of the instrument and thus is not possible in this model. Hence, they are rated equally as 'very strong preferable' as deposit–refund systems because literature statements indicate that collected material in deposit–refund systems (e.g. glass bottles or batteries) are rather diverted from existing collection schemes and not from landfills (Doychinov and Whiteman, 2012; Kaseke, 2005). Extended producer responsibility schemes are also effective in diverting waste from landfills since recycling rates for products covered by the extended producer responsibility increase (Cunha Marques et al., 2012). Its effectiveness thereby is classified as 'moderately more preferable' as deposit–refund systems, but concurrently as 'moderately less preferable' than landfill tax and PAYT since reported recycling rates in literature are on average moderately smaller than reported numbers from landfill tax and PAYT.

Results from the calculations of priority factors are available for the absolute comparison/rating mode and for the relative comparison mode. Figure 2 contains the results for the relative comparison mode and also displays the differences in applying the distributive and the ideal mode. The results of the absolute comparison mode deviate only marginally (see Table 6).

Consistencies of the pair-wise comparisons are examined following the AHP methodology also within the prioritisation of the



	Deposit-refund systems	Extended producer responsibility	Landfill tax	PAYT
Ideal Mode	0.51	0.53	0.89	1.00
Distributive Mode	0.18	0.18	0.30	0.34

Figure 2. Results AHP utility hierarchy according relative comparison mode.
PAYT: pay-as-you-throw.

alternatives. All comparisons from absolute and relative modes lie beneath the critical threshold of 0.1. The prioritisation of the alternatives according to the relative and absolute mode are conducted analogously in the separate cost hierarchy.

Results: Ranking of alternatives according utility, cost and cost-utility ratio

The AHP ranking results for the economic instruments according utility and cost criteria as well as the combination of results, i.e. the cost-utility ratios, are displayed in Table 6. Only priority factors derived from the distributive mode are presented since, a cost–utility ratio is not computable on the basis of the ideal mode.

Cost–utility ratios are calculated according to the described methodology, namely by dividing the priority factor of utility with the priority factor of cost. It is important to mention that a cost–utility ratio greater than 1 is not a valid indication for the instrument's profitability, as it might be the case in investment analyses since priority factors are compared and not absolute values on cost (Meixner and Haas, 2009).

Discussion of the results

In the utility-based assessment, PAYT turns out to be the most prioritised instrument for countries with low municipal waste management performance, closely followed by landfill tax. A key factor for the ranking of PAYT is that the reviewed literature reports strong incentives for waste generators to decrease waste amounts for disposal, at source via a change in consumption behaviour and by diverting waste from landfills via the separation of recyclable fractions (Reichenbach, 2008; Sauer et al., 2008; Slavik and Pavel, 2013). By contrast, landfill tax is not considered to prevent waste generation at source (Hogg et al., 2011), but only by diverting waste from landfills (Watkins et al., 2012). Positive effects of PAYT occurred immediately after its introduction and the negative impacts of PAYT, such as illegal dumping to avoid waste charges (Paul, 2012), only partly occurred, immediately endangering the success of the instrument (Slavik and Pavel, 2013). These negative effects do not necessarily have to occur (Watkins et al., 2012) and can be hampered with accompanying capacity building initiatives and outweighed by the positive effects of PAYT in the long-term (Paul, 2012; Stretz, 2012).

After a gap, extended producer responsibility and deposit–refund systems rank similar with third and fourth priority. A similar ranking of the latter is not surprising since both concepts are related to each other. By contrast, results of the cost-based assessment rank PAYT as the most expensive instrument and landfill tax as the cheapest one, which can be explained by their different needs for infrastructure. A successful PAYT scheme requires a separate collection of waste fractions and a form of bring-in or kerbside collection scheme as well as subsequent treatment infrastructures for recyclable fractions (Tojo et al., 2008), whereas the infrastructure for a landfill tax is basically confined to weighing devices at landfills and administrative capacity (Morris and Read, 2001). The other two instruments are ranked in between, with deposit–refund systems being more costly than extended producer responsibility. Combining both assessments, landfill tax shows the highest cost–utility ratio and therefore has a higher priority than the following extended producer responsibility, PAYT and deposit–refund systems.

The approach to adapt the AHP to the research objectives in order to minimise known critical aspects of the AHP proves to be useful. A sensitivity analysis is conducted with the help of the applied software to examine the volatility of the results (prioritisation of the alternatives) when the weighing factors of criteria change. The analysis reveals that most influential criteria in the utility hierarchy are 'Reduction of landfilled amount' and 'Required infrastructure', since these show the highest weighing factors, while the economic instruments perform very differently regarding both criteria.

The impact on the final results, owing to the applied forms of the AHP (absolute and relative) and to the applied evaluation mode for weighing/priority factors (ideal and distributive), are seen as negligible. Regarding the ideal and distributive mode for calculating priority factors, the ideal mode shows the advantage that the problematic 'Rank reversal' of an AHP (Millet and Saaty, 2000) can be prevented. However, for the derivation of cost–utility ratios, only results from the distributive mode are applicable.

In the broad field of environmental policy with multiple involved stakeholders, the requirements of 'preference independency' and 'non-redundancy' in particular appear to be very difficult to realise. In practice, it is not possible to select AHP criteria without any interference. This also holds true for this research. For example, 'socio-political acceptance', 'equity of burden', 'transparency' and of course involved cost will always be related at least to a limited extent. With the applied setting of criteria, interdependencies were minimised but not eliminated. Furthermore, alternatives within the AHP need to be horizontally independent, i.e. mutually exclusive that is practically not the case for economic

Table 6. Ranking of economic instruments according to utility criteria, cost criteria and cost-utility ratio.

Rank	Instrument	Relative	Absolute
Ranking of utility hierarchy			
1	PAYT	0.34	0.35
2	Landfill tax	0.30	0.32
3	Extended producer responsibility	0.18	0.17
4	Deposit–refund systems	0.18	0.16
Ranking of cost hierarchy			
1	PAYT	0.44	0.43
2	Deposit–refund systems	0.31	0.30
3	Extended producer responsibility	0.13	0.16
4	Landfill tax	0.12	0.11
Ranking according cost-utility ratio			
1	Landfill tax	2.61	2.94
2	Extended producer responsibility	1.35	1.08
3	PAYT	0.78	0.82
4	Deposit–refund systems	0.56	0.52

PAYT: pay-as-you-throw.

instruments in waste management. Hence, this requirement is ensured via the theoretical assumption that a country, having not yet applied economic policy instruments, can initially apply only one instrument owing to limited resources. At a later stage, the effectiveness of instruments then depends on interactions between several policy measures (including regulatory or infrastructural measures). An option to take into account the dependencies between criteria and alternatives is to apply the analytic network process (ANP). In the field of policy instruments though, the AHP typically is used in the available scientific literature. This may be owing to the fact that the ANP can technically consider dependencies between criteria and alternatives, but it fails when it comes to estimate the exact degree of dependencies, which may influence the significance of results to a great extent. Therefore, in our research, a clear prioritisation of alternatives according to the AHP appears to be more appropriate, especially when considering countries with low municipal waste management. However, one should keep in mind that finally, a mixture of policy instruments of different fields will be most successful in diverting waste from landfills (European Environment Agency, 2009).

The critical question in an assessment of economic instruments in waste management using the AHP is the aspect of comparability. Saaty and Vargas (2012) provide the example of considering the AHP to be ‘comparing apples and oranges’. Different economic instruments may be seen as hardly comparable, but the overall assumption of the AHP is that trade-offs between properties are possible in order to make a decision between alternatives that are difficult to compare (Saaty and Vargas, 2012). The performance of each instrument significantly depends on the practical implementation and this depends further on country-specific circumstances. Hence, case studies and articles (e.g. assessing the effectiveness of an economic instrument) do not draw conclusions based on the same assumptions and circumstances, but depend on the implementation form of the instrument. Pair-wise comparisons of the results are therefore not always substantially possible. A specific example is the influence of tax rates of an implemented landfill tax. On the one hand, there are case studies reporting relatively low tax rates, which eventually resulted in only moderate effectiveness of the instrument (Morris et al., 1998; Turner et al., 1998). On the other hand, case studies reported high tax rates that resulted in very strong effectiveness (European Environment Agency, 2009). As a consequence, landfill tax’s performance within the AHP (in comparison with the other instruments) depends on the implemented tax rate. This aspect cannot be totally reflected in the general AHP-based pair-wise comparisons. A potential solution to overcome this obstacle might be the application of a fuzzy AHP. A fuzzy AHP is currently under development and presents an extended version of the regular AHP where the pair-wise comparisons are not conducted via Saaty’s exact fundamental scale, but using modelling techniques of fuzzy theory in order to overcome pair-wise comparisons that are not significantly decidable (Eickemeier and Rommelfänger, 2001).

Owing to the limited data availability, comparisons within the cost hierarchy need to be seen critically. Results for the utility-related comparison are considered to be reliable for decisions in policy making, as long as the aforementioned aspects and the sensitivity analysis are regarded. This is further validated by comparing the results of this AHP-based research with other research findings. To benchmark the results, the most compelling similarities and differences to the findings of Schlegelmilch et al. (2010) are examined. Both research approaches – apart from marginally different interpretation of the instruments’ performances concerning certain criteria – draw the same conclusions and prioritise PAYT (‘Proportional weighing or measuring system’).

Conclusion

The assessment of economic instruments for countries with low municipal waste management performance reveals that − based on utility criteria – the instrument of PAYT should be first prioritised, closely followed by landfill tax. At the same time, PAYT seems to be the most expensive instrument, so that landfill tax performs best in terms of the utility–cost ratio. Available data on utility criteria are seen as valid and decisive, whereas available data on cost criteria are not seen as sufficient for robust conclusions on the cost-based results. The AHP is seen as generally suitable for assessing economic instruments in waste management. Results provide valuable indications on the application of economic instruments. Nevertheless, country-specific conditions need to be taken into consideration along with the results of this AHP application before practical decisions are made. The methodology of the AHP needs to be set up regarding several requirements and taking into consideration experience from other AHP applications. The different modes (absolute and relative comparison, distributive and ideal mode) do not significantly change the final results.

Overall, the bottom line for this research is this: When a theoretic model like the AHP is applied to a practical decision problem, findings will provide indications and information on overall strengths and weaknesses of economic instruments but cannot be seen as generally valid. Instead, economic instruments need to be put in a country-specific context and other factors influencing policy-making need to be considered before a final decision on their implementation is made. Finally, the AHP will create a solid information basis for a decision, but the final decision needs to be made by the decision maker itself.

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