Assessment of information related to waste and material flows

A catalogue of methods and tools

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ISBN: 92-9167-577-6

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1. Introduction and objectives

Integrated environmental assessment (IEA) is increasingly recognised as an important technique for managing the environmental impacts of human actions. It may be defined as the interdisciplinary process of identification, analysis and appraisal of all the relevant natural and human processes, which affect the quality of the environment and environmental resources. The objective of IEA is to facilitate the framing and implementation of optimal policies and strategies, accounting for both environmental effects and other priorities (e.g. cost constraints). Two points worth emphasising about IEA are that it is:

- practical — the purpose is to facilitate making decisions;
- comprehensive — all relevant aspects, which might affect the decision, should be incorporated.

IEA can help managers and decision makers to:

- solve environmental planning and management problems;
- improve their understanding of environmental conditions;
- design protective or remedial strategies (EEA, 1998).

Integrated assessment tools are needed to assess policy-making. Within this context, the 2001 work plan for the European Topic Centre on Waste and Material Flows (ETC/WMF) identified the following key tasks to be addressed:

- to identify a common integrated framework for integrated assessment of waste issues and material flows, based on indicators and linked to policy needs;
- to identify issues to be addressed for prospective analysis linked to policy priorities and possibilities for evaluating policy effectiveness in an integrated way;
- to describe, in the framework of the preparation of the state & outlook report, how waste and material flows issues can be addressed in an integrated way;
- to identify/develop tools for assessment of waste quantities/types linked to material flows (e.g. LCA, waste factors);
- to identify suitable models for testing production of prospective analysis;
- to review existing state of the art and make proposals for methods to agree, review and finalise approach and results of prospective analysis.

Within this context, this technical report aims at:

- addressing the main policy issues relevant to the development of an integrated framework for waste and material flows;
- providing an overview and assessment of existing/available 'assessment tools' relevant for 'waste and material flows' suitable for EEA reporting requirements.

In a first step, the main policy issues, questions and objectives in the field of 'waste and material flows' are identified and the information needs required for an 'integrated environmental assessment' are worked out (Section 2). Section 3 provides an overview of available assessment tools that might be used in this context. Finally, recommendations are given on, for example, which assessment tools should be used for future EEA reporting and which tools should be further developed (Section 4).

2. Main policy questions for the integrated issue of waste and material flows

2.1. Policy shift from 'end-of-pipe' waste management towards integrated 'sustainable resource management'

The issue of 'sustainable use of natural resources' is increasingly being included on the political agenda and accordingly institutional adaptations have been put forward:

- One of the four 'priority areas' within the sixth environmental action programme (6EAP) is 'Sustainable use of natural resources and management of waste' (OJ L 242, 10.9.2002).
- One of the six headline issues within the EU strategy for sustainable development is 'Manage natural resources more responsibly' (CEC, 2001).
- In the preparation of the 6EAP, the Environment DG launched a series of 'Experts' reports on resource management' (http://europa.eu.int/comm/environment/enveco/studies2.htm#26).

In other words, the former policy field 'Waste' seems to being increasingly integrated in the 'new' policy field of 'Sustainable resource management' reflecting the overall shift from an 'end-of-pipe' treatment of the waste issue towards the front of the waste policy hierarchy, i.e. waste prevention through more efficient use of natural resources.

Much of the existing Community environmental policy framework has been established precisely to limit the environmental and health impacts that arise from the use of natural resources. This includes, for example, Community measures aimed at improving the resource efficiency of energy use, the sustainable use of water and soil.

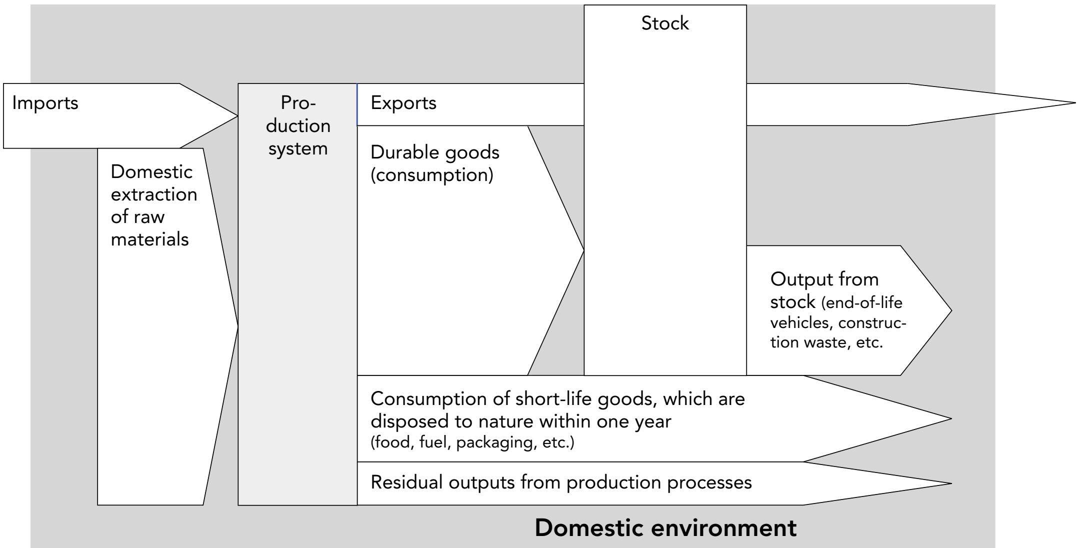
In 2001, the European Commission presented the 6EAP entitled 'Environment 2010. Our future our choice'. It sets out major priorities and objectives for environmental policy over the next five to 10 years. One of four 'priority areas' within the 6EAP is 'Sustainable use of natural resources and management of waste'. Main objectives within this priority area are (OJ L 242, 10.9.2002):

As regards resource efficiency and management:
- to ensure the consumption of renewable and non-renewable resources does not exceed the carrying capacity of the environment;
- to achieve a de-coupling of resource use from economic growth through significantly improved resource efficiency, dematerialisation of the economy, and waste prevention;

As regards waste prevention and management:
- to decouple the generation of waste from economic growth and achieve a significant overall reduction in the volumes of waste generated through improved waste-prevention initiatives, better resource efficiency, and a shift to more sustainable consumption patterns;
- for wastes that are still generated, to achieve a situation where:
  - — the wastes are non-hazardous or at least present only very low risks to the environment and our health;
  - — the majority of the wastes are either reintroduced into the economic cycle, especially by recycling, or are returned to the environment in a useful (e.g. composting) or harmless form;
  - — the quantities of waste that still need to go to final disposal are reduced to an absolute minimum and are safely destroyed or disposed of;
  - — waste is treated as closely as possible to where it is generated.

As regards resource efficiency and management, the 6EAP states that although many of the existing policy measures are directly or indirectly affecting the use of renewable and non-renewable natural resources, the Community still 'lacks a coherent policy focused on achieving an overall decoupling of resource use from economic growth' (OJ L 242, 10.9.2002). Therefore, as a first step, the Community will

Link between resource input flows and waste output flows — Figure 2.1



develop a 'Thematic strategy on the sustainable use of natural resources' for setting priorities and undertake the necessary analysis and data collection in order to identify, which resources are of most concern. The criteria will need to address issues such as whether the environmental damage associated with the use of a particular resource threatens to be long term and irreversible, whether or not substitutes are likely to be available for future generations, etc. A Green Paper on this thematic strategy is due in 2003.

The issue of waste prevention is closely linked to the efficient use of natural resources and will hence form 'a key part of the planned thematic strategy on resource management' (OJ L 242, 10.9.2002). In addition, waste-prevention objectives and priorities will be integrated into the Community's integrated product policy (IPP).

2.2. The link between use of natural resources and the generation of waste

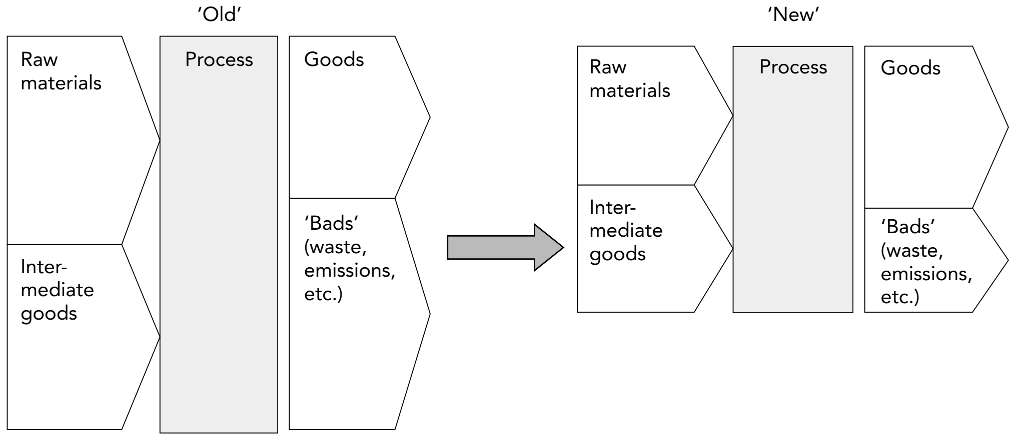
In the above-mentioned policy context, one main task is to identify and implement specific policy measures that reduce the consumption of natural resources for example, by changing demand, by improving the efficiency with which they are used, by preventing the wastage and degradation of these resources, and by improving the rates at which they are recycled back into the economy after they have been used.

The link between the use of natural resources on the one hand and the generation of waste (and other material outflows) is illustrated in Figure 2.1.

All materials entering an economy will sooner or later be released back to the environment in terms of wastes and emissions. This 'industrial metabolism' (Ayres and Simonis, 1994) can be further described in detail. On the input side of the economy, domestic raw materials and imports can be distinguished. Those are further processed in economic production processes. The latter transform the inputs to 'goods' (short-life goods, durable goods, exports) and 'bads' (residuals such like emissions and wastes). Exported goods are leaving the domestic economy. Durable goods are accumulated within the domestic stock (buildings, appliances, infrastructure). The stock itself releases materials to the environment in terms of waste such as end-of-life-vehicles, demolition waste, etc.). Another part of the goods is produced for immediate consumption. Those 'short-life goods' are transformed into waste within one accounting period (one year).

As consumer society gets wealthier and ever more productive, the demand for products increases. Coupled with decreasing product lives, this generates increasing quantities of end-of-life product wastes and associated mining and manufacturing wastes. At the same time, many products are becoming more and more complex using a wide variety of substances, which can further exacerbate the risks from wastes to our health and the environment. It is clear that if we continue with our current consumption and production patterns, this will be translated

Figure 2.2 **Prevention of waste equals more efficient use of inputs**



into increasing quantities of waste — of which a significant proportion will continue to be hazardous.

A clear understanding of processes causing waste generation is needed, so that technically, economically and environmentally feasible options for waste prevention/reduction at source can be applied. Looking at production processes, prevention of waste always means a reduction of material inputs in terms of raw materials and intermediate goods. As illustrated in Figure 2.2, more 'eco-efficient' processes are needed in order to produce the same amount of 'goods' with less input and less 'bads' in terms of wastes and emissions.

2.3. Waste-management policy issues

A lack of aggregate data at the EU level makes it difficult to assess whether the environmental impacts associated with the management of wastes are improving or deteriorating. New waste-treatment facilities meet extremely high operating standards that reduce emissions and risks significantly. Yet, much of our wastes still goes to older and less well managed facilities, partly due to the failure of Member States to properly implement Community waste legislation. The impacts of waste management and waste transport are, therefore, still problematic in many areas of the Community.

In the European Union as a whole, over two billion tonnes of waste are produced each year of which approximately 30 million tonnes are classified as hazardous. Some 50–60 % of the overall solid waste stream is landfilled, though the proportion of landfilled waste varies substantially in individual Member States. In 1989, the EU drew up a policy document entitled 'Waste-management strategy' which set long-term aspirations with regard to the European Union's waste-management legislation and activities. Its main principles were:

- prevention of waste by technologies and products;
- recycling and reuse;
- optimisation of final disposal;
- regulation of transport;
- remedial action.

On 24 February 1997, Council adopted a resolution on a Community strategy for waste management (OJ C 076, 11.3.1997), which is a review of the 1989 strategy (OJ C122/2, 18.5.1990). This resolution underpins the principles of waste prevention first, then recovery and, finally, minimisation of final disposal and confirms the current EU policy on the movements of waste. The resolution gives precedence to the recovery of materials over energy generation and strongly promotes the principle of producer responsibility.

In the 20-year period (1980–2000), the EU has developed a large number of legal documents (directives, decisions and regulations), but the environmental problems still continue to grow.

Therefore, in order to develop effective policies for the future aiming at sustainable development and improved waste management, we have to be able to assess the present state, to analyse possible actions and impacts and to provide projections.

2.4. Main policy questions with regards to waste and material flows issues

The ETC/WMF is currently developing an indicator framework for waste and material flows (ETC/WMF 2001). In this context, main policy questions are being identified distinguishing three criteria following the 6EAP and the waste hierarchy:

1. Conserving natural resources
2. Prevention of waste generation
3. Sustainable management of waste

Conserving natural resources
The main policy question formulated under this criterion is 'Are we getting better with an efficient use of natural resources?'

Further second-level policy questions are:

1(a) How much and which natural resources are used?
1(b) What is the environmental impact associated to the use of natural resources?
1(c) What are natural resources used for?
1(d) How efficient is the use of natural resources?
1(e) To what extent should use of natural resources be reduced?
1(f) To what extent can the use of natural resources actually be reduced?
1(g) What technological innovations can reduce the amount of natural resource used?
1(h) What kind of policy instruments reveal to be more effective in reducing resource use?

Prevention of waste generation
The main policy question under this criterion is 'Is the prevention of non-hazardous and hazardous wastes generation improving?'

Further second-level policy questions are:

2(a) How much and which types of waste are generated?
2(b) Where are they generated?
2(c) What are the drivers of waste generation?
2(d) To what extent should generation of waste be prevented/reduced?
2(e) To what extent can generation of waste be prevented/reduced?
2(f) Which instruments demonstrate to be more effective in achieving prevention of waste production?

Sustainable management of waste
The main policy questions under this criterion are 'Are we moving towards a sustainable management of waste?' and 'Are we moving towards increasing recovery/recycling/reuse instead of disposal?'

Further second-level policy questions are:

3(a) How much and which types of waste are managed/treated and by which technology?
3(b) How much waste is reused and recycled (processed into secondary raw materials)?
3(c) How much and which waste is imported/exported by whom from where to where?
3(d) What are the present and future capacities of waste-treatment facilities?
3(e) What are the environmental impacts associated with the different wastes and their treatment (distinguishing immediate impacts and indirect impacts)?
3.(f) How much solid waste is transmitted to other media (water and air)?
3.(g) What are the socioeconomic effects of waste management/treatment?
3(h) How rapidly are new technologies being implemented and how effective are these regulations and other non-economic policy instruments for improving the management of non-hazardous waste?
3(i) What has been the progress in Member States with formulating and implementing waste-management plans to address the objectives of the EU waste strategy?

The assessment tools and methods have to be capable of analysing the driving forces, the pressures, the state, the impact and the response under the framework of the DPSIR model as well as to answer the aforementioned questions.

2.5. The EEA's policy-relevant indicator-based assessment approach

The EEA and the associated ETCs have been aiming at developing multi-purpose information systems, which as far as possible meet simultaneously the different needs of the Agency and its clients. Development of such information systems at the same time serves as a prerequisite for integrated environmental assessment, to be linked to policy objectives and targets, and having both prospective and retrospective elements.

In the past, the EEA and ETCs made some progress towards the development of such multi-purpose information systems. Most ETCs have established basic databases and developed preliminary indicator-based frameworks for reporting linked to policy objectives. Indicators are key tools for linking policy objectives and targets, for communicating data priorities to countries and for communicating complexity in a simple way for policy-makers and so that the public can understand.

For ETC/WMF this task is still ahead, in particular due to its very recent establishment and due to the dynamic policy developments towards an integration of sustainable resource use and management of waste.

3. Overview of available assessment tools

In this section, an overview of the main assessment tools needed for answering the questions posed in Section 2 is presented. At the end of this section, Table 3.6 presents the benefits and drawbacks of the various tools, as these are described analytically in each paragraph.

3.1. Simulation models

3.1.1. Description

Environmental simulation models are innovative software tools that are used to address issues that are related to environmental management and technology. They are used to store and elaborate environmental data in order to provide conclusions regarding future trends or evaluation of alternative scenarios.

3.1.2. Field of application

Environmental simulation models may be used to determine the environmental implications from the adoption of a policy or specific measures. They may be used during the decision-making process referring to regional / urban development, pollution / waste management, environmental policy measures, sustainable development, resource management, population growth measures, etc.

The main information that environmental simulation models can provide includes:

- waste generation by production processes, product use, management of end-of life products, urban / regional development, implementation of specific policies;
- waste generation, future trends and evolution;
- environmental impacts arising from waste production and its contribution to global environmental problems (greenhouse effect, acid rain, etc.);
- evaluation of alternative scenarios or policies in terms of their environmental, economic and social impacts;
- environmental and economic costs and benefits from the implementation of a project, management technique, etc.;
- optimum levels of recycling, composting, incineration, landfill, etc.;

3.1.3. Benefits

The benefits of using an environmental simulation model are the following:

- they can illustrate the current situation;
- they can estimate the future situation;
- they can provide an integrated insight into a broad range of environmental, economic, and socio-cultural aspects of sustainability;
- they (might) represent a link between economy and environment;
- they are flexible in terms of geographical areas and variables' considerations;
- they evaluate alternative scenarios and allow the decision-maker to find the best solution, in terms of economic and environmental cost;
- they can make reasonable inferences about the environmental implications of different development patterns.

3.1.4. Drawbacks / limitations

Numerous models have been developed, which have several drawbacks, the most important of which are:

- data collection may be difficult and expensive;
- in order to be able to be used by non-experts, an oversimplification of reality occurs;
- most of them show a low level in terms of horizontal and vertical integration;
- they require constant adjustments and modifications;
- they cannot consider all parameters that are related to a specific case;
- they usually address narrowly defined issues;
- they may require special PC capabilities.

3.1.5. Application of simulation models

This section discusses some selected applications of various simulation models. The section describes the various models as clearly as possible using the available information.

The presentation of the selected model applications is structured as follows:

- institute of development;
- description: background information, such as the goal of the study, the target group, capabilities of the model, etc;

- field of application;
- comments: pros and cons of using the particular model.

The selected models are described below.

3.1.5.1. National Technical University of Athens, GEM-E3 MODEL

Institute of development
Partly funded by the European Commission, Programme Joule, DG XII/F1.

- Coordination: National Technical University of Athens.
- Core Teams: Center for Economic Studies, Catholic University of Leuven (CES.KUL) & Centre for European Economic Research (ZEW).
- Contribution teams: IDEI (University of Toulouse), Stockholm School of Economics, Erasme & University of Strathclyde.
- European Commission, Directorate-General XII (1995) 'GEM-E3 computable general equilibrium model for studying economy–energy–environment interactions', September 1995.

Description
The GEM-E3 model (NTUA, 1997) is a general equilibrium model, representing either the European Union Member States or 18 world regions, one by one and linked through trade. It aims at covering the interactions between the economy, the energy system and the environment. The model computes simultaneously the different market equilibrium under the Walras law and, within the macroeconomic equilibrium, it determines the optimum balance for energy demand/supply and emission/abatement.

The core version of the model assumes a perfect competition regime for a price adjustment of markets, in particular for the markets of commodities. Under such a perfect competition regime, a single representative firm producing a commodity is considered per sector. The core version of the model assumes an imperfect competition regime only for the labour market. Extensions of the model have assumed that some sectors operate under an oligopolistic competition regime. In that case, the single representative firm (per sector) assumption is replaced by a consideration of a finite number of firms per sector and the corresponding commodity varieties.

The GEM model has several extensions on the following seven modules:

- environmental module;
- representation of market imperfections;
- world closure operational (used as sensitivity test);
- endogenous technology evolution (full incorporation of endogenous growth mechanisms planned for 1998–99);
- labour-market imperfections and disaggregation;
- IS/LM closure;
- engineering representation of energy.

The objective of the environment module is to represent the effect of environmental policy on the EU economy and on the state of the environment. The current version only covers atmospheric emissions related to the energy use and conversion. Compared to other currently available models, the aim of the introduction of an environment module is to improve the analysis in the following four directions:

- integrated analysis of environmental and energy objectives on a European scale, for example, energy security versus clean air;
- representation of a larger set of environmental policy instruments at different levels: standards, taxes, tradable permits; international, national, sectoral;
- integrated analysis of different environmental problems: simultaneous analysis of global warming and acid rain policy;
- comparative evaluation of source and receptor oriented: damage valuation versus uniform emission reductions.

The environment module contains three components:

1. The 'behavioural' component, which represents the effects of different policy instruments on the behaviour of the economic agents; for example, additive (end-of-pipe) and integrated (substitution) abatement.

2. The 'state of the environment' module, which uses all emission information and translates it into deposition, air-concentration and damage data.

3. The 'policy-support component', which includes representation of policy instruments related to environmental policy, such as taxation, tradable

pollution permits and global constraint emissions; through policy instruments, emissions may influence the behaviour of economic agents as formulated in the model.

The environmental sub-model is used for:

- cost–effectiveness analysis;
- cost–benefit analysis;
- assessment of policy instrument.

Field of application
The model is a part of the EEA model network (EEA, 2001).

The environmental sub-model focuses on three important environmental problems:

- Global warming through CO_2 emissions.
- Problems related to the deposition of acidifying emissions.
- Ambient air quality linked to acidifying emissions and ozone concentration.

Comments
In the future, it is intended that other GHGs (CH_4, CFC, N_2O) will be introduced in the model. It has to be investigated whether the structure of the model could allow its expansion to other modules covering other environmental issues (e.g. in the field of waste and material flows).

3.1.5.2. EEA baseline projection of selected waste streams

Institute of development
On behalf of the European Environment Agency (EEA), the former ETC/W has designed and developed a methodology that addresses generation of selected waste streams, by evaluating and manipulating existing data, as well as predicting the future trends regarding current waste production in 1999 (EEA, 1999b).

Description
The methodology addresses the issue of waste production, providing data on current waste production within the EU and estimating future trends regarding this issue. It refers to municipal/household waste, glass, paper and cardboard waste and end-of-life vehicles and uses certain assumptions and equations to reach conclusions.

More specifically, the main purpose of the methodology is to develop equations that connect waste generation with the relevant economic activities. The produced equations take into account the consumption of goods that result in the generation of waste and contain several coefficients, which relate waste to the output of the relevant economic activities and other macroeconomic aggregates. The output of the methodology consists of two approaches that may be used to make projections. Depending on the available data, it is possible to either use the complex **estimated equation model** approach, which illustrates sufficiently the interrelationship between waste production and several economic parameters and provides a more secure prediction of future trends, or the simplified **constant coefficient model** approach, in which the coefficients have been given specific values (1 or 0) and the equation provides a linear relationship between waste generation and the output of economic activities.

The data that are required in order to be able to estimate the coefficients and use the equations to calculate the past, present and future waste generation include (depending on the case) (EEA, 1999b):

- data on private consumption, disaggregated into the relevant consumer expenditure items;
- data on waste generation (household/municipal, glass, paper, cardboard);
- future trends on private consumption, disaggregated into the relevant consumer expenditure items;
- data and future trends of the gross domestic product in all EEA members countries by kind of activity;
- data and future trends of several other macroeconomic parameters (e.g. exchange rate, population, etc.).

For end-of-life vehicles, a different approach was taken. The approach is based on the Casper model developed for the Environment DG to project air emissions. It was amended for the purpose of the end-of-life vehicles projections on behalf of the ETC/W. The information that is required to make the projections includes the car fleet, an initial age distribution in 1970 of the fleet and a calculated life-time function describing the probability of finding a car of a certain age on the market (EEA, 1999b).

Field of application
The methodology described above provides information and data as well as projections of future trends concerning the production of

selected waste streams, which include the municipal / household waste, glass, paper and cardboard waste and end-of-life vehicles (EEA, 1999b).

Comments

The baseline projections for selected waste streams have a simple methodology, which relates waste generation with economic parameters and forecasting for the sectors considered to contribute to the waste generation. They provide projections for the future production of certain waste streams until 2010. Although most of the data that are required in order for the model to work properly seem rather easy to collect, there have been difficulties to find information for every EU country over the past years.

It is a rather simplified methodology and the results it provides may not be completely validated, they are however indicative of the future trends of waste production. The coefficients that are included in the equations are not always possible to be calculated, hence a number of assumptions are made in order to reach the conclusions. Therefore, the results should be interpreted carefully and mainly used into an aggregated level (geographically or over time) and not in a year-by-year projection.

Despite its limitations, the described model provides a useful tool that elaborates data on waste generation and macroeconomic data and gives indicative estimations of the future trends of waste quantities based on future trends of economic figures.

3.1.5.3. WRc, plc, STOAT

Institute of development

WRc plc, which is the lead organisation of the European Topic Centre on Water, has developed a computerised model, the STOAT model, which refers to wastewater treatment works and sewage sludge production. This model has been developed over the past 10 years and its latest version was released in 1999 (WRc plc, 1999).

Description

The STOAT model is a computerised modeling package designed to dynamically simulate the performance of wastewater treatment works. It enables the full spectrum of the entire wastewater cycle to be simulated. Since wastewater treatment is one of the biggest sludge sources, this model is capable of providing useful information regarding the sewage sludge production and treatment. It allows the user to optimise the processes related to wastewater treatment and sludge production, in terms of sludge and effluent quality, efficiency of treatment plants design and operation, risk minimisation and costs. The user is able to calculate the sewage sludge production and quality for different wastewater treatment processes and evaluate and assess the response of multiple changes with respect to the influent loads, works capacity or process operating conditions, etc. This model also deals with sludge management and treatment techniques and allows the optimisation of such techniques. The STOAT model is capable of comparing the performance of alternative scenarios and determining the best one for wastewater management in terms of sludge production or effluent quality or the most efficient technique for sludge management. Through the alternative scenarios evaluation, it is possible to make future predictions regarding, among others, the sludge production, quality and treatment.

Field of application

The STOAT model is designed to be applied to wastewater management. It enables the understanding, modeling and optimisation of the entire wastewater management process — from customer discharge to receiving water impact and assimilation. Sludge production arising from wastewater management is an integral part of this model, which provides useful information and estimations regarding sludge quality, production and treatment.

Comments

The STOAT model aims at dealing with the wastewater management. Since wastewater management results in sludge production, this tool is capable of modelling sludge production quality and management. Its main advantage is that it considers the full cycle of wastewater management and includes all common treatment processes. It also integrates with sewerage and river quality models and allows transfer of data to other packages. It is a relatively easy-to-use tool but it requires its user to be familiarised with and experienced in the wastewater management sector. It allows focusing on sludge production and treatment and may give an estimation of their future trends. This model provides its user with all the relevant data that can help to identify and apply the best solution in terms of wastewater management and sludge production and treatment.

The applicability of this model to a variety of main policy questions is apparent. The main issues that this model addresses refer to waste reduction and management. It emphasises the optimisation of wastewater treatment and provides the opportunity to reduce and improve the quality of the produced sludge. It also provides estimations regarding the future situation with respect to wastewater treatment and sludge production and facilitates its reduction.

On the other hand, this tool only focuses on wastewater treatment rather than integrated management and does not address the issue of natural resources depletion. The model does not consider the potential recycling of wastewater in order to preserve natural resources. Moreover, although it considers economic parameters, this model fails to address social effects arising from sludge production and wastewater treatment, hence it cannot be considered as a tool that may be used for sustainability studies

The STOAT model is considered to be a useful tool, which may facilitate the effort for minimisation of sludge production, improvement of its quality and use of the most environmentally friendly sludge-treatment techniques. Its modification and expansion in order to consider more variables related to sludge production might result in its better efficiency and its contribution to sustainability.

3.1.5.4. Directorate-General for Economic and Financial Affairs, Eucars

Institute of development

The partial equilibrium model of European car emissions was developed on behalf of the Directorate-General for Economic and Financial Affairs of the European Commission. Its first version was published in 1995 and, since then, two more recent versions were developed (in 1996 and 1997 respectively) (Denis and Koopman, 1998).

Description

The Eucars model was originally developed to study CO_2 emission limitation policies in transport. Its more recent versions address a greater variety of transport policy questions. The Eucars is a mathematical model, which has the core characteristic of having a partial equilibrium nature, namely all relevant transport markets are modelled and cleared through prices. It describes the European private and public car and a significant disaggregation of the vehicle fleet takes place.

Under the Eucars model, the producers' and consumers' decisions are based on a number of exogenous variables such as the oil prices, the infrastructure, the disposable income etc., as well as several instrumental variables (transport policy variables) such as taxes, excises, norms, etc. The overall structure of Eucars consists mainly of two blocks, the production and consumer block, but it also includes several other modules, in order to be able to address all the main parameters and variables that are involved in transport policy-making. These modules address the car market, the fleet turnover, the congestion and average speed, the emissions and allow the evaluation of alternative scenarios under several appraisal parameters.

A brief description of the modules follows, with special emphasis on the fleet turnover module, which refers to the number of new and old cars, the number of second-hand used and scrapped cars.

The **consumption block** describes the allocation of available income by a representative consumer over various categories (e.g. public or private transport, large or small car, car use during peak or off peak hours, etc.) in the form of a decision tree. The decision-making process is described as a series of separable choices in a nesting structure. Since transport activities require money as well as time, the monetary and time costs enter directly into the decision process and the aim is to select the optimum mix of transport services in terms of budget and time.

In the **production block**, the technical characteristics such as fuel consumption, emission factors, etc. of new vehicles and fuels are determined. The producers are required to make every effort to develop vehicles with minimum lifetime costs and minimum emissions. This block consists of two separate modules, one for fuel efficiency and one for emission-reduction technologies. The main feature underlying both modules is that producers select technical characteristics of the various vehicle categories so that the models they put on the market correspond to consumers' preferences, given prevailing taxes, interest rates, fuel prices, other cost components, mileage and emission standards. A critical assumption in this respect is that consumers are somewhat myopic in the perception they have on lifelong cost saving. They do not take real lifetime costs or benefits into account. Their choice is therefore sub-optimal when compared to the fuel economy that would be chosen under rational expectations about future costs and, due to the above assumption, the production outcome (set of emission factors and related costs) is also sub-optimal.

An important set of input data both for the consumer and the production block is related to the age of the car fleet. Hence, the age structure of the fleet is an important element of the Eucars model, not only because the emission profiles differ significantly across vintage, but also since the end-of-life vehicles provide a very significant waste stream that requires special management. Hence, the relative effectiveness of various policy instruments to limit the car emissions as well as the generation of solid waste arising from end-of-life vehicles is strongly dependent on the car fleet. The age structure depends on:

- the stock of old cars transferred from period to period (which depends on the scrappage of existing old cars);
- the number of new cars added to the fleet in each period.

The available number of old cars is reduced over time following scrappage during successive periods. Beginning with the number of cars (at the moment of purchase) of each vintage, and keeping track of successive scrappage in previous periods, the available number of old cars by size and vintage in each period can be calculated.

The parameters of cumulated scrappage and of the initial size of the vintage are indexed to period and vintage (five-year periods). These parameters are transferred and updated between periods, making the model dynamic. The same pattern is followed for the transcription of cumulated scrappage in previous periods. The cumulated scrappage, hence, refers to the cumulated scrappage at the beginning of the simulation period. In the model, it is assumed that no scrappage has yet taken place for vehicles that were introduced into the vehicle fleet in the previous period. The idea behind endogenous scrappage in Eucars is that the scrappage decision is based on a comparison of likely repair expenditures and current vehicle market prices (vintage dependent). The expected repair expenditures are assumed to follow a normal distribution. Furthermore, it is assumed that after repair the vehicle becomes indistinguishable again from other vehicles of its size / vintage class (homogeneity assumption). Non-repaired vehicles cannot be used and have a market value of zero. A fixed proportion of exogenous scrappage represents cars that can no longer be repaired ('total losses'). As consumers are assumed to optimise utility, they will repair the vehicle if the expected repair expenditures are below the second-hand market price of the size / vintage class. Given the homogeneity assumption, it is always better to repair a vehicle if the associated costs are less than the second-hand market price. Vehicles with repair costs above the second-hand market price are scrapped. If governments were to introduce policies to stimulate scrappage, this would affect the choice a consumer has to make. In the set-up chosen in this model, a modest scrappage subsidy would have similar effects to an increase in repair costs, but would, in addition, also have budgetary implications. Hence, 'modest' scrappage schemes can be evaluated in Eucars by increasing the repair costs, and, in addition, increasing the available income by the amount of subsidies given.

The 'supply' of old cars in a specific period can be completely specified, with its dependence on stock previously accumulated and on second-hand market conditions. Demand is a function of relative prices on these and other related markets.

The generalised cost of traffic services consists of a monetary component and a time–cost component. The latter component is determined endogenously as the product of the value of time and travel time under the different driving conditions. The cost of car ownership depends on market prices for new and old cars through depreciation and the use of capacity cost. The variables that influence the determination of the generalised cost of car usage, the costs of car ownership and the car markets include the exogenous component of variable costs (reflecting oil use, mileage dependent insurance etc.), the fuel use per kilometre, the price net of taxes for a specific fuel type, the fuel excises, the value added tax, the exogenous component in the fixed cost of cars, the annual road tax, the depreciation and capacity costs, the purchase price (tax incl.) of the new car, the second-hand price of the cars, and the opportunity cost of capital, which equals the interest rate times the 'book value' of the car.

The congestion module depicts the interrelation of traffic volume and available infrastructure to determine average speed. The assumption is that every additional kilometre has an impact on other users of the same network by reducing speed. This is modelled through aggregate speed-flow curves, one per network (rural, urban peak, urban off-peak, highway) with the assumption that the driving style is homogenous on the network.

The emissions module consists of equations that describe total emissions of NO_x, CO, HC, PM, and NO_2 by size, class, and vintage, which are emitted by various sources.

The Eucars model provides also the opportunity to evaluate alternative scenarios compared to a baseline one. The baseline scenario builds upon the reference situation to which the model is calibrated, and is then established by fixing income and infrastructure growth for the future periods, leaving standards and fiscal instruments unchanged. Once the baseline scenario is obtained, evaluations of simulations are made on the basis of welfare costs. The welfare 'yardstick' integrates all the major social costs components described below: consumer welfare, producer welfare and government revenues, excluding the effects the measures can have on environmental, noise and accident externalities.

Field of application
The Eucars model is designed to analyse the cost-effectiveness of various transport policy measures and address several transport policy questions in terms of air emission objectives. Although its focus is mainly on air emissions, it contains a specific module that refers to the number of old cars, which constitute the source of a very complex and significant waste stream. Therefore, with the appropriate modifications and expansions, it can easily address the issues of waste arising from old vehicles in a greater depth. The model has also been used in simulation exercises where policy scenarios were evaluated by comparison to the baseline scenario that it acquires.

Comments
Eucars model aims at dealing with the transport policy questions and measures and focuses mainly on the cost effectiveness of the measures related to air emissions. This priority on financial considerations rather than the environmental ones illustrates the international precedence of business over the environment and public health.

However, the model's concept and structure allow its expansion in order to address issues such as the production of waste from old cars. Moreover, its structure allows an assessment of the welfare effects of various policy measures, unlike other simulation models that track the effects of transport policies on emissions and fuel use, but cannot assess the welfare costs of such measures. Additionally, the consideration of time costs in combination with the monetary costs provides one of the strongest points of the model. In any case, the model provides a useful tool for establishing rough orders of magnitude of the costs of policy instruments to cut emissions. It allows great potential for modifications and expansion, which can result in the generation of a model that fully addresses the transport policy questions, including the waste arising from old vehicles.

On the other hand, the model's results are mainly an illustration and averaging of the existing situation rather than data that depict real conditions. It contains oversimplifications when using and determining several variables (e.g. travel speeds). Furthermore, several transport elements have not been included in the model, i.e. accidents and noise emissions that have significant welfare effects. Finally, Eucars cannot be used for a spatial evaluation of air quality problems, as it has no geographical dimension. Whilst this could be built into the model to some extent through further differentiation of the road networks, a spatial differentiation of the vehicle fleet composition and behavioural responses is not possible within the current model architecture. These latter features are, however, important characteristics of air quality problems in Europe.

3.1.5.5. Brookhaven Laboratory and Kernforschunganlage, IEA–Markal

Institute of development
The IEA–Markal model was developed by Brookhaven Laboratory and Kernforschunganlage under the aegis of the

International Energy Agency, in 1981. Since then, several developments and improved versions have been published. The Matter–Markal model is the result of the Matter project, a joint project of five Dutch institutes coordinated by the Energy Research Centre of the Netherlands, in the framework of the national research programme on global air pollution and climate change (NOP-MLK) and was carried out between 1995 and 1999. Matter is an acronym for materials technologies for greenhouse gas emission reduction (Gielen et al., 1998; ETSA, 1999; Cosmi et al., 2000; IRG, 2001).

Description

The Matter–Markal model is a member of the Markal family bottom-up system models, which may be used for energy and material systems analysis. It analyses the whole lifecycle of a product. A Markal model is a representation of the economy of a region and models the processes and the monetary, energy and material flows between them, during the generation of a product. Many products and services can be generated through a number of alternative (chains of) processes. The basic components of the model are specific types of energy and emission control technologies. Each is represented by a set of performance and cost characteristics. Both existing and future technologies are entered into the model. It contains a database of several processes, covering the whole lifecycle for both energy and materials. The model calculates the least-cost system configuration, which meets a certain energy, materials and products demand. This system configuration is characterised by process capacities, activities and flows. Processes are characterised by their inputs and outputs of energy and material, their costs and their environmental impact. These environmental impacts refer to gas emissions as well as waste volumes and land requirements.

Since approximately one third of greenhouse emissions are attributed to material flows, there was a need to expand the Markal model to address material flows changes and strategies and determine the optimum combination of technologies and strategies, in terms of environmental and economic costs. This was achieved with the development of the Matter–Markal model. The model considers the following emission-reduction strategies:

- industrial process improvements;
- CO_2 removal from industrial plants and storage in depleted gas fields and aquifers;
- reduction of non-CO_2 GHG emissions through end-of-pipe technology and process substitution;
- reduction of materials consumption through product substitution (e.g. re-useable packaging);
- materials substitution;
- renewable biomass feedstock;
- improved waste-collection and separation systems;
- waste recycling, cascading and energy recovery.

The selection of materials covers all key groups that are related to the greenhouse gases (GHG): ceramic, inorganic, metals, natural organic, plastics, and other synthetic materials, which are further disaggregated in the Matter–Markal analysis. This selection of materials is further based on the uniformity of the production process, the uniformity of the applications and the availability of statistical data regarding the material flows. Waste materials that are modelled are characterised by their fixed chemical composition rather than being modelled as aggregated waste streams, in order to be able to have an insight into the changing of the waste flow composition and hence the changing of energy recovery and recycling potential. The waste material approach with different waste qualities allows modelling of waste cascades.

The Markal model has been successfully used to determine the optimum combination of appropriate waste-treatment technologies and fuel to be used for satisfying the need for efficient and integrated waste management, with the minimum environmental and economical cost. It provides a comprehensive methodology to decide the most efficient waste-management strategies, which promote energy and material recovery and reduce the environmental impacts of waste-management processes. The Markal model, which has been utilised to represent the relationships amongst energy and material flows, is in fact a normative model, technologically oriented and driven by goods and services demands. It allows the user to extend the analysis over a time horizon, based on potential future technological developments.

The first step in applying the Markal approach is the characterisation of the case study in technical and economic terms. This characterisation includes data on energy and material consumption, waste production and the identification of the most suitable waste-management technologies and strategies. The features of each waste-processing technology are determined taking into account the average composition of waste, the existing plants, the social and economic characteristics of the examined region. Each technological option is characterised by its costs (e.g. investments, operating and maintenance, delivery) and by specific environmental parameters (e.g. emissions coefficients, land-use factors).

A reference scenario is needed in order to be used as a baseline for the evaluation of the alternative scenarios in terms of waste-treatment and disposal technologies, which will be constructed. The scenarios are in fact a combination of waste-processing technologies such as landfill, recycling, incineration and composting. Each scenario is then optimised in terms of resource allocation, and use of technologies and is evaluated with respect to its economic cost and environmental impacts.

Field of application

The Markal model is designed to be applied to decision-making processes with respect to the determination of the optimum combination of waste-processing technologies and energy — environmental planning at a regional or local scale. Several OECD and developing countries use it. Some uses of the Markal model include the evaluation of existing and new technologies (e.g. in the field of waste management) and priorities for R & D, the evaluation of the effects of regulation, taxes and subsidies (e.g. landfill tax), prospective analysis of long-term energy balances under different scenarios and estimation of the value of regional cooperation.

Comments

The Markal model is a tool that may be used to analyse material flows and determine the optimum waste-management strategies. It is capable of examining a range of alternative future possibilities if it receives as input projections of energy services and material flows demands, etc. One of the major advantages of the model is that it allows the user to make estimation of future trends, in terms of waste production and management, taking into account present and future market and technological conditions. It examines the whole lifecycle of goods, the material and energy flows and the impacts to resources depletion and environmental degradation. The model is also capable of being implemented for a more complete description of the anthropogenic activities system, via the basic database and reference network that has been set up, in order to analyse and optimise the waste-disposal systems.

On the other hand, the model focuses on waste disposal and treatment rather than waste prevention. It tries to evaluate combinations of different treatment processes from an economic and environmental point of view and fails to address issues such as waste reduction and minimisation. Although its aim is to equally consider the economic and environmental effects of each scenario, this is not done in a proper way. Economic parameters are always considered as the main criterion in determining the optimum waste-management solution. The Matter–Markal focuses mainly on greenhouse gases emissions and fails to consider other adverse environmental effects from waste production, waste management, etc. The model requires numerous assumptions and a great amount of information, which are not always available. Therefore, a high level of simplifications and uncertainty cannot be avoided.

3.2. Lifecycle assessment (LCA)

3.2.1. Description

Lifecycle assessment is a process:

- to evaluate the environmental burdens associated with a product, process or activity by identifying and quantifying energy and materials used, wastes and emissions released to the environment;
- to assess the impact of those energy and material uses and releases to the environment;
- to identify and evaluate opportunities that lead to environmental improvements.

The assessment covers the entire lifecycle of the product, process or activity, encompassing extracting and processing raw materials; manufacturing, transportation and distribution; use, reuse, maintenance, recycling and final disposal.

According to the International Organisation for Standardisation (ISO), an environmental lifecycle assessment (LCA) is analysing the environmental interventions and potential impacts throughout a product's life (i.e. from cradle to grave) from raw material acquisition through production, use and disposal. This is done by compiling an inventory of relevant inputs and outputs of a system (inventory analysis), evaluating the potential impacts of those inputs and outputs (impact assessment), and interpreting the results (interpretation) in relation to the objectives of the study (defined in the goal and scope definition at the beginning of the study). In the definition of LCA, the term 'product' includes not only product systems but also service systems, like for example management systems. The transportation of waste (both in terms of distance travelled and the mode of transportation) from the point at which waste is generated, through the collection and sorting of waste, to where it is treated, recovered or finally disposed of are included within the lifecycle.

LCA encompasses three separate but interrelated components:

- inventories involving energy and raw materials use and the emissions associated with a product, process or activity;
- impact analysis assessing the potential impacts of the environmental loadings identified in the lifecycle inventory;
- improvement analysis identifying opportunities to reduce the environmental impacts identified in the impact analysis through modification of the inventory.

(*Sources:* SETAC, 1993; ISO, 1996).

3.2.2. Field of application

Various policy-makers, such as industries, governmental authorities, NGOs, universities, etc, can apply LCA. Direct applications of LCA are:

- product development and improvement;
- strategic planning;
- public policy-making;
- marketing;
- integrated (solid) waste management.

3.2.3. Benefits

Only with the help of a formal tool like LCA is it possible to make rational judgments on the relative environmental load of alternative end-use products or alternative processes for producing a given product. The case for or against recycling in specific cases also depends on such analysis.

Lifecycle assessment can provide a basis for making strategic decisions on the ways in which particular waste in a given set of circumstances can be most effectively managed. Even where a comparison of different systems does not show a clearly preferred option in terms of quantifiable environmental flows, this indication of environmental performance can be of value to decision-makers (Ayres, 1995).

3.2.4. Drawbacks / limitations

The problems of LCA are:

- the low scientific robustness of weightings and / or loadings used to quantify and assess environmental impacts;
- the determination of the scope of the inventory analysis (where to cut off the process-chains or system);
- the definition of functional unit (goal);
- the results produced by various of LCAs (investigating the same product) differ in practice.

Moreover, LCA has no utility if the underlying physical data are wrong with respect to critical pollutants and cannot address time and location-dependent effects (Ayres, 1995).

3.2.5. Application of lifecycle assessment methodology

3.2.5.1. UK Department of the Environment, LCA for waste management

Institute of development

The lifecycle analysis for waste management was developed and applied by the UK Department of the Environment in 1996 (Barton et al., 1996).

Description

The UK Department of the Environment has produced an LCA methodology that can be developed and applied to assist decision-makers in waste management. It focuses on a method for identifying the environmental burdens that occur during the collection, treatment and disposal of non-hazardous waste.

The method requires activities (unit operations) related to waste management to be defined in a manner that is independent of the waste processed. These unit operations can be defined at varying levels of detail and are used to flowsheet the waste-management system under study.

Two approaches to identify potential burdens for waste management are considered in the study. The first approach involves classifying activities that differ due to the combination of waste handled and the unit operation the waste is undergoing. The second approach, that is the dual classification system approach to burden identification, requires the waste-management system to be defined as a combination of (i) the generic unit operations and (ii) the wastes characteristics.

Many burdens, termed waste-independent burdens, can be identified at this stage. Burdens that depend on the specific characteristics of the waste are identified by allocating the waste / material a selection of relevant waste characteristics and considering what burdens will arise due to interaction of these characteristics and the various unit operations. For specific studies, this step can take into account whether or not the potential burdens identified cross the system boundary.

The unit operations are waste-independent descriptions of all the activities that might be required to manage wastes. They are also used in combination as building blocks to flowsheet and define specific waste-management systems.

The unit operation building blocks can be defined either in broad or narrow terms. The level of the appropriate detail will depend on the system, the nature of the waste and the context and purpose of the study. To accommodate varying levels of detailed breakdown of the waste-management activities into unit operations, a staged approach to classification is adopted.

Field of application
The LCA methodology is used to support the development of environmental legislation and regulation, development of criteria for environmental taxes, standards, or eco-labelling programmes, or to provide consumer information.

Comments
This study has focused on the development of a dual classification system for the identification of potential burdens required for lifecycle inventory (LCI) in order to determine the potential of lifecycle assessment to aid decision-making in the field of waste management. The study illustrates that a general methodology can be developed to identify burdens for the LCI stage that would meet the wide range of goals and system boundaries for which such inventory data may be required.

The dual classification method for identification of potential burdens also facilitates classifying burdens into categories that indicate how and why the burden arises. The method should enable unit operations data to be collected for quantifying many of the waste-independent burdens. These will then be expressed in terms of the required functional unit for the system. Availability of such data would reduce the time and cost of undertaking specific studies. For waste-dependent burdens, energy, mass and materials balance data are needed to quantify burdens for the system studied. These need to be assessed in the context of the full system as it is only when emissions and products cross the system boundary that quantification is required. However, the variety of processes and process configurations used in waste-management systems and the fact that this stage takes the full range of materials, products and residues generated by modern industrial economies will require database and software development to ensure ease of use.

3.2.5.2. Danish Building Research Institute, LCA in the building industry

Institute of development
The Danish Building Research Institute (SBI) designed and developed an LCA tool for use in the building industry, in 1999 (Peterson, 1999).

Description
An LCA tool was developed by the Danish Building Research Institute (SBI). It consists of a database for systematic storing of all quantifiable environmental data, and an inventory tool for the calculation of the potential environmental effects for buildings and building elements. The main design criteria have been flexibility and ease of use. The tool can be used to perform an LCA for any type of product, but it is designed and structured specifically to perform LCAs for buildings and building elements. The tool differs from most other LCA tools currently available by the method it uses to handle uncertainty. Moreover, this tool can contribute significantly to the effective management of construction and demolition wastes.

The tool consists of two databases. The first database contains tables where data are stored, while the second database contains the user interface and inventory tool.

The leading database is grouped in three main sections, which allows different users to use the LCA tool for different processes and at different levels of detail:

- a section containing typical data for different energy sources and means of transport used in the Danish industry;
- a section containing typical data for commonly used materials in Danish buildings;
- a section containing typical data for commonly used building elements in Danish buildings.

The database allows systematic storing of all quantifiable environmental data related to a process. For this reason, it is designed in such a way that determines designating units, raw materials, emissions, effects, processes and references by index.

Field of application
The LCA tool was developed with the intent of being generally usable by the different parties in the building industry who will be able to use it to analyse, compare and improve products, building elements and buildings.

So far, LCA has primarily been used on industrial products, especially packing materials, but in principle the method can be used on any type of product, including buildings.

When performing an LCA for a building, all inputs/outputs related to the building during its entire lifetime are calculated. These include:

- extraction of raw materials;
- production of building materials;
- construction of the building;
- operation and maintenance of the building;
- demolition and removal of the building.

Comments
The SBI's LCA tool is fully functional and the database contains data for most common energy sources, means of transport and building materials used in the Danish building industry.

By using the aforementioned tool, the different parties involved in the building industry can evaluate waste-management options to reduce pollution and waste-management costs, and guide the development of new products with lower environmental impacts and cost–benefits and redesign products to reduce their material intensity.

Despite the fact that the LCA tool is powerful in its present form, there are still a number of areas in which it can be improved. Specifically, more systematic handling is needed for the last phases in the lifecycle of a building such as:

- operation of a building;
- maintenance, specifically automatic calculation of the amounts of building elements replaced during the lifecycle of a building;
- waste handling.

However, the LCA tool in its present form is being used in everyday work at the SBI, and has proven stable, reliable and easy to use.

3.2.5.3. Edwards D., Schelling of Loughborough University, LCA for glass waste transportation

Institute of development
The LCA was applied for the assessment of waste (glass) transportation by Loughborough University in 1999 (Edwards and Schelling, 1999).

Description
The aim of the method is to provide quantitative guidance, based upon environmental impact, for choosing the best waste-management option for a material and, in particular, to show whether it should be recycled. The focus on base materials differentiates the method from the usual LCA of a single product or group of products formed from base material(s). The method quantifies environmental impacts from all stages in the life of materials, from production from raw materials to final disposal and includes impacts apportioned from supporting activity, such as electricity generation and transport. Measures of specific environmental impacts — for example, SO_2 emissions and NO_x emissions — are aggregated whenever possible into environmental loads, in this instance units of polluted air.

Field of application

The primary goal for developing the method and applying it to materials in municipal waste is to resolve the recycle versus waste treatment and disposal dilemma, by comparing the environmental impact of components of household waste under different waste-management schemes. The impact due to product fabrication and use will be the same whether the products are derived from virgin or recycled materials — the same amounts of products are produced and used in either case. Therefore, the impact of different waste-management and recycling scenarios is compared by making LCAs for the materials in the waste, ignoring the impacts due to the product fabrication and product use, reuse, and maintenance stage.

The method applied consists of two phases: (1) inventory analysis — that is, a material and energy flow analysis within defined system boundaries. It provides a mass and energy balance for a material from raw material acquisition to disposal by landfill or incineration. (2) impact assessment — the material and energy input and output flows from the inventory are classified into impact categories, which are called environmental loads and the environmental impacts of the loads are quantified.

Comments

The method was applied to glass transportation. It was found that the specific fuel usage per kg recycling material for consumer transport decreases with increasing material recovery rate.

The presented analysis using the extended model showed that the environmental impacts due to collecting glass do not overweigh the benefits of recycling and that, in order to optimise the use of energy, facilities for collection of recycled glass should be greatly expanded.

However, some limitations of the method derive from the following drawbacks:

- too time consuming and complex;
- the result of the method applied is a number of discrete effect scores that are difficult to interpret;
- limitation of the application of the study to two products (glass and aluminium);
- exact illustrations of costs and times are difficult to provide as they can vary substantially from product to product.

3.2.5.4. Environment Agency for England and Wales, Wisard

Institute of development

The Environment Agency for England and Wales, with support from SEPA (Scottish Environment Protection Agency) and other international parties, has developed the lifecycle assessment software tool called Wisard (waste-integrated systems assessment for recovery and disposal) in 1999 (Environment Agency of England and Wales and Pricewaterhouse Coopers, 2000).

Description

Wisard is a software tool that applies the approved by the International Organisation for Standardisation (ISO) lifecycle assessment methodology to strategic waste-management planning. The software has been developed over a number of years in partnership with the Environment Agency, Eco-Emballage and Ademe (the French Environment Agency). Other national agencies including SEPA are now involved in further development of the tool and all future development will be steered by an international users group involving all the national public agencies who are using Wisard and funding further development.

Wisard uses a standard set of waste types measured in tones. Details are required of the waste types and quantities collected in each individual collection system, and the quantities of each waste type going into the recovery and disposal options selected.

The purpose of the software (Wisard) is to quantify the environmental impacts of collecting and processing municipal solid waste using various lifecycle techniques. These lifecycle techniques rely on databases of information on the environmental inputs and outputs of energy and materials into a system and the environmental costs of processes in that system.

In the case of Wisard, the lifecycle assessment allows the evaluation of various waste-management options. It examines them in terms of resource use and emissions to the environment at every stage in the development and operation of the scenario. These include raw material and energy use in the construction of facilities, manufacture of vehicles, bins, etc; emissions from transportation, waste-management operations as well as the options or benefits of the options tested.

Wisard also enables the user to analyse specific parts of scenarios which show up as having particularly high emissions or costs to identify the specific cause, and show how changing one part of an option, for example, changing lorry type or collection route can affect the overall costs and benefits. The data contained within Wisard come from a number of sources that are identified within the software. All data collected for the Environment Agency have been subject to a peer review process (Bedfordshire Waste Strategy Group, 2001).

Field of application

Wisard software can be used to compare one waste-management scenario with another, as well as to analyse the individual impact of different parts of the waste-management scenario, for example, changing lorry type or collection route. In this way, competent authorities can compare various waste-management options.

Using the information from the forecasting model on predicted waste production, several waste-management system scenarios, that would meet the targets in waste strategy and the landfill directive, can be modelled using Wisard.

Key areas covered are:

- waste transport and other vehicle use;
- waste collection and separation;
- incineration;
- landfill;
- composting and anaerobic digestion;
- recycling of materials.

The Wisard model can also be applied to the appraisal of air quality impacts for municipal waste options or systems. Wisard also allows the following outputs to be modelled:

- acidification;
- stratospheric ozone depletion;
- photochemical smog formation;
- human toxicity for selected emissions.

For other waste streams, an assumed waste composition can be used to allow Wisard to calculate impacts. However, Wisard requires data related to waste types, logistics and proposed recycling/recovery systems. Such data may not always be available for other waste streams, and therefore the model should be used with care (and consistency across options), particularly if the default parameters in the data input stages are selected by the user (Department for Environment, Food and Rural Affairs, www.defra.gov.uk).

Comments

Wisard is a data-intensive tool so the data collected during the strategic waste-management baseline assessment stage will be of critical importance in testing the options. However, if difficulties occur with the data collection, particularly on waste arisings, Wisard does have a standard data set developed by the national household waste-analysis programme, which if applied to every scenario will still allow comparisons of different options to be carried out. For municipal solid waste, the Wisard model can predict releases to land and water. For other waste streams, an assumed waste composition could be used to allow Wisard to calculate impacts.

Moreover, the lifecycle-assessment (LCA) software Wisard can be used to estimate the quantities of greenhouse gases that will be generated by the municipal waste options. Waste streams other than municipal solid waste can be dealt with by Wisard by creating an assumed waste stream composition, paying particular regard to the composition of organic materials. *Inter alia*, Wisard can estimate the consumption of all resources individually and provide two indexes of non-renewable resource use based on resource depletion (percentage of resource remaining) and consumption rate (percentage of current consumption rate).

This tool currently models municipal and similar wastes (but on a later stage it will address other waste streams as well). The Wisard model is reliant on data and fundamental assumptions concerning the nature of waste management, manufacturing and the current economy. For recycling options, further detail is required. Wisard does not cater for the recovery of certain recyclables and reusable material.

Future enhancements are also planned for the Wisard tool, which include the capability to model financial costs and new databases of information on new waste-management technologies and waste-collection vehicles (Department for Environment, Food and Rural Affairs, www.defra.gov.uk).

3.3. Environmental impact assessment (EIA)

3.3.1. Description

The EIA was set up by Council Directive 85/337/EEC and is a thorough study of the effects of an activity or installation on the environment. It is a process by which the effects of certain public and private projects on the environment are identified, assessed and then taken into account by the consenting authority in the decision-making process. The EIA enables projects to be modified in the light of potential impacts identified to eliminate or mitigate them.

It consists of the following parts:

- Goal definition and scoping: description of the project and proposed activity, definition of the environmental issues of greatest importance, determination of the parameters (setting boundaries, consideration of alternatives).
- Data collection: description and quantification of the baseline environmental conditions in the vicinity of the site, identification of all inputs and outputs of the project which may affect the environment.
- Impact assessment: description and quantification of the changes of the environment (both positive and negative, direct and indirect impacts) resulting from these inputs and outputs, assessment of the significance of any impacts arising from these changes by reference to the baseline conditions and appropriate standards and criteria.
- Control of effects: identification of measures that will be adopted to prevent or minimise any significant adverse environmental impacts, iteration and feedback into the design process, report of environmental impacts which will remain even after alleviation measures have been applied ('residual impacts'), planning of measures to compensate for 'residual measures'.
- Alternatives consideration: identification of the best practicable environmental option.
- Communication: adequate participation and consultation before consent decision-making, dissemination of information to interested parties.

3.3.2. Field of application

An EIA is carried out to assess the environmental impacts of:

- the execution of construction works or other installations;
- other interventions in the natural surroundings and landscape including those involving the extraction of mineral resources.

3.3.3. Benefits

The benefits of the EIA process as an environmental assessment tool are the following:

- The EIA provides all the relevant information concerning the environmental viewpoint of a project. It constitutes the input data used in modelling, future scenarios, trends, etc.
- It also provides processing of information, identification of gaps and formulation of suggestions.

3.3.4. Drawbacks/limitations

The drawbacks of the EIA process as an environmental assessment tool are the following:

- It is project-specific and does not provide possible scenarios or future predictions.
- It lacks explicit project definition leading to limited boundaries and application depth.
- It omits formal scooping, discouraging the development of consensus.
- It does not contribute to enhanced/earlier public participation, thus creating a gap in the feedback loop of EIA procedures and methodologies improvement.
- It does not require post-project monitoring, resulting in an inflexible character in future changes.
- It does not include strategic environmental assessment.

3.3.5. Application of environmental impact assessment (EIA)

3.3.5.1. Hong Kong Polytechnic University and University of New South Wales, manufacturing processes modeling

Institute of development

The Hong Kong Polytechnic University and the University of New South Wales carried out the project entitled 'Manufacturing processes modelling for environmental impact assessment' (Choi et al., 1997).

Description — methodology

The key to environmental design is to translate adverse environmental impact into design criteria or to relate design criteria to environmental impact. One of the strategies that is necessary to put environmental impact assessment into product and process design is the lifecycle analysis (LCA).

In this study, a methodology of environmental impact assessment was developed on the basis of the 'material balance' of a process and the relationship amongst different processes. As a result, the amount of solid waste generated, the energy consumed, the wastewater incurred as well as the level of noise were obtained. The case study of the production of a toy train with 12 scenarios was performed to illustrate and examine the assessment model. This study showed that the number of components, the selection of materials and processes and recyclability are essential factors to determine whether the products are environmentally oriented.

For the ease of material balance determination, manufacturing processes were classified into the following categories:

1. Non-shaping processes — processes used for modifying the properties of materials are called ' non-shaping' processes.

2. Shaping processes — processes used for modifying the work piece geometry are called 'shaping' processes.

The shaping category was divided into three main groups: (1) mass-reducing processes, (2) mass conserving processes and (3) joining processes.

Most of the unit operations, for example, turning, injection moulding, piercing, etc., were defined and grouped into nine families, the grouping criteria being based on their process nature. The material balance of each group was identified. The method of quantification for material balance which was used aimed at finding the actual outputs of each unit operation, the amount of solid waste produced, the energy consumed (electricity), the wastewater incurred and the noise generated.

For example, the method of quantifying the solid waste produced was the following:

volume of solid waste = volume of non-recycled/ volume of non-reused part.

Waste estimation: volume of waste (V_W) = volume of raw material (V_R) – volume of product (V_P).

Comments

In the complete assessment model, it was not too difficult to discover the relationship between the product and the manufacturing process in terms of less environmental impact. Referring to the assessment, once the product has been identified, all of the related processes could be determined. So, throughout the quantification, all the drawbacks of each operation incurred by the product would be revealed, including the amount of solid waste, the energy consumption and the wastewater generated as well as the level of noise.

Throughout the case studies, an objective measure of solid waste, energy consumption, wastewater and noise for each product was obtained and it was found that the design of the product, the material selection and the production method are the critical factors causing impact on the environment. Indeed, these factors must be emphasised at the design stage rather than just occurring at the production stage.

3.4. Environmental risk assessment

3.4.1. Description

Environmental risk assessment is the process of identifying, evaluating, selecting, and implementing actions to reduce risk to human health and ecosystems.

The general procedure for an environmental risk assessment study is presented below:

- Hazard identification producing:
  This phase aims at producing a list of potentially hazardous situations. Hazard identification is fundamental for any risk assessment, since no protection measure can be implemented for unidentified hazards.

- Accident frequency and consequence estimation:
  The second phase is composed of two parts: the estimation of the occurrence frequency and of the damage produced by each of the previously identified significant accidents.

- Risk calculation:
  In the third phase, the results of the previous phase are used to estimate the risk

- Risk reduction:
  This phase includes decisions that can be made on further risk reduction or on their acceptability. The analysts have all the

information necessary (generated during the previous phases) in order to identify the best cost-effective improvements (Contini, 1993).

3.4.2. Field of application

Environmental risk may arise from both accidents and routine operations, involving potentially long-term processes and complex environmental behaviour. In fact, risks facing the environment can arise from sources as varied as atmospheric emissions from power stations, leaks from hazardous waste landfills, natural hot spots of radon, or leaks from nuclear power stations, etc. (Slater and Jones, 1999).

Therefore, environmental risk assessment is used in a large number of fields, such as pollution analysis of soils after waste disposal, environmental impact analysis of climate change, etc.

3.4.3. Benefits

The potential benefits of an environmental risk assessment are as follows:

- cost-effective targeting of risk-management resources towards high risks;
- prediction and management of legislative, environmental, economic and public pressures;
- more explicit treatment and better management of uncertainties;
- flexibility in setting and applying criteria and standards;
- reduced risk of non-compliance with environmental regulations and standards;
- improved efficiency of assessments and submissions under different regulatory regimes (Slater and Jones, 1999).

3.4.4. Drawbacks/limitations

Drawbacks of the environmental risk assessment are:

- It is a complex study involving the treatment of a large amount of information by the teams of experts in chemical processes, maintenance, system reliability and consequence calculation.
- There is inevitable uncertainty at some degree due to:
  - — incomplete plant knowledge, which has a considerable effect on the hazard identification phase;
  - — engineering judgment, needed to overcome the problem of missing data and imperfect knowledge of accident evolution, dose-effect relationships, etc. This is an important source of uncertainty, which calls for the need of a multidisciplinary team of experts;
  - — model uncertainty, i.e. inappropriate model, inaccurate model parameters, inadequate validation, model limitations requires simplifications;
  - — data uncertainty, i.e. source term, reliability parameters, time to operator interventions, atmospheric data (e.g. wind rose, stability classes), etc.
- There still is a lack of detailed guidance on methodologies for setting and achieving management goals that have an appropriate balance of technical information and public inputs.
- To date, no generally accepted means has been devised for measuring and interpreting risks to the natural environment, or defining and managing the scale of risks regarded as tolerable by society.
- There is limited agreement on how to add or compare different environmental effects on a common basis.
- Certain policy issues remain unresolved, for example, the basis for trading off or comparing safety, environmental and economic factors, and the basis for setting environmental risk acceptance criteria.
- Methods for costing environmental damage and valuation of environmental resources exist but how they should be used has not been fully established (Slater and Jones, 1999).

3.4.5. Application of environmental risk assessment

This section discusses some selected applications of risk assessment related to waste-management practices.

The description of the selected case studies is structured as follows:

- institute of development;
- identification of the problem;
- the assessment methodology;
- comments.

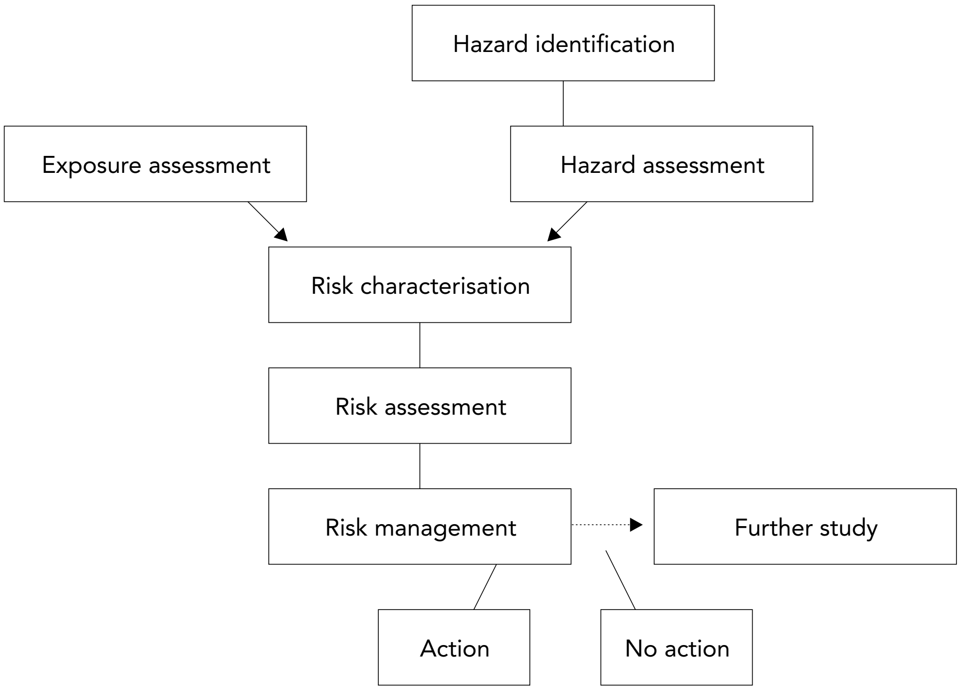
The selected studies are described below.

3.4.5.1. Cornell University, ERA in municipal solid waste composting

Institute of development

The Institute for Comparative & Environmental Toxicology at Cornell University applied the risk-assessment methodology in municipal solid waste

Figure 3.1 **Steps in risk assessment**



composting in order to examine various issues related to the safety of employees and environment (CWMI, 1999).

Identification of the problem

What are the risks in various alternatives for resource recovery and waste management? Who or what is threatened? What is saved or protected? Decisions about environmental risks are made in the face of uncertainties beyond common experience, particularly for new technologies. Municipal solid waste (MSW) composting lacks evaluative data offering a foundation on which to base scientific assessments. With MSW composting, the situation is further complicated by the highly diverse, and often changing, nature of MSW and other materials with which it might be composted.

Historically, composting has both provided a soil conditioner / nutrient source and been a means of waste management of large volumes of sludge and manure. The product can be a clean, odour-free and welcome garden fertiliser, but the process may be messy, odoriferous and subject to many complaints, even though people recognise it as a 'green' alternative to landfills and incinerators. This obvious ambivalence affects the policies and perceptions regarding composting and its products.

Serious, immediate and widespread threats to the environment and consumers presented by MSW composts are not evident. Specific hazards to employees are recognised and being addressed, although there are concerns (see below). Most of the unresolved issues focus on long-term, chronic exposures. Despite uncertainties, those responsible for risk management must act to safeguard public health and the environment. Reasonable regulations must be set and standards for accountability must be determined.

The risk-assessment methodology

Risk assessment is a process engendered by the need to make risk-management decisions in the face of uncertainty. Simulated scenarios and statistical analyses are used to try to determine the potential exposure to hazards, agents and activities for various groups and to assess the potential outcomes of such exposure.

Most risk assessments generally follow a series of steps such as: hazard identification and assessment, exposure assessment, risk characterisation and risk assessment (Figure 3.1).

Hazard identification: In MSW composting, primary hazards include pathogens and their toxins, organic chemicals (many of them are in common household items such as solvents and cleaners), and heavy metals (from items such as batteries and consumer electronics), as well as mechanical and related hazards. In compost products, concerns for consumers and the environment are principally the heavy metals and some persistent organics. Furthermore, potential hazards may come from three sources: those present in MSW, those materials transformed by composting, and those materials created by the composting organisms themselves (endotoxins, spores).

Hazard assessment: The nature of effects on individuals, species, and living systems, as well as the time course over which these effects may take place, are needed to relate exposure to the outcome. Two points are particularly important in a risk assessment: the dose-response relationship (what exposure results in a given level of effect) and the character of the effect itself.

Exposure assessment: Exposure is the frequency, duration and intensity with which an agent or activity is presented to a subject by various routes (inhalation, ingestion, or through the skin (dermal)). Exposure can be direct, as for inhalation of MSW compost dusts and ingestion of compost/soil by children, or indirect by ingestion through the food chain (soil-> crop -> subject or soil -> water -> invertebrate -> fish -> subject). In instances where exposure is known or reasonably suspected to occur, such as the occupational exposure of workers, relatively simple models and assumptions can be used to simulate the nature of the exposure. Where exposure is suspected, but not well described and predictable, the common practice is to monitor potentially affected people and the media (air, water, soil, or food) with which they come in contact. Specific information about the behaviour of the chemicals and the environmental conditions affecting their fate are used to refine our understanding of exposure. Background levels of contamination from other sources, including natural phenomena, must be identified and quantified. Monitoring of the MSW composting process, for example, has been useful in showing that potentially harmful levels of organisms associated with respiratory disease exist only in the immediate vicinity of a disturbed pile, even though such organisms are widely distributed throughout the environment.

Risk characterisation: Risk characterisation sets the stage for risk assessment by developing both the models of exposure-response in test species and human beings and the means to convert one to the other. The exposure and hazard assessments are connected by an appropriate set of risk assessment scenarios — the likely pathways of exposure and conditions of concern. The exposure-response relationship calculated via these scenarios can yield an average or a range of values to be compared to accepted standards by the risk assessor. For MSW composts, risk characterisations are most important for heavy metals and some persistent organics, but have generally paralleled those of sludges.

Comments

Once some knowledge of the distribution of exposures over time and some understanding of the outcomes from different types of hazard is obtained, the formal risk assessment of MSW composting and its products can be undertaken. A large number of assumptions must be made to construct appropriate mathematical models. Various strategies for risk assessment may differ substantially in their assumptions and approach, so different conclusions may be reached.

Uncertainty pervades each step in the risk-assessment process. Some of this uncertainty is either due to the difficulty in making accurate measurements at very low concentrations or is systematic, i.e. due to uncertainty in the models, equations and understanding of the biotic systems involved.

Other uncertainty results from physical and biological variation, i.e. random events such as weather, the frequency of genes in the target populations, etc. Taking all of these sources and types of uncertainty into account in risk assessment offers several challenges for MSW compost.

Research can narrow some of the uncertainty inherent in the risk-assessment process, but risk assessors must provide clear, consistent estimates regarding the level of uncertainty for each step and for the overall process.

Ultimately, the purpose of risk assessment is to assist in risk management, that is, to help regulators, policy-makers, and managers choose an appropriate course of action when necessary. The risk manager must balance many factors beyond the numbers generated in a risk assessment: the needs of communities who seek protection or to minimise their tax expenditures, the concerns of companies which will undertake remediation or want relief from what they see

Table 3.1 **Results of routing scenarios for waste transport to disposal sites**

Routing scenario	Average journey length	Population within 500 m of roads used	Km over extremely vulnerable groundwaters	Estimated years between accidents
Minimise travel time	55	3 498 884	10 607	19
Encourage use of trunk roads	77	2 280 988	16 907	22
Avoid densely inhabited areas	92	2 257 994	24 553	11
Minimise accidents	65	2 986 097	9 830	24

as oppressive regulations, and the interests of diverse agencies and jurisdictions with their own legislative mandates. Decisions must be made about which standards to apply, what groups to place at risk or protect, which remediation strategy should be employed, or what mitigation is immediately needed.

3.4.5.2. University of East Anglia, ERA for transportation of hazardous materials

Institute of development

The School of Environmental Sciences, University of East Anglia, Norwich in Great Britain, has applied GIS as a tool in risk assessment for transportation of hazardous material (Brainard et al., 1996).

Identification of the problem — methodology description

Researchers of the University of East Anglia have been able to access archived data from the 1980s for transport of London's hazardous wastes, which included producer and disposal sites. With the use of a geographical information system, the most likely routes taken by tanker lorries for transport of certain waste classes were modelled. The investigation was narrowed considerably because of concerns about data quality and our desire to get a regional picture of waste movements. These results are for liquid wastes transported by tanker lorries in London and nearby counties, and arising in the 1984–85 period.

The simulations employed four different routing criteria: (i) shortest travel time, (ii) shortest travel time, encouraging use of main roads (resident) population avoidance, (iii) accident avoidance. The simulations were applied for four scenarios (routing through central London, routing used by actual drivers, bizarre routing schemes, convenient routing schemes). To explore the potential risks posed by these waste movements, the possible hazards to the nearest resident population, groundwater supplies, and the predicted accident frequency for each class of road in each scenario were examined. Of the four scenarios, the accident-avoidance one seemed the best all-round for minimising the many risks involved, while the population avoidance one resulted in absurd routing schemes, diverting lorries down completely unsuitable (and more accident-prone) roads. A summary of the findings are presented in Table 3.1.

Comments

Risk analysis is considered as an important tool for decision-making. The benefits of the spatial treatment of risk may be particularly important for environmental risk analysis. The spatial component of risk without extrapolating beyond the known data is one of the most important challenges of the future. Nevertheless, ultimately, interpolation of contaminant data that are rare in space and time is necessary for full evaluation of human risks. Spatial interpolation techniques make assumptions, and may therefore be misleading, incomplete, or incorrect. But, to encapsulate human health risk into a single value in a table may be at least as incomplete or misleading, since the spatial relationships among contaminant values are not retained. The presentation of an interpolated contaminant layer together with bar and pie chart symbols placed at actual sample locations distinguishes between measured and derived concentration values, and provides a means of qualitatively evaluating uncertainty. Such a presentation also communicates the spatial weighting of the sampling design.

3.5. Multi-criteria analysis (MCA)

3.5.1. Description

Multi-criteria analysis (MCA) is an assessment tool for environmental planning and decision-making processes. Environmental planning and decision-making are essentially conflict analyses characterised by sociopolitical, environmental and economic value judgments. Several alternatives have to be considered and evaluated in terms of many different criteria, resulting into a vast body of data, which are often inaccurate or uncertain. To complicate the process further, there typically is a large number of decision-makers with conflicting preferences. The different points of view of various interest groups should also be considered in the process. Therefore, a single, objectively, best solution does not generally exist and the planning process can be characterised as a search for acceptable compromised solutions (Lahdelma et al., 2000).

The core of the MCA is the decision model, which is a formal specification of how different kinds of information are combined together to reach a solution.

To give a better picture of the multi-criteria analysis method, it is essential to proceed in defining the terms of criteria, alternatives and stakeholders. A discrete multiple criteria decision problem consists of a finite set of alternatives that are evaluated in terms of multiple criteria. The criteria provide numerical measures for all relevant impacts of different alternatives. The relevance of different impacts depends on stakeholders' points of view. It is necessary to define precisely how each criterion is measured. Usually, criteria are aggregate values computed from a much larger amount of so-called primary factors, which form the lowest level of information, also known as the assessment level (Lahdelma et al., 2000).

In real-life environmental problems, alternatives can be divided into standard and innovative ones. Standard alternatives are obvious from the decision context alone: the actual project, the so-called zero alternative (rejection of the project), and other alternatives presented by the stakeholders. Innovative alternatives are those emerging through different kinds of negotiations during the process (Lahdelma et al., 2000).

The stakeholders consist of all different people associated with the planning and decision process. They can be classified into standard stakeholders and interest groups. Standard stakeholders include the decision-makers, experts, planners and analysts responsible for the preparations and managing the process, while the interest groups are political parties, civic organisations or residents in the impact area (Lahdelma et al., 2000).

3.5.2. Field of application

MCA is used in environmental planning and decision-making processes in order to clarify the planning process, to avoid various distortions and to manage all the information, criteria, uncertainties and importance of the criteria (Lahdelma et al., 2000).

3.5.3. Benefits

Some of the more important advantages of MCA are considered to be:

- capability to compare scenarios with regards to contradictory objectives;
- facilitation of the process when many criteria are involved;
- bilateral learning between experts and interest groups;
- all people associated with the planning and decision process learn to understand the problem better, as the decision problem immediately becomes clearer after it has been formalised in terms of alternatives and criteria (Lahdelma et al., 2000);
- support to the allocation of resources, since it provides a comprehensive framework for storing all relevant problem information and makes the requirements for new information explicit;
- traceable and transparent process because it ensures that all relevant data, uncertainties, and preferences can be considered explicitly;
- increased discussion between different stakeholders, activated non-participants and focuses the discussion to relevant topics;
- potential for the stakeholders to examine problems comprehensively, not just from their own point of view and to recognise conflicts based on misunderstandings and solve them.

3.5.4. Drawbacks/limitations

Some of the main disadvantages of MCA are presented below:

- In order to use MCA, there is a necessity for comparable data.
- There is the possibility for the selected criteria to be overlapping.
- Clear identification of the stakeholders has to take place, as any argument to include or exclude different stakeholders provides information to the planner about the problem.
- Sometimes, MCA is time consuming as learning during the process may make it necessary to repeat some of the phases.

- Different stakeholders have different points of view and emphasise criteria differently, therefore an allocation of a weight to each criterion is required in order to define the priorities of the decision-makers.

3.5.5. Application of multi-criteria analysis (MCA)

3.5.5.1. University of East Anglia, evaluation of waste-management options

Institute of development

The multi-criteria analysis method was applied for the evaluation of waste-management options, at the Centre of Social and Economic Research on the Global Environment (CSERGE), University of East Anglia, in 1993 (Powel, 1996).

Description

The method used in this study evaluated the site-independent criteria for six waste-disposal options. The multi-criteria model was developed to evaluate incineration, refuse-derived fuel (RDF) and landfill, each with and without recycling. All three waste-management options include the recovery of energy, which is reclaimed as electricity. Landfill gas is recovered from landfill and RDF is burnt on-site in a dedicated boiler. The gaseous emissions arising from the waste disposal options have been calculated using an integrated solid waste-management lifecycle inventory model. Emissions from both energy and materials recovery are included in the analysis. The electricity generated from waste combustion replaces that generated by fossil fuels, thus saving the associated gaseous emissions. The impacts arising from the disposal of ash from incineration and RDF combustion were also included, as were the energy and emissions associated with the transport of waste and recovered materials.

The six waste-disposal options were judged against 15 criteria. These were divided into 10 cardinal and five ordinal criteria. Two of the ordinal criteria could be expressed in monetary values so they were related to internal and external costs. The remaining 13 criteria were divided into two groups, one encompassing resource use and the other covering the environmental impact. Some of the criteria were used where possible, since the data were in several instances either unavailable or not sufficiently accurate. In the latter case, an ordinal ranking method was employed. For ease of comparison, the values were converted so that they conformed to the rule 'the higher, the better'.

The evaluation matrix was two-dimensional with the evaluative criteria forming the rows and the alternatives the columns. In a computer programme, the evaluation matrix with N criteria and P alternatives was first divided into two sub-matrices, one with the C cardinal criteria and the other with the O ordinal criteria. The elements in each matrix were defined by a term e_{ij} where i varies from 1 to C or O, depending on whether the data were cardinal or ordinal, and j varies from 1 to P. A vector was then assigned to each matrix containing the relative weights of the cardinal wc_I or ordinal wo_I criteria, where:

$$\sum_{i=1}^{C} wc_i + \sum_{i=1}^{O} wo_i = 1$$

Each alternative e_{ij} was then compared with every other alternative e_{ik} (where k = 1 to P) for each criterion to produce a dominance score, which represented the degree to which alternative *j* dominates over alternative k over all criteria. Separate dominance scores for the ordinal and cardinal criteria were calculated, using a special equation. For the cardinal data, all of the e_{ij} elements were first standardised and then were used for the calculation of the cardinal dominance. The same happened for the calculation of the ordinal dominance. After these, the calculation of the overall dominance scores (ordinal + cardinals) was possible. Hence, the overall dominance scores were summed to give an appraisal score, which represented the worth of alternative *j* relative to all other alternatives. These appraisal scores allowed the final ranking of the various waste-disposal options.

The priorities of the decision-makers were defined by the allocation of a weight to each criterion. However, the literature on decision theory reveals that such weights are difficult to realise, hence, it is impossible to have a truly representative set of weights. In this study, this allocation of weights allowed for a more comprehensive sensitivity analysis between the three different viewpoints (financial, resource use and environmental impact). First, the criteria within each group were allocated weights relative to one another such that the weights within each group summed to unity.

The sensitivity of the multi-criteria evaluation to cost, resource-use and environmental impact criteria was explored by varying the weights of each criteria group, with the remaining criteria groups being given equal weight so that the total weight is 1. For example, if the weight on cost criteria was increased to 0.8, the other two criteria groups were each allocated a weight of 0.1. In addition, the multi-criteria evaluation was carried out with 100 % weight being given to the internal costs.

In the multi-criteria evaluation, three results were particularly robust. RDF with recycling was the dominant option. Second, recycling was advantageous to the waste-disposal option, apart from when an increased weight was placed on the cost criteria. The third conclusion was that increased weight on the resource-use and environmental impact criteria, rather than on costs, increases the attractiveness of RDF and incineration.

Comments

The application of MCA in this study does not 'discover' a solution to the problem of waste management. It structures the problem of waste management rather than finding the solution. It constructs a formal system, which can aid the decision-maker to understand, specify and model his preferences to increase the coherence of the process itself. In that way, the end results from the evaluation of the waste-management options can be considered less important than the learning process, which takes place in order to obtain these results.

3.5.5.2. European Association of Environmental Management and Education, MCA for WEEE

Institute of development

The study described in the following is a master class thesis carried out in 1999 in the framework of the EAEME (European Association of Environmental Management and Education). It deals with the management of waste from electrical and electronic equipment (WEEE) and examines the selection of the most appropriate scenario for the collection / recycling of WEEE in Greece. This study took place at the National Technical University of Athens in 1999 (Dais, 1999).

Description

In this study, the analytical hierarchy process (AHP) was applied, during which a pair-wise comparison takes place. This means that the best scenario comes out of a binary comparison with all the other scenarios for each criterion. The results are given by a software application named Expert Choice.

The various scenarios developed are based on the six different collection schemes that are described below:

- Drop-off events: One-day events take place, where end-users drop off their obsolete appliances to especially organised facilities.
- Regional approach: Multiple communities host coordinated events on a rotating basis (similar with the above mentioned).
- Permanent collection depot: It is a year-round model. Last owners transport their end-of-life equipment to collection depots.
- Curbside collection: WEEEs are collected either on a periodical basis or by request by the responsible for the municipal solid waste.
- Take-back system: The retailer is obliged to take-back (free of charge or not) old equipment when a new one is purchased.
- Combined collection methods: This model is the coordination of various collection methods.

Considering the above parameters, six potential collection / recycling scenarios were designed. These are:

- Take-back system: A stakeholder is appointed to manage WEEE. The 'an old for a new' principle is brought in action. The customers give back an obsolete appliance, while they purchase a new one of the same type. They pay a deposit when buying a product, which is refunded when they dispose the product to an authorised de-manufacturer / recycler.
- Municipal scenario: The public sector is responsible for the proper management of WEEE. Collected equipment is taken to existing facilities, where sorting and shredding take place. Citizens pay for the proper disposal of WEEE through an increase in taxation.
- Semi-public scenario: Local authorities collect and a private de-manufacturer recycles the collected equipments. New products purchased will include a user fee for their proper management after the end of their usage life.
- Seasonal scenario: A system of drop-off events is set and NGOs participate too. Collected equipment is transported to

existing facilities and shredding takes place.

- Multi-scenario: Incorporation of scenarios 1,2 plus establishment of depots. The main characteristic of this scenario is the collection through parallel routes so as to maximise collection rates.
- 'Do nothing' scenario: Absolutely nothing is done. (Such an alternative should have been rejected earlier in the MCA methodology, by the exclusionary criteria. Nevertheless, it is going to be evaluated in the following analysis only for extracting some more conclusions).

As far as the criteria are concerned, one exclusionary criterion was considered non-satisfactory. The other non-exclusionary criteria were set after singling out the requirements of the WEEE management in Greece. That means that the solution should be as economically independent as possible, achieve as high a collection and recovery rate as possible, avoid secondary environmental effects and be applicable to the special characteristics of population and topography. Hence, economical, technical, environmental and socio-political criteria were selected for the purpose of this project. Each category of criterion is expressed through indicators like for example, capital and operational costs for the economic criterion, recovery rate or monitoring system for the technical criterion, landfilled residues for the environmental criterion and the public participation or the job opportunities for the social criterion.

In the AHP methodology, each stakeholder weights the criteria and indicators and then the analyst initiates the procedure of dialogue, influence and compromise among the stakeholders, until he ends up with commonly accepted weights. The weights are calculated by the software program, which requires a binary comparison among the criteria as well as selected indicators for each category of criteria. The comparison is conducted by the following general statements:

— How much more (or less) important is criterion A than criterion B with regards to the achievement of the overall goal?
— How much more (or less) important is indicator A1 than indicator A2 with regards to the optimisation of criterion A?

The technical criterion is the most important with respect to the achievement of the overall goal. The economic one is the second more important, while environmental and social criteria follow. Apart from criteria, different indicators of the same category appear to have different importance.

After scoring the scenarios, according to the results from the implementation of the AHP methodology, the ranking of the scenarios is derived. Hence, the overall best scenario is the one of 'drop-off events', described earlier.

Comments
The main characteristic of the method is that it allows the expression of their preference to one criterion over another through a pair-wise comparison using a ratio scale. The scale consists of numbers from 1 to 9 and it is called '1 to 9 AHP ratio scale'. Each decision-maker is free to express his opinion on how much more preferable one scenario is over another concerning a certain criterion or indicator. Moreover, the method allows checking the consistency of the judgments (preferences of one factor over another).

The AHP model is simple, it provides weight-assignment features and it also offers the ability for applying sensitivity analysis. On the other hand, the main drawback of the method is that it requires more intensive work than other methods in the pair-wise comparison procedure, especially when many criteria, indicators and alternatives are involved.

The implementation of multi-criteria analysis methodology and more specifically the analytical hierarchy process does not end up in an explicit result, a solution or an answer for the management of WEEEs. However, it helps the decision-makers to study the crucial parameters of the problem and identify the essence of it, getting in general a clearer picture of the problem as well as the possible ways to solve it.

3.5.5.3. University of Sherbrooke, Canada, MCA in sewage sludge management

Institute of development
The Group Stoper of the University of Sherbrooke in Canada studied in 1996 the implementation of multi-criteria sewage sludge management model in a rural municipality (Bellehumeur et al., 1996).

Description

The purposes of this study were: (1) to present and analyse the results of a public consultation concerning the problem of sewage sludge management in a rural municipality, and (2) to model the decision process in order to verify the stability of the decisions made by the committee. This committee was an advisory committee representative of the population, which studied the possible solutions and made recommendations to municipal decision-makers. A panel of experts provided the committee with information concerning the various aspects of sewage sludge management.

Several processes can be used for sewage sludge disposal, but four solutions were selected based on their wide acceptance and their applicability for a small municipality. The four solutions were: (1) composting, (2) landfilling, (3) land application and (4) incineration (by another regional industry).

Each committee member was asked to evaluate each solution on the basis of information provided during previous meetings. They had to express their evaluation numerically by ranking each criterion of each solution. The ranks were the result of committee-members' judgment and had only an ordinal relevance (1 for the worst case and 5 for the best). Moreover, the committee members were asked to rank, on a scale from 1 to 5, the relative importance of each criterion, giving an estimation of the weight of each criterion in the decision process. Then, at the end of the consultation process, each committee member estimated the elements of five-by-four matrix of ranks (five criteria by four solutions) defining an impact matrix, in which the criteria were arrayed as rows and the solutions as columns. They also estimated the vector of ranks (a five-by-one vector) giving the importance (weight) of each criterion in their decision. The impact matrix and the vector of weights were used to verify if the decision resulting from the discussions of the committee corresponded to this qualification carried out individually. In this study, these weights express the preferences of the committee members and were used as parameters in the decision algorithms.

Apart from the four selected solutions, various combinations of solutions such as composting / land application, composting / landfilling, land application / landfilling and composting / landfilling / land application were also considered.

The selection of the most suitable solution considers these broad families of criteria: (1) economics, (2) risk perception of the population, (3) technological features, (4) environmental impacts and (5) human health impacts. These main criteria are then subdivided into several factors, which define the whole criteria matrix.

The main concerns regarding economic aspects of sludge disposal were: treatment costs per ton of dry matter and the production of any useful by-products and / or potential for energy recovery. The economic analysis considered the following costs components: costs of land, equipment, transport, capital, on-site and off-site development, as well as anticipated operating costs of closing the landfills. For the risk perception of the population criterion, 671 randomly selected individuals were selected to answer the questionnaires concerning immediate risk perception, social equity, risk for future generations and public acceptance of each solution, evaluating the answers on a scale from 1 to 5. Technological feature criteria were divided into the following criteria: required level of know-how, equipment complexity and operation complexity. Environmental impacts considered the following criteria: risk of heavy metal and pathogen contamination, risk of gas emission and impacts on plant productivity and diversity. The questions regarding human health impacts considered heavy metal absorption, pathogen ingestion and gaseous inhalation.

The advisory committee ranked the relative importance of each family of criteria in comparison with the others. This information was used to define the weights assigned to each criterion. These weights were used in the multi-criteria decision techniques.

The normalised matrix *Y* was subjected to three different multi-criteria decision techniques: (1) a weighted sum of scores, (2) a fuzzy set model, and (3) the Electre model. These methods are commonly used for studies involving multiple criteria.

- The weighted sum is a simple and straightforward method. It is simply the weighted sum of each criterion for each solution. The normalised scores of matrix *Y* are multiplied by the weights and summed across the rows (criteria) leading to a cardinal index of the overall performances of each solution. The scores of each solution are calculated by specific equations. This method does not take into account the important drawbacks, which can occur, for a given criterion.

- The fuzzy set method can take into account the aspects of uncertainty and vagueness inherent in the definition of an impact matrix. There are specific relationships between a pair of solutions S_j and S_k and a criterion C_I, from where the ranking of solutions derives.
- The Electre model provides very useful information in considering advantages and disadvantages associated with each solution. Hypotheses on the dominance of a solution *j* over a solution *k* are successively tested and concordance and discordance indexes are calculated. The concordance index represents the percentage of criteria (in weight), which agrees with the hypothesis, and on the other hand, the discordance index represents the degree of disagreement with the hypothesis. To interpret the information contained in both concordance and discordance matrices, threshold values (*p* and *q*) are defined to specify the amount of desired concordance and tolerated discordance. The technique consists of the establishment of concordance and discordance levels stating that a dominance hypothesis is justified. The values for *p* and *q* are decided on a trial and error basis. While these values are important to measure the strength of preference, the ranking of solutions does not depend on their choices.

Finally, considering the uncertainties relative to the estimation of criteria and weights and to verify the stability of potential solutions, Monte Carlo simulations were used. More specifically, instead of using the single values to represent a criterion and a weight, the criterion and weight values are drawn at random from a Gaussian distribution centred on the original experimental values. Subsequently, the formula of the multi-criteria decision techniques are applied by using the values drawn at random, allowing the calculation of a probability distribution of possible scores.

The impact estimates of the matrix are mainly qualitative, except for the economic costs. The estimation of qualitative impact values for the combination of solutions is made using a conservative approach, assigning the worst estimation of the combined solutions.

The methods used showed that the solutions of composting and land application emerge as the preferable solutions based on the impact matrix estimation of the Stoper research team. Due to a considerable overlapping of profitability interval, both solutions cannot be distinguished, and differences in mean values are not significant. Solutions of composting-land application and land application-landfilling, which consider combinations of these two solutions, seem to dominate the remaining solutions, but small overlapping in the probability intervals does not allow strong conclusions to be drawn.

Comments

The decision model included criteria employed in the analysis of a waste-management problem relying on interdisciplinary principles, such as economics, technological aspects, environmental risks, human health risks and social perception. The methods used (weighted sum, fuzzy set, Electre) considered features concerning fundamental aspects of environmental impact matrices such as data type, weight information, uncertainties, etc.

Another advantage of the application of the MCA is that it allows further data to gradually be integrated in the models and shows whether or not in the long term the management strategies are adequate for the municipality. However, there is always uncertainty, and therefore it is also necessary to consider the precautionary principle in relation to environmental management.

3.6. Waste factors

3.6.1. Description

Coefficients in general and waste factors in particular are essential tools for providing information on the state of environment, the emissions linked to human activities and the influence of environmental quality on human and ecological health. They are increasingly important for monitoring changes, showing trends and developing projections in the volume and intensity of waste generation.

Environmental factors are in general related to an activity or source, for example, describing emissions linked to an industrial process. They are obtained by relating the quantity emitted to a specific product or source or activity. These factors are based on measured and / or calculated and / or estimated values.

Examples of waste factors are:

- quantity of waste generated per inhabitant and year;
- quantity of paint sludge per car produced.

On the process and enterprise level (micro-level), the development and application of waste factors should be seen in context with environmental management instruments, such as lifecycle assessment, environmental auditing and management (EMAS, ISO). In fact, waste factors are a useful and demanded tool to be integrated into these instruments, as quantitative goals, targets, benchmarks, etc. They help to define the environmental profile of products and processes, to assess environmental effects, and to communicate environmental statements when instruments like EMAS or LCA are applied.

3.6.2. Field of application

Waste factors can be applied on different levels, which are the following:

- National or regional level
  At this level, waste factors operate as an informative tool, which integrates environmental data with economic aspects, compares efficiency of Member States or regions in minimising waste generation and supports the authorities in drawing up their national or regional waste-management plans

- Industrial sector level
  In order to improve material or energy efficiency, these factors express the amount of waste in relation to fuel / energy consumption, to raw material consumption and to end products.

- Enterprise level or production site level
  In order to face even more the challenge of implementing an environmental management and auditing system, waste factors can be applied as tools for the source-oriented 'plan-do-check-act' approach in waste management and considered as indispensable parts of an eco-controlling system.

- Technology level
  Waste factors at this level can be applied so as to plan and assess activities to develop clean technologies and to support their implementation (EEA, 1999a).

3.6.3. Benefits

Some of the main advantages of waste factors are presented below:

- They are simple, easy to interpret and to communicate.
- They show trends over time and give basis for projections.
- They reduce the number of measurement and parameters normally required to give an 'exact' picture or description of the waste generation.
- They point out or characterise problematic areas as well as possibilities and potentials of improvement.
- They provide both topical and representative picture of the waste situation of a source (production process, industrial sector, region, nation).
- They are responsive to changes of the waste generation.
- They provide a basis for comparisons, for example, between industrial sectors, technology alternatives, etc.
- They are based on common scientific standards or (international) consensus.
- They are based on data and information of known quality, adequately documented and updated in regular intervals.
- They are linked to other sectors, for example, economy and society.

3.6.4. Drawbacks / limitaitons

The main disadvantages of waste factors are:

- Despite the manifold activities on waste factors, it has to be realised that for the moment there is no nationally and / or internationally accepted system or set of waste factors for environmentally sustainable development available.
- The development of waste factors has so far been limited partly because of lack of data but also because 'traditional' waste management has been focused on pressure state and impact — referring to the DPSIR-assessment framework (state / impact / response).
- There is still a lack of verified factors which limits the fields of their practical application for the time being.
- Waste factors are not a 'stand-alone' solution, since they should be linked to other environmental factors and indicators

or to economic data according to their purpose (EEA, 1999).

3.6.5. Application of waste factors

3.6.5.1. Eurostat EPIS, conventional material flow balances

Institute of development
Statistical Office of the European Communities — Eurostat.

Description
EPIS is based on the methodology of conventional material flow balances: the input of material and energy into a system or process is considered equivalent to the accumulation and the output of products and other emissions (waste, wastewater, air emissions, etc.) as result of the process within a defined period (EPIS, 1994; EEA, 1999).

With this conceptual framework, EPIS fits easily into both the present used system of sectional economical statistics and the national account.

The model links between environmental data and economic statistics, to consumption and environmental impacts, and to pressures coming from it. EPIS will contribute to the development of pressure indicators by providing data on material flow and emissions of selected harmful substances into air and water. This opens the perspective to calculate the accumulative environmental pressure of different final products. Results are important for the consumption sector and the development of environmentally friendly products.

For waste generated in a production process, both the technology and the material input are considered. The secondary wastes from on-site wastewater or exhaust gas cleaning are considered separately.

Field of application
EPIS started in 1994 with a pilot phase involving France, Germany, Italy and the Netherlands. A second phase included pilot projects in Austria, Finland, Norway, Spain and Sweden, in which consistent data structures were developed, linking economic statistics and process specific data. In addition, input/output data for specific processes were developed (eight-digit Prodcom level). EPIS has been part of Eurostat's project on environmental indicators and green accounting (EPIS, 1994; EEA, 1999a).

Comments
EPIS is based on eight-digit Prodcom process-level; it is not feasible to calculate coefficients (incl. waste) for all Prodcom processes; hence, aggregation — for example, to NACE-two-digit branches — is not feasible.

3.6.5.2. EIPPCB, BREFS

Institute of development
European Integrated Pollution, Prevention and Control (IPPC) Bureau, European Commission — Joint Research Centre Sevilla.

Description
Based on Council Directive 96/61/EC, the IPPC Bureau elaborates documents, which describe selected techniques and give information on (www.eippcb.es):

- consumption and emission levels achievable by using each technique;
- the costs and cross media issues associated with each technique;
- the extent to which each technique is applicable to the range of installations requiring IPPC permits.

The significance of the IPPC directive cannot be underestimated. Material flows and waste generation with management have been integrated in this legal document. So far, quite indefinite 'cleaner technology' has now very concrete definition and real content as BAT — best available techniques. In Sevilla's department of the IPPC Bureau of the JRC, qualified European technical experts are working on BREFs (BAT reference documents). These documents must give for main sectors of industrial activities (IPPC list, incl. waste management) answers to many questions connected with efficient use of natural resources, pollution (waste) prevention and sustainable management of waste — defined limit values, technical potentials, etc. Waste indicators concerning special priority waste categories or industrial sectors have to be linked with BAT. For example, the 'Waste-management' technical working group will elaborate in the nearest future BREFs for waste incineration, landfilling and other waste-management (R & D) operations (IEF Task Force meeting on waste was organised in Brussels, on 4 July 2001).

The European IPPC Bureau exists to catalyse an exchange of technical information on best available techniques under IPPC Directive 96/61/EC and to create reference documents (BREFs) which must be taken into account when the competent authorities of Member States determine conditions for IPPC permits. IPPC will apply to a wide range of industrial activities and the objective of the information exchange exercise is to assist the efficient implementation of the directive across the European Union. The BREFs will inform the relevant decision-makers about what may be technically and economically available to industry in order to improve their environmental performance and consequently improve the whole environment.

Each sector of industry to be covered by the IPPC directive will be addressed by a specific technical working group (TWG) comprising nominated experts from Member States, EFTA countries, accession countries, industry and environmental NGOs. Each TWG is set up for a limited duration in order to provide information and to review the draft reference documents.

Field of application
The IPPC Bureau has already published first results in (draft) documents on best available techniques, giving detailed information about the material flow in installations in these industrial sectors.

Comments
So far, BREFs have been finalised for approximately 20 technical processes; those BREFs do not contain technical coefficients (including waste factors) and it is not foreseeable that they will.

3.6.5.3. Federal Statistical Office, Germany, annual waste generation by economic sectors

Institute of development
Research project: Federal Statistical Office, Germany — Integrated Environmental and Economic Accounting, Fraunhofer Institut f¸r Systemforschung und Innovationstechnik (funded by Eurostat) (Marscheider-Weidemann et al.,1997).

Description
The objective of this research project was to develop an estimation methodology to compile annual waste generation by 58 (60) economic sectors (waste NAMEA). The estimation methodology is based on waste factors derived from primary statistics only available every three years. Detailed waste categories were considered and physical coefficients were established that represent, for example, the relationship between waste generation and the related production process. Those coefficients were fed into a stepwise estimation procedure to derive waste generation by NACE sectors (Marscheider-Weidemann et al., 1997).

Field of application
The Federal Statistical Office used the aforementioned methodology to compile annual waste NAMEAs until 1995.

Comments
Due to changes in primary waste statistics, the methodology will have to be updated for the years up from 1996.

3.6.5.4. Eurostat, NAMEA

Institute of development
Eurostat and several national statistical offices.

Description
NAMEA (national accounts matrix including environmental accounts) is a statistical tool developed in the Netherlands. In general, NAMEA tables show environmental variables (e.g. air emissions, wastewater, wastes, etc.) by producing economic sectors (including private households) following national accounting rules (system of national accounts, SNA, or respectively European system of accounts, ESA) (Eurostat, 2000).

NAMEAs constitute a statistical framework showing how industry sectors and households contribute to several environmental concerns like emissions of air pollutants, wastewater and wastes. It is further possible to include environmental protection expenditure, eco-taxes, use of natural resources, and land use, etc. Thanks to their compatibility with national accounts, NAMEAs are also closely linked to monetary and physical input/output tables (Eurostat, 1999, 2000).

Waste NAMEA tables show the sectoral breakdown of several waste variables. Hence, there is conceptually a close relationship to the waste statistics regulation format. Data on waste generation, and on waste recovery and disposal collected according to the proposed regulation on waste statistics should be fully compatible with the NAMEA framework. Ideally, the waste NAMEAs should be able to trace the ‘journey’ of waste through the economy, from generation to disposal. First, waste NAMEAs show the total of certain waste streams broken down by generating economic sector (including private households) (Eurostat, 1999).

Secondly, waste NAMEAs allow comparative analysis of waste generation by sectors, in particular the relationship between socioeconomic variables, such as employment, gross value added, gross output, etc., and the generation of certain waste streams (see, for example, methods developed on the basis of decomposition analyses by de Haan, 2000).

This enables, thirdly, the possibility to calculate sectoral waste coefficients, for example, how much waste is generated to produce one unit of gross output or gross value added or how much waste is generated per employee.

Field of application

Eurostat has been supporting the compilation of NAMEAs through a series of NAMEA workshops since 1995. The focus has been laid on air emission NAMEAs. On the third NAMEA workshop in November 1998, some pilot studies on waste NAMEAs were discussed (Eurostat, 1999, 2000).

While the regulation on waste statistics is still pending, it has been premature to lay down specific guidelines on how to compile waste NAMEAs and Eurostat did not want to push for the development of waste NAMEAs on the European level. Nevertheless, some Member States have performed pilot studies on waste NAMEAs aiming to explore to what extent it was feasible to compile data on waste in a NAMEA-like framework.

In some of the pilot studies, the countries only investigate the possibility for compiling waste NAMEAs and in many other countries, the outcome is that present data availability does not allow allocation of waste data to branches. Another frequent conclusion is that NAMEAs relating to emissions to air and water are first priorities and waste NAMEAs would be part of future efforts.

In eight countries, activities can be noted regarding allocation of waste generation in one way or another to branches according to the NAMEA definitions, namely Germany, Ireland, the Netherlands, Austria, Finland, Norway, Belgium and Luxembourg.

A harmonised framework on how to integrate waste statistics into the NAMEAs has not yet been agreed upon on the European level. All pilot studies include allocation of waste generated to industries and households but the approaches in the pilot studies differ — especially when it comes to the division on types of waste. The data arising from the future regulation on waste statistics will be useful for compiling waste NAMEAs. Eurostat will consider establishing a task force for developing a framework and guidelines for waste NAMEAs. In eight Member States, NAMEAs on natural resources exist in terms of pilot studies.

Comments

In some countries, experiences have been made with deriving waste coefficients from NAMEAs. In Germany, within a research project commissioned by the Federal Statistical Office (see above), an estimation procedure has been developed that allows the allocation of total waste generation to production sectors based on physical coefficients. Those waste NAMEA tables are regularly published by the Federal Statistical Office (2000).

3.7. Geographic information systems

3.7.1. Description

Several definitions have been developed and adopted concerning the geographic information systems (GIS), depending on the type of application that the system is used for. These include:

- Toolbox-based definitions: For example, GIS is an information technology, which stores, analyses and displays both spatial and non-spatial data.
- Database definitions: For example, GIS is any manual or computer-based set of procedures used to store and manipulate geographically referenced data.
- Organisation-based definitions: For example, GIS is a decision support system involving the integration of spatially referenced data in a problem-solving environment.

The major components of GIS include:

- A data input subsystem, which collects and / or processes spatial data derived from existing maps, remote sensors, etc.
- A data storage and retrieval subsystem, which organises the spatial data in a form which permits them to be quickly retrieved by the user for subsequent analysis, as well

as permitting rapid and accurate updates and corrections to be made to the spatial database.
- A data manipulation system and analysis subsystem, which performs a variety of tasks such as changing the form of data through user-defined aggregation rules or producing estimates of parameters and constraints for various space–time optimisation or simulation models.
- A data reporting subsystem, which is capable of displaying all or part of the original database as well as manipulated data and the output from spatial models in tabular or mapped form. The creation of these map displays involves what is called digital or computer cartography. This is an area which represents a considerable conceptual extension of traditional cartographic approaches as well as substantial change in the tools utilised in creating the cartographic displays.
- A subsystem responsible for the graphical user interface interacting with the user and the programming language within the GIS environment (Korre, 2000).

3.7.2. Field of application

The use of computers for mapping and spatial analysis is constantly developing in automated data capture, data analysis and presentation in several broadly related fields. This multiplicity of effort in several initially separate but closely related fields has resulted in the emergence of general purpose GIS.

In the field of environmental and waste management, GIS may be used in applications involving soil pollution, air pollution modelling, water quality modelling, site characterisation, allocation of facilities, etc. (Korre, 2000).

3.7.3. Benefits

The spatial data handling and storage capabilities of GIS coupled with their ability to transform the original spatial data held allows researchers to answer different queries and develop environmental impact simulation models, which can account for the interaction between various forms of environmental impact and geographic features. Analysis is possible on topological or spatial geographic data, their non-spatial attributes or on both the spatial and non-spatial data together. The transformation capabilities allow interactivity with the user to achieve the required analysis. Hence, it is possible to examine a range of various alternatives in a project with the best possible information.

The efficiency, utility, flexibility and speed in providing users with information and in reducing the overall size and redundancy of the database are all affected by the database structure. This makes the design and layout of the database structure one of the most critical areas in the design of the GIS implementation. Some of the common abilities of the GIS include:

- menu-driven contouring using the triangulation method;
- three dimensional surface representations in contour or triangulated irregular network (TIN) model representation;
- generation of cross sections through topography groundwater or other generated surfaces;
- volumetric computations of differences between surfaces, which is useful in planning remediation.

Besides the above-mentioned capabilities of the GIS, there are specialised software tools that can extend the range of information that the system provides (Korre, 2000):

- borehole stratigraphy drawings;
- cross sections;
- fence diagrams;
- isopleth contours;
- rendering of intersections and sub-surfaces.

3.7.4. Drawbacks/limitations

The main disadvantage of the GIS is the fact that it is not able to predict future situation in terms of environmental degradation, in case a specific scenario is adopted, for example, a specific site is selected for landfill. The GIS is mainly a descriptive assessment tool, which may be used in collaboration with other models to simulate environmental impacts and project future trends.

Additionally, GIS software does not have the capability to represent continuous volumes such as an ore-body or pollution plume. Moreover, the main difficulties in constructing an effective GIS are those of data entry to the database. Data collection is the most time-consuming and expensive stage during the application of GIS, since these systems require a very detailed and wide range of data and their manipulation is very complex. GIS is not user-friendly and its application is rather difficult for ordinary citizens. Furthermore, the collected data usually do not reflect the actual conditions of the site, therefore there is always need for site verification. Finally, besides the data problems, many organisations lack GIS experts as well as have deficiencies in GIS implementation, management and support.

3.7.5. Geographical information systems

3.7.5.1. BRITE/Euram programme BRE2-CT92-0 168, environmental simulation and impact assessment

Institute of development
This study was carried out by the Imperial College of Science, Technology and Medicine (UK), the Instituto Superior Tecnico (Portugal), the Outokumpu Zinc Tara Mines Ltd (Ireland) and the Sociedade Mineira de Neves-Corvo S.A. (Portugal). The project was funded by the European Commission under the BRITE/Euram programme (BRE2-CT92-0 168) (Durucan et al., 1995).

Description
This case study refers to an environmental simulation and impact assessment system using a geographic information system so as to facilitate the understanding of the interaction between minerals extraction and the environment.

The main objectives of the project were:

- to combine a geographic information system with simulation modelling techniques and advanced geostatistical methods with the purpose of developing an environmental simulation and impact assessment system;
- to extend the model for use as an information tool in order to achieve improved overall environmental management.

Environmental impacts have both spatial and temporal components. As the temporal modelling capabilities of GIS are limited, numerical prediction models for the simulation of environmental impacts were developed and integrated within the GIS. These environmental simulation models combined the advantages, and benefits of advanced geostatistics and numerical modelling techniques were integrated into a GIS system to enable both spatial and temporal impact analysis.

The environmental impact categories that were considered included air pollution, groundwater quality, river water quality and heavy metal contamination in soil and plants. A common graphical user interface to input/output environmental data and to run the simulation models within the GIS was also developed. A comprehensive and reliable set of environmental data is required at operating mines in order to make informed decisions on environmental quality. The industrial partners of the project had already established a comprehensive environmental monitoring programme prior to the beginning of this project. These programmes were further strengthened through the purchase of monitoring equipment to support the specific needs of this project and through the development of well-structured **environmental databases**. The system utilised a geographical information system for its spatial database for input, output and spatial operations.

The following sets of data were collected for each mine site, digitised and stored in the spatial database of the GIS used:

- topography;
- geographic features;
- road and railway routes;
- urban and rural settlement areas;
- land use and land cover;
- mine sites and buildings;
- infrastructure;
- waste types, disposal sites;
- water, air, soil, noise, vibration and biological monitoring sites.

The upgraded monitoring systems and the databases developed at each of the two mines that were under investigation were essential for the validation of the developed environmental impact modelling software and for demonstrating the overall impact assessment concept based around the GIS graphical user interface developed.

Field of application
Different fields of application for the system that was developed are:

- prediction of the temporal nature of environmental impacts using numerical simulation and analysis of the interaction between spatial and non-spatial environmental attributes;
- optimisation of siting procedures;
- interactive analysis of monitored environmental data;
- preparation of comprehensive environmental impact statements,

identification of critical areas, definition of preventative data and measures;
- preparation of emergency action plans based on predictions, quick reaction to cases of emergency through interactive analysis of environmental variables.

Comments

The Instituto Superior Tecnico developed several advanced geostatistical methodologies and techniques to characterise the spatial and space–time dispersion of soil pollutants, river water quality parameters and groundwater properties. Researchers at Imperial College developed numerical models for the prediction of air quality, groundwater flow and pollutant transport, blasting vibration around mine sites and related structures.

The use of simulation models in the minerals results in:

- understanding the pollution mechanisms around the industrial site;
- predicting the environmental impacts associated with the production activities both as an EIA tool and as environmental management and control tool during production;
- providing and / or improving data for the simulation models used.

Recent developments in computer graphics and database management systems created the platform for the development of integrated environmental management systems. The spatial data handling and storage capabilities of GISs coupled with their ability to transform the original spatial data in order to answer different queries, have enabled the researchers to develop an environmental impact management system, which integrates the developed simulation models in the project with a GIS, under a graphical user interface (GUI).

This particular project is a well-structured, systematic approach to environmental management and contributes at a great degree to the effective environmental management in the minerals industry. It is a useful tool for minimisation of waste production and places emphasis on the use of best available sources of information and the suitable presentation of this information. It tries to implement the best practicable technology in monitoring and modelling the behaviour of the environment.

3.7.5.2. Aquater S.p.A., GIS for solid urban waste-disposal areas

Institute of development

This case study was developed by G. Della Bella, L. Patata and A. M. Rossolini from Aquater S.p.A., S. Lorenzo in Campo (PS), Italy (Bella et al., 1995).

Description

This case study refers to a method for siting solid urban waste-disposal areas, in conformity with Italian legislation, based on geographical information systems (GIS). The selected study area was the province of Foggia.

The objective of the developed methodology was to assist the technical or political users who, during preliminary siting, must apply general criteria for siting of suitable waste-disposal areas.

The methodology developed includes two stages:

- First stage (general screening): Large-scale data processing for the determination of the area's suitability. At this stage, no limiting conditions for toxic and hazardous waste-disposal areas are taken into consideration.
- Second stage (detailed screening): Detailed screening in chosen areas, including processing of detailed data.

Two types of criteria are used during both stages for definition and assessment of suitable areas:

- Exclusion criteria: Based on current legislation, they point out areas that are unsuitable for waste disposal. Their application leads to ruling out in advance a large portion of the territory from the examined area.
- Desirable and undesirable criteria: They define characteristics, although not essential, of desirable areas, in other words, characteristics that are undesirable but not unacceptable. Their application requires the use of a scale of values and relative weights and results in the construction of a suitability map. These criteria can directly interpret legislation or can be the product of thematic mapping based on interpretation of legislation.

The methodology involves two different approaches, both related to the analysis capabilities of GIS:

- Index overlay method, in which data are processed by attributing weights to the thematic maps and to the categories contained therein (scores). The product of this approach is a suitability map that determines the most suitable areas.
- Multi-criteria decisional analysis, in which separate objectives / criteria are determined, but weights are not attributed to the parameters.

The results obtained by applying the index overlay method only for the first stage are presented. It should be noted that application of the second stage to selected areas demands more detailed data.

Defined information plans or their subsets were combined and weights were attributed. The weights attributed to each map are expressed so that the sum is equal to 100 %. In assigning weights to the scores, a scale ranging from 5 to 0, where 5 indicates highest suitability and 0 the lowest, is used.

The values obtained were then reclassified on the basis of the highest or lowest value and at intervals of previously defined value. This operation produced a suitability map with six classes.

In order to have easier interpretation, the results were processed once again, taking into consideration various combinations of factors. Therefore, the 'good' class appeared substantially larger and was reclassified so that it could be divided into nine quality classes arranged in increasing order. In this manner, the final result is a map that contains 13 classes:

- 1: very good
- 2–10: good
- 11: moderate
- 12: poor
- 13: very poor

The last result clearly expresses the suitability of sites within the classes that appeared as the best during general processing. Moreover, the 'index overlay' method offers the opportunity to attribute different weights to every thematic map that is considered, once the criteria to be adopted within each information plan have been decided by means of scores.

The final product, the suitability map, indicates the highest or lowest capacity of an area to house a waste-disposal plan. As the weights vary, the suitable areas tend to combine together in certain zones. Evidently, the criteria established by the scores are extremely selective.

Within the first stage, GIS also enables the following operations:

- Direct overlay of information on mines, quarries and disused mining sites on the suitability map and their reclassification.
- Extraction of local details from the suitability map, for instance within a municipal area or a group of administrative units.

In the second stage, a detailed processing was carried out in a few selected areas.

Field of application
This case study is a useful tool for siting waste-treatment and disposal sites.

Comments
This application of GIS is considered to be useful, as it contributes to the effective provision of suitability maps (first phase) and the detailed site selection for waste disposal (second phase). However, it is not supposed to substitute the *in situ* investigations that are normally conducted in the area surrounding the selected site or the detailed surveys carried out within the waste-disposal area.

3.8. Remote sensing

3.8.1. Description

Remote sensing is the science and art of obtaining information on an object, area or phenomenon without coming into physical contact with it, through the analysis of data acquired from a distance.

The remote sensing technical approach steps, irrespective of the specific view under which the investigation is conducted, are the following:

- Recognition of elements, groups of elements, similarities and differences / changes, as well as of groups of similarities and differences / changes in the area under examination, using the photo interpretation and remote sensing methodology's supporting material (maps, statistical and other ancillary information).

- Analysis of these similarities and differences/changes, establishment of their relationship and interactions and evaluation of their importance.
- Correlation with the environment, using photo interpretation keys and results of field control and technical samplings by logical or automated procedure.
- Classification of similarities and differences, following the appropriate specifications imposed in each case, by visual or automated procedures and their necessary combinations to integrate and synthesise partial approaches.
- Evaluation and characterisation of the findings related to the specific sets of data, which have been promptly recognised or constitute possible alternative solutions.
- Feedback: findings resulting from the previous stages are used to improve the final results by repeating the stages of the technical approach.
- Evaluation of all the available spatial and qualitative information (literature) for the greater area under investigation, in order to support this specific study (e.g. cartographic, statistical, bibliographical, climatic, etc., data, thematic maps, aerial photographs, remotely sensed images, etc).

3.8.2. Field of application

Remote sensing is used in scientific and technical fields, such as exploration, inventory, mapping and management of natural and human resources of a country/region, physical planning, exploration, detection and mapping of land use (Rokos, 1979; Lo, 1986).

3.8.3. Benefits

The advantages of remote sensing are the following (Lo 1986; Hatzopoulos, 1996):

- minimisation of field work;
- information collection without direct contact with the object;
- control of desired accuracy;
- homogeneity in the determination or interpretation of a large number of spots of the object;
- automatisation to a large degree;
- low cost with respect to performing software analysis;
- creation of a permanent record of the environment at the moment of taking the picture.

3.8.4. Drawbacks/limitations

- It requires experienced personnel to evaluate properly the information deriving from the use of remote sensing.
- The cost of the acquisition of aerial photographs and satellite images is quite high.
- Remote sensing is not able to predict a future situation in terms of environmental degradation, in case a specific scenario is adopted, for example, a specific pollutants plume. Remote sensing is mainly a descriptive assessment tool, which may be used in collaboration with other models to simulate environmental impacts and project future trends.

3.8.5. Application of remote sensing (RS)

3.8.5.1. Lockheed Martin Energy System, RS in environmental management

Institute of development

Lockheed Martin Energy Systems, Energy Research and Utility Services, managing the environmental management activities at the East Tennessee Technology Park, Oak Ridge Y-12 Plant, Oak Ridge National Laboratory (US Department of Energy, 1997).

Description

The environmental management remote-sensing program was established in 1992 to apply the benefits of remote-sensing technologies to environmental restoration and waste-management programs at five Departments of the Energy Oak Ridge Operation facilities (i.e., the three Oak Ridge Reservation facilities, the Paducah Gaseous Diffusion Plant, the Portsmouth Gaseous Diffusion Plant and adjacent off-site areas). The remote-sensing program:

- manages routine and special surveys at Oak Ridge Operation facilities;
- applies of state-of-the-art remote-sensing technologies;
- conducts data transformation, integration and analyses required to make the information valuable to environmental management.

The remote-sensing program provided beneficial recourse to various facilities through diverse survey activities. Information derived from the remote-sensing program is important in order to:

- obtain screening level information for locating potential contamination sources;
- aid in site characterisation efforts;

- establish baselines for comparison with future conditions;
- provide a database of information of the detailed analysis, comparisons, integration with field measurements and map data;
- assist in remedial investigation planning and remediation effectiveness;
- aid in long-term monitoring of environmental improvements from restorations activities;
- locate and document land-use and waste site activity;
- provide fuel geographic database improvements.

Methodology
The remote-sensing program applied state-of-the-art remote-sensing and geophysical technologies to manage routine and remotely sensed examinations of areas under investigation and adjacent off-site areas.

Remote-sensing surveys provide data necessary for documenting changes in land-use and waste site activity, as well as associated impacts of these changes, on vegetation and water resources. Low-altitude radiological surveys, multispectral scanning, photographic surveys (natural colour and colour infrared) conducted at several altitudes offer a broad range of landscape characterisation data. Repeated multispectral scanner imagery and gamma photographic surveys allow monitoring of degradation that might occur in waste-containment vessels and monitoring of improvements from restoration efforts and cleanup at the later states in the remediation lifecycle. Additionally, airborne geophysical methods extend the surveillance to several metres into the soil, allowing identification of anomalies recorded as magnetic or resistivity changes. Data fusion and analysis of remote-sensing data create effective means for identifying unknown waste sites and contaminant transport pathways.

Comments
This program is of value throughout the remediation lifecycle by providing efficient site characterisation, detection of temporal changes associated with contaminant transport or remediation efforts and geographic database improvements (e.g. facility layout, land cover, topography). This tested program provides a cost-effective and time-efficient means for monitoring large areas of landscape for hazardous waste sites and waste site impacts, particularly in light of mandated lifecycle for cleanup operations.

High-resolution photographic, multispectral, radiological and geophysical data can be gathered in a timely, cost-effective manner that is impossible by spot ground surveys. These data sets are used to improve the resolution of known waste sites and to detect waste sites that might be previously unknown. They are also used to monitor remediation efforts and subsurface contaminant transport for cleanup progresses to completion.

The integration of remote-sensing data sources is a cost-effective method for environmental screening, aiding site characterisation and monitoring large facilities. This sensing method provides a fast, economic way to delineate the locations of known disposal areas, confirm the location of undocumented disposal sites, locate the major concentrations of buried wastes and aid environmental sampling planning. Applying this program can reduce restoration costs by improving efficiency in all phases of the effort and can direct the attention and funding to the most serious problems.

The ability to acquire, manage and analyse the vast amounts of remote-sensing information is vital to identifying and characterising environmental restoration problems, modelling and assessing their impacts, prioritising and designing effective cleanup solutions, meeting regulatory requirements and long-term monitoring to verify efficiency and compliance.

3.8.5.2. Aperture project, waste landfills monitoring

Institute of development
The study was carried out in the framework of Aperture project (environmental typological space mapper facilitating the implementation of European legislation) which was funded by the European Commission in 2000 (Aperture, 2000).

Description
In this study, remote-sensing technology was applied in order to monitor waste landfills and to detect the illegal landfill activity. The main aim of Aperture was to investigate if and how high-resolution earth observation (EO) data can be effectively used in environmental analysis. The remote-sensed data are periodically received.

The main objective was to develop a methodology based on remote sensing and techniques that are broadly accepted in order to map and categorise environmental sensitive areas of Europe according to various environmental issues. This methodology can be directly used by various authorities and non-governmental organisations to assess the environmental impact at local scale and to serve as a baseline for facilitation of environmental policy development.

The first step of the whole procedure was to set the channel combinations in order to help the discrimination of landfill targets from vegetated areas, since the former mostly act as bare soil like spectral signature. This is the reason why SPOT / HRV-XS and channels 1–4 of Landsat TM were firstly selected for this study. One of the key elements to differentiate landfill from other bare soil areas is the shape of the target — making the spatial resolution of sensors more crucial. Another key element is the temporal availability of satellite images, which determine the possibility of illegal investigation in the past.

The methodology used entails the following steps according to the Aperture methodology specifications: image acquisition, image pre-processing, image processing and production of an environmental legislation compliance map (ELCM).

The only pre-processing carried out after receipt and checking of the raw data were geometric corrections. The process of geo-correction complies with the quality control requirements of the Aperture project and is the only mandatory pre-processing step.

The processing of images for landfill identification consisted of image contrast enhancement techniques. The goal was to improve the visual interpretability of an image by increasing the apparent distinction between features in the scene.

After all these enhancement procedures, images were displayed on screen and visually interpreted by an analyst having the knowledge of landfill targets.

Amongst the set of indicators one can mention:

- Brightness: Bright areas are those not covered with filled ground, natural vegetation and plantation.
- Shapes: The landfills often have an irregular curved shape or a regular shape when the landfill is inside a quarry.
- Features: Roads can indicate the presence of an active landfill.

The final product of the data analysis was a map that contains data related to illegal landfill activity.

Field of application

Through the implementation of the remote-sensing technology, the following can be achieved:

- detection of waste landfills;
- detection of dangerous waste in landfills;
- detection of contamination of soil and groundwater pollution;
- measurement of distances between landfills, water bodies and urban areas;
- determination of quarries (active and closed).

Governmental authorities and other environmental institutions can use the remote-sensing technology in order to check compliance with law for decision-making and policy development.

Comments

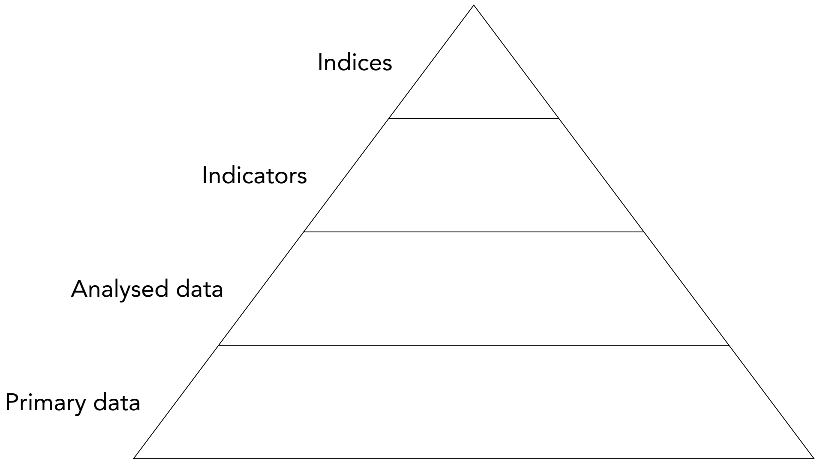
In the processing and image analysis, the Aperture methodology failed to define a common procedure for all case studies mainly because of the variety of the environmental problems examined, the accuracy required and the satellite images acquired.

Satellite images have immense potential value in the environmental sector and can have significant importance as historical evidence in the cases where ground inspections can no longer be available.

The spatial resolution of the available satellite data and the request for automatic processing constitute some of the week points of the remote-sensing technology. The availability of ancillary data can also cause some problems.

In general, through the Aperture project, a cost-effective methodology was developed which results in categorising areas according to various environmental issues.

Figure 3.2 The information/indicator pyramid (SCOPE, 1995; WRI, 1995)



3.9. Indicators

3.9.1. Description

When there is need to move smoothly from an abundance of detailed field data to summarised information for international and national level purposes, indicators and indices are used (SCOPE, 1995; UNDPCSD, 1995; WRI, 1995).

Indicators and indices (aggregate indicators) are important tools that assist decision-makers in formulating and implementing plans for management at local, national and international levels. An indicator is an elementary datum or a simple combination of data capable of measuring an observed phenomenon. It is selected according to a variety of criteria (e.g. accessibility, updating frequency, spatial and temporal coverage).

Indicators are there to enhance the communication about the environment and to serve as a tool for policy-making. To make this communication process work, simplicity is needed. Indicators simplify a complex reality. They have to fulfil scientific, functional and pragmatic requirements, for example, the consideration of ecological context, transparency and reproducibility, comprehensibility, policy relevance, international comparability and justifiable expenditure (EEA, 2001a).

An indicator distils information derived from analysing data obtained by monitoring and data collection. Raw data or statistics do not make an indicator without the results of analysis and synthesis. As a bare minimum, an explanation must be given of the (possible) causes of change (or lack of change) shown by the indicator (EEA, 2001a).

There are different types of indicators useful in the context of supporting environmental policy: descriptive indicators, performance indicators and efficiency indicators (EEA, 2001a).

In conclusion, indicators must be: specific, measurable, achievable, relevant and time-bound.

3.9.2. Field of application

Indicators can be used to track progress over time, or compare characteristics between one or more communities, companies, agencies, departments, products or processes. By examining these indicators over time or between different regions, communities, etc., identification of improvements or setbacks in resource use and waste generation can be tracked. By using indicators, the relative success of different source-reduction efforts can be examined.

Moreover, indicators and indices can be used to quantify likely environmental ecosystem and health impacts and risks especially from hazardous waste disposal. Also, they can be used to illustrate the shift in industrial strategy away from end-of-pipe processes towards waste recycling, cleaner production and integrated lifecycle analysis (Granados et al., 1999).

3.9.3. Benefits

The use of indicators and indices is very important as they have the following advantages:

- They contain condensed and summarised information.
- They can reflect past, present and future actions related to environmental issues.

- They allow the assessment of changes in relation to the goals and targets.
- They can show improvements or setbacks over time since they are a comparative scientific tool.
- Indicators allow a selection of statistics and data to be collected, because they focus on the most relevant pieces of information.

3.9.4. Drawbacks / limitations

The main disadvantages concerning indicators and indices are the following:

- The quality of data, which is used for the determination of indicators, is often questionable because there are no standardised procedures and sometimes 'guess' work is involved.
- The determination of indicators still takes place on an isolated, scientific case study basis and therefore they are not suitable to provide an overall picture for larger areas. Each indicator is representative of a component of a whole environmental issue (Walz, 2000).
- In determining indicators, it is not always easy to elaborate and comprehend simple and direct links between different sources of data, due to constraints in available time, human and financial resources (Walz, 2000).
- The number of indicators is still too great to be able to fulfil the information and communication functions at first sight, therefore work should be done on a greater degree of aggregation.
- Sometimes, the message behind an indicator is lost, therefore a good graphical presentation of the information is needed (EEA, 2001a).

3.9.5. Application of indicators

3.9.5.1. EEA, ETC/WMF, draft on core set of indicators on waste and material flows

Institute of development

ETC / WMF, EEA (EEA, 2000; EEA 2001).

Description

The EEA has asked the ETC / WMF to outline and define the need for indicators to describe the waste and material flows under the perception of the DPSIR framework, the waste hierarchy, sustainable development and the six EAPs. This framework and core set of indicators should in the long-term perspective (five to 10 years) make it possible to make a comprehensive description of the state and outlooks for waste and material flow. The results of this ETC / WMF project are being published in an EEA technical report.

Both the Commission and the EEA have developed sets of relevant indicators for the environment as the 'best available information' on waste and material flows. The Environment DG has developed the headline indicators and Eurostat the environment pressure indices, while the EEA is working with a core set of indicators (environmental signals series). The best-needed information is not always available today. Therefore, there is a need for 'a vision' on what should be the indicators of tomorrow for policy-making and information for the public at large.

Hence, the ETC / WMF has developed a comprehensive indicator framework with derived core indicators for waste and material flows, based on the following strategic main policy objectives:

- conserving natural resources;
- prevention of waste generation;
- sustainable waste management.

Field of application

The EEA assessment reports

EEA assessment reports are based on the use of indicators for information assessment (as environmental signals reports). Indicators are also used as key variables to communicate environmental information to EEA stakeholders as well as in the development of various models.

3.9.5.2. OECD, core sets of environmental indicators

Institute of development

OECD (Organisation for Economic Cooperation and Development), Paris (OECD, 1998, 1999, 2001).

Description

The OECD has long been a pioneer in the field of environmental indicators with the development and publication of the first international sets of environmental indicators and their regular use in country environmental performance reviews (environmental policies assessment series).

OECD environmental indicators are used in reporting, planning, clarifying policy objectives and priorities, budgeting and assessing performance. They assist in the implementation, development and harmonisation of environmental policies and also help to incorporate environmental concerns in decision-making, to promote sustainable development at national and international level and to evaluate national environmental performance (assessment).

The OECD developed several sets of indicators each responding to a specific purpose:

- the OECD core set of environmental indicators;
- several sets of sectoral indicators;
- key environmental indicators drawn from the core set.

Indicator-based assessments for OECD member countries are regularly published in so-called environmental performance reviews.

Field of application

The OECD core set

The OECD core set helps track environmental performance and progress towards sustainable development. In the 1998 publication 'Towards sustainable development: environmental indicators', the term 'Core indicators' was used. The indicators presented in the fields of waste and resource use are more or less the same as presented in the OECD Environmental Data Compendium published in 1999:

- Amounts of waste generated
  - By sector (7.1A)
  - By selected waste streams (7.1B)
- Municipal waste
  - Generation of municipal waste (7.2A)
  - Composition of municipal waste (7.2B)
  - Collection and disposal of municipal waste (7.2C)
- Hazardous waste
  - Production, movement and disposal of hazardous waste (7.3)
- Waste recycling
  - Waste-recycling rates — paper and cardboard (7.4A)
  - Waste-recycling rates — glass (7.4B)
- Waste treatment and disposal installations
  - Waste-treatment and disposal installations (7.5)
- Nuclear waste
  - Nuclear waste: spent fuel arisings (7.6).

The OECD key environmental indicators

A smaller set of key environmental indicators has been published by OECD in 2001 on the occasion of the OECD Environment Ministers Meeting in April 2001. It is intended to give a broad overview of environmental issues in OECD countries.

The 10 key environmental indicators are grouped in five indicators representing pollution issues and five indicators representing the issue of natural resources and assets (see following table).

Table 3.2 **OECD environmental Indicators**

Pollution issues		Available indicators ([1])	Medium-term indicators ([2])
Climate change	1.	CO_2 emission intensities	Index of greenhouse gas emissions
Ozone layer	2.	Indices of apparent consumption of ozone depleting substances (ODS)	Same, plus aggregation into one index of apparent consumption of ODS
Air quality	3.	SO_x and NO_x emission intensities	Population exposure to air pollution
Waste generation	4.	Municipal waste-generation intensities	Total waste generation intensities, indicators derived from material flow accounting
Freshwater quality	5.	Wastewater treatment connection rates	Pollution loads to water bodies
Natural resources and assets			
Freshwater resources	6.	Intensity of use of water resources	Same plus sub-national breakdown
Forest resources	7.	Intensity of use of forest resources	Same
Fish resources	8.	Intensity of use of fish resources	Same plus closer link to available resources
Energy resources	9.	Intensity of energy use	Energy efficiency index
Biodiversity	10.	Threatened species	Species and habitat or ecosystem diversity. Area of key ecosystems

([1]) Indicators for which data are available for a majority of OECD countries and that are presented in this report.
([2]) Indicators that require further specification and development (availability of basic data sets, underlying concepts and definitions).

Environmental pressure indicators for the themes of 'Resource depletion' and 'Waste' Table 3.3

Resource depletion
Water consumption (RD-1)
Energy use (RD-2)
Increase in territory permanently occupied by urbanisation (RD-3)
Inputs of phosphate to agricultural land (RD-4)
Electricity production from fossil fuels (RD-5)
Timber balance (RD-6)
Waste
Waste landfilled (WA-1)
Municipal waste landfilled
Hazardous waste landfilled
Waste incinerated (WA-2)
Municipal waste incinerated
Hazardous waste incinerated
Hazardous waste (WA-3)
Hazardous waste generated
Hazardous waste recovered
Hazardous waste incinerated
Hazardous waste landfilled
Municipal waste generated (WA-4)
Municipal waste generated
Generation of industrial waste (WA-5)
Generation of industrial waste
Waste/material recycled (WA-6)
Recycling of paper
Recycling of packaging glass
Non-recycled municipal waste (UP-2)
Municipal waste landfilled
Municipal waste incinerated

3.9.5.3. Eurostat, environmental pressure indicators

Institute of development
Eurostat (Eurostat, 2001).

Description
On a regular basis, Eurostat publishes so-called environmental pressure indicators comprising 60 indicators related to 10 environmental themes, which include resource depletion, dispersion of toxic substances, urban environmental problems, waste and water pollution and water resources. The indicators had been selected and ranked by a panel of several European environmental experts.

Field of application
The following table presents the environmental pressure indicators for the 'Waste' as well as the 'Resource depletion' theme.

With regard to waste and material flows, the following indicators are included in the Eurostat set of sustainable development indicators.

3.9.5.4. UN, indicators of sustainable development

Institute of development
United Nations Department of Economic and Social Affairs — Division for Sustainable Development (UN, 2000).

Description
Four years after the Rio Conference, The United Nations Commission on Sustainable Development (UNCSD) developed numerous activities to promote sustainable development. These led to the adoption of a work programme (1995) on the indicators of sustainable development. A list of 132 indicators was developed and tested. As a result of the 1996–99 testing phase of CSD list of sustainable development indicators,

Table 3.4 **Eurostat's sustainable development indicators with relevance for waste and material flows**

Material consumption (ECON 9)
Material consumption in the EU, 1980 and 1997 (preliminary estimates))
EU-15 total material requirement — 1997
Generation and disposal of municipal waste (ECON 13)
Municipal waste collected
Municipal waste landfilled and incinerated)
Generation of industrial waste (ECON 14)
Generation of industrial waste, by sector
Mining, manufacturing and construction waste arising
Generation and disposal of hazardous waste (ECON 15)
Total generated hazardous waste (according to national definition)
Disposal of hazardous waste (landfill, incineration)
Generation and disposal of radioactive waste (ECON 16)
Recycling of waste — paper, glass (ECON 17)
Recycling rate glass
Recycling rate paper
Waste-treatment and disposal facilities (ECON 18)
Waste-treatment facilities (Number of treatment plants; incinerators, landfill sites)

the framework employed in the CSD work programme to guide the selection of sustainable development indicators has evolved from a driving force-state-response approach towards one focussing on themes and sub-themes.

With the background of the national testing experience and the overall orientation to decision-making needs, the Expert Group on Indicators of Sustainable Development recommended that the framework be re-focused to emphasise policy issues or main themes related to sustainable development. To meet this recommendation, the framework has been revised and re-structured in an iterative and inclusive way through a consultant study, the Barbados workshop, and a consultative group of experts.

Field of application

The new theme framework, as presented in September 2000, comprises

- sustainable development dimensions (social, environmental, economic, institutional),
- 15 themes;
- 39 sub-themes;
- 58 'core' indicators ([1]).

Under the economic dimension the following indicators with relevance to waste and material flows have been chosen:

Table 3.5 **Waste and material flows indicators**

Theme	Sub-theme	Indicator
Consumption and Production patterns	Material consumption	Intensity of material use ([1])
	Waste generation and management	Generation of industrial and municipal solid waste
		Generation of hazardous waste
		Generation of radioactive waste
		Waste recycling and reuse

([1]) Alternative indicator: total material requirement (TMR).

(1) Although, the UN CSD has called it 'core' indicators, this set has the character of 'key or headline' indicators in the sense of this report, i.e. standing at the top of the UN CSD information pyramid.

Comments
The framework and its set of sustainable development indicators meets the CSD indicator programme objective of having an agreed core set available for all countries to use by the year 2001.

3.10. Cost–benefit analysis (CBA)

3.10.1. Description
Cost–benefit analysis (CBA) is a tool for decision-makers in order to assess the positive and negative effects of a project or policy. All impacts are measured in both physical and monetary values. As a result, it is usually necessary to estimate the monetary value of environmental effects, which do not have a price from the market mechanism. The idea behind the CBA is simple; a project should be carried out if the benefits exceed the costs.

There are different approaches to carry out CBAs, but the main stages are:

- definition of project (definition of purpose, setting project boundaries, choosing baseline and alternative scenarios);
- physical quantification of relevant impacts (inventory of resource use, emissions, etc.; an environmental impact analysis is carried out);
- monetary valuation of (environmental) effects;
- discounting of cost and benefit flows;
- calculation of net present value of baseline and alternative scenarios;
- sensitivity analysis of important parameters (e.g. the discount rate).

There are several methods of estimating the monetary values of the environmental impacts. One is to reveal preferences by asking how much individuals are willing to pay for an environmental improvement, or to study real estate prices in areas with a healthy environment. Another is to estimate the costs of avoiding a certain negative effect.

3.10.2. Field of application
CBA can basically be carried out to assess and weigh the importance of the positive and negative effects of any project or contemplated change in policy. However, it is a precondition that the effects can be measured. Examples are to build a bridge or keep the ferry, to increase recycling or incineration of paper, and studying different ways of treating and disposing of waste oils.

3.10.3. Benefits
The benefits of the CBA as an assessment tool are the following:

- It studies which projects or policies are efficient in terms of their use of resources.
- The results are presented in a clear and easily understandable way, as the positive and negative effects of a scenario are summed up into one monetary figure (the net present value).
- The CBA gives a good overview of the result of different scenarios.

3.10.4. Drawbacks / limitations
Some of the main disadvantages of CBA are presented below:

- It may not be possible to measure all impacts, direct as well as indirect, in physical units.
- There is uncertainty involved in estimating the monetary value of several environmental impacts and thus it may not be possible to value all impacts in monetary terms. Some people even question the ethic in valuing environmental impacts in monetary terms.
- The distributional effects may not be included in the CBA.
- The assumptions made (e.g. the prices and discount rate) may change during the lifetime of the project lifetime changing the preferred outcome. 3.10.5. Application of cost–benefit analysis (CBA)

3.10.5. Recycling of packaging materials

Institute of development
RDC Environment and Pira International have been consultants for the European Commission (EC Commission, 2001).

Description
The main purpose of this study was to analyse the cost and benefit patterns of packaging recycling and reuse in the context of potential targets for the revision of the packaging and packaging waste directive. This description will only focus on the analysis of the recycling targets.

The materials included in the study were plastics, paper / cardboard, steel, aluminium, composites and glass. For each material, one, two or three packaging applications (e.g. LDPE films and PET bottles) were chosen as the case study, so a total of 10 case studies were carried out.

For each case study, a number of scenarios were chosen as combinations of population density (high or low), selective collection scheme (bring scheme or separate collection), achieved recycling rate and waste-management option (landfill or incineration).

The internal costs were defined as the operational costs incurred by industry. The total internal cost of each scenario is the sum of all costs minus the sum of all revenues, and it is given per tonne of the packaging application. For each scenario, the internal costs are given as a range of minimum and maximum cost depending on the waste-management system (share being recycled and either landfilled or incinerated).

The external costs are the environmental costs. First, for each scenario, the environmental inputs and outputs are estimated according to a lifecycle assessment (the inventory of a LCA). Secondly, each environmental input or output is classified according to the environmental impacts to which it may contribute, and characterised according to its potential to contribute to that impact. Finally, an economic valuation is applied to each environmental impact category.

The total social cost of a scenario is then the sum of the internal plus the external costs. On the basis of this information, the optimal recycling ranges for each packaging application were identified among the different scenarios.

A number of sensitivity analyses are made, though basically two types of parameters are considered: uncertainties arising from methodological choices (e.g. energy model) and from scenario choices (e.g. transport distances).

The optimal recycling rate for each Member State was estimated on the basis of the packaging mix in the country (both industrial and household packaging waste) and the optimal recycling ranges.

Likewise, the optimal recycling rate for each packaging material at EU level was estimated. The optimal recycling rate for material in a specific Member State is the weighted average of the optimum targets for the different applications in this Member State.

Comments

The study is a final draft report only and the European Commission has invited a stakeholder consultation on the study.

At least two comments on the study can be made. Firstly, only two options for recycling levels have been analysed (either low or high achievable recycling rates). Thus, it is not possible to determine the optimal level of recycling very precisely. As a result, the precision in the analysis is at best to indicate that no recycling, a low recycling rate or a high recycling rate has the best cost–benefit ratio.

Secondly, a sensitivity analysis has been carried out where the internal costs are calculated using a +/– 20 % range. It is difficult to validate this type of sensitivity analysis. Some of the cost parameters that vary are likely to vary in the same direction for all the scenarios. An alternative option would be to use a probability distribution function. As many of the parameters and variables can be assumed to be independent, there is a low probability that all values are at the high end or at low end and accordingly the range of the resulting total costs is less than when the high–low approach is used.

Overview of the benefits and drawbacks of the assessment tools Table 3.6

	Simulation models	**Lifecycle analysis**	**Environ-mental im-pact assess-ment**	**Environ-mental risk assess-ment**	**Multi crite-ria analysis**	**Waste fac-tors**	**Geograph-ic informa-tion systems**	**Remote sensing**	**Indicators**	**Cost–ben-efit analy-sis**
Main benefits	Illustrate the current and esti-mate the future situ-ation, eval-uate alternative scenarios.	Holistic ap-proach that provides informa-tion so that environ-mental im-pact can be minimised over prod-uct life-time.	Provides environ-mental in-formation of a certain project, and may be used for modelling scenarios.	Compares the severity of risks from what-ever sourc-es, explicit manage-ment of risks.	Able to compare scenarios with con-tradictory objectives and many criteria, transpar-ent proc-ess, allows involve-ment of stake-hold-ers.	Easy to in-terpret and communi-cate, re-duce the number of parame-ters nor-mally required.	Able to handle spatial data and allow the users to perform a number of queries.	Minimises the expen-sive field work, ho-mogeneity in the de-ter-mina-tion or inter-preta-tion.	Con-densed and sum-marised in-formation, can be used for as-sessing the changes in relation to targets.	Deter-mines the benefit or cost to so-ciety, the results are presented in an un-der-stand-able way.
Main draw-backs	Data col-lection may be difficult and expen-sive, over-simplificati on occurs, cannot consider all parame-ters.	Definition of system bounda-ries and functional unit are im-portant for the out-come, may be difficult to weigh different environ-mental im-pacts.	Project-specific as-sessment, lacks ex-plicit project definition leading to limited bounda-ries and applica-tion.	Complex study to carry out, all informa-tion may not be available, no detailed guidance on meth-odologies and how to interpret the risks.	Necessary to have compara-ble data, criteria may be over-lapped, the allocation of weights to each cri-terion may proved to be difficult.	No nationa lly or inter-nationally accepted system of waste fac-tors exist yet, de-pend on availability of data, cannot stand alone but should be linked to other data.	Mainly a descriptive tool, not able to predict fu-ture trends, data col-lection is expensive.	Requires experi-enced per-sonnel, cost of ac-quisition of aerial pho-tographs are high, not able to predict fu-ture degra-dation.	Data often not compa-rable be-cause of no harmo-nised col-lection method, not yet de-veloped fully to pro-vide an overall pic-ture for larger are-as.	Perhaps not possi-ble to measure all impacts, difficulties in measur-ing all envi-ron-mental impacts in monetary units.
Field of appli-cation	Determine environ-mental im-plications from adop-tion of a policy or specific measures, future trends in environ-mental im-pact.	Product policy, product develop-ment and improve-ment.	Construc-tion works and other interven-tions in the natural sur-roundings and land-scape.	Accidents and routine operations involving potentially long-term processes.	Environ-mental planning and deci-sion-mak-ing process.	Used for different purposes, e.g. to inte-grate envi-ronmental data with economic aspects, and as part of environ-mental manage-ment in produc-tion.	Mapping and spatial planning purposes.	Mapping and spatial planning purposes.	Used to track progress over time or compare charac-ter-istics be-tween one or more communi-ties, com-panies, products, processes etc.	Environ-mental planning and deci-sion-mak-ing process.

4. Conclusions

The main findings of the previous chapters are summarised in this section.

First conclusion: 'Getting the information basis right' — An indicator framework on waste and material flows is needed as a prerequisite for integrated assessment.

Integrated assessment of the waste and material flow issue is only feasible on the basis of adequate statistics and indicators. Yet, on the European level, insufficient statistical information on waste and material flows is currently available.

The EEA has progressed in the development of a core set of WMF indicators. This set will provide the basic information needed to assess waste and material flows issues covering all aspects of waste generation / management and material inputs into the economic cycle.

However, 'getting the information right' will need some five to 10 years since it is dependent on the implementation of the waste statistics regulation. In the meantime, assessment will be based on only limited, currently available information.

Second conclusion: 'EEA assessment will to a large extent be based on indicators'.

Through its close link to policy objectives, the above-mentioned indicator framework will also serve as the 'backbone' for integrated assessment in the field of waste and material flows. These indicators with high policy relevance will be used by the EEA for regular reporting (EEA environmental signals series) and indicator-based assessment similar to the transport and environment reporting mechanism (TERM).

The use of indicators applies to the assessment of existing information as well as to describe future trends, for example, forecasting of expected waste quantities in the forthcoming years on the basis of historic trends and the development of economic activities.

Third conclusion: 'Twofold approach recommended for prospective analyses'.

Prospective analysis — one established 'building block' of the EEA's integrated assessment for policy-making and reporting — aims at anticipating future trends of driving forces and pressures. By this, emerging issues may be identified and existing policies may be evaluated with regard to reaching their objectives. Further, prospective analyses can support elaboration of policy responses needed in the future.

As far as waste and material flows are concerned, a twofold approach is recommended:

1. In order to generate outlooks or projections for the main aggregated indicators on waste and material flows, the existing simulation model framework of the EEA should include a module on waste and material flows (see fourth conclusion).

2. For the projection of selected waste streams and material flows separate ETC / WMF models should be developed (see fifth conclusion).

Fourth conclusion: 'Elaborate the extension of existing simulation models by a waste and material flow module.

The existing EEA model should be extended by main waste and material flow variables in a stepwise approach starting from waste factors connecting economic performance (e.g. GDP, gross value added, gross output, national income, etc.) with waste and material flow quantities.

A macroeconomic model (GEM E3) constitutes the core of the existing EEA model framework (see Section 4.1.1). It links the main socioeconomic driving forces to various energy and air emissions modules that are also part of the model framework. It has to be investigated whether it is feasible to design a module on waste and material flows that can use the output of a macroeconomic model. The module then needs to include algorithms that reflect changes in the ratios between the driving forces, the economic variables and the waste generation.

This approach should lead to outlooks to be used, for example, in EEA outlook reports. For prospective analyses serving more detailed environmental policy-making issues, more specific models simulating selected priority waste and material streams (e.g. end-of-life vehicles, sewage sludge, WEEE, etc.) should be developed (see fifth conclusion).

Fifth conclusion: 'Develop information and assessment tools on selected waste and material streams'.

In order to be able to support the development of the indicator framework of the EEA with regard to more detailed policy-making issues, more specific models are required.

EU waste policies and legislation have been focusing on selected priority waste and material streams (packaging, end-of-life vehicles, WEEE, sewage sludge). There is a need to improve data and information on generation and management for a number of waste streams, including projections on future waste arisings. The EEA and ETC/WMF already work in this field by developing a model predicting future waste arisings and the potential emissions of dangerous substances into the environment. Technically sound assumptions and coefficients will be used, in order to link expected waste quantities and emissions of dangerous substances with the respective waste-generating activities.

The long-term objective is to develop a model that will enable the user to:

- estimate future quantities of priority waste streams based on existing data from past years;
- link waste quantities with dangerous substances that can potentially be transferred into the environment if wastes are not managed properly;
- prepare 'what-if' scenarios related to policy and management issues.

Sixth conclusion: 'LCA to be used for assessments of products and processes'.

Lifecycle assessment is a decision-support tool through which evaluation of the environmental burdens associated with a product, process or activity can be carried out. If, in the future, the EEA wants to undertake product- or process-specific assessments, LCA would be an appropriate tool.

Seventh conclusion: 'GIS and remote sensing for spatial issues'.

So far, GIS and remote sensing have not been part of EEA integrated assessment for policy-making and reporting in the field of waste and material flows since spatial issues on the local and regional level are subject to national and regional authorities' decision-making. Spatial issues associated to waste and material flows include for example the location of landfills and incineration plants, the identification of quarries, the selection of the routing and the monitoring of the transportation of waste and raw materials, etc. If this kind of detailed information ever will be needed, GIS and remote sensing can be used to develop a rather detailed picture of activities related to waste management.

5. References

Aperture project, 'Detection of illegal landfill activity in Italy. Environmental typological space mapper facilitating the implementation of a European legislation', European Commission, 2000.

Ayres, R. U. and Simonis, U. E., *Industrial metabolism*, United Nations University Press: Tokyo, New York, 1994.

Ayres, R. U., *Lifecycle analysis: A critique*, Resources, Conservation and Recycling, 1995.

Barton, J. R., Dalley, D. and Patel, V. S., *Lifecycle assessment for waste management*. Waste Management, 1996.

Bedfordshire Waste Strategy Group, *Lifecycle assessment of options for municipal waste for Bedfordshire and Luton waste strategy*, February 2001.

Bella, D. G., Patata, L. and Rossolini, A. M., *Geographical information systems (GIS): A tool for siting waste-disposal areas*, Aquater S. p. A., S. Lorenzo in Campo (PS), Italy, Fifth International Landfill Symposium Sardinia, 1995.

Bellehumeur, C., Vasseur, L., Ansseau, C. and Marcos, B., *Implementation of a multi-criteria sewage sludge management model in the southern Quebec municipality of Lac-Megantic, Canada*, Group Stoper, University of Sherbrooke, Canada, 1996.

Brainard, J. S., Lovett, A. A. and Parfitt, J. P., 'Assessing hazardous waste transport risks using a GIS', *Int. J. of GIS*, 10(7), pp. 831–849, 1996.

Choi, A. C. K., Kaebernick, H. and Lai, W. H., 'Manufacturing processes modelling for environmental impact assessment', *Journal of Materials Processing Technology*, 1997.

Commission Decision 94/3/EC of 20 December 1993 establishing a list of wastes pursuant to Article 1(a) of Council Directive 75/442/EEC on waste.

Commission Decision 2000/532/EC of 3 May 2000 replacing Decision 94/3/EC establishing a list of wastes.

Commission Directive 94/69/EC of 19 December 1994 adapting to technical progress for the twenty-first time Council Directive 67/548/EEC on the approximation of laws, regulations and administrative provisions relating to the classification, packaging and labelling of dangerous substances.

Commission Directive 96/54/EC of 30 July 1996 adapting to technical progress for the 22nd time Council Directive 67/548/EEC on the approximation of the laws, regulations and administrative provisions relating to the classification, packaging and labelling of dangerous substances.

Commission Directive 97/69/EC of 5 December 1997 adapting to technical progress for the 23rd time Council Directive 67/548/EEC on the approximation of the laws, regulations and administrative provisions relating to the classification, packaging and labelling of dangerous substances.

Commission Directive 98/73/EC of 18 September 1998 adapting to technical progress for the 24th time Council Directive 67/548/EEC on the approximation of the laws, regulations and administrative provisions relating to the classification, packaging and labelling of dangerous substances.

Commission Directive 98/98/EC of 15 December 1998 adapting to technical progress for the 25 time Council Directive 67/548/EEC on the approximation of the laws, regulations and administrative provisions relating to the classification, packaging and labelling of dangerous substances.

Commission Directive 2000/32/EC of 19 May 2000 adapting to technical progress for the 26th time Council Directive 67/548/EEC on the approximation of the laws, regulations and administrative provisions relating to the classification, packaging and labelling of dangerous substances.

Commission Directive 2000/33/EC of 25 April 2000 adapting to technical progress for the 27th time Council Directive 67/548/EEC on the approximation of laws, regulations and administrative provisions relating to the classification, packaging and labelling of dangerous substances.

Commission of the European Communities: *A sustainable Europe for a better world: A European Union strategy for sustainable development (Commission's proposal to the Gothenburg European Council)*, COM(2001)264 final, Brussels, 2001.

Contini, S., *An introduction to risk-analysis procedures*, Commission of the European Communities, Joint Research Centre, Ispra Establishment, Institute for Systems Engineering and Informatics, I-21020 ISPRA (VA), Italy, 1993.

Cosmi, C., Cuomo, V., Macchiato, M., Mangiamele, L., Masi, S. and Salvia, M., 'Waste-management modelling by Markal model: a case study gfor Basilicata region', *Environmental Modeling and Assessment*, No 5, Baltzer Scienve publishers BV, 2000.

Council Decision 94/904/EC of 22 December 1994 establishing a list of hazardous waste pursuant to Article 1 (4) of Council Directive 91/689/EEC on hazardous waste.

Council Directive 67/548/EEC of 27 June 1967 on the approximation of laws, regulations and administrative provisions relating to the classification, packaging and labelling of dangerous substances.

Council Directive 75/442/EEC of 15 July 1975 on waste.

Council Directive 75/439/EEC of 16 June 1975 on the disposal of waste oils.

Council Directive 76/403/EEC of 6 April 1976 on treatment and disposal of PCBs and PCTs.

Council Directive 76/464/EEC of 4 May 1976 on pollution caused by certain dangerous substances discharged into the aquatic environment of the Community.

Council Directive 78/176/EEC of 20 February 1978 on waste from the titanium dioxide industry.

Council Directive 78/319/EC of 20 March 1978 on toxic and dangerous waste.

Council Directive 84/631/EEC on transfrontier shipment of toxic or hazardous waste.

Council Directive 85/337/EEC of 27 June 1985 on the assessment of the effects of certain public and private projects on the environment.

Council Directive 85/339/EEC on the reduction of beverage containers' volume.

Council Directive 85/469/EEC on transfrontier shipment of toxic or hazardous waste.

Council Directive 84/631/EEC on requirements of transfrontier shipment of toxic or hazardous waste.

Council Directive 86/278/EEC of 12 June 1986 on the protection of the environment, and in particular of the soil, when sewage sludge is used in agriculture.

Council Directive 87/101/EEC of 22 December 1986 amending Directive 75/439/EEC on the disposal of waste oils.

Council Directive 89/369/EEC of 8 June 1989 on the prevention of air pollution from new municipal waste incineration plants.

Council Directive 89/429/EEC of 21 June 1989 on the reduction of air pollution from existing municipal waste-incineration plants.

Council Directive 90/170/EEC on the approval of the OECD decision about the control of the transfrontier shipment of toxic or hazardous waste.

Council Directive 91/156/EEC of 18 March 1991 amending Directive 75/442/EEC on waste.

Council Directive 91/689/EEC of 12 December 1991 on hazardous waste.

Council Directive 94/31/EC of 27 June 1994 amending Directive 91/689/EEC on hazardous waste.

Council Directive 94/67/EC of 16 December 1994 on the incineration of hazardous waste.

Council Directive 96/61/EC of 24 September 1996 concerning integrated pollution prevention and control.

Council Directive 1999/31/EC of 26 April 1999 on the landfill of waste.

Council Regulation (EEC) No 259/93 of 1 February 1993 on the supervision and control of shipments of waste within, into and out of the European Community.

CWMI: *Risk assessment methodology in municipal risk solid waste composting.* Cornell Waste-management Institute, 1999.

Dais, D., *Development of an integrated management scheme for recycling of waste from electrical and electronic equipment (WEEE), The case study of Greece*. European Postgraduate Programme in Environmental Management (EAEME), Athens, 1999.

De Haan, 'Decomposing annual changes in pollution according to their causes: A NAMEA time series analysis', Final report of the project 'The further development of the NAMEA and its application in the Netherlands' (unpublished), 2000, CBS, Voorburg.

Denis, C., Koopman, G. J., *Eucars: A partial equilibrium of European CAR emissions*. European Commission Directorate-General II, August 1998.

Department for Environment, Food and Rural Affairs web site: http://www.defra.gov.uk/.

Directive 96/56/EC of the European Parliament and the Council of 3 September 1996 amending Directive 67/548/EEC on the approximation of laws, regulations and administrative provisions relating to the classification, packaging and labelling of dangerous substances.

Directive 1999/33/EC of the European Parliament and of the Council of 10 May 1999 amending Council Directive 67/548/EEC as regards the labelling of certain dangerous substances in Austria and Sweden.

Directive 2000/53/EC of the European Parliament and of the Council of 18 September 2000 on end-of life vehicles — Commission statements.

Durucan, S., Johnston, G. J., Warner, A. L., Johnston, P. R., Unlu, Y., Clarici, E., Pereira, H. G., Soares, A., Pereira, M. J., Patinha, P., Ribeiro, L., Franco, A., Sarmento, P., Boyle, F., O'Reilly, B., Walsh, L., Brady, E. and Waugh, D., *Environmental simulation and impact assessment system for the mining industry*, Project funded by the European Commission under the BRITE/Euram programme, 1995.

EC Commission, 'Evaluation of costs and benefits for the achievement of reuse and the recycling targets for the different packaging materials in the frame of the packaging and packaging waste Directive 94/62/EC', draft final report, May 2001.

Web site: http://europa.eu.int/comm/environment/waste/public_discussion.htm.

Edwards, D. W., Schelling, J., *Municipal waste lifecycle assessment Part 2: Transport analysis and glass case study*, Trans Ichem, 1999.

EEA, *Computer-based models in integrated environmental assessment, Technical report No 14*, Copenhagen, February 1998.

EEA, *Development and application of waste factors — an overview, Technical report No 37*, Copenhagen, November 1999a.

EEA, *Development of baseline projections for selected waste streams, Technical report No 28*, September 1999b.

EEA, *Environmental signals 2001:European Environment Agency regular indicator report — Environmental Assessment Report No 6*. Copenhagen, 2000.

EEA, *The EEA indicator fact sheet model used for environmental signals 2000 and 2001*, 2001a.

EEA, *Air pollution outlooks — an evaluation, integrated assessment methodologies and tools applied to air pollution and greenhouse gases*, 2001b.

EEA, *Environmental signals 2001:European Environment Agency regular indicator report — Environmental Assessment Report No 8*. Copenhagen, 2001c.

Environment Agency of England and Wales, *Waste-integrated systems assessment for recovery* *and disposal (Wisard)*, Pricewaterhouse Coopers, 2000.

EPIS, *Environmental pressure information system*, Eurostat, Brussels / Belgium, 1994.

ETSA, Energy technology systems analysis program, *Markal Brief Description*, 1999, web site: www.ecn.nl / unit_bs / etsap / markal.

ETC / WMF, 'Draft technical report development of an indicator framework on waste and material flows', Copenhagen, 2001.

European Commission Integrated Pollution Prevention and Control Bureau, web site: http: / / eippcb.jrc.es / pages / FActivities.htm.

European Parliament and Council Directive 94 / 62 / EC of 20 December 1994 on packaging and packaging waste.

Eurostat, *Pilot studies on NAMEAs for air emissions with a comparison at European level — Theme 2*. Economy and Finance Studies and Research series, Luxembourg, 1999.

Eurostat, *Waste NAMEAs — the development on EU level — background*, Document tabled at the 4th NAMEA Workshop 20 and 21 June 2000.

Eurostat, *Environmental pressure indicators — 2001 edition*, Eurostat, Luxembourg, 2001a.

Eurostat, *Measuring progress towards a more sustainable Europe: Proposed indicators for sustainable development — Data 1980–99*, Eurostat Theme 8 Environment and Energy, Luxembourg, 2001b.

Gielen, D. J., Gerlagh, J. and Bos, A. J. M., *MATTER 1.0 — A Markal energy and materials system model characterisation*, Energy Research Centre of the Netherlands, ECN-C-98-065, 1998.

Granados, A. J., Peterson, P. J., 'Hazardous waste indicators for national decision-makers', *Journal of Environmental Management*, 55, pp. 249–263, 1999.

Hanley, N. and Spash, C. L., *Cost–benefit analysis and the environment*, Edward Elgar Publishing Ltd, 1993.

Hatzopoulos, J., *Photogrammetry and remote sensing*, University of Aegean, 1996.

IRG, International Resources Group, *Energy planning and the development of carbon mitigation measures — Using the Markal family of models*, USA, 2001.

International Organisation for standardisation (ISO), *Environmental management systems — Specification with guidance for us*, ISO 14001, 1996.

Jones, R. N., 'An environmental risk assessment / management framework for climate impact assessment', CSIRO Atmospheric Research, PBI Aspendale Victoria 3195, Australia, *Natural Hazards 23*, pp. 197–230, 2001.

Korre A., *Introduction to geographic information systems (GIS)*, T. H. Huxley School, Imperial College, 2000.

Lahdelma, R., Salminen, P. and Hokkanen, J., 'Profile using multi-criteria methods in environmental planning and management', *Environmental Management* Vol.26, No 6, pp. 595–605, 2000.

Lillesand, T. M. and Kiefer, R. W., *Remote sensing and image interpretation*, fourth edition, Wiley publ., 1999.

Lo, C. P., *Applied remote sensing*, London and New York, Longman, 1986.

Marscheider-Weidemann, Frank et al., *Materialflu? spezifischer Abfallarten und Abfallkennziffern bedeutender Bereiche*, FhG Institut fur Systemtechnik und Innovationsforschung, Karlsruhe / Germany, 1997 (unpublished draft).

McCarty, L. S. and Power, M., 'Short survey: "Approaches to developing risk-management objectives: an analysis of international strategiesî', *Environmental Science and Policy* 3, pp. 311–319, 2000.

NTUA, *GEM — E3 model for the European Union*, 1997.

OECD, *Towards sustainable development: environmental indicators*, Paris Cedex, 1998.

OECD, *OECD environmental data compendium 1999*, Paris Cedex, 1999.

OECD, *Environmental outlook*, 2001a.

OECD, *Key environmental indicators*, Paris Cedex, 2001b, web site: http://www.oecd.org/env/min/2001/products/.

OJ C 122/2 Council resolution of 18 May 1990 on the Community strategy for waste management.

OJ C 076 Council resolution of 11 March 1997 on the review of the Community strategy for waste management.

OJ L 242 Decision No 1600/2002/EC of the European Parliament and of the Council of 22 July 2002 laying down the sixth community environment action programme.

Peterson, E. H., 'LCA tool for use in the building industry, *International Journal of Low Energy and Sustainable Buildings*, 1999.

Petersen, R., Ravn, A. and Mortensen, N. H., *Report on an overall data model for ETC/Waste*, European Environment Agency, Technical report No 23, July 1999.

Powell, J. C., 'The evaluation of waste-management options', *Waste Management & Research* 14, pp. 515–526, 1996.

Proposal for a directive of the European Parliament and of the Council on waste electrical and electronic equipment.

Proposal for a directive of the European Parliament and of the Council on the restriction of the use of certain hazardous substances in electrical and electronic equipment.

Rokos, D., *Photointerpretetion and remote sensing*, National Technical University of Athens, 1979.

Saarikoski, H., 'EIA procedure — Environmental impact assessment (EIA) as collaborative learning process', *Environmental Impact Assessment Review*, 2000.

SCOPE, 'Environmental indicators: systematic approach to measuring and reporting on the environment in the context of sustainable development', paper by the project on indicators of sustainable development of the scientific community on problems of the environment (SCOPE) presented at an International Workshop on Indicators of Sustainable Development for Decision-Making, Gent, Belgium, 1995.

Scottish Environment Protection Agency, http://www.sepa.org.uk.

SETAC, Society of Environmental Toxicology and Chemistry, *Guidelines for lifecycle assessment: A 'code of practice'*, SETAC — Europe, Brussels/SETAC — North America, Pensacola, 1993.

Sheate, B., *Introduction to environmental impact assessment*. Environmental Policy and Management Group, ICCET, 1998.

Slater, D. and Jones, H., 'Environmental risk assessment and the environment agency', *Journal of Hazardous Materials* 65, pp. 77–91, 1999.

WRc plc, *STOAT — PLAN IT STOAT MODELS.*, 1990, web site: www.wrcplc.co.uk.

UN, *United Nations Department of Economic and Social Affairs — Division for Sustainable Development*, 2000.

UN, *United Nations Department of Economic and Social Affairs — Division for Sustainable Development*, 2001.

UNDPCSD, *Work programme on indicators for sustainable development,* presented during the third session of the Commission on Sustainable Development, April 1995.

US Department of Energy, Oak Ridge Operations, *Environmental management (EM) remote-sensing program*, 1997, web site: http://www.ornl.gov/~ept/rs/.

Walz, R., 'Development of environmental indicator systems: Experiences from Germany', *Environmental Management* Vol. 25, No 6, pp. 613–623, Springer-Verlag NY, 2000.

WRI, *Environmental indicators: A systematic approach to measuring and reporting on environmental policy performance in the context of sustainable development*, World Resources Institute, Washington DC, 1995.

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Assessment of information related to waste and material flows

2003 – 63 pp. – 21 x 29.7 cm

ISBN 92-9167-577-6