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IMPACT ASSESSMENT ON MEASURES ADDRESSING FOOD WASTE TO COMPLETE SWD (2014) 207 REGARDING THE REVIEW OF EU WASTE MANAGEMENT TARGETS

Annex 12: An Overview of the European Reference Model on Waste

Contents

1.0 Introduction

This Annex is intended to provide a brief overview of the European Reference Model on Municipal Waste Management which has been used for analysing the policy options put forward in this Impact Assessment (IA). DG Environment at the European Commission, working with the European Environment Agency, commissioned Eunomia and Copenhagen Resource Institute (CRI) to develop this model which covers all 28 EU Member States. This model has been used, firstly, to develop scenarios which aid understanding of the gap between likely waste management performance in specific Member States and the targets for recycling, recovery and landfill diversion under existing legislation. In addition, it can be used to quantify the impact of different scenarios in respect of impacts on the environment, including (but not limited to) greenhouse gas emissions, job creation, and costs.

This short overview will briefly cover the following:

- How the model was developed;
- The baseline waste management scenarios in Member States;
- The core components of the model and how these are interlinked; and
- The key assumptions that underpin the analyses in each component.

It is important to note that a summary Annex such as this can only provide a very high level overview of the model. The technical documentation which accompanies the model[1] runs into many hundreds of pages and it is therefore not possible to fully expand on all of the assumptions that are made in the model; however, we endeavour here to provide a summary of the key points and assumptions that are essential to the results presented in this IA.

The model, built as a spreadsheet tool in Microsoft Excel 2010, is populated with national waste management data for all Member States (including Croatia). At its core sits the mass flow modelling, where data on waste arisings, recycling, and residual waste treatment are recorded for each Member State. The model has been designed to provide projections for the period 2010 to 2030. The model is to be housed and maintained by the EEA and should provide a useful resource for analysing the impacts of European waste policy.

2.0 Model Creation

As well as initiatives taken by individual Member States to establish national projections, two particular studies have been taken at European level to model waste generation and management:

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[1] Eunomia Research & Consulting and Copenhagen Resource Institute (in development) *Development of a Modelling Tool on Waste Generation and Management*, Report for the European Commission DG Environment, www.wastemodel.eu

- The first undertaken for DG Environment in the context of an impact assessment on biowaste developed a modelling tool on municipal solid waste (MSW) generation and management;[2] and

- The second undertaken for the European Environment Agency supported by the European Topic Centre on Sustainable Consumption and Production calculated waste generation and treatment projections for each Member State, including the modelling of greenhouse gases (GHGs).[3]

These pieces of work provided a starting point for the development of the European Reference Model on Municipal Waste Management. The principles and methodologies established in the previous work have been used to develop a new model, built from scratch as a fit for purpose tool.

It is an important tool for national and pan-European strategic planning. Therefore, in order to ensure that it could be used to best effect, consultation with relevant personnel in government departments with responsibility for waste management was seen to be essential. Furthermore, industry consultation was also seen to be important to the model's development, and this was sought as a means of improving the quality of the information in the model.

As part of the model development relevant officials in all Member States were identified and sent a detailed questionnaire which requested country specific information which was required for input into the model. These questionnaires were sent out prior Member States being visited in person to gather further information and to better understand the missing data gaps in the questionnaires which had been returned prior to these face-to-face meetings. Nineteen Member States were visited by members of the project team and these visits helped to develop a much more detailed view of Member States' current performance and future plans with respect to waste management.[4] The countries which were not visited were felt to already being doing relatively well in terms of waste management and a substantial amount of information and data is already publically available; thus, information on these countries was gathered via the country questionnaire that was sent out and publically available sources of information.

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[2] Arcadis & Eunomia (2010) *Assessment of the Options to Improve the Management of Bio-waste in the EU*, Report for the European Commission http://ec.europa.eu/environment/waste/compost/developments.htm

[3] ETC/SCP (2011) *Projections of Municipal Waste Management and Greenhouse Gases*, Prepared by Bakas et al., 89 pp. Copenhagen, Denmark http://scp.eionet.europa.eu/publications/2011WP4

[4] The following Member States were visited: Bulgaria, Croatia, Cyprus, Czech Republic, Estonia, Finland, France, Greece, Hungary, Italy, Latvia, Lithuania, Malta, Poland, Portugal, Romania, Slovakia, Spain, and Sweden.

Industry was consulted via an online consultation which was hosted on the project's official website.[5] This consultation sought to obtain further information from stakeholders on the following:

- Waste composition;
- Collection systems operated in Member States and collection costs; and
- Treatment system costs.

These sources of information were used as sources of input data for the model which had been developed by the project team.

3.0 Baseline Scenarios Included in the Model

Baselines have been developed within the model based on information gathered from a series of Member State visits and interviews with relevant national waste departments, and a questionnaire led data gathering exercise for non-visited countries.

The first challenge of this work was to formulate a reasonable understanding of current Member State waste management performance (i.e. how municipal waste arises and gets managed). This is not always straightforward, not least because the availability and quality of information and recent data varies from Member State to Member State. Beyond the current situation, future projections are required essentially to predict how total waste arisings, waste prevention, recycling, residual waste treatment and disposal levels will evolve over time.

For current performance, existing data sources (Eurostat data, the 2013 EEA "Managing Municipal Solid Waste" reports for each country[6] and any further specific national waste management studies) give an indication of the waste management practices in the Member States. The questionnaires and Member State visits conducted as part of the model development (Section 2.0) helped supplement and explain such information and allowed for the inclusion of finer levels of detail in the modelling, and in certain cases have led to an adjustment of the official statistics (such as figures reported for total municipal waste).

For future performance, an understanding is needed of the policies, strategies and plans for investment in municipal waste infrastructure. For countries where National Waste Plans (or similar) have recently been developed, and policies have been announced or put in place to deliver the intended objectives, then the likely progression is more certain. For other countries where national planning is less recent, currently still in development or simply less thorough, then future expectations must be tempered.

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[5] European Commission (2013) *Waste Management Model*, www.wastemodel.eu

[6] EEA (2013) *Managing municipal solid waste - a review of achievements in 32 European countries* http://www.eea.europa.eu/publications/managing-municipal-solid-waste

With this in mind, two baselines and one steady state waste management projection are established based on the existing data and the gathered information. These are defined as follows:

- Business As Usual Scenario: Steady State Waste Management:
    - This assumes that the levels of recycling and the share of waste treatment systems remain constant after the last reported year. This provides a base case against which to compare the more dynamic future projection baselines (and scenarios in the further analysis).
- Baseline 1: Likely Outlook Based on Current Information:
    - The primary baseline presents an objective view of likely future waste management based upon realistic expectations for the performance of deliverable future waste management systems. For certain Member States it is likely to be a more moderated and objective version of the second baseline scenario. It is intended to highlight what might be the outcome if nothing happens other than:
        - Waste prevention / preparation for re-use measures whose implementation has already commenced take full effect;
        - Collection systems remain as they are, unless a clear programme of roll-out of new systems is underway or committed to; and
        - Residual waste facilities for municipal waste either already built, or in the construction phase are fully utilised. These plans will affect assumptions about how residual waste is managed
- Baseline 2: Member State Intentions:
    - This secondary baseline simply reflects Member States' stated intentions. This implies a less critical review of what is likely to happen in future, and takes Member State intentions 'at face value'. Where Member State plans or intentions have not yet been published or made available, it was necessary to project conservatively.

The policy options reviewed in this IA are against an assumed baseline of full implementation. This baseline assumes that existing targets are all implemented in all Member States on time. Apart from measures taken to improve implementation such as improved statistics, promotion of economic instruments, improvement of the functioning of the EPR schemes, no additional changes in the legislation are included in this scenario.

4.0 Outline of Model Components

A full description of the mass flow model, together with technical documentation on the individual modules, can be found in the reporting documents that are being produced as part of the European Reference Model Project. The intention here is to summarise the model in context of the IA and explain how it was used to model the policy scenarios included in this document.

A schematic of the overall model is depicted in Figure 4-1. From this it can be seen that the main model calculations consists of six modules, or components, these include:

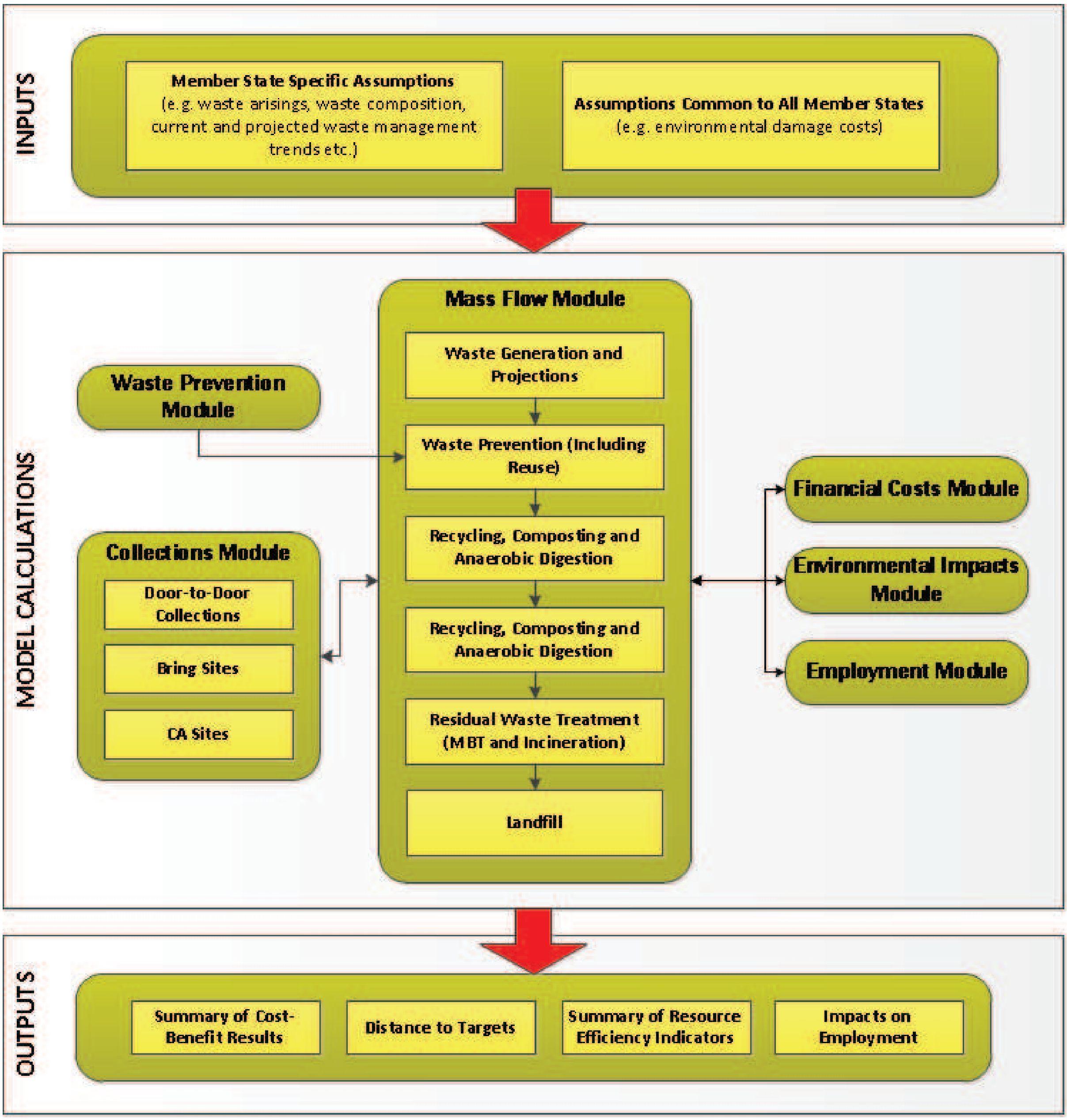
- Mass Flow Module – the central core of the model which accounts for all material flows at each level of the hierarchy and how they are treated/managed;
- Waste Prevention Module – this standalone module allows the impacts and implementation costs of various waste prevention initiatives to be calculated for Each Member State;
- Collections Module – this module is used to define how municipal waste is collected in each Member State and what the costs and logistics of this are;
- Financial Costs Module – this module, based on the mass flow of MSW, will calculate the costs of managing it via different pathways (e.g. via landfill, incineration and/or recycling);
- Environmental Impacts Module – this includes the modelling of both GHGs and local air emissions (direct and avoided emissions are monetised so as to compare directly with the financial costs); and
- Employment Module – this module is used to quantify the impacts that proposed policy changes will have on employment.

The outputs of the model are summarised in two separate modules and include the following:

- Summary of Cost-Benefit Analysis results;
- Assessment of the distance to European waste directive targets;
- Indicators relating to resource efficiency; and
- An evaluation of anticipated impacts on employment.

Each of the modules are introduced below with, as far as possible, important assumptions being highlighted to provide clarity on the approach that was taken.

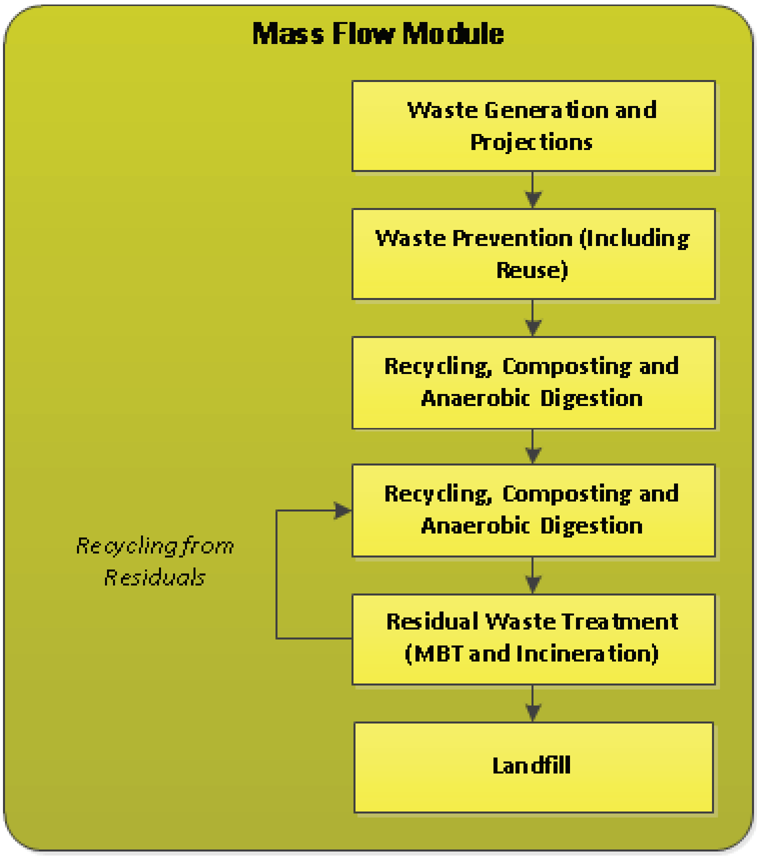
Figure 4-1: Overall Model Schematic



4.1.1 Mass Flow Module

A conceptual depiction of the mass flow model is given in Figure 4-2. The flow of waste within the excel model follows the principle of the waste hierarchy, and individual sheets are included in the model for recording tonnages generated and managed at each level of the hierarchy. For instance, the first modelling sheet lays out total generated municipal waste tonnages. The second sheet accounts for the impacts of any waste prevention initiatives that come out of the Waste Prevention Module (Section 4.1.2). All waste prevention impacts, assuming there are any, are then subtracted from the total projected amount of generated waste. The remaining waste is then collected for recycling, composting, and anaerobic digestion. All residual waste is available for residual waste treatment, notably incineration or mechanical and biological treatment (MBT). Note that these processes can extract additional materials for recycling and this is factored into the calculations for recycling rates in the model. The remaining waste (rejects from recycling and residual treatment) and waste not subject to any treatment goes to landfill. Each of the levels of the Mass Flow Module are briefly introduced below.

Figure 4-2 Overview of the Mass Flow Module



A more detailed outline of the approach taken to the mass flow modelling is presented in Figure 4-3. The intention of the Mass Flow Module is to ensure that all tonnages of waste that are generated, are accounted for by the sum of the recovery and treatment pathways, including mass losses where relevant. There is also a clear distinction between mixed refuse and segregated waste collection, which provides greater clarity concerning the nature of the treatment of organic waste in particular.

Clearly to operate a model with a more intricate flow of material as depicted by Figure 4-3, additional information is needed. Nevertheless, these additional pieces of information are needed for a model of this nature because:

a) Collection systems have related costs and impacts;

b) Treatment plants (including those considered by the current Eurostat Methodology as ‘pre-treatment’ plants) have related costs and impacts; and

c) All tonnages (including uncollected waste) need to be accounted for or the financial costs and environmental impacts will be incomplete and consequently flawed.

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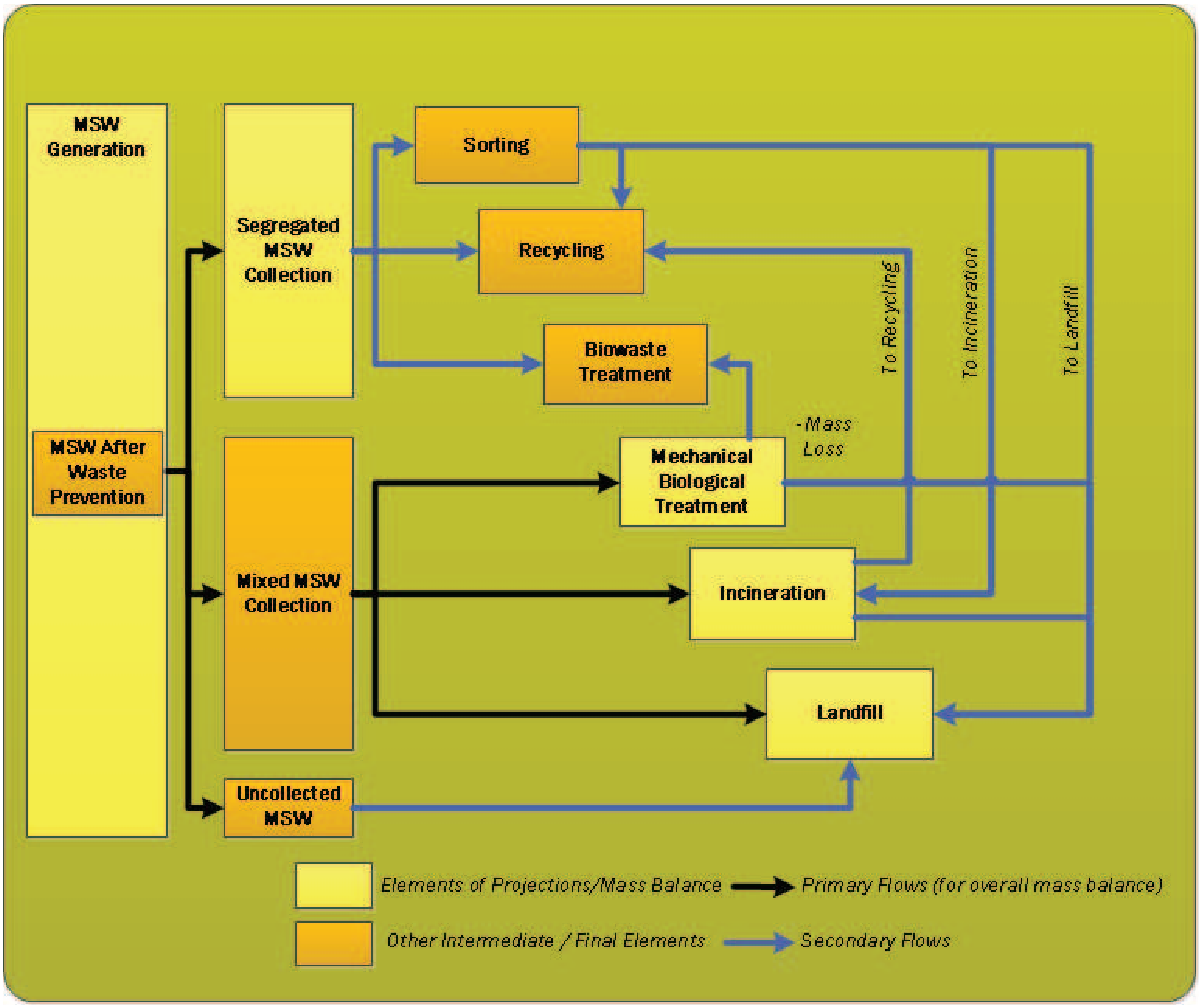
Figure 4-3: Approach Taken to Mass Flow Modelling



Note: Imports and Exports excluded from this presentation but intended to be accounted for in the model.

4.1.1.1 Waste Generation and Compositon

Waste Generation

As stated above each Member State (including Croatia) was contacted and asked to complete a questionnaire which was designed to obtain the necessary country specific information for input into the model. In terms of developing forward projections of MSW arisings for each Member State we used, where these were made available, projections that had been produced by the Member States themselves. In situations where Member States had not produced their own projections we produced independent projections based on the 2012 work by the ETC/EEA.[7] Full details of these projections can be found as a technical Annex in the report documents associated with the European Reference Model on Waste.[8]

Waste Composition

The model includes 51 fractions of MSW as indicated in Table 4-1. These fractions were selected following detailed consideration of:

- The available Member State compositional datasets;
- Requirements for reporting of data on specific materials to enable calculation of performance against the various European waste Directives; and
- Requirements for the model to perform distinct functions to meet the broader purposes and objectives for this model, i.e. the ability to model the environmental impact of the treatment of individual waste fractions.

Where Member States provided us with compositional breakdowns of their municipal waste stream we inputted this into the model based on the compositional breakdown shown in Table 4-1. Where information on composition could not be obtained directly from the Member State we used information obtained as part of research conducted by the ETC for the EAA in 2009.[9]

Table 4-1 Waste Fractions Included in the Model

Compositional Waste Fractions in the Model	
Biowastes	**Plastics (continued)**
Food	Non-packaging rigid plastics
Garden	Film packaging (bags etc)
Other biowastes	Non-packaging films
Wood	**WEEE**
Wood packaging	Large household appliances
Other wood	Small household appliances
Paper / Cardboard	IT and telecommunications equipment
Non-packaging paper	Consumer equipment and photovoltaic panels

[7] ETC / EEA (2012b) *Revision of the MSW Generation Projection Equations Based on Additional Data Points for 2009 and 2010,* Prepared by Andersen, F. M. et al. in 2012

[8] Eunomia Research & Consulting and Copenhagen Resource Institute (in development) *Development of a Modelling Tool on Waste Generation and Management*, Report for the European Commission DG Environment, www.wastemodel.eu

[9] ETC/SCP (2009) *Europe as a Recycling Society - Present Recycling Levels of Municipal Waste and Construction & Demolition Waste in the EU*, Prepared by Christian Fischer and Mads Werge, Working Paper No 2/2009

Compositional Waste Fractions in the Model	
Packaging paper	Lighting equipment
Cardboard	Electrical and electronic tools
Textiles	Toys, leisure and sports equipment
Clothing and footwear	Medical devices
Other textiles	Monitoring and control instruments
Glass	Automatic dispensers
Packaging glass	Rubble, soil
Non-packaging glass	Furniture
Metals	**Batteries and accumulators**
Mixed cans	Portable batteries
Steel cans	Accumulators
Aluminium cans	**Other wastes**
Aluminium foil	ELVs
Other scrap metal	Haz (exc WEEE)
Plastics	Fines
Plastic bottles	Inerts
Other rigid plastic packaging	Other

By multiplying the total waste arisings for each country by their MSW composition it is possible to come up with the projected waste arisings by material stream. This then feeds down into the lower tiers of the hierarchy as shown in Figure 4-2.

4.1.1.2 Waste Prevention

The Waste Prevention Module (see Section 4.1.2) allows a number of waste prevention initiatives to be modelled over the period 2010 to 2035 (e.g. food waste reduction programmes, the promotion of reusable nappies, and reducing unsolicited mail). The output from this module is a total waste prevention impact (in tonnes) for the selected range of waste prevention initiatives which are selected. This total tonnage is broken down by material and feeds directly into the waste prevention component of the Mass Flow Module. The prevented waste is then subtracted from the total amount of MSW generated to come up with a final projection of MSW arisings in each Member State.

The model recognises that not all MSW is managed by the formal sector. The model therefore requires that the ‘collection coverage’ be defined for each Member State. The larger the informal waste sector in a country the lower the collection coverage was assumed to be. In all countries with an informal sector it was assumed that the collection coverage improves over time (the point at which 100% coverage is achieved naturally varies from country to country).

For material that is not collected by the formal sector it was assumed that it goes to landfill. For all other waste – that is, waste managed by the formal sector – the model assumes that this is collected via official means and therefore is available for recycling, composting, and other forms of treatment and disposal.

4.1.1.3 Recycling, Composing, and Anaerobic Digestion

In order to split all formally collected MSW by the different tiers of the hierarchy the Mass Flow Module requires that current and future trends are defined for the following:

- Material recycling;
- Composting/anaerobic digestion;
- MBT;
- Incineration; and
- Landfill.

These inputs are defined as proportions of total waste arisings and are used to apportion the amount of waste that passes through each tier of the hierarchy presented in Figure 4-2. In order to set up the baseline scenarios these parameters were defined for each Member State based on information that was made available through the detailed country questionnaire, face-to-face interviews, and a search of publically available documents (see Section 3.0 for a discussion of the baseline scenarios).

Data on current recycling and composting rates in the different Member States was largely obtained from Eurostat. However, in a few instances these rates were adjusted slightly after discussions with Member State representatives who were able to provide updated figures that had emerged since the figures had been reported to Eurostat. The amount of material collected for recycling and/or biotreatment in the future is determined by the projected trends in recycling rates.

The model is able to adjust the treatment share between in-vessel composting (IVC), open air windrow (OAW) and anaerobic digestion (AD). Different types of energy recovery from anaerobic digestion can also be modelled.[10]

4.1.1.4 Residual Waste Treatment

MBT

As stated above, the amount of MSW requiring treatment via MBT or incineration is determined by current levels of treatment and what is believed to be likely future trends. Mechanical biological treatment is a residual waste treatment, where mixed waste is sent to an integrated plant for mechanical treatment (separation, shredding) and a biological treatment. The biological treatment typically consists of mixed waste composting or more rapid 'biodrying' (for production of a fuel), and may also include an anaerobic digestion element. The outputs from MBT plants can go to a variety of sources:

- Recovered recyclables (e.g. metals and plastics can get recycled) can contribute to recycling rates;
- Refuse Derived Fuels (RDF) can be sent for incineration at EfW plants or cement kilns; and
- Stabilised or rejected waste can be sent to landfill.

[10] The following AD energy recovery schemes are included in the model: electricity only; combined heat & power (CHP); gas to grid; and gas to vehicle fuel.

The proportion of material which goes to each source can be assigned in the model based on the type of MBT facilities that are operating in each Member State. Five variants of MBT have been defined in the model. They include:

- MBT 1 – Biostabilisation;
- MBT 2 – Biodrying no plastics recycling;
- MBT 3 – Biodrying with plastics recycling;
- MBT 4 – AD based; and
- MBT 5 – Basic sorting + energy generation.

Assumptions concerning the level of recycling, RDF production, mass loss etc. are specific to the five types of MBT included in the model. Extraction rates from residual treatments for recycling are calculated as the ratio between output (for recycling etc.) and input for a given material.

Incineration

Four incineration variants have been included in the model:

- Incineration – Electricity only;
- Incineration – Combined Heat and Power (CHP);
- Incineration – Heat only; and
- Incineration – No energy recovery.

The proportion of residual waste going to each type of facility is defined for each Member State. The efficiency with which metals are recovered from incineration facilities is modelled based on a recent literature review undertaken by Grosso et al, which suggested that 70% of the ferrous metal could be recovered as well as 30% of the non-ferrous metal.[11] As shown in Figure 4-2, all recovered metals are taken out of the residual waste stream and added to the recycling stream where they count towards the overall recycling rate reported by the model.

4.1.1.5 Landfill

Landfilling is the final part of the waste management chain. This Mass Flow Module has been developed to ensure a mass balance between the MSW generated (after waste prevention has been taken into account) and the waste treatments outlined above.

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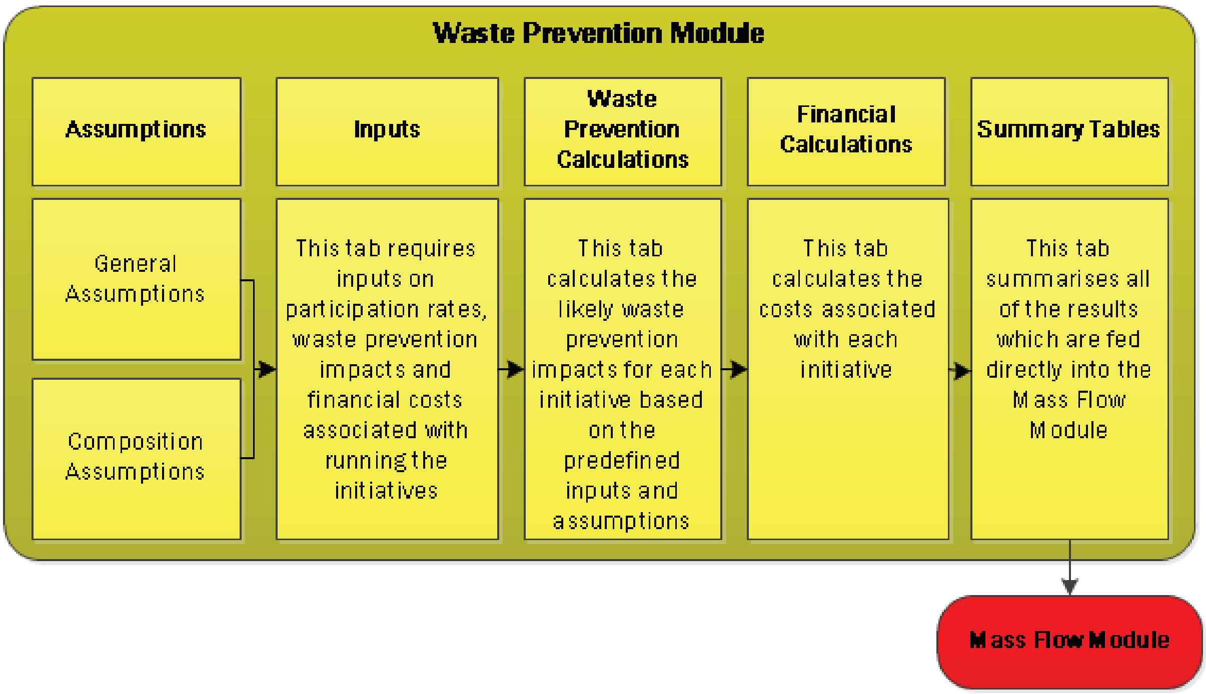
[11] Grosso M, Biganzoli L and Rigamonti L (2011) A Quantitative Estimate of Potential Aluminium Recovery from Incineration Bottom Ashes, Resources, *Conservation and Recycling*, Vol. 55, pp. 1178-1184

As discussed in Section 4.1.1.2, all uncollected waste is assumed to go to landfill. In addition, all the rejects from sorting facilities are assumed to be MSW sent to landfill and /or incineration. For this reason, the amount of waste landfilled calculated in the model may conservatively give a higher figure than amounts sent to landfill as reported by Eurostat.

4.1.2 Waste Prevention Module

An overview of the Waste Prevention Module is presented in Figure 4-4 which illustrates the model processes. From this it can be seen that user defined inputs, along with a number of assumptions, feed into the Waste Prevention and Financial Calculations sheets. These results are amalgamated in the Summary Tables. The results presented in the Summary Tables then feed directly into the waste prevention component of the Mass Flow Module.

Figure 4-4: Overview of the Waste Prevention Module



The Waste Prevention Module allows for the waste prevention impact and financial cost of the following initiatives to be calculated:

- Home composting;
- Say no to unsolicited mail;
- Promotion of reusable nappies;
- Door stepping campaign promoting the prevention of food waste;
- Media based campaign promoting the prevention of food waste;
- Campaign to promote General Waste prevention initiatives;
- Paint reuse at bring sites;
- Community swap days;

- Reducing the size of residual waste containers;
- No side waste policies;
- Pay as you throw; and
- 'Other' initiative.

The waste prevention impact of any initiative depends on two factors:

1. The number of people/households participating; and

2. The amount of waste prevented by each participant.

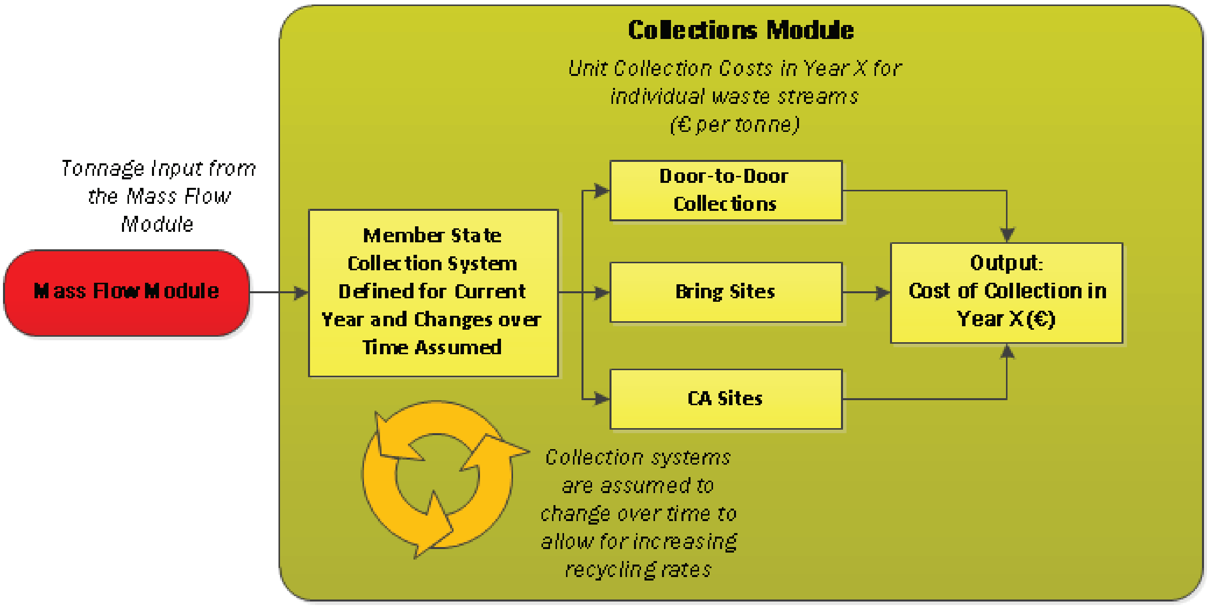
Each initiative uses the above logic to calculate the amount of waste that is likely to be prevented if it were to be implemented. Naturally, the number of participants involved and the amount of waste prevented will depend on a number of factors, for example, the type of initiative, the socioeconomic demographic of the target population and the degree to which an initiative is promoted by the authorities. As such, careful consideration needs to be given to the inputs in this section to ensure that they are in alignment with the amount of funding that is made available to promote the initiative, and to ensure that the amount of waste prevented per participating household/person is realistic for the country being modelled.

As stated above and shown in Figure 4-4, the waste prevention impacts arising from the implementation of these initiatives feed through into the Mass Flow Module. For the sake of brevity further details and assumptions will not be outlined here, instead the reader is referred to the documentation that accompanies the European Reference Model on Waste.

4.1.3 Collections Module

An overview of the Collections Module is provided in Figure 4-5 below. Information on the tonnages of mixed and segregated MSW collected is inputted into the Collections Module from the Mass Flow Module. The current collections systems in operation in all Member States have been defined in the model and changes in these systems are assumed over time to allow member states to improve their recycling rates.

Figure 4-5: Overview of the Collections Module



Further details on the assumptions underpinning the Collections Module can be found in the technical documentation which accompanies the model.

4.1.4 Financial Costs Module

As part of the modelling exercise we have sought to make financial cost estimates as country-specific as possible. There are some limits as to how much detail can be developed in this respect, but the approach gives, we believe, a sensible compromise between the desirability of generating country specific cost data, and the difficulties experienced in finding country specific cost figures.

Consequently, for modelling individual waste collection and treatment process we have tended to fall back on data for which we have sound knowledge of the breakdown in costs, and have sought to adapt that to the specific Member State situation through varying specific cost factors to reflect local markets (for example labour), and with various taxes (for example on landfill) and subsidies (for example feed-in-tariffs for renewable energy).

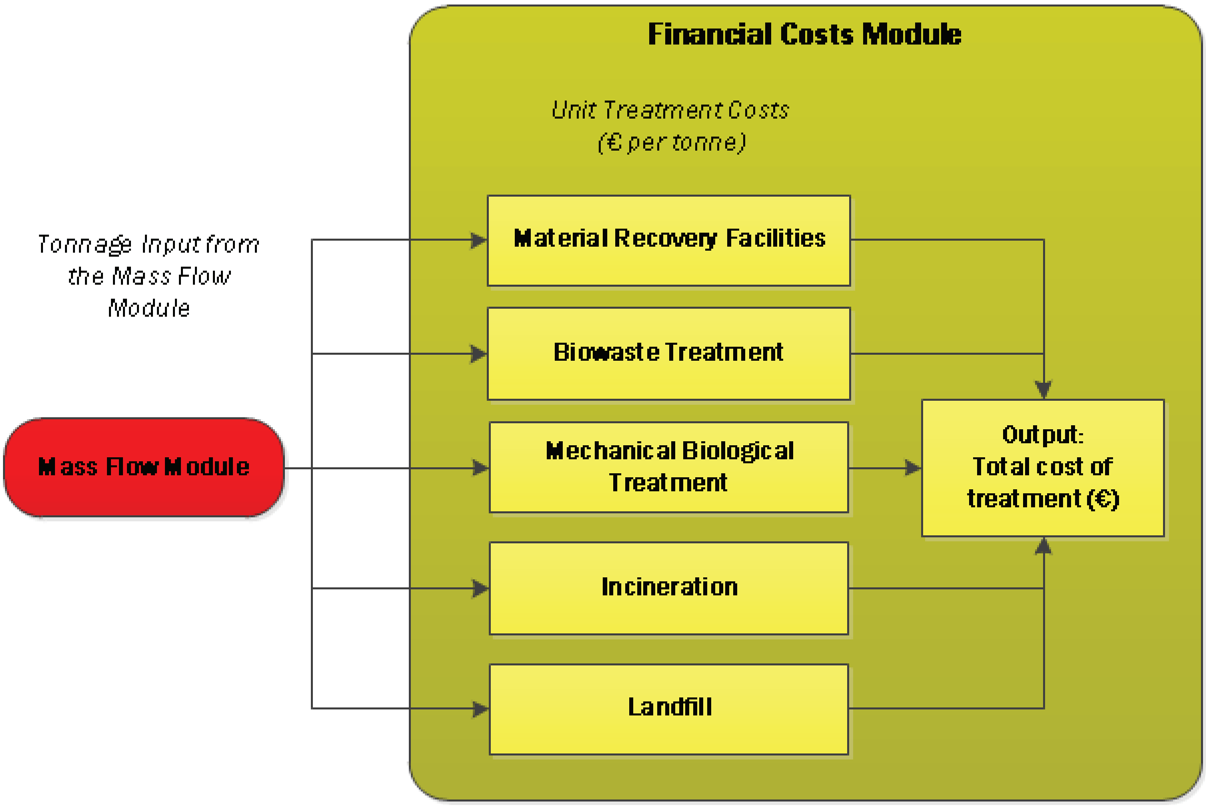
We have attempted to research and use up to date figures for Member State specific data, but specific figures may have changed since the time of writing.[12] The following subsections lay out the generic approaches and assumptions used in the financial cost

[12] Prices taken as 2012 figures, accepting that financial years have different start and end points. An approximation is taken where data comes from countries like the UK where the financial year runs from April to end March (in this case UK 2012/13 prices are taken in the model as 2012 prices).

modelling which are not specific to individual treatments (for example the financial cost terminology, the cost of finance, revenues from energy sales, labour rates in individual member states etc.).

An overview of the module is presented in Figure 4-6. A summary of the unit costs of treating a tonne of waste via each of the treatment technologies listed in this figure is presented at the end of this section in Table 4-9. In essence, the tonnage output from the Mass Flow Module is multiplied by the calculated unit cost of treatment and/or disposal to come up with a final cost. Some of the assumptions pertaining to how these unit costs are described here, with further details being provided as part of the technical documentation that is being produced as part of the modelling project.

Figure 4-6: Overview of the Financial Costs Module



4.1.4.1 Note on Costs with Regard to Gate Fees

Where matters of cost are concerned, the waste sector is typically used to dealing with the issue in terms of 'gate fees'. Gate fees are not 'costs', and there are various reasons why the gate fee at a facility may differ from costs, as they might be conventionally understood. Gate fees may, depending upon the nature of the treatment, be affected by, inter alia:

1. Local competition (affected by, for example, haulage costs);
2. Amount of unutilised capacity available at facilities;

3. The desire to draw in, or limit the intake of, specific materials in the context of seeking a specific feedstock mix;

4. Strategic objectives of the facility operator; and

5. Many other factors besides.

Any one of these can influence the market price, or gate fee, for a service offered by a waste management company.

Another feature of the waste treatment market is the use of long-term contracts in the municipal waste market to procure services where the private sector is involved. The nature and length of these contracts, and the nature and extent of the risks which the public sector may wish to transfer to the private sector, influences the unitary payment, or gate fee, offered under any given contract. The nature of risk transfer may relate, for example, to technology and its reliability, or to specific outputs which a contract seeks to deliver (e.g. energy, materials), and these may, in turn, relate to existing policy mechanisms.

The key point is that the nature of the risk transfer associated with a given contract affects gate fees. In the municipal waste sector, contract prices may typically be wrapped up in the form of a single payment, which may be composed of a number of different elements associated with the delivery of the contract against the specified outputs. This 'unitary payment' is typically determined on a contractual basis, and so is somewhat different to gate fees which might be realised at facilities operating in a more openly competitive market. In the approach used in this study, issues of risk transfer are not considered.

It should also be noted that whilst some of the major items of infrastructure for treating municipal waste have been financed using project finance, it remains possible that corporate finance could be used to support projects, or that public funding could be available to fund projects. This would have the effect of changing the cost of capital used to support any given project.

Generally, therefore, the costs we have developed will be different to 'gate fees' or payments which may be experienced in a given contractual agreement, or spot market transaction, though they will approximate to them in competitive markets which are not characterised by over-supply of capacity of one or other type.

It should also be recognised that different treatments are more and less sensitive to variables which underpin the analysis of costs. For example, changes in the cost of capital affect the unit (per tonne) cost of more capital intense treatments in a more significant way than is the case for those processes with lower unit capital costs (such as waste collection). Similarly, assumptions concerning landfill taxes, and levels of support for renewable energy outputs will affect different treatments in different ways. Value added taxes, on the other hand, are not typically charged on waste equipment and operations, and do not therefore appear in the model.

4.1.4.2 Accounting Principles and the Cost Metrics Included in the Model

The model is intended both as a tool to indicate the financial implications within the waste industry of changes in waste management, as well as calculating the net costs and benefits including (as far as possible) environmental impacts. For the former, the model calculates costs under a *'private metric'* (reflecting the costs as discussed in Section 4.1.4.1 above). For the latter, a *'social metric'* is used. Additionally, a *'hybrid'* between the two metrics is included to indicate the level of actual economic activity in the waste sector. The three metrics can be defined as follows:

- The **'Private Metric'** is intended to represent the market conditions from the perspective of those undertaking waste operations or those developing and operating facilities. It uses retail prices, includes taxes and subsidies, and applies a weighted average cost of capital (WACC, typically 10-15%) to capital equipment. Taking a treatment facility as an example, this approach essentially indicates an approximate 'break even' gate fee, inclusive of taxes, at a level where the facility would cover its capital and operating costs under typical market conditions.

- The **'Social Metric'**, on the other hand, is appropriate for use in cost benefit analyses and impact assessments attempting to calculate an overall cost to society. This metric uses the European Commission's standard 4% discount rate for inter-temporal comparisons within impact assessments.[13] Subsidies and taxation are also stripped away so as to only value the true '*resource cost'* of an activity. This also avoids any double counting of environmental effects that are intended to be internalised within environmental taxes and subsidies. Under this metric, environmental damage costs can be added to, the financial costs so as to determine, for instance, whether the impact of a policy is positive or negative with respect to society.

- The **'Hybrid Metric'** is essentially to attempt to put a measure on the economic activity within the municipal waste sector. To summarise the approach, it values capital investments in the same way as the private metric, but excludes all taxes and subsidies.

The net present value of any future investments or contextual changes in the waste sector uses the Commission standard 4% discount rate (the social rate of time preference), no matter which approach is considered.

All costs are calculated and displayed in real terms at 2012 prices in the model, using the EU average GDP deflator for historic years (as shown in Table 4-2) or the European Central Bank price stability target for future years (*"below but close to 2% over the medium term"*)[14].

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[13] European Commission (2009) *Impact Assessment Guidelines*, 15 January 2009, SEC (2009) 92.

[14] European Central bank Website (Accessed 11/6/2013), , Monetary Policy > Strategy > Definition of price stability http://www.ecb.int/mopo/strategy/pricestab/html/index.en.html

Table 4-2: Historic and Future GDP Deflators Used in the Model

2004	2005	2006	2007	2008	2009	2010	2011	2012	Future years
2.7%	1.9%	2.3%	2.9%	0.4%	-1.6%	2.4%	0.8%	3.1%	2%

Source: Eurostat mid year (Q3) seasonally adjusted price index (percentage change compared to corresponding period of previous year, based on 2005=100 and national currency (including 'euro fixed' series for euro area countries). Data for the European Union (27 countries) and Croatia. Gross domestic product at market prices. Eurostat online database, GDP and main components - Price indices [namq_gdp_p] accessed 11/6/2013.

4.1.4.3 Disposal Taxes

The current taxes for landfill and incineration for each Member State are shown in Table 4-3. These figures are compiled from a range of sources, with data from the 2012 ETC/SCP source[15] taking precedence, where available, over other data from more disparate and historic sources.

[15] ETC/SCP (2012) Overview of the Use of Landfill Taxes in Europe, prepared by Christian Fischer, Mathias Lehner and David Lindsay McKinnon of the Copenhagen Resource Institute, April 2012 http://scp.eionet.europa.eu/publications/WP2012_1/wp/WP2012_1

Table 4-3: Taxes on Landfill and Incineration by Member State (prices in nominal terms)

Member State	Landfill Tax - Municipal (€/tonne)						Other waste taxes (€/tonne) 2012 prices unless otherwise indicated			
	2010	2011	2012	2013	2014	2015+	Hazardous disposal*	Incineration tax	MBT residues	Incineration residues
Austria	€ 87.00	€ 87.00	Ban on landfilling of untreated waste from Jan 2012. Landfill via MBT only (tax applied as shown to right)				€ 29.80	€ 8.00	€29.80	
Belgium - Flanders	€ 79.56	€ 79.56	€ 79.56	€ 79.56	€ 79.56	€ 79.56		€ 7 (2008)		
Belgium - Wallonia	€ 65.00 [indexed]	€ 65.52	€ 67.55	€ 68.90	€ 70.28	€ 71.69	As landfill	€ 8.00		€12.50
Belgium - Brussels	No data, assume all exported to other two regions at their respective rates of tax									
Belgium - weighted	TBC	TBC	TBC	TBC	TBC	TBC	TBC	TBC		TBC
Bulgaria	€ 1.53	€ 1.53	€ 4.00	€ 8.00	€ 18.00	€ 18.00				
Cyprus										
Czech Republic	€ 20.00	€ 20.00	€ 20.00	€ 20.00	€ 20.00	€ 20.00	€ 68.00 (2011)			
Denmark	€ 63.00	€ 63.00	€ 63.00	€ 63.00	€ 63.00	€ 63.00	€ 21.30[16]	€ 44.00 (2008)**		
Estonia	€ 12.00	€ 12.00	€ 12.00	€ 12.00	€ 12.00	€ 12.00	€ 12.00 (2010)	€ 7.00		
Finland	€ 30.00	€ 40.00	€ 40.00	€ 50.00	€ 50.00	€ 50.00				
France	€ 20.00	€ 20.00	€ 30.00	€ 30.00	€ 30.00	€ 40.00	€ 20.00 (2010)	€ 11.20[17]		
Germany										
Greece										

[16] Rising to €63.00 in 2015

[17] Rising to €14 from 2013

Member State	Landfill Tax - Municipal (€/tonne)						Other waste taxes (€/tonne) 2012 prices unless otherwise indicated			
	2010	2011	2012	2013	2014	2015+	Hazardous disposal*	Incineration tax	MBT residues	Incineration residues
Hungary										
Ireland	€ 30.00	€ 50.00	€ 65.00	€ 75.00	€ 75.00	€ 75.00				
Italy	€ 30.00	€ 30.00	€ 30.00	€ 30.00	€ 30.00	€ 30.00	€ 5.16 – € 25.82			
Latvia	€ 4.27	€ 7.11	€ 9.96	€ 9.96	€ 9.96	€ 9.96	€ 21.34			
Lithuania	€ 22.00	€ 22.00	€ 22.00	€ 22.00	€ 22.00	€ 22.00				
Luxembourg										
Malta										
Netherlands	Previously €107.00 but abolished in January 2012									
Poland	€ 26.60	€ 26.60	€ 26.60	€ 26.60	€ 26.60	€ 26.60				
Portugal	€ 4.00	€ 4.00	€ 4.00	€ 4.00	€ 4.00	€ 4.00	€ 6.00 (2011)	€ 1.07 (2011)		
Romania										
Slovakia										
Slovenia	€ 11.00	€ 11.00	€ 11.00	€ 11.00	€ 11.00	€ 11.00	€ 22.00 (2010)			
Spain - Catalan only	€ 10.00	€ 12.00	€ 12.00	€ 12.00	€ 12.00	€ 12.00		€ 5.50 (2011)		
Spain - remainder										
Spain - weighted	TBC	TBC	TBC	TBC	TBC	TBC		TBC		
Sweden	€ 47.00	€ 47.00	€ 47.00	€ 47.00	€ 47.00	€ 47.00	€ 47.00			€47.00
United Kingdom	€ 57.60	€ 67.20	€ 76.80	€ 86.40	€ 96.00	€ 96.00			As landfill	€3.13
Croatia										

Notes:

- **Hazardous disposal tax applied in the modelling to incineration air pollution control residues.*
- ***Source: Fischer (2008) The use of landfill and incineration waste taxes in selected EU countries, Presentation for the European Environment Agency, April 2008, http://www.ea-swmc.org/download/CBPII/Landfill%20and%20%20incineration%20taxes170408.pdf*
- *In Italy, prior treatment by Incineration and MBT leads to a discount in landfill tax, but this is not specified and varies in value so has not been included in the modelling. For hazardous disposal we take an average value of €15.50/tonne.*

- *For Spain, relevant taxes on municipal waste are only known to be charged in Catalonia.*[18] *Within the modelling for Spain, we multiply the tax by the current relative quantity of waste originating from Catalonia by the total for Spain as a whole. A higher landfill tax rate (€21/tonne) is payable in Catalonia if the municipality does not operate separate biowaste collection. As of 2010, however, at least 692 of the 947 municipalities of Catalonia had implemented separate biowaste collection, and this number continues to increase. As such, the assumption going forward for the financial modelling is that the lower rate applies.*

- *For Belgium, rates are different in Flanders, Wallonia and the Brussels Capital Region. Once again, a weighting is conducted across the three regions depending on arisings from one to the other. We note that any waste generated within Flanders attracts the Flanders taxes even if shipped for treatment or disposal outside the region.*

- *UK prices converted at €1.2 per pound.*

[18] Ignasi Puig Ventosa (2011) *Landfill and Waste Incineration Taxes: The Spanish Case,* Presentation at Brussels 25th October 2011, ec.europa.eu/environment/waste/pdf/strategy/5.%20Landfill%20and%20incineration%20taxes%20in%20Spain%20Ignasi%20Puig%20%282%29.pdf

4.1.4.4 Revenue from Electricity Sales

Ideally it would be possible to accurately establish, for each Member State, the wholesale prices that generators would receive for the electricity they produce. However, this process is complicated due to a number of factors. The first of these is the lack of properly developed and integrated wholesale markets within the EU. Ultimately, there may be a single European energy market with a single wholesale price at any one time, but currently the market is fragmented, and in a number of cases, such as Romania and Bulgaria, prices are set by the Government regulator. Where wholesale markets do exist, and data is available, it is not clear what proportion of this price would be received by the generator, and how much might be taken by the supplier.

As a proxy, we have used, as a first step, Eurostat's most recent half-yearly electricity prices, without taxes, for industrial consumers.[19] These values are shown in Table 4-4.

Table 4-4: Prices for Electricity for Industrial Consumers in each Member State (2012)

Member State	Revenue from Electricity Sales (€/MWh)	Member State	Revenue from Electricity Sales (€/MWh)
Austria	€ 88.80	Latvia	€ 111.00
Belgium	€ 96.10	Lithuania	€ 114.00
Bulgaria	€ 76.60	Luxembourg	€ 97.00
Cyprus	€ 226.20	Malta	€ 180.00
Czech Republic	€ 101.70	Netherlands	€ 85.50
Denmark	€ 85.60	Poland	€ 90.70
Estonia	€ 68.20	Portugal	€ 99.20
Finland	€ 67.30	Romania	€ 82.80
France	€ 63.20	Slovakia	€ 122.70
Germany	€ 87.80	Slovenia	€ 86.60
Greece	€ 102.80	Spain	€ 113.80
Hungary	€ 101.70	Sweden	€ 77.00
Ireland	€ 136.70	United Kingdom	€ 115.60
Italy	€ 143.80	Croatia	€ 93.30

Source: Eurostat

In using prices for one of the larger groups of industrial users (country specific prices become increasingly sparse when looking at the largest consumers), and stripping out taxes, it is expected that the prices are a reasonable, if slightly elevated, reflection of the variations in wholesale prices between Member States. While these figures may not accurately represent the wholesale price, they have the benefit of having been gathered using a standard methodology.

[19] Eurostat (2012) Energy Statistics Database (data are for 2012 S2, industrial consumers) available at

http://appsso.eurostat.ec.europa.eu/nui/show.do?dataset=nrg_pc_205&lang=en Accessed 12/6/12

We then adjust these figures to represent an assumed differential between wholesale prices and prices for industrial consumers, and a further differential between wholesale prices and the prices that a generator would receive. We assume the price received by generators to be 60% of the price for large industrial consumers, giving the data in Table 4-5.

Table 4-5: Assumed Electricity Revenues for Generators in each Member State

Member State	Revenue from Electricity Sales (€/MWh)	Member State	Revenue from Electricity Sales (€/MWh)
Austria	€ 53.28	Latvia	€ 66.60
Belgium	€ 57.66	Lithuania	€ 68.40
Bulgaria	€ 45.96	Luxembourg	€ 58.20
Cyprus	€ 135.72	Malta	€ 108.00
Czech Republic	€ 61.02	Netherlands	€ 51.30
Denmark	€ 51.36	Poland	€ 54.42
Estonia	€ 40.92	Portugal	€ 59.52
Finland	€ 40.38	Romania	€ 49.68
France	€ 37.92	Slovakia	€ 73.62
Germany	€ 52.68	Slovenia	€ 51.96
Greece	€ 61.68	Spain	€ 68.28
Hungary	€ 61.02	Sweden	€ 46.20
Ireland	€ 82.02	United Kingdom	€ 69.36
Italy	€ 86.28	Croatia	€ 55.98

Source: 60% of data in Table 4-4

These values represent the back stop position for sale of electricity to the grid within the modelling, and the revenue that may be derived under the social or hybrid accounting metrics. Price support mechanisms are also often relevant for generation of electricity when calculated under the private metric, and are discussed further in Section 4.1.4.5.

4.1.4.5 Levels of Support for Renewable Electricity

For reasons outlined in the technical annex on financial costs that accompanies the EU waste model, some caution needs to be applied in the interpretation of data on renewable support mechanisms. Furthermore, the very nature and level of support mechanisms in EU countries is in a considerable state of flux, and are unlikely to remain stable in future years. The impact of the Renewable Energy Directive, setting even more ambitious targets for the proportion of electricity to be generated by renewables is likely to promote a revision of schemes across the EU.[20] The values used for the modelling are shown in Table 4-6, though the value applied in the calculation of prices under the private metric are the greater of either this data or the data in Table 4-5.

[20] Directive 2009/28/EC. Available at http://eur-lex.europa.eu/LexUriServ/LexUriServ.do?uri=OJ:L:2009:140:0016:0062:EN:PDF

Table 4-6: Levels of Support for Renewable Electricity Identified for each Member State - 2012 figures

Member State	Renewable Electricity Support – Landfill Gas (€/MWh)	Renewable Electricity Support – Incineration (€/MWh)	Renewable Electricity Support – Anaerobic Digestion (€/MWh)
Austria	€ 5.00	-	€ 130.00
Belgium	€ 90.00	-	€ 90.00
Bulgaria	€ 115.00	-	€ 205.00
Cyprus	€ 114.50	-	€ 135.00
Czech Republic	€ 110.00	-	€ 110.00
Denmark	€ 110.00	-	€ 110.00
Estonia	€ 53.70	-	€ 53.70
Finland	€ 83.50	-	€ 83.50
France	€ 97.45	-	€ 81.21
Germany	€ 58.90	-	€ 60.00
Greece	€ 99.45	-	€ 200.00
Hungary	€ 110.00	€ 119.69	€ 50.00
Ireland	€ 81.00	-	€ 100.00
Italy	€ 140.00	-	€ 140.00
Latvia	€ 75.48	-	€ 75.48
Lithuania	€ 120.00	-	€ 120.00
Luxembourg	€ 120.00	-	€ 120.00
Malta	-	-	-
Netherlands	€ 70.00	-	€ 70.00
Poland	€ 63.58	-	€ 63.58
Portugal	€ 102.00	-	€ 115.00
Romania	€ 54.00	-	€ 27.00
Slovakia	€ 93.08	-	€ 144.88
Slovenia	€ 66.17	-	€ 129.15
Spain	€ 88.70	-	€ 88.70
Sweden	€ 23.20	-	€ 23.20
United Kingdom	€ 111.04	-	€ 111.04
Croatia	-	-	€ 159.00

Main source: Res Legal (2013) Legal sources on renewable energy, accessed 28/4/2013, http://www.res-legal.eu/en/search-by-country/
Additional sources:
http://www.schoenherr.eu/news-publications/legal-insights/bulgaria-the-energy-regulator-announced-the-new-feed-in-tariff-and-the-available-grid-for-renewable-energy-projects-in-bulgaria-for-2012-2013

4.1.4.6 Levels of Support for Renewable Heat

In the absence of a well-developed market for renewable heat, and the associated lack of up-to-date figures, we note that caution must be exercised in the interpretation of the figures applied in relation to renewable heat sales. The values used for the modelling are shown in Table 4-7.

Table 4-7: Revenue from Heat Sales in Member States - 2012 figures

Member State	Revenue from Heat Sales (€/MWh)	Member State	Revenue from Heat Sales (€/MWh)
Austria	€ 62.04	Latvia	€ 36.16
Belgium	€ 47.94	Lithuania	€ 36.16
Bulgaria	€ 25.34	Luxembourg	€ 47.94
Cyprus	€ 0.00	Malta	€ 0.00
Czech Republic	€ 41.67	Netherlands	€ 47.94

Member State	Revenue from Heat Sales (€/MWh)	Member State	Revenue from Heat Sales (€/MWh)
Denmark	€ 72.49	Poland	€ 32.05
Estonia	€ 25.25	Portugal	€ 0.00
Finland	€ 34.32	Romania	€ 24.42
France	€ 49.31	Slovakia	€ 36.20
Germany	€ 57.60	Slovenia	€ 37.45
Greece	€ 0.00	Spain	€ 0.00
Hungary	€ 38.98	Sweden	€ 56.60
Ireland	€ 27.53	United Kingdom	€ 27.53
Italy	€ 69.42	Croatia	€ 37.45

4.1.4.7 Labour Cost Ratios Between Member States

The costs of labour, taxes and social security and associated rates used in the modelling are shown in Table 4-8. These are used to proportionally weight the labour related costs associated with the individual technologies which are included in the model.

Table 4-8: Labour Costs Used as Ratios Between Member States

	Mean Net Annual Earnings €	Tax rate (% of salary)	Social Security and other labour costs paid by employer (% of total labour costs)	Mean Gross Annual Earnings €
Austria	€ 35,653	21%	26%	€ 67,359
Belgium	€ 42,850	26%	29%	€ 95,117
Bulgaria	€ 4,009	21%	18%	€ 6,538
Cyprus	€ 26,552	0%	12%	€ 30,304
Czech Republic	€ 11,206	14%	25%	€ 18,404
Denmark	€ 54,524	35%	11%	€ 102,392
Estonia	€ 10,089	16%	25%	€ 16,965
Finland	€ 38,920	18%	24%	€ 67,150
France	€ 31,207	18%	30%	€ 60,373
Germany	€ 36,997	30%	22%	€ 78,152
Greece	€ 25,398	16%	0%	€ 30,236
Hungary	€ 9,403	24%	28%	€ 19,428
Ireland	€ 35,321	6%	23%	€ 49,980
Italy	€ 29,766	21%	30%	€ 60,341
Latvia	€ 8,086	29%	21%	€ 16,172
Lithuania	€ 6,935	17%	27%	€ 12,480
Luxembourg	€ 51,197	15%	13%	€ 70,920
Malta	€ 25,398	8%	14%	€ 32,903
Netherlands	€ 42,567	22%	23%	€ 76,794
Poland	€ 9,988	22%	16%	€ 16,230
Portugal	€ 15,884	14%	18%	€ 23,390
Romania	€ 5,415	26%	21%	€ 10,254
Slovakia	€ 9,609	13%	25%	€ 15,461

Slovenia	€ 20,218	23%	14%	€ 31,950
Spain	€ 27,802	9%	27%	€ 43,441
Sweden	€ 36,314	20%	29%	€ 70,240
United Kingdom	€ 34,434	20%	12%	€ 50,750
Croatia*	€ 9,403	18%	16%	€ 14,269

Sources:
Tax and social security rates from Deloitte (2012) Tax Highlight 2012 Slovenia,
http://www.deloitte.com/assets/Dcom-Global/Local%20Assets/Documents/Tax/Taxation%20and%20Investment%20Guides/2012/dttl_tax_highlight_2012_Slovenia.pdf
Labour rates from Eurostat
http://epp.eurostat.ec.europa.eu/portal/page/portal/labour_market/earnings
Note: Croatia not included in this dataset so assume earnings as for Hungary which has similar GDP per capita.

4.1.4.8 Summary of Country Specific Costs for Waste Treatments

Table 4-9 presents draft country specific costs for the various waste treatments for each Member State under the private cost metric (i.e. including all taxes and revenues, and using the higher costs of capital). Details on how these costs were derived can be found in the technical appendix on financial costs which accompanies the model.

Table 4-9: Member State Specific Waste Treatment Costs Summary (2012 prices)

Total Unit Treatment Costs: Private Metric	Composting/Digestion				Incineration				MBT				Landfill
	Open Air Composting	In-Vessel Composting	Anaerobic Digestion	Electric Only	CHP	Heat Only	Combustion Only	Bio-stabilisation	Biodrying with no Plastics Recycling	Biodrying with Plastics Recycling	AD based MBT	Residual MRF + Combustion	
Austria	€ 30	€ 50	€ 64	€ 107	€ 117	€ 30	€ 90	€ 110	€ 95	€ 91	€ 95	€ 68	€ 124
Belgium	€ 30	€ 50	€ 80	€ 111	€ 129	€ 56	€ 96	€ 109	€ 98	€ 94	€ 98	€ 69	€ 108
Bulgaria	€ 24	€ 43	€ 26	€ 90	€ 115	€ 61	€ 70	€ 62	€ 71	€ 68	€ 71	€ 47	€ 30
Croatia	€ 24	€ 43	€ 40	€ 87	€ 108	€ 47	€ 73	€ 64	€ 73	€ 69	€ 73	€ 49	€ 33
Cyprus	€ 25	€ 44	€ 51	€ 41	€ 95	€ 100	€ 73	€ 70	€ 77	€ 73	€ 77	€ 52	€ 42
Czech Republic	€ 25	€ 44	€ 55	€ 86	€ 106	€ 43	€ 75	€ 69	€ 75	€ 71	€ 75	€ 51	€ 44
Denmark	€ 30	€ 49	€ 76	€ 151	€ 155	€ 58	€ 131	€ 106	€ 98	€ 94	€ 98	€ 69	€ 97
Estonia	€ 25	€ 44	€ 70	€ 97	€ 121	€ 65	€ 74	€ 72	€ 76	€ 72	€ 76	€ 51	€ 51
Finland	€ 27	€ 47	€ 74	€ 105	€ 125	€ 59	€ 80	€ 86	€ 87	€ 83	€ 87	€ 60	€ 64
France	€ 27	€ 46	€ 73	€ 117	€ 130	€ 49	€ 91	€ 83	€ 85	€ 81	€ 85	€ 57	€ 60
Germany	€ 26	€ 46	€ 81	€ 100	€ 112	€ 29	€ 83	€ 78	€ 86	€ 82	€ 86	€ 57	€ 37
Greece	€ 24	€ 43	€ 33	€ 85	€ 126	€ 101	€ 74	€ 66	€ 76	€ 72	€ 76	€ 50	€ 30
Hungary	€ 24	€ 43	€ 67	€ 49	€ 82	€ 44	€ 72	€ 63	€ 73	€ 70	€ 73	€ 49	€ 28
Ireland	€ 28	€ 48	€ 67	€ 78	€ 109	€ 66	€ 78	€ 97	€ 88	€ 84	€ 88	€ 62	€ 98
Italy	€ 26	€ 45	€ 56	€ 76	€ 88	€ 8	€ 78	€ 78	€ 83	€ 80	€ 83	€ 56	€ 46
Latvia	€ 25	€ 43	€ 63	€ 81	€ 105	€ 49	€ 74	€ 68	€ 74	€ 71	€ 74	€ 50	€ 41
Lithuania	€ 24	€ 43	€ 50	€ 78	€ 102	€ 47	€ 71	€ 61	€ 72	€ 68	€ 72	€ 48	€ 26
Luxembourg	€ 26	€ 45	€ 63	€ 94	€ 112	€ 40	€ 80	€ 74	€ 83	€ 80	€ 83	€ 56	€ 31
Malta	€ 24	€ 44	€ 58	€ 59	€ 108	€ 101	€ 75	€ 66	€ 76	€ 72	€ 76	€ 51	€ 29
Netherlands	€ 31	€ 51	€ 83	€ 101	€ 117	€ 42	€ 82	€ 120	€ 99	€ 95	€ 99	€ 71	€ 143

Total Unit Treatment Costs: Private Metric	Composting/Digestion				Incineration				MBT				Landfill
	Open Air Composting	In-Vessel Composting	Anaerobic Digestion	Electric Only	CHP	Heat Only	Combustion Only	Bio-stabilisation	Biodrying with no Plastics	Biodrying with Plastics Recycling	AD based MBT	Residual MRF + Combustion	
Poland	€ 26	€ 44	€ 67	€ 129	€ 153	€ 96	€ 115	€ 75	€ 77	€ 73	€ 77	€ 53	€ 59
Portugal	€ 24	€ 43	€ 54	€ 87	€ 127	€ 101	€ 75	€ 66	€ 75	€ 71	€ 75	€ 50	€ 33
Romania	€ 24	€ 43	€ 69	€ 90	€ 116	€ 64	€ 73	€ 63	€ 72	€ 69	€ 72	€ 48	€ 33
Slovakia	€ 26	€ 45	€ 47	€ 76	€ 101	€ 48	€ 72	€ 82	€ 79	€ 75	€ 79	€ 55	€ 78
Slovenia	€ 25	€ 44	€ 53	€ 93	€ 114	€ 50	€ 76	€ 72	€ 78	€ 74	€ 78	€ 53	€ 44
Spain	€ 25	€ 44	€ 66	€ 89	€ 131	€ 108	€ 82	€ 70	€ 79	€ 75	€ 79	€ 53	€ 34
Sweden	€ 28	€ 48	€ 85	€ 117	€ 128	€ 43	€ 96	€ 95	€ 90	€ 87	€ 90	€ 63	€ 85
United Kingdom	€ 29	€ 48	€ 65	€ 85	€ 114	€ 66	€ 78	€ 100	€ 89	€ 86	€ 89	€ 61	€ 107

4.1.5 Environmental Impacts Module

This section introduces the Environmental Impacts Module and, as far as possible, outlines some of the technical assumptions used in the modelling of the environmental impacts of the different waste management methods used by Member States. An overview of the Module is presented in Figure 4-7. From this it can be seen that the tonnage inputs are received from the Mass Flow Module (broken down by waste stream). The Environmental Impacts Module considers the environmental impacts associated with the following types of waste management:

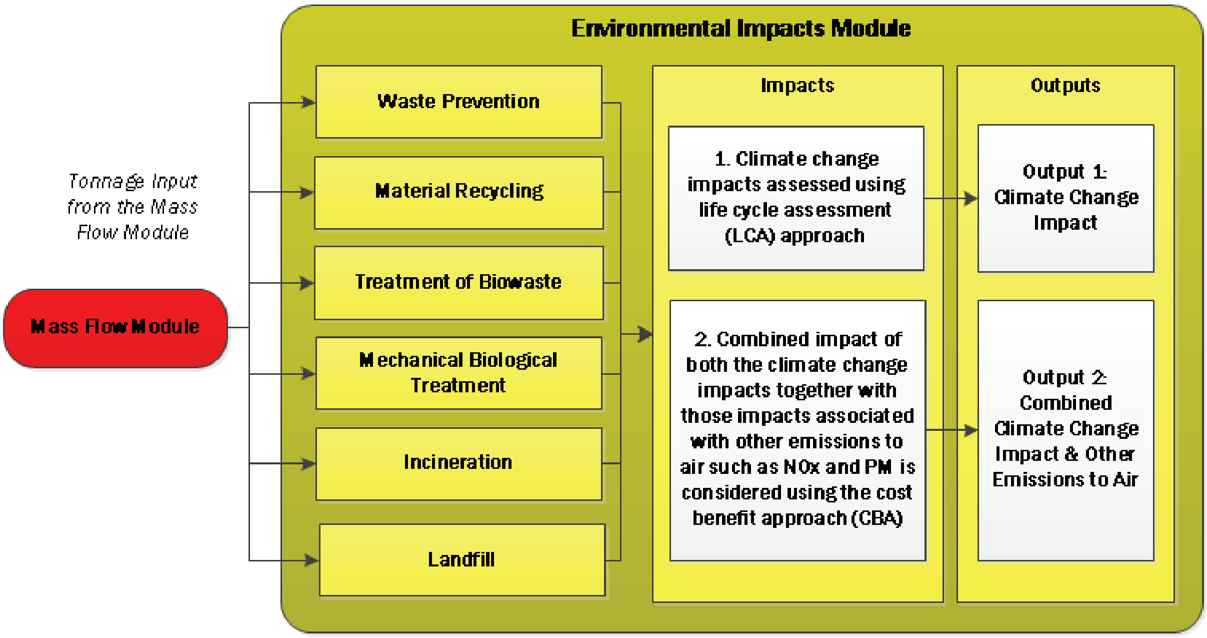
- Waste prevention;
- Recycling;
- The treatment of source segregated biowaste such as food and garden waste;[21]
- Mechanical Biological Treatment (and related) methods for managing residual waste;
- Incineration of residual waste; and
- Landfill of residual waste.

It can be seen from Figure 4-7 that the model uses two methods to assess the impacts of managing waste via each of the above routes:

- Climate change impacts are considered using the life cycle assessment (LCA) approach. Results in this case consider the impact in tonnes of CO_2 equivalent;
- The combined impact of both the climate change impacts together with those impacts associated with other emissions to air such as NOx and PM is considered using the cost benefit approach (CBA). Pollutant impacts are given a monetary value, such that the outcome can be considered in €. For the climate change impacts, the CBA model builds on the analysis undertaken for the LCA, as the two assessment methods use the same pollution inventory.

[21] The model separately considers both composting and anaerobic digestion processes.

Figure 4-7: Overview of the Environmental Impacts Module



4.1.5.1 Assessing the Impacts

In general, the modelling is based around a cost benefit framework. This type of approach seeks to understand the environmental consequences of different approaches to waste management in terms of the monetised impact of the changes being made. In principle, this allows for trade-offs to be made between the resource costs of any change, and the environmental benefits associated with them. The approach is rooted in 'life-cycle thinking', in that it considers not only direct emissions, but also, avoided emissions associated with the recycling of materials, or the generation of energy by waste management processes. It seeks, however, to express the impact of emitting pollutants, or avoiding their emission, in monetary terms.

There are some limitations regarding the extent to which this can be undertaken. For example:

- For all pollutants other than those (like greenhouse gases) which exert a global impact (i.e. an impact which is the same irrespective of the location of their emission), the impact is dependent upon the location of the emission. The location of the emission will determine the likely exposure of key receptors, whether they be human beings or other living organisms, or buildings (as with acidifying pollutants, for example). In such cases, the link between the emission and the impact is highly localised. Work in respect of understanding the link between the emission of a pollutant, and its impact, is furthest advanced where air pollutants are concerned. For some of these, ongoing work at the European level allows for some variation in the damage costs depending upon the country from which the emission originates, For others, a single value for the whole of Europe has been used;

- Whilst waste treatment processes may also lead to emissions to soil and water, research in respect of the quantification, at the margin, of the related impacts of this is less well advanced. As such, it has not been possible to include these in the model. It is expected that the impacts of these would be highly location specific, depending on the nature and quality of the medium into which the pollutant was emitted;

- Where the emissions have a global impact, the issue of the location of the emission is less of an issue. However, where climate change emissions are concerned, there are a range of values suggested for the value of damages caused by marginal emissions of greenhouse gases into the environment. It should be noted that the value of ETS allowances in the market place does not reflect a measure of the damages caused by emissions of greenhouse gases (GHGs). Rather, it represents the cost, at the margin, of ensuring the overall level of emissions remains below the specified cap for the sectors covered by the EU-ETS;

- Waste management facilities also give rise to a loss in amenity, related to dust, noise, odour, and other forms of nuisance. These tend to be experienced by people and businesses in close proximity to a facility (or close to transport routes linked to a facility). There is a body of literature related to the assessment of disamenity at waste facilities, but it remains largely focused on landfill and incineration. Whilst the model allows for the inclusion of such values, the default approach is not to include them given the potential for bias associated with the absence of values for some facility types.

- Air Emissions other than the following are not included in the analysis: CO_2, CH_4, N_2O, NH_3, NOx, PM2.5 / PM10, SO_2, VOCs, Arsenic, Cadmium, Chromium, Nickel, 1,3 Butadiene, Benzene, PAH, Formaldehyde, and Dioxin. These air pollutants cover all of the pollutants which are routinely monitored at waste treatment plant, although plant will not typically measure the emission of all of those listed above (for example, most facilities do not regularly measure emission to air of formaldehyde). The list reflects those pollutants for which the environmental impacts are best understood and for which the most robust emissions measurement data is available. Although the analysis is based on emissions harmful to human health, there is a good overlap between the health impacts and ecological damage.

- The model does not consider the potential impact of bioaerosol pollution, as no exposure response relationship has yet been developed for this type of pollutant.

- No emissions to land have been included other than in respect of incinerator fly ash residues. This almost certainly means that the treatment of landfills is too favourable. In the case of the latter, impacts are more likely to occur over long timescales – potentially beyond the 100 year cut off point considered as the boundary of the analysis.

- The model considers the relative impact of compost application in comparison to the use of synthetic fertiliser, and as such the impact of compost utilisation on nitrate pollution is considered. Aside from this, the model does not consider the impact of water pollution as at present no damage cost data exists with which to consider the impact of water pollution.

- We have not considered external costs associated with construction of facilities. It is generally stated that these account for a small proportion of the overall impacts. However, it is difficult to be quite so sanguine about this when a cost-benefit perspective, incorporating non-zero discount rates, is employed. All construction-related externalities occur early in time (by definition). Consequently, the construction related externalities will weigh proportionately greater in an analysis using discounting than in one where no discounting is used. Even where such an approach is used, however, the construction related impacts remain relatively insignificant in comparison the emissions to air. In addition, many of the materials with the greatest embedded environmental impacts (i.e., the metals) are likely to be recovered for recycling when the facility is decommissioned, reducing the overall burdens.

- The effect on household time has not been considered in this study.

- The consumption of water at facilities is also not considered within the model.

Further details the rationale for these omissions from the analysis can be found in the documentation that accompanies the European Reference Model on Municipal Waste Management. [22]

The set of data that we have used for the assessment of the externalities associated with emissions to air is based on modelling recently undertaken for the European Environment Agency (EEA).[23] Table 4-10 and Table 4-11 present the assumptions used in the model for the pollutants affecting air quality, reflecting the damage to human health. The EEA data also includes a monetary cost for the climate change impacts, which are attributed a cost of €33 per tonne of CO_2 equivalent emissions. The damage costs arising from the CO_2 impacts are based on the estimated marginal abatement cost based on the approach developed by the UK Government.

Our model uses the EEA value for the carbon damage cost out to 2029. After this point, we have based our assumption on the price projections given in the latest iteration of the EU-ETS and provided to us by DG Clima which suggest the cost of each EU Allowance unit (EUA) to be €35 in 2030 and €57 in 2035. For values after 2035 (used in the modelling of future landfill emissions) the model allows for impacts to be calculated using a fixed value of €57, or a declining impact based on the application of the EC's discount rate of 4%.

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[22] Eunomia Research & Consulting and Copenhagen Resource Institute (in development) *Development of a Modelling Tool on Waste Generation and Management*, Report for the European Commission DG Environment, www.wastemodel.eu

[23] The methodology used is summarised in: European Environment Agency (2011) Revealing the Costs of Air Pollution from Industrial Facilities in Europe, EEA Technical Report No 15/2011, November 2011

The model uses the following assumptions to calculate the global warming potential of the main greenhouse gases:[24]

- Methane is assumed to have a GWP of 25. This value is based on emissions of fossil methane. However, most methane emissions in the waste sector are biogenic methane emissions. A credit is applied to account for the differential in impact between the fossil and biogenic methane impacts in landfill. As a consequence of the credit, the effective GWP for biogenic methane is 22.25; and

- N_2O is attributed a GWP of 298.

The above assumptions have been taken from the fourth assessment report of the IPCC. It is understood that the yet to be finalised fifth version of the assessment report will indicate an increase in the GWP for methane from 25 to 28 (if climate carbon feedbacks are excluded within the analysis) or 34 (including the impact of the climate carbon feedbacks). As the fifth report is currently scheduled for publication in January 2014, the project team consulted with DG Environment and DG Clima in respect of the inclusion of the revised assumptions for the GWP in the model. We have been advised to retain the assumptions from the fourth report, as the second phase of the Kyoto Protocol – currently being transposed into EU legislation – is based on the assumptions contained within this report. As such, we understand that European climate change policy will not be updated to reflect data from the fifth report until 2020 at the earliest.

4.1.5.2 System Boundaries

The environmental model covers the following aspects of the waste management system:

- The fuel use associated with waste collection (for residual waste, source segregated organic material and dry recyclables) as well as impacts associated with sorting recyclables;
- Benefits associated with dry recyclables (calculated by comparison with the impacts associated with producing material from virgin inputs);
- Impacts associated treating source segregated organic material; and
- Impacts associated with treating residual waste.

4.1.5.3 Dealing with Impacts over Time – the Discount Rate

There are two ways in which the issue of time has to be considered in the context of the existing model:

1. First, the model is designed to project waste management out to the year 2030. Impacts will, therefore, occur at different points in time depending upon the year in which waste is consigned to one or other management method; and

[24] IPCC (2007) Synthesis Report

2. Second, some waste management processes – notably biological processes (landfill, composting, anaerobic digestion, MBT) – give rise to emissions which occur over an extended period of time after the waste was first received.

In order to account for the different time period in which impacts occur, the model applies a social discount rate of 4% (which is the value proposed for use in Impact Assessments undertaken by the European Commission).

For waste treatments which lead to emissions over an extended time horizon, such as landfill, then if the material is landfilled in Year X, the model assigns all the impacts associated with future emissions from the waste landfilled in Year X, discounted in the appropriate manner, to that year. We believe this gives the most realistic view to policy makers of the effect of changes in waste management in that it assigns the effect to the year in which a given change takes place.

Table 4-10: Damage Costs Applied to the Air Pollutants (2010 Prices) – Key Air Pollutants

Country	NH3	NOx	PM2.5	PM10	SO2	VOCs
Austria	€ 15,696	€ 12,383	€ 30,569	€ 19,850	€ 10,094	€ 812
Belgium	€ 27,980	€ 8,566	€ 44,388	€ 28,823	€ 11,392	€ 1,980
Bulgaria	€ 6,561	€ 5,929	€ 19,809	€ 12,863	€ 4,300	-€ 132
Cyprus	€ 17,569	€ 9,013	€ 27,591	€ 17,916	€ 7,390	€ 378
Czech Republic	€ 1,372	€ 665	€ 13,288	€ 8,629	€ 1,441	-€ 49
Denmark	€ 20,340	€ 8,887	€ 21,430	€ 13,915	€ 8,693	€ 498
Estonia	€ 8,011	€ 3,919	€ 11,231	€ 7,293	€ 4,835	€ 735
Finland	€ 6,982	€ 1,954	€ 7,328	€ 4,759	€ 4,353	€ 214
France	€ 4,639	€ 1,470	€ 7,333	€ 4,762	€ 3,024	€ 253
Germany	€ 10,877	€ 10,633	€ 31,239	€ 20,285	€ 9,893	€ 1,023
Greece	€ 21,117	€ 14,314	€ 45,861	€ 29,780	€ 12,650	€ 1,283
Hungary	€ 5,214	€ 1,694	€ 18,724	€ 12,158	€ 3,238	€ 62
Ireland	€ 17,195	€ 11,801	€ 30,195	€ 19,607	€ 8,389	€ 269
Italy	€ 2,420	€ 4,109	€ 15,656	€ 10,166	€ 5,960	€ 642
Latvia	€ 13,497	€ 8,629	€ 36,601	€ 23,767	€ 8,218	€ 643
Lithuania	€ 5,882	€ 3,106	€ 9,961	€ 6,468	€ 4,570	€ 381
Luxembourg	€ 5,923	€ 4,702	€ 9,978	€ 6,479	€ 5,118	€ 453
Malta	€ 23,898	€ 12,545	€ 33,080	€ 21,480	€ 10,241	€ 1,831
Netherlands	€ 8,077	€ 588	€ 16,271	€ 10,565	€ 2,926	€ 282
Poland	€ 20,319	€ 7,970	€ 40,980	€ 26,610	€ 13,180	€ 1,432
Portugal	€ 13,308	€ 6,803	€ 21,018	€ 13,648	€ 7,536	€ 581
Romania	€ 4,806	€ 1,389	€ 24,644	€ 16,002	€ 3,682	€ 331
Slovakia	€ 7,722	€ 9,256	€ 21,448	€ 13,927	€ 6,323	€ 162
Slovenia	€ 18,882	€ 10,482	€ 21,163	€ 13,743	€ 8,184	€ 294
Spain	€ 17,909	€ 10,308	€ 22,464	€ 14,587	€ 8,360	€ 517
Sweden	€ 5,445	€ 3,440	€ 19,934	€ 12,944	€ 5,463	€ 302
United Kingdom	€ 6,516	€ 2,370	€ 11,521	€ 7,481	€ 3,204	€ 381
Croatia	€ 15,583	€ 5,326	€ 25,322	€ 16,443	€ 8,033	€ 1,007

Table 4-11: Damage Costs Applied to the Air Pollutants (2010 Prices) – Heavy Metals

Country	Arsenic	Cadmium	Chromium	Nickel	1, 3 Butadiene	Benzene	PAH	Form-aldehyde	Dioxins/furans
Austria	€ 369,000	€ 29,000	€ 39,000	€ 4,000	€ 500	€ 80	€ 1,315,000	€ 220	€ 28,000,000
Belgium	€ 435,000	€ 50,000	€ 67,000	€ 6,700	€ 840	€ 120	€ 1,332,000	€ 360	€ 28,000,000
Bulgaria	€ 328,000	€ 17,000	€ 22,000	€ 2,200	€ 280	€ 50	€ 1,304,000	€ 120	€ 28,000,000
Cyprus	€ 340,000	€ 20,000	€ 27,000	€ 2,700	€ 340	€ 50	€ 1,307,000	€ 140	€ 28,000,000
Czech Republic	€ 371,000	€ 30,000	€ 40,000	€ 4,100	€ 500	€ 80	€ 1,315,000	€ 220	€ 28,000,000
Denmark	€ 323,000	€ 15,000	€ 20,000	€ 2,000	€ 250	€ 40	€ 1,301,000	€ 110	€ 28,000,000
Estonia	€ 301,000	€ 8,300	€ 11,000	€ 1,100	€ 140	€ 30	€ 1,296,000	€ 60	€ 28,000,000
Finland	€ 304,000	€ 9,100	€ 12,000	€ 1,200	€ 150	€ 30	€ 1,296,000	€ 60	€ 28,000,000
France	€ 390,000	€ 33,000	€ 49,000	€ 4,800	€ 610	€ 90	€ 1,320,000	€ 270	€ 28,000,000
Germany	€ 420,000	€ 45,000	€ 61,000	€ 6,100	€ 760	€ 110	€ 1,328,000	€ 330	€ 28,000,000
Greece	€ 330,000	€ 17,000	€ 23,000	€ 2,400	€ 290	€ 50	€ 1,304,000	€ 120	€ 28,000,000
Hungary	€ 368,000	€ 29,000	€ 39,000	€ 3,800	€ 480	€ 70	€ 1,314,000	€ 210	€ 28,000,000
Ireland	€ 324,000	€ 15,000	€ 20,000	€ 2,000	€ 260	€ 40	€ 1,302,000	€ 110	€ 28,000,000
Italy	€ 380,000	€ 33,000	€ 44,000	€ 4,400	€ 540	€ 80	€ 1,317,000	€ 240	€ 28,000,000
Latvia	€ 307,000	€ 10,000	€ 13,000	€ 1,300	€ 160	€ 30	€ 1,297,000	€ 70	€ 28,000,000
Lithuania	€ 316,000	€ 13,000	€ 17,000	€ 1,700	€ 220	€ 40	€ 1,300,000	€ 90	€ 28,000,000
Luxembourg	€ 377,000	€ 32,000	€ 43,000	€ 4,300	€ 530	€ 80	€ 1,317,000	€ 240	€ 28,000,000
Malta	€ 312,000	€ 12,000	€ 15,000	€ 1,500	€ 200	€ 30	€ 1,298,000	€ 80	€ 28,000,000
Netherlands	€ 446,000	€ 53,000	€ 71,000	€ 7,200	€ 890	€ 130	€ 1,334,000	€ 390	€ 28,000,000
Poland	€ 358,000	€ 26,000	€ 35,000	€ 3,500	€ 430	€ 70	€ 1,312,000	€ 190	€ 28,000,000
Portugal	€ 331,000	€ 18,000	€ 24,000	€ 2,400	€ 300	€ 50	€ 1,305,000	€ 120	€ 28,000,000
Romania	€ 339,000	€ 20,000	€ 27,000	€ 2,700	€ 330	€ 50	€ 1,306,000	€ 140	€ 28,000,000
Slovakia	€ 366,000	€ 28,000	€ 38,000	€ 3,700	€ 470	€ 70	€ 1,313,000	€ 210	€ 28,000,000
Slovenia	€ 371,000	€ 30,000	€ 40,000	€ 4,100	€ 500	€ 80	€ 1,315,000	€ 220	€ 28,000,000
Spain	€ 329,000	€ 17,000	€ 23,000	€ 2,200	€ 280	€ 50	€ 1,304,000	€ 120	€ 28,000,000
Sweden	€ 318,000	€ 13,000	€ 18,000	€ 1,800	€ 230	€ 40	€ 1,300,000	€ 90	€ 28,000,000
United Kingdom	€ 376,000	€ 32,000	€ 42,000	€ 4,300	€ 530	€ 80	€ 1,316,000	€ 230	€ 28,000,000

Croatia	€ 349,000	€ 23,000	€ 31,000	€ 3,100	€ 390	€ 60	€ 1,309,000	€ 160	€ 28,000,000

4.1.5.4 Energy Generation

Given that the scenarios appraised in this study reflect changes to current waste management, the use of the marginal energy source appears to be the right approach to take within the current analysis. However, determining which is the marginal source across each Member State is not straightforward. A detailed discussion of this subject is provided in the documentation which accompanies the model. [25]

As part of the consultation process undertaken as part of the project Member States were asked to supply specific data on the marginal electricity and heat generation source including projections of this data going out to 2030. Respondents were also asked to provide information on the generation mix for both types of energy. Responses were received from some member states in respect of the marginal source of electricity generation, although the majority were not able to provide any information in respect of the marginal heat source, and few provided information in respect of future variations in the mix. The approach taken in the model is as follows:

- Where countries have supplied us with assumptions on the marginal sources, this data is incorporated into the model;
- Where only the grid mix data was supplied by MS, this was used in the model;
- Where no information on energy generation was supplied by the Member State we have used data on the electricity and heat generation mix from the IEA and European Commission (see tables below).

Table 4-12 presents the assumptions used for electricity impacts for each Member State in 2011 and Table 4-13 presents the heat mix for each Member State in 2011. The emission factors (i.e. air pollutants) associated with the generation of heat and electricity from each of the sources identified in these tables are presented are summarised within the documentation accompanying the model.

Table 4-12: Electricity Generation Mix – EU Member States

Member State	Coal	Gas	Nuclear	Renewables[1]	Other[2]
Austria	7.29%	17.88%	0.00%	72.00%	2.83%
Belgium	6.74%	32.13%	51.76%	7.02%	2.35%
Bulgaria	48.71%	5.17%	31.47%	13.79%	0.86%
Croatia	25.99%	0.00%	0.00%	48.01%	25.99%
Cyprus[3]	0.00%	0.00%	0.00%	0.00%	100.00%
Czech Rep.	59.20%	1.19%	33.08%	6.32%	0.21%
Denmark[4]	91%	5%	0%	24.84%	4%
Estonia[3]	0%	2%	0%	9%	89%

[25] Eunomia Research & Consulting and Copenhagen Resource Institute (in development) *Development of a Modelling Tool on Waste Generation and Management*, Report for the European Commission DG Environment, www.wastemodel.eu

Member State	Coal	Gas	Nuclear	Renewables[1]	Other[2]
Finland[4]	100%	0%	0%	0%	07%
France[3]	5%	4%	78%	10%	2%
Germany	43.40%	13.31%	22.77%	16.18%	4.33%
Greece	55.71%	17.96%	0.00%	13.78%	12.54%
Hungary[3]	18%	30%	44%	2%	5%
Ireland[3]	28%	62%	0%	8%	3%
Italy	14.84%	50.32%	0.00%	24.61%	10.23%
Latvia[4]	0.00%	100%	0.00%	0%	0.00%
Lithuania	0.00%	60.38%	0.00%	28.30%	11.32%
Luxembourg	0.00%	73.31%	0.00%	24.99%	1.70%
Malta[4]	0.00%	0.00%	0.00%	2%	98%
Netherlands	23.44%	60.53%	3.73%	8.16%	4.14%
Poland[4]	100%	0%	0%	0%	0%
Portugal[4]	0%	100%	0%	0%	0%
Romania	34.16%	12.05%	19.14%	33.50%	1.16%
Slovak Rep.	16.35%	7.53%	53.84%	19.59%	2.69%
Slovenia[4]	100%	0%	0%	0%	0%
Spain[3]	9%	32%	21%	31%	8%
Sweden[4]	0%	100%	0%	0%	0%
UK[4]	0%	100%	0%	0%	0%

Notes:

1. *Includes biofuels and biomass*
2. *Includes oil and waste*
3. *Fuel mix data supplied by Member State*
4. *Marginal source data supplied by Member State*

Sources: IEA Statistics (available from www.iea.org/stats/); European Commission Country Factsheets (available from http://ec.europa.eu/energy/observatory/countries/doc/2012-country-factsheets.pdf)

Table 4-13: Heat Generation Mix – EU Member States

Member State	Coal	Gas	Oil	Biomass	Other
Austria	5%	44%	10%	33%	9%
Belgium	0%	86%	0%	2%	12%
Bulgaria	37%	49%	9%	0%	6%
Croatia	0%	0%	0%	0%	0%
Cyprus	0%	0%	0%	0%	0%
Czech Rep.	68%	23%	2%	2%	4%
Denmark	26%	28%	5%	20%	21%
Estonia[1]	0%	42%	26%	31%	0%
Finland	35%	25%	8%	27%	5%
France	10%	61%	16%	0%	13%
Germany	32%	49%	2%	3%	14%
Greece	99%	0%	1%	0%	0%
Hungary	13%	76%	6%	2%	3%
Ireland	0%	0%	0%	0%	0%
Italy	1%	60%	35%	3%	3%
Latvia[1]	1%	81%	2%	16%	0%
Lithuania[1]	0%	73%	3%	23%	1%

Member State	Coal	Gas	Oil	Biomass	Other
Luxembourg	0%	0%	0%	100%	0%
Malta[1]	0%	0%	95%	2%	3%
Netherlands	11%	77%	4%	1%	7%
Poland[1]	0%	31%	18%	51%	0%
Portugal	0%	70%	30%	0%	0%
Romania	25%	64%	9%	2%	0%
Slovak Rep.	23%	53%	12%	6%	7%
Slovenia[1]	57%	31%	2%	10%	0%
Spain	0%	0%	0%	0%	0%
Sweden[2]	0%	0%	0%	100%	0%
UK[2]	0%	100%	0%	0%	0%

Notes

1. *Fuel mix data supplied by Member State*
2. *Marginal source data supplied by Member State*

Sources: IEA Statistics (available from www.iea.org/stats/); European Commission Country Factsheets (available from http://ec.europa.eu/energy/observatory/countries/doc/2012-country-factsheets.pdf)

Table 4-14 confirms the emissions factors used to estimate the impacts of electricity generation for the different generation sources considered within the current analysis, whilst Table 4-15 confirms the emissions factors used to estimate the impacts of heat generation.

Table 4-16 presents the emissions factors used for diesel combustion. The source of the emissions data is the ecoinvent database, which includes for the majority of fuels a dataset considered to be representative of European facilities.

Table 4-14: Emissions Factors for Electricity Generation (tonnes pollutant / kWh)

	CO2e	NH3	NOx	PM	SO2	VOCs
Gas	0.4	1.4034E-10	2.5304E-07	1.275E-09	1.6263E-09	1.5578E-09
Coal	0.8	2.6636E-10	7.1098E-07	2.428E-09	4.1141E-08	1.6624E-08
Nuclear	0.001	1.4504E-10	3.8024E-09	6.398E-10	1.6195E-08	1.8067E-10
Renewables	0.001	3.675E-11	8.6228E-09	1.619E-09	1.3942E-08	2.3682E-09

Source: ecoinvent

	Arsenic	Cadmium	Chromium	Nickel	1, 3 Butadiene	Benzene	PAH	Formaldehyde	Dioxins/furans
Gas	2.76E-15	2.3269E-15	1.2903E-16	2.2382E-12	2.0709E-19	1.7024E-12	2.4785E-13	1.9003E-12	6.3519E-19
Coal	6.735E-12	1.7428E-12	1.3353E-13	1.4377E-11	6.5556E-19	1.0881E-14	6.5846E-13	2.996E-11	1.5426E-18
Nuclear	2.006E-13	3.1833E-13	8.9085E-15	6.4668E-12	1.3962E-18	1.6996E-11	2.5287E-13	1.0827E-11	4.2164E-19
Renewables	3.126E-13	8.2309E-14	3.0718E-14	2.623E-12	6.548E-19	2.8188E-11	2.1087E-13	5.3271E-12	3.6474E-18

Source: ecoinvent

Table 4-15: Emissions Factors for Heat Generation (tonnes pollutant / kWh)

	CO2e	NH3	NOx	PM	SO2	VOCs
Gas	0.2	2.97E-11	1.37E-07	1.18E-09	9.53E-09	1.09E-09
Coal	0.3	1.52E-10	9.13E-07	1.82E-07	2.27E-06	8.03E-09
Oil	0.25	6.47E-11	1.23E-07	5.97E-09	2.35E-07	2.22E-09
Solid biomass	0.001	8.31E-09	7.31E-07	5.61E-07	1.73E-08	5.19E-08

Source: ecoinvent

	Arsenic	Cadmium	Chromium	Nickel	1, 3 Butadiene	Benzene	PAH	Formaldehyde	Dioxins/furans
Gas	1.47E-13	9.46E-14	6.94E-15	4.75E-12	6.74E-18	1.46E-09	3.65E-11	3.72E-10	1.36E-18
Coal	1.14E-10	7.35E-12	1.02E-10	9.36E-11	1.21E-17	2.28E-09	5.38E-13	3.79E-10	9.08E-17
Oil	1.31E-12	2.95E-12	1.95E-14	3.59E-11	2.13E-18	6.37E-10	1.95E-12	3.59E-11	9.77E-19
Solid biomass	4.91E-12	3.47E-12	2.00E-13	3.06E-11	1.41E-17	4.38E-09	5.33E-11	6.27E-10	1.59E-16

Source: ecoinvent

Table 4-16: Emissions Factors for Diesel Combustion (tonne / litre)

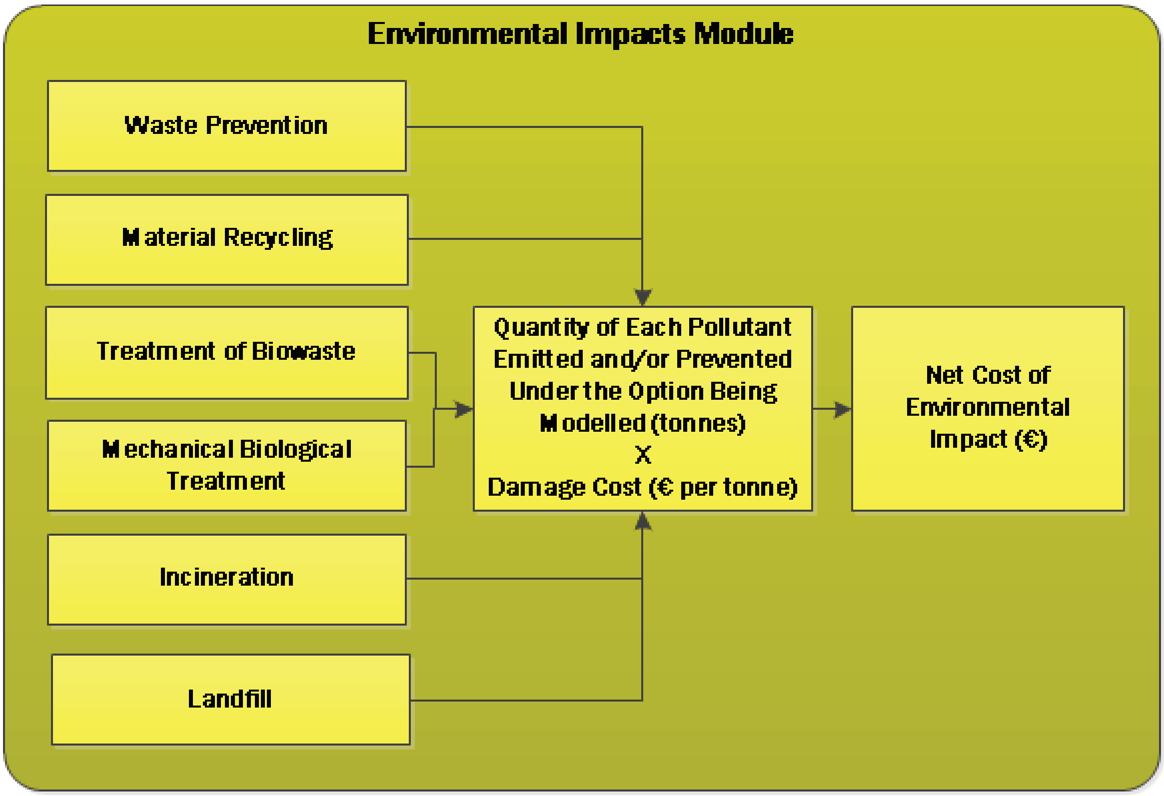
	CO2e	NH3	NOx	PM	SO2	VOCs	Arsenic	Cadmium
Diesel	0.0026	6.83E-10	1.30E-06	5.78E-08	2.48E-06	2.34E-08	1.39E-11	3.12E-11
	Chromium	Nickel	1, 3 Butadiene	Benzene	PAH	Formaldehyde	Dioxins/furans	
Diesel	2.06E-13	3.79E-10	2.25E-17	6.73E-09	2.05E-11	3.79E-10	1.03E-17	

Source: ecoinvent

4.1.5.5 Impacts of Differente Waste Mangement Options

Section 4.1.5.1 outlines the damage costs that were used to monetise the impact of climate change and air pollution resulting from a number of common pollutants. Simply put, the model uses these damage costs and multiplies them by the quantity of each air pollutant that is created or avoided by the option that is being modelled. This process is summarised in Figure 4-8.

Figure 4-8: Calculating the Damage Costs Resulting from Emissions to Air



The model includes default assumptions for the amount of air emissions that arise or are avoided from each of the waste management options shown in Figure 4-8. These are very briefly introduced below.

Waste Prevention

Table 4-17 presents the data on avoided manufacturing burdens for key waste materials. The table shows the data on avoided greenhouse gas burdens and that associated with the main air quality impacts.[26] Biogenic CO_2 emissions are also separately presented where data is available.

[26] In addition to the impacts shown in the table, there will also be some avoided heavy metal burdens not shown in the table, but these typically have a relatively minor impact in comparison to those shown in the table

Table 4-17: Avoided Manufacturing Burdens

Material	Global Warming Potential, tonne CO_2 eq. per tonne material (excl. biogenic CO_2)	Biogenic CO_2 (tonne CO_2 eq. per tonne material)	Air Quality Impacts (tonne pollutant per tonne of material)					
			NH_3	NOx	$PM_{2.5}$	PM_{10}	SO_2	VOCs
Paper	0.96	3.01E-03	2.00E-05	0.00379	3.42E-05	6.90E-05	3.90E-03	7.54E-05
Card	1.32	3.25E-03	1.63E-05	0.00351	4.71E-05	1.20E-05	4.08E-03	9.46E-05
Plastics	1.95	1.08E-06	3.13E-06	3.23E-03	8.25E-05	3.17E-05	4.10E-03	9.38E-05
Glass	0.88	1.19E-03	2.09E-06	0.00316	5.72E-05	5.37E-05	0.0039	0.00022472
Ferrous metal	1.79	1.76E-03	8.67E-06	0.003803	0.001461	0.003126	0.004	0.00026858
Non-ferrous metal	11.46	2.52E-02	5.84E-05	0.0171	0.002025	0.006594	0.0349	0.0020501
Food waste	3.80	No data	5.32E-04	3.49E-03	3.70E-05	7.70E-05	1.46E-03	3.87E-05
Textiles	26.12	4.62E-02	0.017222	0.077	0.001379	0.000809	0.153	0.0016132
Wood	0.41	0.56	6.00E-05	1.80E-03	4.00E-04	6.00E-05	7.40E-04	0.0012
WEEE	5.28	0.01	1.7572E- 5	0.0138	0.001261	0.001258	0.0238	0.000806

Sources: ecoinvent and Sima Pro life cycle databases; Stoessel F, Juraske R, Pfister S and Hellweg S (2011) Life Cycle Inventory and Carbon and Water Footprint of Fruits and Vegetables: Application to a Swiss Retailer, Environmental Science & Technology, 46, pp3253-3262

Recycling

A summary of assumptions with regard to the climate change impacts of recycling different materials is presented in Table 4-18 which also contains the sources of the information used.[27] The climate change impacts associated with recycling are global impacts – as such, there is no difference in the impact of one tonne of CO_2 emitted within Europe's geographical boundaries to the same quantity emitted outside Europe.

Table 4-18: Impacts of Dry Recycling – Values Used in the Model

	GWP	Biogenic CO_2	Source
Card	-0.001	-1.421	ecoinvent
Newsprint	-0.231	-0.258	ecoinvent
Bottle plastics	-1.182	0.042	APME (via WRATE)
Mixed dense plastics	-1.075	0.056	APME (via WRATE)
Textiles	-4.459	-0.604	WRATE
Wood	-0.062	0.000	Prognos
Glass - aggregate	-0.025	-0.001	WRATE
Glass - containers	-0.229	0.001	British Glass
Ferrous metal	-1.631	-0.003	ecoinvent
Non-ferrous metal	-9.17	-	EEA
WEEE	-1.482	-	UN University

Sources: ecoinvent; WRATE; Huisman, J., et al (2008) 2008 Review of Directive 2002/96 on Waste Electrical and Electronic Equipment – Study No. 07010401/2006/442493/ETU/G4, United Nations University, Bonn Germany, cited in Zero Waste Scotland (2011) The Scottish Carbon Metric, report for Scottish Government, March 2011; Prognos / IFEU / INFU (2008) Resource Savings and CO_2 Reduction Potential in Waste Management in Europe and the Possible Contribution to the CO_2 Reduction Targets in 2020, October 2008

[27] A literature review outlining the rationale for using these figures has been produced as part of the modelling project.

The air quality impacts of recycling are considered under the CBA approach. Whereas a number of authors have considered the climate change benefits of recycling, much less data is publicly available regarding the air quality impacts of recycling.

Where damage cost data is used within the assessment, air quality impacts vary geographically across European Member States. This makes it possible to estimate impacts where the emissions are known to occur in EU countries. However, both the recycling of the material, and the location of the 'avoided primary production' might well be outside the EU. There is a long history of exports of fibres to Asia, whilst the export of plastics for recycling has also become increasingly significant. For scenario analysis, therefore, it would ideally be known where any additional material was going to be recycled, in what location primary production was being avoided, and what the relevant set of damage costs would be in those countries. In practice, these questions are difficult to answer, not least because no damage cost data exists for countries outside of Europe. These issues add a further layer of complexity to the consideration of the air quality impacts associated with dry recycling, where some of both the primary and secondary manufacture of certain materials is likely to take place outside Europe, and where material flows across Member States are also likely to occur.

High level data on European production and the extra-European imports and exports of the materials commonly recycled is available through several databases as well as via publications of the European trades associations and other publications of the European Commission.[28] The project team also surveyed Member States for information on the proportion of collected recyclate exported outside of Europe for re-processing, and received relevant information in this respect from a number of countries. This data is summarised in Table 4-19. The data is used to inform the decision for the inclusion or exclusion of the air quality benefits associated with recycling.

Where the available data suggests a significant proportion of both the primary and secondary manufacture takes place within Europe, the air quality benefits of recycling are included within the analysis. This is assumed to be the case for paper/card, plastics, glass and wood. Although a significant proportion of metal reprocessing takes place within Europe, a significant proportion of the primary manufacture takes place outside it. The latter is also true for a significant proportion of primary textiles manufacture, and in this case a significant proportion of material collected through "recycling" collections is actually sold for resale in countries outside of the EU. Air

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[28] Relevant information can be found in Comext and Market Access Databases (see http://epp.eurostat.ec.europa.eu/newxtweb/ and http://madb.europa.eu/madb/indexPubli.htm). Other sources: Ecorys / Danish Technical Institute / Cambridge Econometrics / CES ifo / Idea Consult (2008) Study on the Competitiveness of the European Steel Sector: Within the Framework of Sectoral Competitiveness Studies ENTR/06/054, Final Report for DG Enterprise and Industry, August 2008; Plastics Europe (2010) Plastics – the Facts 2010: An Analysis of European Plastics Production, Demand and Recovery for 2009; CEPI (2013) Key Statistics: European Pulp and Paper Industry 2012

quality benefits associated with recycling are therefore excluded for these materials, as the impacts are felt to be too uncertain to be quantified using damage cost data.

Given this methodology, the principal air quality impacts used in the model are outlined in Table 4-20 which provides this information in terms of the tonnes of pollutant per tonne of recyclate.

Table 4-19: Treatment of Air Quality (AQ) Benefits from Recycling in the Cost-Benefit Analysis (CBA)

	Location of primary manufacture	Reprocessing of recyclate	Treatment of AQ benefits in the CBA
Paper / card	A significant proportion currently takes place within the EU	Some is exported but the majority is remanufactured within the EU	AQ benefits of recyclate included
Plastic	A significant proportion currently takes place within the EU	Some is exported but the majority is remanufactured within the EU	AQ benefits of recyclate included
Textiles	A significant proportion currently takes place outside of the EU	Recycled textiles largely treated within the EU but textiles suitable for reuse may be exported outside it	AQ benefits of recyclate excluded
Wood	A significant proportion takes place within the EU	Much is reused within the EU although relatively little is recycled	AQ benefits of recyclate included
Glass	Most takes place within the EU	Not typically exported outside the EU	AQ benefits of recyclate included
Ferrous metal	A significant proportion of primary steel production takes place outside of the EU	A significant proportion of steel reprocessing takes place within the EU	AQ benefits of recyclate excluded
Non-ferrous metal	A significant proportion of primary aluminium production takes place outside of the EU	A significant proportion of aluminium reprocessing takes place within the EU	AQ benefits of recyclate excluded

Sources: Comext database (see http://epp.eurostat.ec.europa.eu/newxtweb/) and Market Access Databases (see http://madb.europa.eu/madb/indexPubli.htm); Ecorys / Danish Technical Institute / Cambridge Econometrics / CES ifo / Idea Consult (2008) Study on the Competitiveness of the European Steel Sector: Within the Framework of Sectoral Competitiveness Studies ENTR/06/054, Final Report for DG Enterprise and Industry, August 2008; Plastics Europe (2010) Plastics – the Facts 2010: An Analysis of European Plastics Production, Demand and Recovery for 2009; CEPI (2013) Key Statistics: European Pulp and Paper Industry 2012

Table 4-20: Principal Air Quality Impacts of Dry Recycling– Values Used in the Model

	Tonnes of pollutant per tonne of recyclate					
	NH3	NOx	PM2.5	PM10	SO2	VOCs
Card	0.0000505	-0.00122	-0.000385	-0.00000646	-0.0000065	-0.000161
Newsprint	-0.00000333	-0.00122	-0.000128	-0.0000073	-0.00000735	-0.0000443
HDPE (bottles)	0.00000914	-0.00227	-0.000108	0.000000565	0.00000488	-0.00351
PP PS (mixed dense plastic)	0.00000577	-0.00221	-0.0000984	-0.00000414	0.00000318	-0.00302
Wood	-2.26E-07	-5.89E-06	-0.00000475	0.0000057	0.0000034	-0.0000751
Glass aggregate	-0.00000107	-0.000122	-0.00000412	-7.47E-07	-0.00000265	-0.0000266
Glass container	-0.00015	-0.000588	-0.0000429	-0.00000573	-0.0000277	-0.0000533

Notes:

Recycling processes also result in minor benefits in respect of heavy metal emissions, which are not shown in the table.

Air quality impacts for metals and textiles are not included in the model.

4.1.5.6 Biowaste Treatment

Composting

The following assumptions have been made with regard to air emissions from open-air windrow and in vessel composting facilities.

Greenhouse Gases

Our assumptions for biogenic CO_2 generation assume the production of a relatively mature compost, such that more of the gas is emitted during the composting phase than would be the case with a less mature product.

There is some debate as to whether methane is emitted in any significant quantities at well managed compost sites. Some have suggested that where process is managed correctly, methane emissions will be negligible as those that occur in the middle of the composting mass will be oxidised at the surface of the composting piles.[29]

For enclosed facilities we assume emissions of 700 g of CH_4 per tonne of waste to facility, whilst the figure for open (windrow) processes is taken to be 50 g of CH_4 per tonne. These values reflect the lowest values seen in Amlinger et al (2008) and are taken to be indicative of well managed composting processes.[30]

N_2O emissions from composting plant are closely linked to ammonia emissions and are therefore discussed below.

Nitrogenous Emissions

There are two principle sources of nitrous oxide emissions in composting processes:

- Direct emissions of the gas to air from the composting process itself; and
- Additional emissions resulting from the use of biofilters in enclosed processes to reduce emissions of ammonia.

For enclosed (in vessel) facilities, we assume the use of a biofilter. This has the effect of converting some of the ammonia to N_2O, such that emissions of the latter are higher for enclosed facilities. Ammonia emissions are therefore higher at open air facilities, where no such abatement equipment can be used. Data in this respect is presented in Table 4-21. Ammonia emissions are somewhat higher for food waste as the material typically contains more nitrogen than is the case with garden waste.

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[29] Dimitris P. Komilis and Robert K. Ham (2004) Life-Cycle Inventory of Municipal Solid Waste and Yard Waste Windrow Composting in the United States, Journal of Environmental Engineering, Vol. 130, No. 11, November 1, 2004, p.1394

[30] Amlinger F, Peyr S and Cuhls C (2008) Greenhouse Gas Emissions from Composting and Mechanical Biological Treatment, Waste Management and Research, 26, pp47-60

Table 4-21: Nitrogenous Emissions to Air from Composting Facilities

	Open air composting facilities (g gas per tonne of waste treated)	Enclosed (in vessel) composting facilities (g gas per tonne of waste treated)
N_2O	100	150
Ammonia – food waste	540	27
Ammonia – garden waste	339	17

Emissions of ammonia can be further reduced through the use of a scrubber prior to the biofilter. This is not included within the model as the technology is not employed as standard throughout Europe. The approach taken in the model will therefore overestimate pollution impacts from enclosed facilities in countries such as Germany and Austria where the use of this type of abatement equipment is more prevalent. The use of such equipment can result in a reduction in ammonia emissions of 80%.

VOCs

Relatively few studies make reference to emissions of VOCs. In the UK, however, the Environment Agency did measure emissions from sites suggesting VOC emissions in the order of 25 g per tonne of waste treated at the facility.[31] This figure is reduced for in-vessel facilities where it is assumed the use of biofilters reduces the emissions by 80%. The use of biofilters is assumed to result in zero damage cost for the remaining 20% of VOC emission (i.e. the biofilter is assumed to remove those pollutants that result in the health effects).

In addition to the above impacts the model also takes into account the benefits of using compost on agricultural land as this helps to offset the use of chemical fertilisers. Further details on this and the assumed energy use at composting facilities can be found in the documentation which accompanies the model.

Anaerobic Digestion

As is the case with composting processes, direct emissions to air from AD systems result both from the treatment process itself as well as from the use of the digestate. In addition to biogenic CO_2 emissions, some fugitive methane emissions occur. Further emissions impacts arise from the combustion of the biogas during its utilisation for energy generation; as such emissions impacts are typically higher than is the case for composting processes, although the energy generation also results in avoided emissions impacts which are discussed below. Assumptions are presented in Table 4-22.

[31] Environment Agency (2000) Life Cycle Inventory Development for Waste Management Operations: Composting and Anaerobic Digestion, R&D Project Record P1/392/4

Table 4-22: Emissions from the AD process

	Emissions impacts, tonnes pollutant per tonne of waste treated
Biogenic CO_2	
Food waste	0.45
Garden waste	0.27
CH_4	
Food waste	0.002
Garden waste	0.001
NH_3	1.25E-05
NOx	0.00025
PM	0.00002
SO_2	0.00002
VOCs	0.00004

In addition to the process emissions, additional climate change impacts result from the use of digestate:

- Assumed to be 0.05 tonnes CO_2 equivalent per tonne of feedstock where food waste is the feedstock;
- Assumed to be 0.98 tonnes CO_2 equivalent per tonne of feedstock where garden waste is the feedstock.

Energy requirements for the AD process are typically met through energy generated at the plant. Benefits from energy generation included within the model account for the use of energy through the AD process, taking into account the electricity and heat used by the AD process.

Assumptions regarding the net energy generation for each option are outlined in Table 4-23, which presents values for food and garden waste. The data confirms that energy generation from garden waste is much lower than that of food waste, as garden waste is more resistant to the anaerobic degradation process. Avoided emissions from the energy generation are calculated based on the data presented in Section 4.1.5.4.

Table 4-23: Energy Generation from AD Facilities

	Biogas combustion in a gas engine		Upgraded biogas (bio-methane)	
	Electricity (kWh / tonne of waste)	Heat (kWh / tonne of waste)	Gas grid[1] (kWh / tonne of waste)	Vehicle fuel[2] (litres vehicle fuel / tonne waste)
Food	376	182	915	80
Garden	161	78	395	38

Notes

1. *Bio-methane utilised in this way is assumed to offset an equivalent amount of natural gas.*
2. *Bio-methane utilised in this way is assumed to offset an equivalent amount of diesel combusted in a heavy goods vehicle*

4.1.5.7 Landfill

Data on the generation of landfill gas from the degradation of the organic waste streams was obtained from the ETC/EEA landfill model.[32] This allowed for the development of country-specific emissions factors for landfilled wastes. The ETC/EEA landfill model was developed on the basis of the 2006 IPCC guidelines.[33] Methane emissions were calculated on the basis of a first order decay model, provided by the IPCC and used by countries for the National Inventory Reporting (NIR).[34]

Some of the main environmental assumptions associated with lanfilling are presented below.

Gas Capture Assumptions under the Life Cycle and Cost Benefit Approaches

The model assumes that 50% of the landfill gas is captured from all sites in all Member States.

Gas Capture Assumptions under the Inventory Approach

The ETC/EEA model assumes a maximum feasible recovery rate for landfill gas of 50%. This percentage is considered a maximum technically achievable recovery rate, and it has been used as the maximum, regardless of the values reported in the NIR and CRF.[35] For countries with a recovery rate smaller than 50%, the model uses the countries' reported recovery figures. Estimates of gas collection are based on 2007 data which was reported in 2009.

Oxidation of Landfill Gas

Some of the uncaptured landfill gas will be oxidised as it passes through the cap to the surface, the proportion being dependent upon the nature of the cap. The model assumes that this is 10%, based on information from the IPCC and US EPA; however, it is acknowledge that in many cases this may overestimate fugitive emissions of methane occurring from landfill.

Direct Emissions to Air

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[32] ETC/EEA (2009). Waste model developed internally by the European Topic Centre for the EEA for internal use. Supporting Documentation for the model: ETC/SCP (2011). Projections of Municipal Waste Management and Greenhouse Gases. Prepared by Bakas et al., 89 pp. Copenhagen, Denmark.

[33] IPCC (2006). 2006 IPCC Guidelines for National Greenhouse Gas Inventories Volume 5 Waste.

[34] Excel model available from IPCC (2006). 2006 IPCC Guidelines for National Greenhouse Gas Inventories Volume 5 Waste.

[35] Some countries in their reporting claim that higher methane extraction rates are attainable; however given the uncertainties associated with modelling these impacts a more conservative approach has been taken

Direct emissions to air will relate to gas generation assumptions and landfill gas management. Impacts from landfilled waste occur over a considerable time period. The approach used to consider the effect of this time delay is outlined for each assessment method.

Life Cycle Approach

Thee life cycle approach used in the model considers only the climate change impacts through calculating the GWP of each treatment method.

Landfill impacts are calculated over a 100 year period, with the total impact over this period being attributed to the year in which the waste is deposited. Impacts are only considered for the biogenic materials (food and garden waste, paper, textiles, wood, miscellaneous combustibles and fines). At the end of the 100 year period, some of the biogenic carbon remains un-emitted. The GWP results for landfill are therefore adjusted with a credit for the un-emitted biogenic carbon, which is intended to account for the exclusion of the biogenic CO_2 impacts from the GWP calculation.

The size of the credit will depend on the assumptions contained within the MS landfill models in respect of the behaviour of the degradable organic carbon, and will also vary between different types of organic waste. For example:

- Where food waste is landfilled in Austria, 50% of the biogenic carbon is assumed to be stored at the end of the period of analysis, leading to a temporary storage credit of 366 CO_2 eq. per tonne of food waste (food waste is assumed to contain 200 kg of biogenic carbon);
- Where paper is landfilled in Spain, 192 kg of carbon is assumed to be stored out of a total of 300 kg of biogenic carbon, leading to a temporary storage credit of 704 kg CO_2 equivalent per tonne of paper.

Some biogenic carbon is converted in landfills to methane, not CO_2. Under the life cycle methodology the impact of the methane emissions is adjusted downwards by an amount equivalent to the GWP associated with the emissions of CO_2 from the amount of carbon in the emitted methane. This approach results a smaller credit to the landfill emissions than that applied to account for the sequestration effects. For example:

- For food waste landfilled in Austria with a methane emission of 33 kg the credit for the biogenic carbon emitted as methane is 91 kg CO_2 equivalent;
- For paper landfilled in Spain with a similar methane emission of 32 kg the credit for the biogenic carbon emitted as methane is 89 kg CO_2 equivalent.

Cost Benefit Approach

Where the cost benefit methodology is used, the model applies a discount rate for time delayed emissions such as those from landfill. This approach includes the biogenic CO_2 emissions and so there is no need to make allowance for sequestration (long-term storage).

The cost benefit methodology considers air quality impacts as well as the climate change impacts. Whilst landfill gas is principally comprised of methane and carbon dioxide, approximately 1% of the volume of the gas is made up of trace elements. This can include up to 150 substances including halogenated organics, organo-sulphur compounds and aromatic hydrocarbons depending on the nature of the waste.[36]

The gases which are emitted in any one year are assumed to be related to the quantity of methane or CO_2 produced, depending upon whether one is considering raw gas or gas once combusted – as is shown in Table 4-24. Methane emissions to the atmosphere and methane emissions captured are both used to estimate, on a proportional basis, emissions of different trace gases in a given year using the relative composition of gas outlined in below. The way this is done is to normalise the concentrations (by weight) so that:

- Where gas is flared (i.e., captured but not used for energy generation), the emissions of other gases are calculated with reference to the studies by Enviros et al and White et al. The way this is done is by calculating the CO_2 content of flared gas and calculating the emissions of other gases through the quantities relative to CO_2 as specified in the two studies mentioned;
- A similar approach is used to calculate fugitive emissions, but in this case, the other emissions are calculated relative to the calculated quantity of methane emissions; and
- For gas which is emitted from the gas engine following its utilisation for energy generation, the emissions of other gases are calculated using the quantities estimated in other studies relative to calculated CO_2 emissions.

Table 4-24: Non Greenhouse Gas Emissions to Air from Landfilling

	Emissions mg/Nm^3 landfill gas			Source
	Fugitive Ratio to CH_4	Flaring Ratio to CO_2	Energy generation Ratio to CO_2	
Methane	1	0.001818	0.005714	Enviros
Carbon dioxide	1.733333	1	1	Enviros
Carbon monoxide	3.03E-05	4.09E-04	4.09E-04	White et al
Hydrogen sulphide	4.66E-04	1.69E-08	1.69E-08	White et al
Hydrogen chloride	2.67E-06	8.64E-05	1.14E-05	Enviros
Hydrogen fluoride	5.33E-07	1.82E-05	1.14E-05	Enviros
Chlorinated HC	8.10E-05	5.10E-06	5.10E-06	Enviros
Dioxins and furans	0	3.36E-13	5.43E-13	Enviros

[36] Komex (2002) Investigation of the Composition and Emissions of Trace Components in Landfill Gas, R&D Technical Report P1-438/TR for the Environment Agency, Bristol

	Emissions mg/Nm³ landfill gas			Source
	Fugitive Ratio to CH_4	Flaring Ratio to CO_2	Energy generation Ratio to CO_2	
Total Particulates	0	3.64E-05	0.00002	Enviros
Nitrogen oxides	0	0.000455	0.002571	Enviros
Sulphur dioxide	0	0.000545	0.0002	Enviros
Cadmium	0	0	2.86E-07	Enviros
Chromium	7.12E-08	1.25E-08	1.25E-08	White et al
Lead	2.00E-08	2.49E-09	2.49E-09	White et al
Mercury	1.41E-08	2.49E-09	4.57E-09	Enviros
Zinc	1.68E-07	6.64E-11	6.64E-11	White et al
Nickel	0	0	3.71E-08	Enviros
Arsenic	0	0	4.57E-09	Enviros
Total VOCs	0.000333	7.73E-06	0	Enviros
Non-methane VOCs	0	8.64E-06	8.57E-05	Enviros
1,1-dichloroethane	0.000036	0	0	Enviros
Chloroethane	1.33E-05	0	0	Enviros
Chloroethene	1.47E-05	0	0	Enviros
Chlorobenzene	0.000032	0	0	Enviros
Tetrachloroethene	0.000044	3.64E-08	5.71E-07	Enviros
Poly-chlorinated biphenyls	0	0	0	White et al
Benzene	3.2E-06	0	0	Enviros

Source: Adapted from White P R, Franke M and Hindle P (1995) Integrated Solid Waste Management: A Lifecycle Inventory, Blackie Academic & Professional, Chapman and Hall; Enviros, University of Birmingham, RPA Ltd., Open University and Thurgood M (2004) Review of Environmental and Health Effects of Waste Management: Municipal Solid Waste and Similar Wastes, Final Report to Defra, March 2004

There are some inconsistencies in this approach, the principal one being that the White et al data make little allowance for changes in the level of oxidation of methane through the cap of the landfill site. Our model incorporates this as a variable. It is important to appreciate here that oxidation may appear not only at the cap (and typical estimates in the literature are 10%), but also in the leachate, so that total oxidation of methane to carbon dioxide may be greater than is sometimes suggested.

Landfills produce less of the pollutants for which dose response functions are tolerably well known. No external damage costs have therefore been developed for many of pollutants listed in Table 4-24. These figures include impacts associated with the use of diesel at the facility, and a small amount of avoided emissions resulting from the generation of electricity from landfill gas.

Energy Generation

For landfilled wastes, avoided impacts relate solely to energy generation from captured landfill gas, as no recyclate is recovered through the process. The amount of energy generated is directly related to the amount of landfill gas that is generated and subsequently captured. Assumptions used with regard to the generation of electricity from landfill gas are presented in Table 4-25.

Table 4-25: Assumptions Used for Electricity Generation from Landfill Gas

Parameter	Value
Proportion of landfill gas used to generate energy	50%
Gas engine efficiency	35%
Calorific value of methane	38 MJ / kg

The proportion of methane contained within landfill gas varies by member state, depending on the assumptions contained in the National Inventory Reports. For most member states, it is assumed that 50% of the carbon contained in waste forms methane, although several (the Netherlands and the Czech Republic) assume 60%, whilst Denmark assumes the same proportion is 45%.

4.1.5.8 Incineration

Emissions to Air

Greenhouse gas emissions occurring as a result of the incineration of waste will be dependent upon the carbon content of the dry material, along with the overall efficiency of energy generation that results from the combustion of that material. As such, climate change impacts are directly dependent on the outputs from the Mass Flow Module for each Member State. Table 4-26 presents the assumptions used in the model in respect of the carbon content of waste materials.

N_2O emissions are modelled based on previous research undertaken by Eunomia on behalf of WRAP.[37] The considerable uncertainty with respect to these emissions is acknowledged within the EU BREF note, which provided a range of 5.5 – 66 g N_2O per tonne of waste treated by the facility.[38] We use the mid-point of these values within the current analysis. CH_4 emissions are negligible from incineration facilities.

[37] Eunomia (2007) Emissions of Nitrous Oxide from Waste Treatment Processes, Report to WRAP, July 2007

[38] European Commission (2006) Integrated Pollution Prevention and Control: Reference Document on Incineration, August 2006

Table 4-26: Carbon Content of Waste Materials

Waste Category	Carbon content, % fresh matter	
	Biogenic	Fossil
Biowastes	16%	
Food	13%	
Garden	18%	
Other biowastes	16%	
Wood	32%	
Wood packaging	32%	
Other wood	32%	
Paper / Cardboard	32%	
Non-packaging paper	32%	
Packaging paper	32%	
Cardboard	31%	
Textiles	15%	
Clothing and footwear	15%	15%
Other textiles	5%	25%
Glass		
Metals		
Plastics		60%
Plastic bottles		60%
Other rigid plastic packaging		60%
Non-packaging rigid plastics		55%
Film packaging (bags etc)		56%
Non-packaging films		56%
WEEE		5%
Large household appliances		5%
Small household appliances		5%
IT and telecommunications equipment		5%
Toys, leisure and sports equipment		40%
Other		
Rubble, soil		
Furniture	10%	10%
Batteries and accumulators		
Other wastes		
ELVs		
Haz (exc WEEE)		
Fines	7%	
Inerts		
Other	9%	8%

When analysis of pollution impacts is undertaken using the damage cost approach, typically the most significant contribution to the total pollution impacts comes from the

NOx pollution. The model therefore considers emissions from incineration facilities with SNCR installed to control the NOx, and those that use SCR. Emissions data for incineration facilities included in the model are detailed in Table 4-27.

Table 4-27: Emissions from Incineration Facilities

	Emissions to air, tonnes pollutant per tonne of material treated	
	Incineration with SNCR	Incineration with SCR
NH_3	1.46E-05	1.46E-05
NOx	0.000828	0.000214
$PM_{2.5}$	4.87E-06	4.87E-07
PM_{10}	9.74E-06	9.74E-07
SO_2	3.9E-05	9.74E-06
VOCs	3.9E-06	9.74E-07
Arsenic	8.77E-09	8.77E-09
Cadmium	9.74E-09	9.74E-09
Chromium	5.84E-09	5.84E-09
Nickel	7.79E-09	7.79E-09
Dioxins/furans	1.52E-13	1.52E-13

Sources: Information Centre for Environmental Licensing (2002) Dutch Notes on BAT for the Incineration of Waste, Report for the Ministry of Housing, Spatial Planning and the Environment, The Netherlands, February 2002; European Commission (2006) Integrated Pollution Prevention and Control: Reference Document on Incineration, August 2006; ExternE (1999) Externalities of Energy, Vol 10: National Implementation, prepared by CIEMAT for the European Commission, Belgium; Chang M B, Huang C K, Wu J J, and Chang S H (2000) Characteristics of heavy metals on particles with different sizes from municipal solid waste incineration, Journal of Hazardous Materials 79(3): pp229-239

Energy Use and Generation

The model assumes the incinerator uses 82 kWh of electricity per tonne of waste and 3 litres of diesel in line with values seen in several literature sources as well as recent permit applications for proposed incineration plant in the UK.[39]

As is the case with the climate change emissions from the incineration process, the energy content of the residual waste treated by the plant is directly linked to the composition of the feedstock. Table 4-28 presents assumptions used in the model in respect of the calorific values of waste materials. The data presented is the net calorific value as received by the plant.

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[39] Riemann I (2006) CEWEP Energy Report (Status 2001-2004): Results of Specific Data for Energy, Efficiency Rates and Coefficients, Plant Efficiency Factors and NCV of 97 European W-t-E Plants and Determination of the Main Energy Results, updated July 2006; VITO (2000) Vergelijking van Verwerkingsscenario's voor Restfractie van HHA en Niet-specifiek Categorie II Bedrijfsafval, Final Report

The model separately considers the performance of four types of incineration plant:

- Facilities generating only electricity;
- Plant generating electricity and exporting heat for use outside the plant;
- Facilities exporting only heat;
- Incineration plant combusting waste without utilising the energy that is generated through the combustion process.

The model has been set up so that different assumptions regarding generation efficiencies for each of the four types of plant can be made for each Member State; in addition, there is scope for these efficiencies to vary annually from 2011 to 2030 where such data is available for individual Member States.

Table 4-28: Calorific Values of Waste Materials

Waste Material	Calorific value, MJ / kg fm (as received)
Biowastes	6
Food	5
Garden	8
Other biowastes	6
Wood	15
Paper / Cardboard	12
Non-packaging paper	12
Packaging paper	12
Cardboard	12
Textiles	13
Clothing and footwear	13
Other textiles	13
Glass	
Metals	
Mixed cans	
Steel cans	
Aluminium cans	
Aluminium foil	2
Other scrap metal	
Plastics	34
Plastic bottles	34
Other rigid plastic packaging	34
Non-packaging rigid plastics	30
Film packaging (bags etc)	32
Non-packaging films	32
WEEE	3
Large household appliances	3
Small household appliances	3

Waste Material	Calorific value, MJ / kg fm (as received)
IT and telecommunications equipment	3
Toys, leisure and sports equipment	25
Other	
Rubble, soil	
Furniture	10
Batteries and accumulators	
Other wastes	
End of life vehicles	
Hazardous waste	
Fines	3
Inert	
Other	14

Sources: Phyllis Database for Biomass and Waste, available from http://www.ecn.nl/phyllis/; Beker D and Cornelissen A A J (1999) Chemische Analyse Van Huishoudelijk Restafval: Resultaten 1994 en 1995, National Institute of Public Health and the Environment, Nederland; Davidsson A, Gruvberger C, Christensen T, Hansen T and la Cour Jansen J (2007) Methane Yield in Source-sorted Organic Fraction of Municipal Waste Management, Waste Management 27 pp.406-14; Komilis D, Evangelou A, Giannakis G, Lymperis C (2012) Revisiting the elemental composition and the calorific value of municipal solid wastes, Waste Management, 32(3), pp372-381

Where no data was provided by MS on the efficiency of incineration facilities the model uses the default assumptions for energy generated at incineration plant presented in Table 4-29. This data was confirmed as being a reasonable representation of typical operating efficiencies for European plant through consultation with the European Suppliers of Waste to Energy Technology (ESWET) and the Confederation of European Waste to Energy Plants (CEWEP). Some member states provided specific information as to the efficiency of their plant; where this was the case, the data was incorporated into the model.

Table 4-29: Energy Generation Efficiencies for Incineration Plant – Default Values

	Gross electricity generation efficiency (% exported of total energy content)	Heat utilisation (% heat used of total energy content)
Electricity only	25%	-
CHP	14%	42%
Heat only	-	80%

Recycling

The efficiency with which metals are recovered from incineration facilities is modelled based on a recent literature review undertaken by Grosso et al, which suggested that 70% of the ferrous metal could be recovered as well as 30% of the non-ferrous metal.[40] The materials recovery is assumed to result in offset emissions as described in Table 4-18.

The mass flow model also assumes that bottom ash is also recovered for recycling. However, this results in only negligible environmental benefits and as such this has not been included in the environmental model.

Landfilled Residues

Air pollution control residues from waste incineration facilities consist of a mix of unspent reagents and chemicals extracted from the flue gas. They are typically treated as hazardous waste and are usually required to be sent to hazardous waste landfills. Chlorine, sulphur, heavy metals and dioxins are likely to be concentrated in the air pollution control residues produced by incinerators. Ironically, the better flue gas cleaning systems perform, the more likely it becomes that toxic materials are concentrated in these residues.

Several recent studies indicate that long-term impacts of landfilling this hazardous material may be significant. In a Dutch study comparing the costs and benefits of landfill with those of incineration, the environmental damages associated with air pollution control residues were considered as the most important externality associated with treatment in an incineration facility.[41]

One life-cycle study suggests:

> *'The evaluation of waste incineration technologies largely depends on the assessment of heavy metal emissions from landfills and the weighting of the corresponding impacts at different points in time. Unfortunately, common LCA methods hardly consider spatial and temporal aspects.'*[42]

Using a geochemical model to model some pollutants, the same study concluded:

> *'Landfills might release heavy metals over very long time periods ranging from a few thousand years in the case of Cd to more than 100,000 years in the case of Cu. The dissolved concentrations in the leachate exceed the quality goals set by the Swiss water protection law (GSchV) by a factor of at least 50.'*

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[40] Grosso M, Biganzoli L and Rigamonti L (2011) A Quantitative Estimate of Potential Aluminium Recovery from Incineration Bottom Ashes, Resources, Conservation and Recycling, 55, pp1178-1184

[41] Dijkgraaf E and Vollebergh H (2004) Burn or Bury? A Social Cost Comparison of Final Waste Disposal Methods, Ecological Economics, 50: pp233-247

[42] Hellweg S (2000) Time- and Site-Dependent Life-Cycle Assessment of Thermal Waste Treatment Processes, Dissertation submitted to the Swiss Federal Institute of Technology

We have not included these impacts in our model due to the limited data associated with their impacts, and the long timescale over which such impacts might be expected to occur.

4.1.5.9 Mechanical Biological Treatment

The following types of MBT facility have been included in the model, reflecting the most commonly used approaches:

- The stabilisation of the degradable fraction to reduce impacts from landfilling;
- Biodrying to produce a fuel subsequently used in an incinerator;
- Processes that use AD to treat the biodegradable element of residual waste; and
- Processes that only undertake the mechanical element of the MBT process to recover recyclate from the residual waste, termed in the model as a Residual MRF facility.

Each type of MBT has different environmental impacts associated with it. Given the summary nature of this overview the details will not be summarised here. Instead the reader is referred to the technical documentation that accompanies the EU waste model.

4.1.6 Employment Module

The aim of the Employment Module is to derive figures for the rate of employment per tonne of waste managed in different waste management operations (e.g. collection, landfilling, incineration, etc.). A graphical overview of the Employment Module is provided in Figure 4-9 which shows how it is linked to the Mass Flow Module outlined above. Employment in waste management is given in terms of number of full time equivalent (FTE) jobs per 10,000 tonnes of waste processed (also referred to as 'employment intensity'). These employment intensity factors are scaled in the model by the quantity of waste managed in different ways to derive:

- An estimate of employment in a particular waste management projection; and

- An estimate of the net impact on employment from one scenario compared to another.

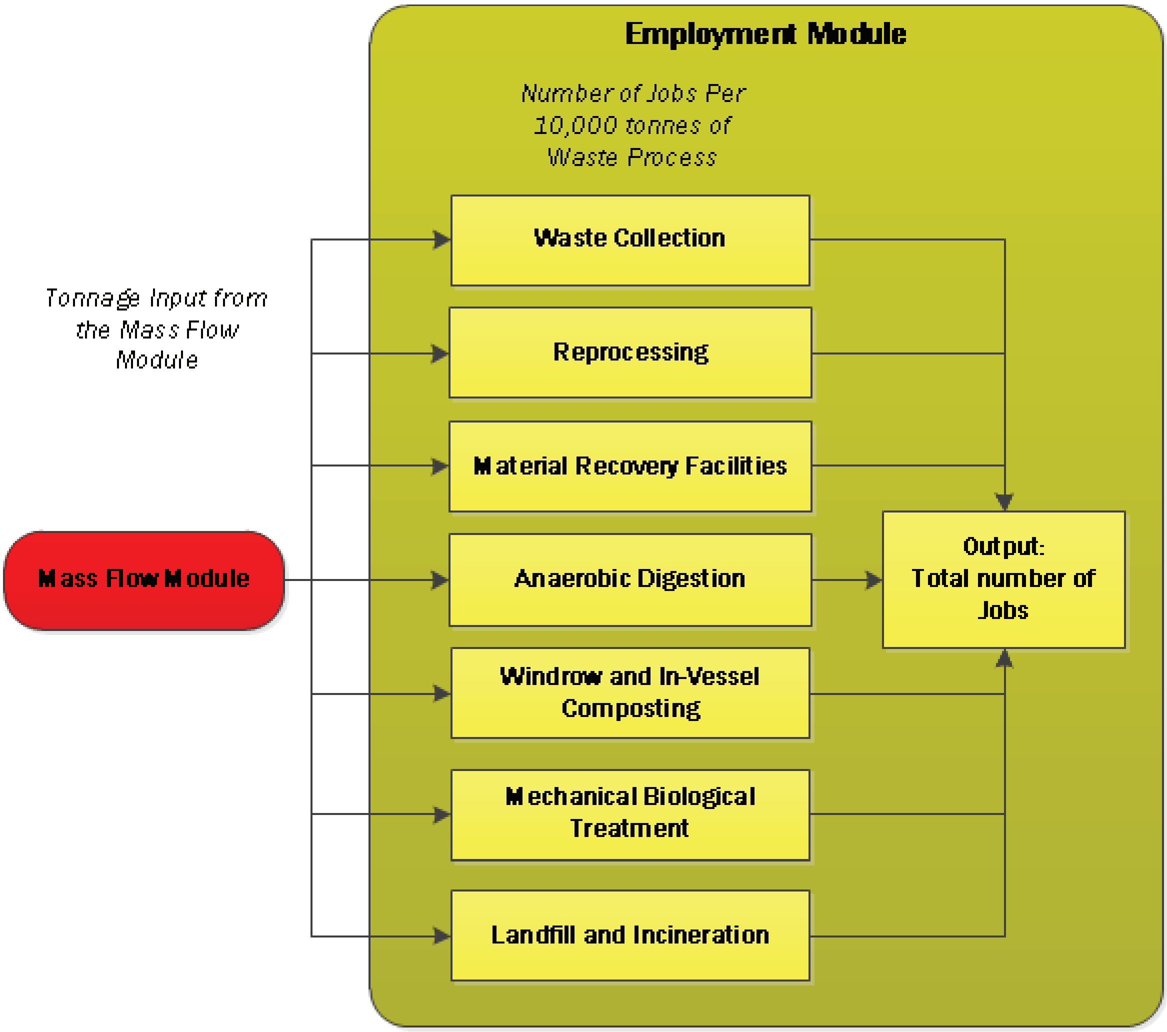
The OECD has previously recognised the intrinsic difficulties in the analysis and interpretation of employment data in the waste management industry.[43] An issue of particular salience relates to the difficulties that arise as a result of the industry's heterogeneous nature. This makes direct comparisons between studies less justifiable. Methodological inconsistencies within the literature exacerbate this issue, and are discussed further below. In recognition of the limitations inherent to the existing literature, a survey micro study was also conducted into employment in waste management facilities.

As shown in Figure 4-9 this Module takes into account employment in relation to the following:

- Reprocessing;
- Material Recovery Facilities;
- Anaerobic Digestion;
- Windrow and In-Vessel Composting;
- Mechanical Biological Treatment:
- Landfill and incineration; and
- Waste Collection.

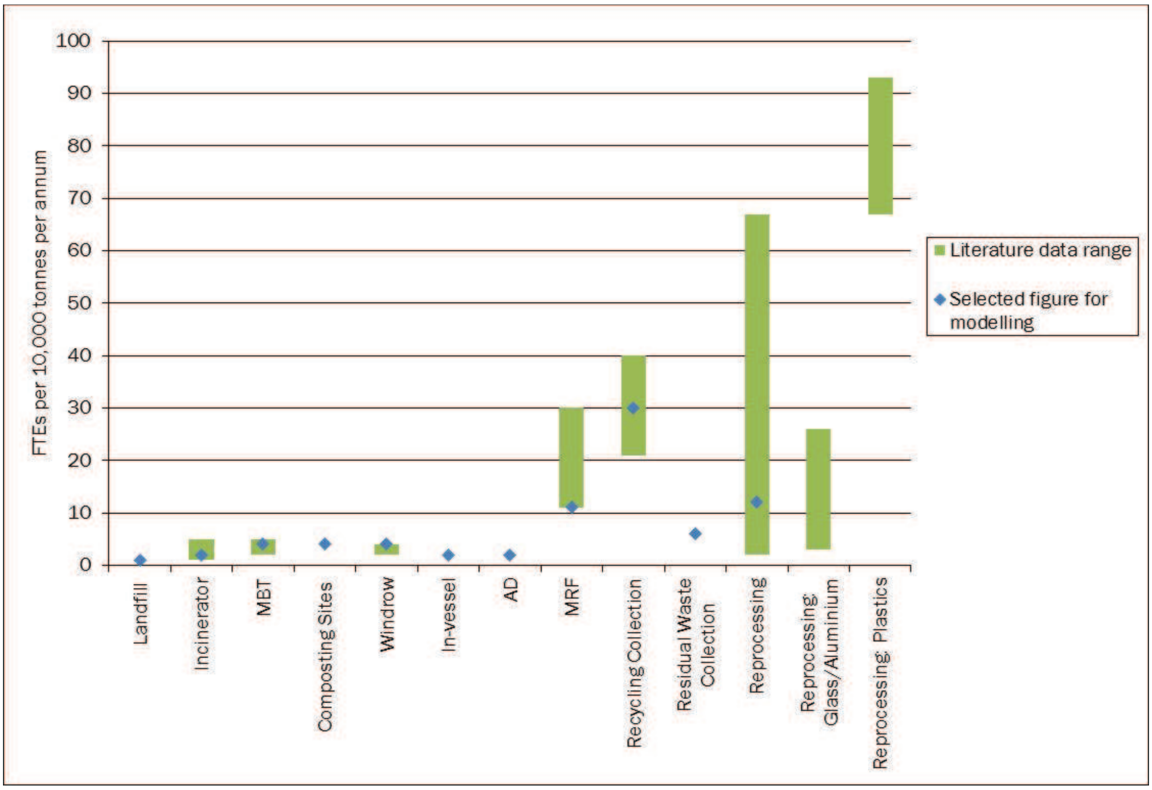
[43] OECD (1996) *The Global Environmental Goods and Services Industry*, Paris, OECD.

Figure 4-9: Overview of the Employment Module



A summary of the research that was conducted to substantiate the employment intensities for each of the above is included in the documentation that accompanies the European Reference Model on Waste. The results of this research are shown in Figure 4-10 which identifies the employment intensity values which were used in the model.

Figure 4-10: Range in Employment Intensities from Literature Review and Selected Figures for Modelling



4.1.7 Costs-Benefit Analysis Results

This component of the model collates the results coming out of the Environmental Impacts Module and the Financial Costs Module and presents the information in the form of easy to interpret charts and graphs.

4.1.8 Distance to Targets

For any model run, this component of the model calculates the distance that each Member State is from the targets set out in the following European waste Directives:

- Landfill Directive Article 5(2) targets;
- Waste Framework Directive Article 11(2)(a) target;
- Packaging and Packaging Waste Directive Article 6(1) targets; and
- WEEE Directive Article 7(1) target.

The results of these analyses can be very helpful as reference to identify if the option being modelled will allow the Member State to meet the above targets.

4.1.9 Resource Efficiency Indicators

One intended purpose of the European Waste Model was to be able to use it to track a number of 'Resource Efficiency Indicators' (REIs) relating to waste and material management in the European Union. One of the key model output therefore includes a summary of the following seven REIs:

1. ***Per Inhabitant MSW Generation***
   The model can report on waste generated per inhabitant. In seeking to ensure that by 2020 waste per inhabitant is in absolute decline, a clear issue is that different countries currently have different waste generation per inhabitant, and these differences are likely to persist, to varying degrees, over coming years. As such, the intent ought to be to maintain municipal waste per inhabitant below a certain level. However, this approach can be complicated by the fact that wastes of varying scope can be included under the definition 'municipal'.

2. ***Recycling Rate (dry)***
   Where 'dry' (i.e. materials other than food waste and garden waste) materials are concerned, the recycling rate is a useful indicator of performance in respect of resource efficiency.

3. ***Residual Organic Waste per Inhabitant***
   Where wet materials are concerned, the recycling rate is susceptible to significant influence depending upon the approach to collecting waste. For example, where garden wastes are separately collected free of charge, in suburban areas, this can increase recycling rates significantly, even where some of this material might not otherwise have needed to be collected and been managed within the home (so would not have arisen as waste). It is be more appropriate, therefore, to estimate the quantity of organic waste which is not separately collected for composting or anaerobic digestion. This gives an indication of how much uncaptured organic waste there is in the residual waste stream, and thus indicates the effectiveness of approaches to prevention and source separation.

4. ***Residual Waste per Inhabitant***
   A measure already considered in certain countries / regions, is the quantity of residual waste per inhabitant. The merit of this indicator is that it captures the extent to which waste has move into the upper tiers of the hierarchy, and no longer requires management as residual waste. To the extent that the Roadmap seeks to ensure that only non-recyclable waste is incinerated (or, presumably, sent to MBT, or landfilled, etc.), then this indicator captures both the recycling efforts and the efforts made in respect of waste prevention. It may also be considered also a 'fair' indicator in comparing Member States.

5. ***Proportion of Waste Landfilled***
   Although aligned with the Roadmap's vision, the merits of whether this is a suitable indicator of performance are less clear than some of the other indicators included in the model. Nevertheless, since it is straightforward to calculate, it is reported through the model.

6. ***GHG Savings Relative to Hypothetical Maximum***
   A further interesting measure of resource efficiency is to estimate the GHG

savings from the management of waste relative to what would be achieved if 100% of the dry material was recycled, 100% of the food waste was digested, and 100% of the garden waste was composted.[44] This gives an indication of how close the existing system is to the maximum GHG savings. In calculating this indicator, the modelled impact from landfilling needs to assume that all emissions associated with the landfilling of waste are assigned to the year in which they are deposited. However, in principle, this gives a useful proxy for the 'resource efficiency' of the waste management system. It may be noted that a similar approach has been used in respect of setting recycling rates in Scotland, where a carbon metric is used to calculate recycling rates.

7. *Municipal Material Captured for Recycling vs Material used in the EU*
It would be of interest to consider the impact of recycling on the consumption of raw materials. In principle, although recycling will reduce the consumption of raw materials, it might not necessarily do so within the EU. Considerable quantities of material are exported for recycling either within the EU (intra-EU trade) or to non-EU countries (extra-EU trade). Without detailed knowledge and understanding of the flows of imports and exports of secondary materials, the extent to which recycling reduces the EU's import dependency is not clear.

In the absence of this type of information, therefore, the principle, indicator which could inform the value of improved waste management is

> *"The quantity of material captured for recycling relative to the quantity of the same material used in the EU."*

Evidently, this is somewhat artificial where the model does not include all waste streams. Where materials arise principally as industrial wastes, for example, the proportion of overall demand which could be met by the recycled municipal waste material is unlikely to be especially high. Nevertheless, as a comparative indicator (i.e. to assess changes over time or between scenarios), and to indicate the contribution to total material demand, we include the above indicator in the model.

[44] We note that 100% recycling of all materials might not be considered possible, but this does serve to highlight the closeness to a hypothetical maximum without entering into discussion regarding what 'maximum rates' of recycling might be (noting also that views on 'maximum rates' seem to be increasing over time).