JRC Scientific and Technical Reports

Inventory of Existing Studies Applying Life Cycle Thinking to Biowaste Management

Analysis of Existing Studies that Use a Life Cycle Approach to Assess the Environmental Performance of Different Options for the Management of the Organic Fraction of Municipal Solid Waste

EUR 23497 EN - 2008

JRC
EUROPEAN COMMISSION

Institute for Environment and Sustainability

The mission of the Institute for Environment and Sustainability is to provide scientific-technical support to the European Union's Policies for the protection and sustainable development of the European and global environment.

European Commission
Joint Research Centre
Institute for Environment and Sustainability

Contact information
Address: T.P. 460 - 21027 Ispra (VA) Italy
E-mail: lca-waste@jrc.it

Tel.: +39 0332 785880
Fax: +39 0332 78 5601

http://ies.jrc.ec.europa.eu/
http://www.jrc.ec.europa.eu/

JRC 47277

EUR 23497 EN
ISBN 978-92-79-09768-3
ISSN 1018-5593
DOI 10.2788/95667

Luxembourg: Office for Official Publications of the European Communities

Printed in Italy

Inventory of Existing Studies Applying Life Cycle Thinking to Biowaste Management

Analysis of Existing Studies that Use a Life Cycle Approach to Assess the Environmental Performance of Different Options for the Management of the Organic Fraction of Municipal Solid Waste

Authors: Bart Krutwagen; Jaap Kortman; Koen Verbist

IVAM research and consultancy on sustainability, The Netherlands

Editors: Raffaella Bersani, Rana Pant, David W. Pennington

European Commission Joint Research Centre, Italy

The document was prepared under JRC contract no.382460 F1SC on “Life cycle guidelines for the management of municipal biodegradable waste” by IVAM research and consultancy on sustainability, Roetersstraat 33 - 1018 WB Amsterdam, Netherlands.

CONTENTS

List of Tables

List of Figures

List of acronyms

COM – Commission Communication

EU – European Union

EC – European Commission

JRC – European Commission’s Joint Research Centre

LCA – Life Cycle Assessment

LCI – Life Cycle Inventory

LCIA – Life Cycle Impact Assessment

LCT – Life Cycle Thinking

Mg – Megagram (1 metric tonne)

MSW – Municipal Solid Waste

RDF – Refuse-Derived Fuel

TOC – Total Organic Compounds

1 Introduction

1.1 Background

The European Commission has driven the development of environmental policy to ensure the inclusion of life cycle thinking. In June 2003, the European Commission launched a number of activities to strengthen life cycle thinking in policy and business. The Integrated Product Policy (IPP) Communication (COM(2003)302) aimed at improving the environmental performance of products (both goods and services) throughout their life-cycles, from the extraction of raw materials, through the production of materials, intermediates, and products and their use, to the recycling and final disposal of remaining waste ("cradle to grave"). In December 2005, the important role of life cycle thinking was further recognised and strengthened in the Commission's Thematic Strategies on the Sustainable Use of Natural Resources (COM(2005)670) and on the Prevention and Recycling of Waste (COM(2005)666). The Sustainable Consumption and Production Action Plan (SCP) (COM(2008) 397/3) integrates and further strengthens these policies, aiming to lower the overall environmental impact and consumption of resources of products associated with their complete life cycles.

In its Thematic Strategy on the Prevention and Recycling of Waste, the Commission proposed to clarify the objectives of waste policy under the Waste Framework Directive in order explicitly to apply life-cycle thinking. EU waste policy should aim to reduce the negative environmental impact of waste generation and management and to contribute to an overall reduction of the environmental impact of the use of resources.

The action taken under the Thematic Strategy will contribute to continuing to move waste flows away from landfill. As waste moves away from landfills it will be channelled into a variety of options higher up the waste hierarchy, which will be generally better for the environment and better utilise related resources.

The environmental benefits of waste policy are complex because they occur at different stages of the life cycle and in different forms and can consequently be difficult to quantify or compare. But waste policy needs to contribute to minimising environmental impact taking into account the entire life cycle of products. Therefore the Thematic Strategy foresees the preparation of guidance documents, in particular:

- Publication of guidelines for Member States on applying life cycle thinking to management of biodegradable waste;
- Publication of basic guidelines to make life cycle tools easily usable in waste policymaking, with an agreed approach and methodology.

For the management of biodegradable waste that is diverted from landfills, there is no single environmentally best option. The environmental balance of the various options available for the management of this waste depends on a number of local factors, inter alia collection systems, waste composition and quality, climatic conditions, the potential of use of various waste derived products such as electricity, heat, methane-rich gas or compost. Therefore strategies for management of this waste should be determined at an appropriate regional scale, with consistent guidance provided by the Member States and European Commission for the use of life cycle thinking.

The Commission committed to produce guidelines on applying life cycle thinking for the management of biodegradable waste and will communicate these guidelines to Member States and invite them to revisit their national strategies. These guidelines will also assist local and regional authorities that are generally responsible for drawing up plans for management of municipal waste.

This report presents the first outcome of the study "Development of European Life Cycle Thinking Guidelines for the Management of Municipal Biodegradable Waste", presenting the outcomes of an inventory analysis of existing studies concerning the application of the life cycle approach to biowaste management. In this report the main conclusions of the analysis are presented as a first step for the definition of a related life cycle guidance document for biodegradable waste.

1.2 Approach of the analysis

In this study Biodegradable Municipal Waste is considered as the organic biogenetic fraction of municipal waste from garden and kitchen and is indicated as "biowaste"[1].

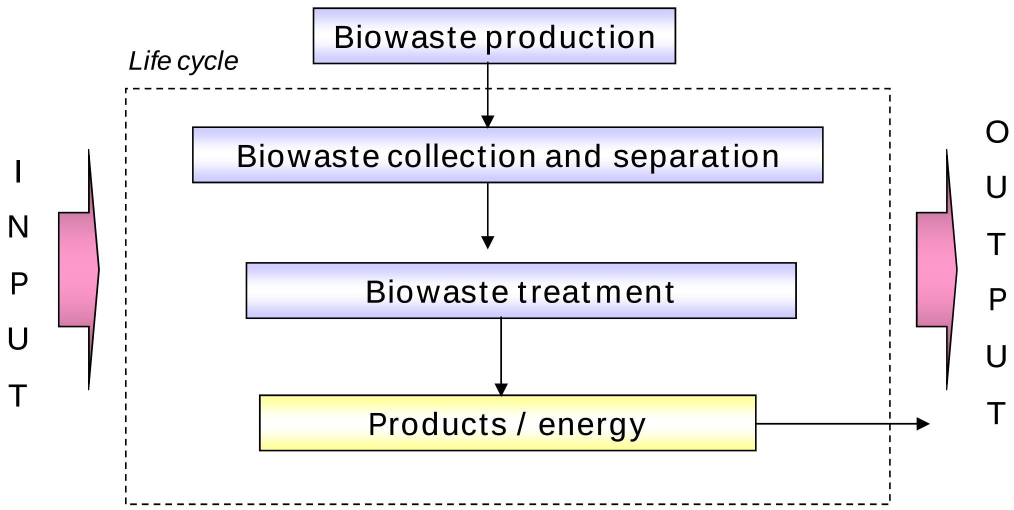
Other in principle biodegradable organic waste, such as paper and organic textiles, are not taken into account. In this study these others are considered as separate waste streams that may contaminate in small amounts the stream of kitchen and garden waste. This deviation from the broader definition of the European Waste Directive is taken because paper and (to a lesser extend) organic textiles have their own separate collection routes in most countries. This deviation is supported by the final report to the European Commission, by Erunomia Research and Consulting (1998) stating "It is commonly felt that paper recycling is a better option than the application of biological treatment (from Economic analysis of options for managing biodegradable municipal waste)". There is however a trend noticeable to allow the addition of biodegradable materials like bioplastics packaging, compostable diapers, etc. to separated biowaste. Although this trend can be expected to grow, it is still not common practice in the EU and therefore not taken into account in this study. Policymakers should however take notice of this trend and should consider possible side effects.

In December 2005, the important role of life cycle thinking was recognised and strengthened in the Commission's Thematic Strategies on the Sustainable use of Natural Resources and on the Prevention and Recycling of Waste. Life Cycle Thinking is in this study applied for the management of biowaste, therefore the analysis of existing studies in this report is structured along the life cycle.

The EU waste policy aims to reduce the negative environmental impact of biowaste management and to contribute to an overall reduction of the environmental impact of the use of resources. The environmental assessment of the (dis-) advantages of the various biowaste management options is complex because they occur in different phases of the biowaste lifecycle, during collection, treatment and recycling, while contributing to different environmental effects, ranging from greenhouse effects, material depletion, acidification and toxicity for humans and ecosystems. The environmental assessment of biowaste management requires therefore detailed description of inputs of resources and outputs of emissions and useful products that are related to these different phases.

Furthermore, the environmental impact of the various biowaste management alternatives depends on a number of local factors, such as the distance between collection and treatment facilities, the energy recovery efficiency of the treatment plant and the required quality of recycled products, such as compost, according to local standards. Therefore the selection of a favourable method for the management of biowaste should consider a life cycle approach as indicated in

Figure 1 Main phases of the life cycle of biowaste



This analysis and the report are structured along the main phases of the life cycle of biowaste. This life cycle starts in this context of waste management with the collection of municipal biowaste, which is generated by households, followed by waste treatment and

[1] The definition of Biowaste as proposed by the European Parliament in the legislative resolution on the proposal for a directive of the European Parliament and of the Council on waste (ref. T6-0029/2007) notes: *'biowaste' means waste of animal or plant origin, for recovery purposes, which can be decomposed by micro-organisms, soil-borne living organisms or enzymes; soil material with no significant biowaste content and plant remains from agricultural production falling within the scope of Article 2(3) are not biowaste.*

ending in possible recycling and energy recovery. In the collection phase a pre-treatment and/or storing of biowaste may be included[2].

The life cycle of biowaste has been organised with help of a shortlist that consists of the selected collection and treatment methods, the options for recycling and energy recovery and important local factors that can significantly influence the magnitude of environmental effects from the various life cycle stages. Based on the shortlist, an analysis and summary have been made of the most recent scientific LCA studies on biowaste. This analysis is focussed on two objectives:

- conclusions on environmental effects of the management of municipal biowaste in general;
- conclusions on the regional/local factors that may influence the environmental performance of the alternative options for the management of biowaste.

86 existing studies have been collected and arranged into the Biowaste LCA literature Database (see Chapter 8 Literature list). These studies were collected from the existing knowledge base, from an internet search and from the input of stakeholders that were actively approached during the project. Not all studies that were collected have been added to the list in case their relevance was too low or where not adding new or relevant information. Most of the studies were recently produced (between 2000 and 2007). Most studies were conducted for European countries with an emphasis on Denmark, Sweden, Germany, and the Netherlands. A few studies come from outside the European Union, namely Australia and the USA.

The literature has been screened on a number of aspects. Firstly by noting the collection and treatment methods they consider. Secondly, by noting the local factors that were assessed in these studies for their potential influence on the environmental performance, like recycling and recovery options, technology efficiency, collection system, climate differences etc. Thirdly, by assessing the quality, transparency and data availability of the life cycle inventory and impact assessment. The results from the screening have been compiled in an overview table (see Chapter 9 Literature screening) to aid users that are looking for specific aspects of environmental assessments of biowaste management. The bulk of the data found in the literature concern the assessment of different treatment options, while considerable less attention has been given in these studies to the collection methods and other local factors that may influence the environmental performance.

Finally the conclusions have been screened for relevant conclusions and guiding principles for the selection of the favourable method for biowaste management. These conclusions will be used to support the definition of the guidelines for biowaste management.

[2] It is important to note that the life cycle of biowaste is the final part of other product life cycles, e.g. of food. The entire life cycle of products can also be modelled. Added benefits include highlighting the relative importance of e.g. waste prevention. However, for waste management, waste related studies often start with the collection of waste as a baseline. Equally, for biodegradable waste management, where recycling is not an option, knowledge of the upstream impacts is not considered essential and will not alter the outcome of the study.

2 Biowaste generation

2.1 Composition of biowaste

According to a European Commission study on waste management options [26], the total amount of municipal waste generated in Europe (EU15) in the year 2000 was about 186.000 kiloton/year. The average biodegradable fraction in Europe lies between 29-32% of the total municipal waste [85]. This fraction is however varying between countries, from 22% in the United Kingdom to 49% in Greece. This corresponds with an average biological waste generation of 122 kg/person/year in the EU-15 [85]. However, recent studies[3] have suggested biodegradable fractions as high as 65-70% in e.g. Malta and Cyprus.

The waste fractions that are considered in this study are:

1) Integral municipal waste.
2) Kitchen-, food- and garden waste, a fermentable fraction including what is covered by "VFG-waste" (vegetable, fruit, garden). This is the non-ligneous fraction of biowaste. Often there is a subdivision of VFG waste stream in food waste and non-ligneous garden waste (grass clippings, dead leaves etc).
3) A "green fraction" often called "green, yard or garden waste" which is made of the ligneous fraction of garden waste, such as tree pruning, dead branches, tree trunks, etc.

Paper can also be considered as biodegradable fraction[4]. According to a study by ACR+ [85], it is commonly felt that separate paper recycling is a better option than biological treatment. Paper will therefore in this study only be included as impurities in biowaste (see also 1.2)[5].

The composition of biowaste from households generally varies between countries/regions according to a range of factors, including geographical location, season, the urban or rural character of the area, type of settlement, standard of living, culture and food & drink habits, etc. The design of collection schemes and the level of promotion of home composting will also have an influence on the composition [85].

[3] K. Koneczny et al. Environmental Assessment of Municipal Waste Management Scenarios: Part I – Data collection and preliminary assessments for life cycle thinking pilot studies. EUR 23021 EN - 2007

[4] The landfill directive defines any waste that is capable of producing gas as biodegradable.

[5] If the share of these impurities is large this may offset the results from this study. Anyone using these results should be aware that the results are limited to the described waste fraction.

Belgium, Luxembourg and the Netherlands have a high percentage of biodegradable waste [85]. This can partly be explained by the separate collection of not only kitchen waste, but also garden waste. In Mediterranean areas, high percentages for fermentable waste can be explained by [85]:

- a large use of vegetables and fruits in the daily diet and in the preparation of meals;
- the effect of tourism generating waste from meals;
- the lower presence of packaging because of a less wealthy economy, and the lower use of pre-cooked or frozen products.

3 Biowaste collection

3.1 Overview and selection of collection methods

There are roughly four different methods to collect biowaste. These methods are considered in this study:

1) Prevention
2) Separate collection
3) Mixed collection (integral/separate)
4) Integral collection.

Prevention of biowaste simply reduces the amount of biowaste that needs to be collected and treated. Prevention of the actual generation of biowaste by changing the behaviour of consumers is preferable as a first step, as per the waste hierarchy, but is outside the scope of this study and is not been considered here.

Home-composting is, in some studies, considered as a form of prevention, as diversion of waste from the municipal waste flow. While being more a peculiar form of treatment than a prevention process, home composting is interesting especially in areas with gardens because the compost can be directly used without transport for improving the soil of gardens. This avoids the use of other soil improvers, while its potential for use in energy generation is not available. It is however uncertain if home-composting is to be preferred over other types of biowaste treatment due to lack of data on home-composting. In a recent EU study [35], home composting has been modelled as an intermediate between aerobic and anaerobic digestion without energy recovery; results showed high impacts mainly due to the emission of methane as greenhouse gas.

The burning of biowaste at home is not considered as a preferable option because the incineration at home cannot be carried out in an efficient way with emission control and generally does not lead to the production of energy or other types of positive results.

Separate collection avoids the contamination of biowaste with other municipal waste. Biowaste becomes thereby theoretically available for high-quality recycling, like composting. The way this separate collection takes place can influence the amount of biowaste offered for collection. For instance the transition from using bags to large containers has in some cases lead to an increase of the collected amount of biowaste with 30% to 40%, while the adoption of a pay-per-kg system such as DIFTAR leads to decreases of the collected amount. These differences in collected amounts are often not taken into account in LCA studies because the starting point is considered to be the amount that is collected and not the amount that is generated.

In sub-urban areas a **mix of collection** methods is applied where e.g. garden waste has a separate collection in a bring system and biodegradable kitchen waste is still being collected integral with the other municipal waste.

Within the high-density urban areas the collection of biowaste is often **integral in combination with non-biodegradable waste**, because of the difficulties (comfort and hygiene) with organising separate collection where there is little space and lower separation discipline. Collected waste is either taken directly to a treatment facility or first to a central waste transfer station from which the waste is later transported to treatment. These central transfer stations are sometimes used for pre-treatment and/or storage of biowaste.

These four collection methods have been selected to further analyse the literature.

3.2 Availability of literature and data regarding selected collection methods

The list of biowaste life cycle literature was screened for available information and LCA data on collection methods for biowaste (Chapter 8 and Chapter 9). In Table 1 the selection is presented of the most relevant literature for collection from this list. They are organised per collection method. Literature with high relevance includes directly usable LCA data, with a wide scope and of good quality. Literature with medium relevance includes also usable data but is less comparable due to research choices, limited scope or less quality[6].

Table 1 Overview of most relevant literature concerning the methods of biowaste collection

	Literature (Ref. Chapter 8)	
Selected collection methods	**High relevance**	**Medium relevance**
Collection in general	86, 38, 70, 77	
Prevention	35, 85	41, 61
Separate collection	1,2,4,6,7,9,16,24,25, 35, 85	19,20,21,26,34,36,38,39,57,61,77,81
Mixed collection (integral/separate)	2,4,16,25,35,85	19,20,21,26,38,61
Integral collection	1,4,6,7,9,24,25,35,85	20,21,26,36,57,61

Based on the conclusions of the studies, a number of relevant factors are identified that influence the environmental performance of collection methods. Separate collection of biowaste in high density urban areas is more expensive because of the lower production per household and has equally potentially higher environmental burden than in less dense populated areas [86]. This means that the distinction between urban, sub-urban and rural areas in the environmental assessment of collection methods can be relevant.

[6] The quality has been assessed on the basis of detail of the inventory, the used impact assessment and the general argumentation that are presented in the study.

The choice of the collection system also influences the composition of the collected waste (sorting instruction for consumers, bag material) [38] and the methane production and thereby affects the overall environmental impact of the management of biowaste.

Transportation of waste in general seems of low importance to the overall environmental impact of biowaste management [e.g. 70]. The influence of truck transportation on the total environmental impact is often low, according to [77]. In general it is expected that the collection phase has a relatively small influence on total environmental impact [70], while this will influence the choice of management options overall.

However, it is proposed to include some factors like transportation distance and means of transport in the guidelines because in some cases (long distances) these impacts are not negligible and the choice of collection method can also influence the environmental impact of the treatment and recycling of the biowaste. Equally, while an issue may not have the highest impact in a life cycle it can still be where the highest potential for improvement exists. It is therefore important to retain the consideration of such factors, particularly if this is where decision-makers can have a big influence.

The following set of local factors that influence the total environmental impact is therefore suggested for inclusion in the development of the guidelines:

Table 2 Set of selected local factors (collection methods)

Local factors
Transportation means (size and/or type truck)
Frequency of collection per waste fraction
Distance to waste transfer station

These selected methods and local factors shall be taken as a minimum, but may be extended in the definition of the guidance document if other methods or factors turn out to have also a significant influence on the environmental impact.

4 Biowaste treatment

4.1 Overview and selection of treatment methods

There are different methods in which biodegradable waste is currently being treated. For each of these treatment methods there are again a number of factors that can influence environmental performance. A limited set of treatment methods was selected for this study. This set covers the treatment methods, which are mostly utilised. Methods that are not commonly used are not taken into account. These methods can be included later, which is particularly important for emerging technologies.

For the selected treatment methods, a few important variations in the treatment are taken into account that influence the environmental impact, e.g. for incineration the variation with or without energy recovery are assessed as different methods (see Table 3).

Table 3 Set of selected treatment methods

Treatment methods	Further characterisation
Landfill	With or without methane recovery, legal and illegal dumping
Composting	Open and closed types, central and home composting
Incineration	With and without energy/heat recovery, efficiency of the recovery
Anaerobic digestion	Pre- and after-treatment of organic matter
Gasification	Based on garden waste

Landfill of biowaste leads to the release of e.g. CO_2 and methane. The methane can be collected and combusted for energy production. If biowaste is integrally collected with other municipal waste and then landfilled it will come into contact with other (toxic) substances such as heavy metals. The, often, acid and moist environment of the biowaste will help releasing these substances into toxic leachate. Also separately collected biowaste can contain heavy metals, which originate from the soil. The leachate can be treated, depending on the landfill method.

Incineration: Depending on the type and efficiency, incineration of biowaste can generate electricity and/or heat, which will thereby avoid energy production from other (e.g. fossil) sources. Incineration normally will lead to CO_2 production, exhaust fumes and a (toxic) final waste fraction that needs to be landfilled. Incineration takes most often place in a municipal waste incinerator for mixed municipal waste. In some cases, garden waste is incinerated as a small extra fraction in coal fired electricity plants as a renewable resource. For incineration with energy recovery it is not necessary to have separately collected biowaste.

Composting can be divided into two major methods, namely open and closed methods. Open methods release the greenhouse gas methane in large amounts into the open air, while the closed vessel methods make it possible to collect the methane for combustion. The resulting product can be a mature (or stabile) or immature (or fresh) compost depending on the processing duration. Mature compost is no longer active and does not produce CO_2 or methane in large quantities in contrast with immature compost. Both types have useful but different applications in agriculture. The accumulation of heavy metals from compost in agriculture may occur under certain circumstances. Among other issues, heavy metals may originate from the soil where the biomass has been growing and the content is locally dependent. In case of composting it is very important to have separate biowaste collection to produce a high-quality compost.

Anaerobic digestion of biowaste is a treatment method aimed at the production of methane for electricity, heat production or the production of synfuels[7]. It is especially suitable for wet organic matter such as kitchen waste. The remaining digested sludge from anaerobic digestion can often be applied as compost if the content of heavy metals meets the compost standards (see Table 10). Otherwise the remaining sludge needs to be incinerated or landfilled. Both separate collected biowaste as well as biowaste from integral collection of municipal waste can be utilised for anaerobic digestion. Biowaste from integral collection has the disadvantage of being of lower quality due to contamination from other municipal waste.

Gasification of biowaste is aimed at the production of energy and synfuels. This method is based on heat treatment and is most commonly utilised to produce CO, that can be turned into synfuels. Drier matter, such as woody garden waste, is most suitable for this application. Depending on the quality of the remaining ashes, they can be used as fertilizer. Otherwise they need to be landfilled.

Next to the types of treatment methods, also a set of local factors are selected that can influence the environmental impact of treatment methods (see Table 4).

Table 4 Set of selected local factors (treatment methods)

Local factors
Energy recovery and recycling efficiency
Waste composition / contamination
Availability of treatment facilities
Distance from storage to treatment facility
Transportation means (truck, train, inland vessel)

The energy recovery efficiency does not only differ significantly per treatment method but also between installations that utilise the same treatment method. To have an accurate assessment it is vital to take this local factor into account.

[7] Synfuels are synthetic derived fuels, often based on biological resources, in contrast with fossil fuels based on processed crude oil.

The biowaste composition and quality is an important factor in the assessments for several reasons. The content of carbon and water determine the lower heating value and thereby the energy recovery efficiency. The content of nitrogen (N), phosphorous (P), potassium (K) and carbon (C) and heavy metals determine the potential for recycling products, like compost or fertilizers. Finally the content influences the applicability for different treatment methods. Biowaste with high water content is e.g. more suitable for digestion than for gasification.

Important parameters regarding the composition are given in Table 5.

Table 5 Relevant composition parameters

Relevant composition parameters	In relation to:
Nitrogen (N), Phosphorous (P), Potassium (K)	Application as compost / fertiliser
Carbon (C)	Lower heating value and soil improver
N/C ratio of end product	Indication of maturity of compost
water	Lower heating value
Heavy metal content	Red flag indicator for applicability in agriculture

A practical but important factor represents the regional availability of treatment facilities, both in type, distance and capacity. If only incineration without energy recovery and enough capacity is available at close range it may turn out to have a better environmental performance than a high efficiency incinerator with a high yield of energy recovery but at a very long distance, depending on the relative importance of emissions from transport. It may also mean that investing in upgrading or adding new treatment facilities with a high level of efficiency is an opportunity to improve the environmental performance of the biowaste management.

The available transport mode is also relevant in such trade-off decisions. If train or inland vessels are available for transporting biowaste, this may resolve the lack of more local efficient treatment capacity.

The methods and local factors as reported in this paragraph have to be taken into consideration for the development of the guidance document.

4.2 Current treatment of biowaste in the EU

Biological treatment of biowaste varies considerably from country to country in the European Union. According to a study by COWI A/S [86], half of the EU-15 and all the new Member States still have to initiate biowaste collection and handling schemes in order to meet the targets of the EU landfill Directive[8]. Treatment processes in use for biowaste range from landfill to biological treatment, like composting and anaerobic digestion, incineration as

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

well as more technologically advanced but not yet common thermal treatment methods such as gasification and pyrolysis.

Table 6 gives an overview of the different treatment options for Europe, as presented in a study by the European Commission [26].

Table 6 Share of different treatment options in the EU-15 and new member states

Average as percentage of treated biowaste

Composting	Anaerobic Digestion	Landfill	Incineration	MBT/ Landfill*
21,0 %	1,1 %	60,1 %	16,5 %	1,3 %

* MBT/landfill: This means landfill of biowaste after Mechanical Treatment of biowaste. MBT is used to separate valuable fractions from waste for recycling or to separate fractions of different quality with different treatment requirements.

The most commonly used treatment option for biowaste in Europe is still landfill, although the Landfill Directive suggests the diversion of waste from landfill. This is the case in many new Member States like Poland, Slovenia, Estonia, Cyprus and Hungary[9], but also in the United Kingdom, Ireland, Spain and Greece. Table 7 gives a more detailed overview of the different treatment options within different countries of the European Union as presented by COWI A/S [86].

Table 7 Different treatment options for biowaste per country

Country	Landfill**** (%)	Incineration (%)	Biological treatment***** (%)
Sweden*	36~	43	21
Portugal*	61~	24	15
Ireland*	96	0	4
Denmark**	2	70	28
Luxembourg**	7	52	41
Netherlands**	12	44	44
Belgium**	16	40	44
Austria**	18	26	56
Germany**	25	50	25
France**	37	48	15
Italy**	69	22	9
Finland**	70	23	7
Spain**	81	8	11
Greece**	89	10	1

[9] See also K. Koneczny et al. Environmental Assessment of Municipal Waste Management Scenarios: Part I – Data collection and preliminary assessments for life cycle thinking pilot studies. EUR 23021 EN - 2007

Country	Landfill**** (%)	Incineration (%)	Biological treatment***** (%)
UK**	96	0	4
Poland***	97	0	3
Slovenia***	98	0	2
Estonia***	100	0	0
Cyprus***	100	0	0
Czech Republic***	73~	8	19
Hungary***	91~	9	0

* Situation in 2004, management of food and green waste [86].
** Biowaste landfilled (extrapolated from biowaste produced in 1995)
*** Data on new member states, 2002
**** Landfill including landfill after MBT
***** Biological treatment includes composting and anaerobic digestion
~ Number has slightly been adapted to retrieve a 100% total (presuming differences are caused by differences in base year)

As can be noted from the table, it is clear that for some countries like Luxembourg, The Netherlands, Belgium and Austria, biological treatment is the main treatment option. Of the different biological treatment options for biodegradable waste, composting is the most commonly used option (see also Table 6).

4.3 Availability of literature and data regarding selected treatment methods

A long list of literature was screened for the general conclusions on the environmental impact of biowaste and available LCA data on treatment methods for biowaste (see Chapter 8 and 9).

In Table 8, the most relevant literature is presented in a list, which is organised per selected treatment method.

Literature with high relevance includes relevant conclusions and directly usable LCA data, with a wide scope and of good quality. Literature with medium relevance includes less valuable conclusions and data due to research choices and a limited scope.

- **Table 8 Overview of most relevant literature concerning the methods for biowaste treatment**

	Literature (Ref. Chapter 8)	
Treatment method	**High relevance**	**Medium relevance**
Treatment methods in general	1, 2, 4, 70, 77, 36	
Selected methods		
Landfill	1, 2, 4, 16, 35	17, 19, 20, 21, 26, 31, 49, 61, 62, 69,70, 71, 80, 81, 82, 83, 84
Composting	1, 2, 4, 6, 7, 9, 16, 24, 25, 35, 85	17,19, 20, 21, 26, 34, 36, 39, 49, 50, 56, 57, 61, 69, 70, 71, 77, 81, 82, 83, 84
Incineration without energy recovery	1, 4, 35	19, 26, 57, 61, 80, 81, 82, 83, 84
Incineration with energy recovery	1, 4, 6, 7, 9, 16, 35	17,19, 20, 21, 26, 36, 39, 40, 49, 50, 57, 61, 62, 69, 70, 71, 77, 81, 82, 84
Anaerobic digestion	1, 4, 16, 85	17, 20, 21, 26, 31, 34, 36, 38, 40, 50, 53, 57, 69, 70, 71, 81, 82, 83, 84
Gasification	1, 2, 4	20, 21, 26, 39, 50, 57, 83
Fuel production	-	40, 57
Other methods (not selected)		
Fluidised bed combustion	1	-
Pyrolyse	-	21, 26, 84
Mechanical Biological Treatment	85	21, 26
Biocell	-	31
Food to wastewater treatment	-	32, 36
Thermal conversion	-	40

There are a number of conclusions that can be drawn from the selected literature regarding the environmental performance of the treatment options and the relevant factors that may influence the environmental impact of the treatment methods.

A general recurring and clear conclusion indicates the poor environmental performance of the landfill of biowaste in comparison to other treatment methods. This is in line with the EU landfill directive. Landfill of biowaste should therefore be avoided, particularly from uncontrolled landfills, see e.g. [70] and [36]. The differences in environmental impact of the other selected treatment methods are less unambiguous. In [70] it is concluded that there are small difference in environmental impact between incineration and aerobic digestion but both have a better environmental importance compared to composting. While in a recent European study [35] the process of anaerobic digestion plus composting with energy recovery has a lower environmental impact compared to incineration.

The environmental performance of the treatment methods can vary considerably as a result of local factors. For example, the environmental impacts of anaerobic treatment are mainly affected by site specific conditions, such as climate, methane emissions, soil type and agricultural practice as well as substituted energy source [38]. In many studies the influence of heavy metals in various treatment methods is not clear [77]. In [86], the importance is reported to consider also the environmental effects of post treatment of remaining residue from digestion.

The environmental benefits of compost differ strongly and are not always clear in LCAs [45]. If compost is e.g. used as top over of landfill sites, the positive impact is usually low [77]. Depending on the chosen time horizon, compost can function as a carbon sink (short time horizon); however if a long time horizon is chosen (indefinite) then there is no carbon sink to be expected. Also the measures that are taken to reduce GHG emissions from (windrows) composting are important for the overall impact of composting [77]. Furthermore, as addressed in the next section, alternative composts being replaced will influence the environmental performance.

One should consider also that not all treatment methods are as well performing for different types of biowaste. For example, the digestion of biowaste is not always possible especially in the case of garden waste that may contain a large quantity of indigestible (woody) parts [86].

The general conclusion is therefore that:

- Landfill should be avoided.
- Local factors can be very relevant for the environmental impact of treatment methods.
- Different types of biowaste require different treatment for optimal results.

5 Recycling and recovery of energy

5.1 Overview and selection of recycling and recovery methods

The management of biowaste often results in recycling products and energy recovery. These biowaste-based products avoid the use of other products and often result in positive environmental benefit.

Table 9 lists the considered products from recycling of materials and energy recovery and the related avoided products. Apart from these products, remaining waste streams may occur from the treatment method, which are also listed.

Table 9 Considered avoided products and waste streams

Selected treatment methods	Avoided products	Remaining waste streams
Landfill	Gas, electricity, heat (if methane is recovered)	Leachate
Composting	Peat, fertilisers	Waste from impurities to incineration
Incineration without energy recovery	Soil (for landfill cover)	Residue to final waste (landfill)
Incineration with energy recovery	Electricity, heat	Residue to final waste (landfill)
Anaerobic digestion	Electricity, heat, uncontaminated digested sludge to agriculture	Contaminated digested sludge to incineration
Gasification	Gas, electricity, heat	Residue to final waste (landfill)
Fuel production	Diesel, methanol, gas	Residue to final waste (landfill)

The fraction of the treated biowaste that will be turned into actual recycling products and energy recovery depends on the quality and composition of the initial biowaste. This is especially the case for recycling products, such as compost as soil improver.

In order to ensure the quality of compost, legal standards are developed by different countries (see Table 10). They make it possible to identify products that do not fulfil the standards.

Table 10 Standards (contents of heavy metal in mg per ton dry matter) for compost in some countries and possible EU standards [85]

Country	Cd	Cr (tot)	Cr (VI)	CU	Hg	Ni	Pb	Zn
Ireland	1.5	100	-	100	1	50	150	350
Sweden	1	100	-	100	1	50	100	300
Portugal	20	1000		1000	16	300	750	2500
EC class 1	0.7	100		100	0.5	50	100	200
EC class 2	1.5	150		150	1	75	150	400
(EC organic farming)	0.7	70	0	70	0.4	25	45	200

Many Member States have currently their own standards for the quality of compost. It is clear that there are significant differences. It is therefore necessary to consider the significance of these variations in terms of environmental impacts. In the formulation of the guidance document, a default value should be used (e.g. possible EU standards), but where possible the standards that are currently in use by the Member States can be included.

It is important to note that the heavy metals in compost may be originating from the natural sources in soil on which the plants have been grown. Firstly this means that heavy metal content of biowaste is region dependent. Secondly this means that for environmental assessments it has been argued to leave heavy metals out of the modelled system because they do not originate from the biomass itself. This approach has e.g. been chosen in [1]. On the other hand it is clear that compost with a content of heavy metals above the standards is not allowed to be used in agriculture. Furthermore, omission of heavy metals can create bias towards some management options when assessing their impact.

It is proposed to use a “red flag” approach in guidelines to avoid the use of compost that is not in compliance with applicable standards.

5.2 Availability of literature and data regarding selected recycling and recovery methods

LCA data on the material and energy products in Table 9 are available in most known LCA databases, including the European ELCD core database[10]. The data to be used for the guidelines shall be consistent and comparable.

Especially, data on the different electricity mixes of countries are relevant because they provide insight into the possibilities for environmental benefits through the avoided production of electricity of each country where electricity is produced from biowaste. Countries that have, on average, a greater environmental impact from their electricity mix will therefore benefit more from the production of electricity out of biowaste.

[10] http://lca.jrc.ec.europa.eu/

Overall, the literature screened in this study suggests that the environmental benefits and performance of treatment methods are largely determined by the opportunities for recycling and energy recovery and the related avoided products. For example, incineration is a more favourite treatment method if the produced energy replaces non renewable energy sources [70, 77, 36]. As the environmental benefits of the avoided products are often greater than the negative environmental impact of the collection and treatment of biowaste, it is recommended to optimise treatment and collection based on the selection of the most interesting option for recycling or energy recovery from biowaste.

The best options for recycling of biowaste are depending on local factors. It is recommended in the literature to make a good choice between biowaste used as soil improver or as energy source, according to what is locally needed mostly [86] while still considering broader trade opportunities. Compost is important in regions with poor soils [86]. In case of energy recovery, the avoided energy source is crucial for the outcome of the environmental assessment and should be matter of attention [38].

The general conclusion is therefore that:

- Use of high quality and consistent data in LCA is important for comparability reasons.
- Environmental benefits are largely determined by the opportunities for recycling and energy recovery and the related avoided products.
- The best options for recycling of biowaste are dependent on local factors.

6 Local and regional differences

Various studies reviewed point out that the environmental effects of biowaste management methods are influenced by local and regional factors:

- Climate zones
- Need for soil improvement
- Types and quantities of biowaste
- Potential markets for recovered products from biowaste (including heat)
- Institutional and legal framework
- Political decisions.

The relevance of these factors is discussed in the following paragraphs.

6.1 Climate zones

A regional difference that affects the choice of the collection and treatment method of biowaste is the climate.

Higher temperatures during the year can require more frequent (separate) collection to avoid premature decomposition of the biowaste, for example, leading to nuisance and unhealthy situations. In case of open air types of composting, the microbiological processes for composting require a certain temperature range to be sustained. Also the speed of these processes is affected within this range. A low temperature will slow down the process. As the production of biowaste is not distributed evenly over the year, especially for garden waste that is typically produced during the warmer season, this does not have to present a big problem, in this case.

Other waste treatment methods that involve a temperature treatment can also depend on the climate zone and require more energy to keep process temperatures at required levels, such as anaerobic digestion and gasification. This increase of energy consumption can reduce the overall environmental performance of the treatment method.

The effects of climate are not taken into account in the reviewed assessments. The influence on the environmental performance of the different climate zones needs more study.

6.2 Needs for soil improvement

Manmade compost is a substitute for e.g. peat-based compost and for mineral fertilisers. As a soil conditioner, compost can improve various aspects of soils. Examples are the water drainage, increasing of the water holding capacity, improving the nutrient holding capacity, as a source of organic matter, etc. [see e.g. 45, 85, 86].

Depending on regional specialisation in arable and livestock farming, regional situations can vary strongly from soils that are being depleted of organic matter, to soils with an excess of organic sources of nutrients [86, 36]. In regions with depleted soils and over exploitation of peat-bogs the production of compost can be more urgent than in other regions, or products can be transported to regions where they are more useful.

Typically the benefits of composts are not quantified in LCAs in absolute terms. Studies generally compare the relative advantages and disadvantages of manmade compost for e.g. peat-based compost and for mineral fertilisers, assuming the same functional performance.

6.3 Types and quantities of biowaste

The regional composition of biowaste in households varies according to a range of factors, including geographical location, seasons, the urban or rural characteristics of the region, type of settlements, standard of living, food and drink habits.

In European countries between 22% and 49% of municipal solid waste consists of food and garden waste. In some Mediterranean regions this proportion is much larger and consists of high percentages of fermentable waste (up to 70%) because of a relatively large use of vegetables and fruit in the daily diet, tourism that generates extra waste from meals and a lower presence of packaging waste due to a less wealthy economy.

6.4 Potential markets for recovered biowaste products

The chosen treatment option will also determine the type and amount of recovered products produced from biowaste. Market prospects for recycling and recovering of energy differ strongly from one region to another. For example the demand for compost is influenced by various factors, such as the costs for collection and production, the quality of compost, the applications (agriculture, landscaping, hobby gardening), the agricultural situation, market prices depending on offer/demand ratios, availability of other products, product recognition and customer trust.

6.5 Institutional and legal framework

In addition to the European Landfill Directive that limits the amount of biodegradable waste for landfill to 35% of 1995 level by 2016[11], European regions have to comply with national regulations and policies regarding the management of biowaste. Important national regulations include the quality standards for compost that differ strongly from country to country and regulations for the quality of the soils.

[11] Council Directive 1999/31/EC of 26 April 1999 on the landfill of waste

Other instruments that influence the management of biowaste are banning from landfill (Germany, Austria), mandatory separated collection schemes (Austria, Catalonia, Denmark, Netherlands, or town like Venice), subsidies for the use of compost (Piedmont and Emilia Romagna regions in Italy) and national standards on minimum environmental effects of treatment (Netherlands).

6.6 Political decisions

The goals aimed at by politicians regarding biowaste treatment and the environment, in general, change over time and can differ regionally. For instance the goal to reduce certain emissions contributing to climate change is currently very important. This can influence the relative importance given to different impact categories such as toxicity effects, eutrophication, etc. If explicit weighting is used to e.g. reflect these preferences, then different weighing sets can lead to different conclusions. This is a well know methodological issue within LCA [36].

7 Discussion

7.1 Conclusions regarding the analysis of existing studies

This report presents the outcome of the analysis of existing studies on the management of municipal biowaste using a life cycle perspective. For the elaboration of the analysis, a division of the most relevant phases in the life cycle of biowaste was made, namely collection, treatment and recycling and energy recovery. Furthermore local and regional factors were selected, which are likely to have a strong influence on the environmental impact of biowaste management, such as the waste composition and the recycled products. The main conclusions with respect to the environmental impact, the data on environmental effects of biowaste management and the factors that influence these environmental effects in the life stages are summarised.

In general, the data about the environmental impact of most of the treatment and collection methods were collected from 86 existing studies (see Chapter 8 Literature list).

The three main collection methods, namely separate collection, integral collection and mixed combinations of separate and integral collection, are covered well in these studies. Most studies are oriented towards separate collection. The most common treatment methods are also described well, such as windrow composting and incineration in a municipality waste incinerator with energy recovery.

Data gaps occur, however, within the variations of the different treatment options. For example, illegal landfilling or biowaste burning at home is not described in the existing studies. Also home composting is given little attention. No detailed data are found for the distinction between types of collection techniques, such as bags versus containers. Usually only one scenario is assessed for each collection method with a fixed average distance and frequency of collection.

In most cases recycling and energy recovery from biowaste are described and taken into account within the life cycle system. However, there is limited explicit information about the implications of soil improvement capabilities of compost.

In the studies less attention is given to variations in relevant local and regional factors, such as climate differences, differences in soil, differences in technical performance of one type of treatment method, potential markets for recovered products, differences in legal frameworks and eco-efficiency of a treatment method for different population densities. The composition of biowaste is usually described but the impact of variations in composition is not.

Life Cycle Assessment data have in most cases been presented as Life Cycle Impact Assessment results and in fewer cases as Life Cycle Inventory (emission and resource consumption) data.

In practise the results from these studies are difficult to compare because of differences in:

- assumptions e.g. regarding transport distances, waste composition, etc;
- differences in inventory method e.g. detail in questionnaires, primary or secondary data sources, etc;
- modelling e.g. completeness in modelled substances for emission, stages and system boundaries;
- used LCA databases for background processes e.g. for electricity and heat production;
- used impact assessment methods.

To draft the guidance document, it is therefore necessary to use good quality LCI data, compiled in a consistent manner and with a high completeness regarding the selected collection and treatment methods. The different treatment methods need to equally be assessed according to a standard procedure, which ensures a high level of comparability between the different treatment methods. The International Reference Life Cycle Data System (ILCD) with its associated data network and handbook will therefore be essential in this context.

7.2 Preliminary concepts for possible guidelines on biowaste management

When comparing the results of the studies, a number of conclusions are drawn:

- From an environmental point of view, landfill of biowaste, even in optimal conditions regarding methane capture, treatment of leachate and in compliance with regulations, should be generally avoided in favour of other treatment options. The main reason for this is that in the case of landfill there is hardly any or inefficient recycling of biowaste.
- Another important finding from the literature is that, next to landfill, there is not one conclusive “best” waste treatment option. This finding is based on the conclusion of studies that have compared the different treatment options, see e.g. [71]. The variations in the LCA results are largely depending on local factors such as the availability of recycling and energy recovery options, the avoided products and the efficiency of treatment facilities. These local/regional factors can change the order of most preferred treatment method fairly easy.
- The other considered treatment methods have the potential to improve environmental performance by optimising the recycling of materials and recovery of energy. The positive environmental effects of recycling and energy recovery are related to the avoided products (e.g. electricity, fertilizers etc). These positive effects can exceed the environmental burden of the waste collection and treatment itself, while further benefits may be achieved through waste prevention that are generally not quantified in waste management studies.

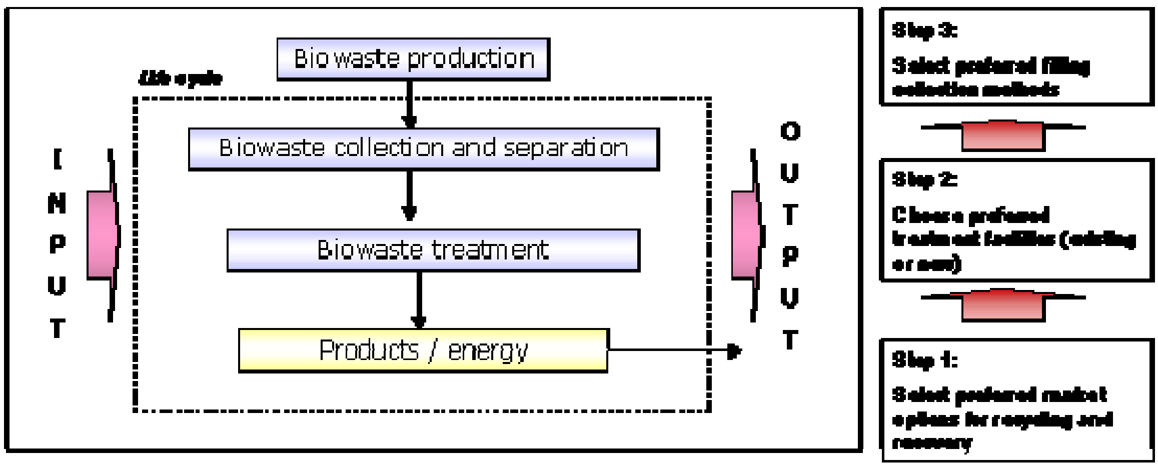
- In most cases not one but a system of treatment methods need to be applied to get an optimal environmental performance. This is firstly because one treatment option may require further treatment of a residual waste stream. This is e.g. the case for anaerobic digestion, where a remaining digested waste stream still needs to be composted or incinerated.
- The collected waste can differ considerably in composition, depending on the source where the waste is collected from and the type of collection. For instance integral collected waste from dense urban areas has a different composition than separately collected waste from rural areas. These differences can influence the efficiency of treatment and recovery considerably.
- The availability of options for recycling and energy recovery seems to be an important factor that influences the total environmental performance of biowaste management and should therefore be an important guiding principle for the development of guidelines for the management of biowaste.

From this, two basic principles for the development of the guidelines are recommended:

1. Exploit recycling and energy recovery as far as possible, avoiding lost opportunities through landfilling.
2. Start with an inventory of opportunities for the recycling of biowaste or energy recovery from biowaste (in combination with the expected avoided products) and optimise biowaste management according to these options.

This approach can be called the “reverse chain management”, which means that it is preferred to start by selecting the most optimal waste management approach from the end of the chain (at the recycling and recovery phase) and then working your way back through the logical and most efficient choices regarding biowaste treatments and finally the waste collection that facilitates the requirements for the recycling and recovery best. Based on these principles, the guidance document can be formulated (see Figure 2).

Figure 2 The reverse chain management approach



In order to decide if certain local factors are of importance, the biowaste guidance should therefore not simply give the most favourable treatment option but should present some options to test the sensitivity of treatment options to local factors.

8 Literature list

Nr	Authors	Title	Source	Place	Date
1	AOO.	Environmental Impact Assessment of Different Waste Treatments for Kitchen and Garden Waste. (MILIEUEFFECTRAPPORT LANDELIJK AFVALBEHEERPLAN Achtergronddocument A14, Uitwerking “gft-afval”)	National Waste Management Plan 2002-2012. Ministry of Environment, AOO Dutch Waste Management Council, (in Dutch)	Utrecht (NL)	2002
2	AOO.	Environmental Impact Assessment of Garden Waste. (MILIEUEFFECTRAPPORT LANDELIJK AFVALBEHEERPLAN Achtergronddocument A15, Uitwerking “groenafval-afval”)	National Waste Management Plan 2002-2012. Ministry of Environment, AOO Dutch Waste Management Council, (in Dutch)	Utrecht (NL)	2002
3	R.J. Saft (IVAM) and W. Elsinga, in BioCylce International	"Source Separation, Composting - A Win For Greenhouse Gas Reduction"	August 2006		2006
4	IVAM	IVAM LCA Data 4.05	IVAM	Amsterdam (NL)	2006
5	Tim Brethouwer, R.J. Saft	LCA and the carbon Balance in the Netherlands	ORBIT2006		2006
6	Elsinga, W., Saft, R.J. (IVAM)	GFT-afval scheiden aan de bron essentieel voor duurzaam afvalbeheer	In: Gemeentereiniging en Afvalmanagement 2, 6-9 (in Dutch)		2006
7	R.J. Saft, H.A.L. van Ewijk	De winst van compost (de profit of compost)	IVAM		2005
8	R.J. Saft, H.A.L. van Ewijk	Life at the landfill gets crowded	Biocycle, August 2006		2006
9	Grontmij Nederland bv & IVAM UVA bv	A Life Cycle Assessment for Vegetable, Fruit and Garden Waste, Review of the LCA accompanying the 2003 Netherlands National Waste Plan			2004

Nr	Authors	Title	Source	Place	Date
10	Presentation at JRC by Marco Kraakman, prepared by IVAM and the Dutch Waste Management Council	LCA on the organic fraction of household waste in the Netherlands			2004
11	R.J. Saft (IVAM)	Diseases suppressiveness, Input for Round Table meeting compost on March 2 2004	February 24 2004 (in Dutch).		2004
12	cancelled				
13	R .J. Saft, H.A.L. van Ewijk	Afval Biomassa: Lust of Last. Notitie ten behoeve van het Ministerie van VROM (Biowaste: a burden or a pleasure)	Note commissioned by the Dutch ministry of housing and environment - 24 September 2004	Amsterdam (NL)	2004
14	IVAM	Waste Management and LCA	A training week dedicated to waste management and LCA within the COST Action 530 framework organised by IVAM and Sofia University St. Kliment Ohridski. September 26-30	ozopol, Burgas area (BG)	2005
15	R.J. Saft , H.A.L. van Ewijk	Status Paper: Dutch LCA experiences with Biowaste Management	IVAM	Amsterdam (NL)	2006
16	Baky, A. Eriksson, O.	Systems Analysis of Organic Waste Management in Denmark.	Danish EPA, Environmental Project No. 822, 2003		2003
17	Bjarnadottir, H.J. et al	Guidelines for the use of LCA in the waste management sector.	Linuhönnun consulting engineers and DNV, Nordtest report TR 517		2002
18	Björklund, A.	Environmental systems analysis of waste management, with emphasis on substance flows and environmental impact.	Licentiate Thesis, TRITA-KET-IM, Dept. of Chemical Engineering and Technology, Royal Institute of Technology, Stockholm, Sweden	Stockholm (SE)	1998
19	ECOTEC Research and Consulting Ltd.	Beyond the bin: the economics of waste management options.	Report to Friends of the Earth, UK Waste and Waste Watch		2000
20	Grant, T. et al	Life Cycle Assessment of Waste and Resource Recovery Options (including energy from waste).	RMIT – Centre for Design (Nolan – ITU)	Melbourne (AUS)	2003

Nr	Authors	Title	Source	Place	Date
21	Hogg D. et al.	Economic analysis of options for managing biodegradable waste.	Report to the European Commission, EUNOMIA Research and Consulting, HDRA Consultants, ZREU and LDK ECO		2002
22	McDougall, F.R. et al	Integrated Solid Waste Management: A Life Cycle Inventory - 2nd Edition., Ltd.	Blackwell Science	Oxford (UK)	2001
23	Murata, M.	Life cycle assessment of food waste recycling and management.	Master thesis Kyoto University, 2000	Kyoto (JP)	2000
24	Saft, R.J., Kortman J.	Composting of kitchen and garden waste: evaluation of some… in the National Waste Management Plan. (Nadere beschouwing van de LCA voor GFT-afval in het MER-LAP)	IVAM UvA bv, 2004 (in Dutch, English version in prep.)	Amsterdam (NL)	2004
25	Sharma, G., Campbell A.	Life cycle inventory and life cycle assessment for windrow composting systems.	NSW Department of Environment and Conservation, University of New South Wales/Recycled Organics Unit	Melbourne (AUS)	2003
26	Smith, A.	Waste management options and climate change. 2001	Report for the European Commission, AEA Technology	UK	2001
27	Strutz, F.	Life cycle comparison of five engineered systems for managing food waste (brief summary and interpretation).	University of Wisconsin	US	1998
28	US EPA	Solid waste management and greenhouse gasses, a life cycle assessment of emissions and sinks. Second edition.	EPA 530-R-02-006	US	2002
29	Vogt et al.	Ökobilanz Bioabfallverwertung – Untersuchungen zur Umweltverträglichkeit von Systemen zur Verwertung von biologisch-organischen Abfällen. Deutsche Bundesstiftung Umwelt / Ifeu, 2002.	Deutsche Bundesstiftung Umwelt / Ifeu	DE	2002
30	Weitz, K.	A decision support tool for the life cycle management of municipal solid waste.	RTI International		2002
31	A. Fliedner a, O.	Anaerobic Treatment of Municipal Biodegradable	Royal Institute of Technology, Dept. of	Stockholm	

Nr	Authors	Title	Source	Place	Date
	Eriksson a, J. -O. Sundqvist b, B. Frostell a	Waste	Chemical Engineering and b Swedish Environmental Research Institute, Box 210 60, S-100 31	(SE)	
32	Carol Diggleman and Robert K. Ham	Household food waste to wastewater or to solid waste? That is The Question	Waste Management Research 2003; 21; 501	Milwaukee (US)	2003
33	Francesco Di Maria and Stefano Saetta	Life cycle assessment for municipal solid waste management improvements -the case of a 100.000 inhabitant Italian town	Dipartimento di Ingegneria Industriale	Perugia (IT)	
34	Trine Lund Hansen et al.	Life cycle modelling of environmental impacts of application of processed organic municipal solid waste on agricultural land (EASEWASTE)	Institute of Environment & Resources, Technical University of Denmark	Lyngby (DK)	2006
35	Karol Koneczny and David Pennington	Environmental Assessment of Municipal Waste Management Scenarios: Part II – Detailed Life Cycle Assessments	EN 23021 EN/2 (European Commission JRC – Institute for Environment and Sustainability)	IT	2007
36	U. Sonesson, A. Bjorklund, M. Carlsson, M. Dalemo	Environmental and economic analysis of management systems for biodegradable waste	Resources, Conservation and Recycling 28 (2000) 29–53	Uppsala (SE)	2000
37	Wanichpongpan, W. Gheewala, S.H. Towprayoon, S. Chiemchaisri, C.	Landfilling of municipal solid waste in a life cycle perspective	This paper appears in: Environmentally Conscious Design and Inverse Manufacturing, 2003. EcoDesign '03. 2003 3rd International Symposium on Publication Date: 8-11 Dec. 2003On page(s): 163- 170. Joint Graduate Sch. of Energy & Environ., King Mongkut's Univ. of Technol., Bangkok, Thailand;	Bangkok (TH)	2003
38	Trine Lund Hansen	Quantification of environmental effects from anaerobic treatment of source-sorted organic household waste	Ph.D Thesis September 2005 Institute of Environment & Resources Technical University of Denmark	DK	2005
39	Weidema, BP; Wesnaes, M; Christiansen, K;	Life cycle based cost-benefit assessment of waste management options	Presentation for ISWA annual congress, 2006, Copenhagen	DK	2006

Nr	Authors	Title	Source	Place	Date
40	Kolev, A; Routsolias, P; Sasu, L.	LCA of the environmental impact from anaerobic digestion, incineration and thermal conversion process for household organic waste treatment	Ecosphere, KTH, Environmental Strategies Research-FMS	Stockholm (SE)	2006
41	Özeler, D; Yetis, Ü; Demirer, GN	LCA of municipal solid waste management methods: Ankara case study	Environment International	Ankara (TR)	2006
42	ECN	Phyllis, database on biomass and waste	http://www.ecn.nl/phyllis/	NL	2006
43	Kirkeby, JT; Birgisdottir, H; Hansen, TL; Christensen, TH	Evaluation of environmental impacts from municipal solid waste management in the municipality of Aarhus, Denmark (EASEWASTE)	Waste Management Research 2006; 24:16-26	DK	2006
44	Hansen, TL; Christensen, TH; Schmidt, S	Environmental modelling of use of treated organic waste on agricultural land: a comparison of existing models for LCA of waste systems	Waste Management Research 2006; 24:141-152	DK	2006
45	Abdissa, MK; Ji, X; Nijkamp, R; Sereti, A; Stols, H; Uwimana, B	How environmentally stable is compost?	Wageningen University, Academic Master Cluster	Wageningen (NL)	2007
46	Coleman, T	Life cycle assessment - supporting waste management	Environment Agency for PEER Environmental Technology Seminar	Montpellier (FR)	2006
47	Toffoletto, L	A perspective on LCA application in the waste industry	Veolia Environnement for PEER Environmental Technology Seminar	Montpellier (FR)	2006
48	-	Parallel session 2a – solid waste management	PEER Environmental Technology Seminar	Montpellier (FR)	2006
49	Vroonhof, JTW, Croezen, HJ	Afvalverwerking en CO2 Quickscan van de broeikasgasemissies van de afvalverwerkingsector in Nederland 1990-2004	CE Oplossingen voor milieu, economie en technologie	Delft (NL)	2006
50	AOO.	MER-LAP 2002-2012	National Waste Management Plan 2002-2012. Ministry of Environment, AOO Dutch Waste Management Council, (in Dutch)	Utrecht (NL)	2002

Nr	Authors	Title	Source	Place	Date
51	Barlaz MA, Kaplan O, Ranjithan SR	The application of life-cycle analysis for solid waste management in Delaware, USA	North Carolina State University	Raleigh, North Carolina (US)	2006
52	ILUET	Umweltrelevanz der dezentralen kompostierung, klimarelevante gasemissionen, flüssige emissionen, massenbilanz, hygienisierungsleistung	Technisches büro für landwirtschaft	Perchtoldsdorf (DE)	2003
53	Ostrem, K	Greening waste: anaerobic digestion for treating the organic fraction of municipal solid wastes	Earth Engineering Center, Columbia University	Columbia University (US)	2004
54	Weiland, P	Biomass digestion in agriculture: a successful pathway for the energy production and waste treatment in Germany	Eng. Life Sci	Weinheim (DE)	2006
55	Schleiss, K	Life cycle implications of biological treatment	Environment & compost consulting	Grenchen (DE)	
56	Favoino, E	Powerpoint: Biowaste and climate change	Scuola Agraria del Parco	IT	2007
57	Vis, M; Feil, F	Onderzoek verwerking GFT afval, eindrapportage	Biomass technology group	Enschede (NL)	2005
58	Siebert, S; Reinhold, J	Management of organic applications to enhance soil organic matter, powerpoint	Bundesgütegemeinschaft Kompost e.V.		2006
59	Kehres, B	Profitable effects of using compost as discovered from good professional experience	Bundesgütegemeinschaft Kompost e.V.	Orbit	2006
60	cancelled				
61	Kaplan, PO; Ranjithan, SR; Barlaz, MA	The application of life-cycle analysis to integrated solid waste management planning for the State of Delaware	North Carolina State University	Raleigh, North Carolina (US)	2006
62	Torfs, R; Linden van der, A; Rabl, A; Zoughaib, A; Taylor, T;	SusTools Tools for sustainability: development and application of an integrated framework: evaluation of treatment options for municipal solid waste and	EC DG Research	BE	2005

Nr	Authors	Title	Source	Place	Date
	Arnold, S; Diakoulaki, D; Mavrotas, G; Holland, M	stakeholder workshops and multicriteria analysis			
63	-	Success stories on composting and separate collection	European Commission DG Environment	BE	2000
64	-	Applying compost, benefits and needs	European Commission Seminar proceedings, Brussels	BE	2001
65	Amlinger, F	Heavy metals and organic compounds from wastes used as organic fertilizers	Working group Compost Consulting and development	AU	2004
66	Vrancken, KC; Torfs, R; Linden van der, A	Evaluation of waste treatment processes for MSW rest fraction	Proceedings workshop on system studies in waste management	Stockholm (SE)	2001
67	Vrancken, KC	Evaluation of treatment scenario's for rest fraction of MSW and non-hazardous industrial waste, management summary.	VITO	BE	2001
68	Vrancken, KC; Torfs, R	Evaluation of treatment scenario's for MSW rest fraction, using various demonstrated techniques	Proceedings ISWA World Congress 2001	Stavanger	2001
69	Sundqvist, J	System analysis of organic waste management schemes – experiences of the ORWARE model	IWA, resource recovery and recycling in organic solid waste management	SE	2004
70	Sundqvist, J	Assessment of organic waste treatment	Renewable-based technologies	SE	2005
71	Sundqvist, J	How should municipal solid waste be treated – a system study of incineration, material recycling, anaerobic digestion and composting	IVL, Swedish Environmental Research Institute	SE	2005
72	Hansen, TL; Svärd, A; Angelidaki, I; Schmidt, JE; Jansen, J; Christensen, TH	Chemical characteristics and methane potentials of source-separated and pre-treatment organic municipal solid waste	Water Science and Technology Vol. 48, Nr4 pp 205-208	DK	2003
73	Bruun, S; Hansen, TL; Christensen, TH;	Applications of processed organic municipal solid	Environmental modelling and assessment	DK	2006

Nr	Authors	Title	Source	Place	Date
	Magid, J; Jensen, LS	waste on agricultural land – a scenario analysis	2006: 11:251-265		
74	Hansen, TL; Sommer, SG; Gabriel, S; Christensen, TH	Methane production during storage of anaerobically digested municipal organic waste	J. Environmental Quality 35:830-836 2006	DK	2006
75	Kirkeby, JT; Birgisdottir, H; Hansen, TL; Christensen, TH	Environmental assessment of solid waste systems and technologies: EASEWASTE	Waste Management and Research 24:3-15 2006		2006
76	Hansen, TL; Schmidt, JE; Angelidaki, I; Marca, E; la Cour Jansen, J; Mosbaek, H; Christensen, TH.	Method for determination of methane potentials of solid organic waste.	Waste Management 2004 24:393-400	DK	2004
77	Boldrin, A	Environmental assessment of garden waste management in Herning Kommune	Institute of Environment & Resources, Technical University of Denmark	DK	2007
78	-	Biotechnology (biogas and composting)	Technical University of Denmark	DK	2007
79	-	Use-on-land	Technical University of Denmark	DK	2007
80	cancelled				
81	Crowe, M; Nolan, K; Collins, C; Carty, G; Donlon, B; Kristofferson, M;	Biodegradable municipal waste management in Europe Part 1: strategies and instruments	European Environment Agency	DK	2002
82	Crowe, M; Nolan, K; Collins, C; Carty, G; Donlon, B; Kristofferson, M;	Biodegradable municipal waste management in Europe Part 2:strategies and instruments, appendices	European Environment Agency	DK	2002
83	Crowe, M; Nolan, K; Collins, C; Carty, G; Donlon, B;	Biodegradable municipal waste management in Europe	European Environment Agency	DK	2002

Nr	Authors	Title	Source	Place	Date
	Kristofferson, M;	Part 3: Technology and market issues			
84	Brodersen, J; Juul, J; Jacobsen, H	Review of selected waste streams: sewage sludge, construction and demolition waste, waste oils, waste from coal-fired power plants and biodegradable municipal waste	European Environment Agency	DK	2002
85	Caroline Saintmard	Managing Biodegradable Household Waste: What prospects for European Local Authorities?	ARC+	Brussels (BE)	2005
86	COWI A/S	Preliminary impact assessment for an initiative on the biological treatment of biodegradable waste.	COWI A/S	Brussels (BE)	2004

9 Literature screening

Figure 3 Analysis of the literature: treatment and collection methods

nr	LCA	non-LCA	Treatment methods									Collection methods						Period	Country
			included	landfilling	Integral incineration	incineration with energy recovery	composting	gasification	anaerobic digestion	fuel production	other	included	prevention	separate	mixed (integral/ separate)	integral	integral incl. industrial waste		
1	x		x		x	x	x	x	x			x		x		x		2000-2010	NL
2	x		x				x	x			x[12]	x		x	x			2000-2010	NL
3	x		x	x	x		x					x		x		x		2006	NL
4	x		x	x	x	x	x	x	x		x	x		x	x	x		2000-2010	
5	x																		
6	x		x			x	x					x		x		x		2000-2010	NL
7	x		x			x	x					x		x		x		2000-2010	NL
8	x		x	x	x		x					x		x		x		2006	NL
9	x		x			x	x					x		x		x		2004	NL
10																			
11	x		x				x											2004	NL
12																			
13	x		x			x			x									2004	NL

[12] fluidised bed combustion

nr	LCA	non-LCA	Treatment methods									Collection methods						Period	Country
			included	landfilling	Integral incineration	incineration with energy recovery	composting	gasification	anaerobic digestion	fuel production	other	included	prevention	separate	mixed (integral/ separate)	integral	integral incl. industrial waste		
14	x		x				x					x		x				2006	NL
15	x		x				x					x		x				2006	NL
16	x		x	x		x	x		x			x		x	x				DK
17	x		x	x		x	x		x										Nordic Countries
18	x																		
19	x			x	x	x	x							x	x			2000	UK
20	x		x	x		x	x	x	x					x	x	x		2003	AUS
21	x		x	x		x	x	x	x		x[13]			x	x	x			EU
22	x																		
23	x		x		x		x	x											JP
24	x		x				x					x		x		x		2005-2010	NL
25	x		x				x					x		x	x	x			AUS
26	x		x	x	x	x	x	x	x		x[14]			x	x	x		2000-2020	EU
27	x		x	x	x		x											1998	US
28	x		x	x	x	x	x					x						2000-2010	US

[13] Pyrolyse and Mechanical Biological Treatment
[14] Pyrolyse and Mechanical Biological Treatment

nr	LCA	non-LCA	Treatment methods									Collection methods						Period	Country
			included	landfilling	Integral incineration	incineration with energy recovery	composting	gasification	anaerobic digestion	fuel production	other	included	prevention	separate	mixed (integral/ separate)	integral	integral incl. industrial waste		
29	x																		
30			x	x	x		x												US
31	x		x	x					x		x[15]								SE
32	x		x	x		x	x				x[16]	x		x		x		1995-2005	US
33	x		x	x		x			x										IT
34	x		x				x		x			x		x				2005-2010	DK
35	x		x	x	x	x	x				x[17]		x	x	x	x		2005-2015	EU
36	x		x			x	x		x		x[18]	x		x		x		2000-2005	SE
37	x		x	x								x	x					2003	TH
38	x		x						x			x		x	x			2005-2010	DK
39	x		x			x	x	x				x		x					EU
40	x		x			x			x	x	x[19]							2006	SE
41	x		x	x		x			x			x	x		x	x		2006	TR
42		x																	NL

[15] Biocell
[16] Food to wastewater treatment
[17] Home incineration, home composting, uncontrolled landfill, composting with energy recovery
[18] Liquid organic waste trough sewage, with a separation of urine for fertilisation goals
[19] Thermal Conversion Process

nr	LCA	non-LCA	Treatment methods									Collection methods						Period	Country
			included	landfilling	Integral incineration	incineration with energy recovery	composting	gasification	anaerobic digestion	fuel production	other	included	prevention	separate	mixed (integral/ separate)	integral	integral incl. industrial waste		
43	x			x		x			x					x				2006	DK
44	x																	2005	DK
45	x		x				x											2007	NL
46	x																		
47	x		x	x														2006	FR
48	x																	2006	FR
49	x		x	x		x	x											2006	NL
50	x		x			x	x	x	x									2002	NL
51	x		x	x		x	x												US
52		x	x				x											2003	AU
53		x	x						x									2004	US
54		x	x						x									2006	DE
55	x		x			x	x		x										CH
56	x		x				x											2007	UK
57		x	x		x	x	x	x	x	x	x			x		x		2005	NL
58		x	x				x											2006	DE
59		x	x				x											2006	DE

nr	LCA	non-LCA	Treatment methods									Collection methods						Period	Country
			included	landfilling	Integral incineration	incineration with energy recovery	composting	gasification	anaerobic digestion	fuel production	other	included	prevention	separate	mixed (integral/ separate)	integral	integral incl. industrial waste		
60																			
61	x		x	x	x	x	x						x	x	x	x		2006	US
62	x		x	x		x												2005	EU
63	x		x				x							x				2000	EU
64		x	x				x											2001	EU
65		x	x				x											2004	AU
66	x		x			x		x										2001	BE
67	x		x			x		x										2001	BE
68	x		x			x		x										2004	BE
69	x		x	x		x	x		x									2004	SE
70	x		x	x		x	x		x									2005	SE
71	x		x	x		x	x		x									2005	SE
72		x	x						x									2003	DK
73	x		x				x		x									2006	DK
74		x	x						x									2006	DK
75	x		x	x		x	x		x									2006	DK
76		x																2004	DK

nr	LCA	non-LCA	Treatment methods									Collection methods						Period	Country
			included	landfilling	Integral incineration	incineration with energy recovery	composting	gasification	anaerobic digestion	fuel production	other	included	prevention	separate	mixed (integral/ separate)	integral	integral incl. industrial waste		
77	x		x			x	x							x				2007	DK
78	x		x				x		x									2007	DK
79	x		x				x		x									2007	DK
80		x	x	x	x	x	x						x	x					
81		x	x	x	x	x	x		x					x				2002	EU
82		x	x	x	x	x	x		x									2002	EU
83		x	x	x	x		x	x	x		x[20]							2002	EU
84		x	x	x	x	x	x		x		x[21]							2002	EU
85		x	x				x		x		x[22]		x	x	x	x		2005	EU

[20] Pyrolyse
[21] Recycling
[22] Home composting, Mechanical/Biological Treatment (MBT)

Figure 4 Analysis of the literature: included parameters and variables

nr	Adjusted for variables					Avoided products considered		Data availability
	Waste composition	Climate	Geo. scale	Tech. Level	Pop. Density	Energy	Product	
1	x		x	high	m,h	x	x	x
2	x		x	high	m,h	x	x	x
3								
4	x		x	high	m,h	x	x	x
5								
6	x		x	high	m,h	x	x	x
7	x		x	high	m,h	x	x	x
8								
9	x					x	x	x
10								
11								
12								
13						x		
14							x	
15							x	
16	x		x					x
17								x
18								

nr	Adjusted for variables					Avoided products considered		Data availability
	Waste composition	Climate	Geo. scale	Tech. Level	Pop. Density	Energy	Product	
19			x		x			x
20	x		x		x			x
21	x	x						x
22								
23								
24								x
25	x	x						x
26	x							x
27								x
28						x		
29								
30								
31								x
32								x
33								
34								x
35	x			high	urban	x	x	x
36								x
37						x	x	

nr	Adjusted for variables					Avoided products considered		Data availability
	Waste composition	Climate	Geo. scale	Tech. Level	Pop. Density	Energy	Product	
38								x
39	x							
40	x					x	x	x
41								
42	x							x
43								
44								
45								
46								
47								
48								
49						x	x	x
50						x	x	x
51								
52								
53								
54								
55						x	x	x
56								

nr	Adjusted for variables					Avoided products considered		Data availability
	Waste composition	Climate	Geo. scale	Tech. Level	Pop. Density	Energy	Product	
57	x			x		x	x	
58							x	
59							x	
60								
61	x				x	x		
62						x	x	x
63								
64								
65								
66						x		
67						x		
68						x		
69						x	x	
70						x	x	
71						x	x	
72								
73								
74								
75								

nr	Adjusted for variables					Avoided products considered		Data availability
	Waste composition	Climate	Geo. scale	Tech. Level	Pop. Density	Energy	Product	
76								
77							x	x
78						x		
79								
80								
81								
82								
83								
84								
85	x	x	x	x	x	x	x	
86								

European Commission

EUR 23497 EN – Joint Research Centre – Institute for Environment and Sustainability
Title: Definition of life cycle thinking guidance document for biowaste management - Inventory of existing studies.
Authors: Bart Krutwagen; Jaap Kortman; Koen Verbist
Editors: Raffaella Bersani, Rana Pant, David W. Pennington
Luxembourg: Office for Official Publications of the European Communities
2008 – 49 pp. – 21.0 x 29.7 cm
EUR – Scientific and Technical Research series – ISSN 1018-5593
ISBN 978-92-79-09768-3
DOI 10.2788/95667

Abstract
European waste policy aims at reducing the negative environmental impact associated with waste generation and management and to contribute to an overall reduction of the environmental impact of the use of resources.
The Commission Communication on the Thematic Strategy on the Prevention and Recycling of Waste (COM (2005) 666) promotes life cycle thinking (LCT) in waste policies at European level and contains proposals to encourage and assist Member States in implementing this approach. This includes specific provisions in the accompanying proposal for a new Waste Framework Directive, as well as the preparation of guidance documents, in particular to the management of biodegradable waste that is diverted from landfill.
In this context, the European Commission's Joint Research Centre is conducting a project aimed at the development of European life cycle thinking guidelines for the management of waste. The present report is the first outcome of the project, focusing on biodegradable waste and presenting the results of an analysis of existing studies on the application of the life cycle approach to biowaste management and treatment options. In this report the main conclusions of the analysis are presented as a first step for the definition of the life cycle guidance document for biodegradable waste management.
The analysis showed that for the management of biodegradable waste that is diverted from landfills, there is no single environmentally best option. The environmental assessment of the advantages and disadvantages of the various biowaste management options is complex because they occur in different phases of the biowaste lifecycle, during collection, treatment and recycling, while contributing to different environmental effects, ranging from greenhouse effects, material depletion, acidification and toxicity for humans and ecosystems.
The analysis equally highlights that the environmental balance of the various options available for the management of this waste depends on a number of local/regional factors, inter alia collection systems, waste composition and quality, climatic conditions, the potential of use of various waste derived products such as electricity, heat, methane-rich gas or compost.
In particular, the positive environmental effects of recycling and energy recovery are related to the avoided products (e.g. electricity, fertilizers etc). These positive effects can exceed the environmental burdens of the waste collection and treatment, while further benefits can exist from waste prevention. Therefore the availability of options for recycling and energy recovery seems to be one of the most important factors that influences the total environmental performance of biowaste management and should be an important guiding principle for the development of European guidelines for the management of biowaste.

How to obtain EU publications

Our priced publications are available from EU Bookshop (http://bookshop.europa.eu), where you can place an order with the sales agent of your choice.

The Publications Office has a worldwide network of sales agents. You can obtain their contact details by sending a fax to (352) 29 29-42758.

The mission of the JRC is to provide customer-driven scientific and technical support for the conception, development, implementation and monitoring of EU policies. As a service of the European Commission, the JRC functions as a reference centre of science and technology for the Union. Close to the policy-making process, it serves the common interest of the Member States, while being independent of special interests, whether private or national.

LB-NA-23497-EN-C

JRC
EUROPEAN COMMISSION

Publications Office
Publications.eu.int

9 789279 097683