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WASTEREUSE

Project: Best practices for agricultural wastes (AW) treatment and reuse in the Mediterranean countries
www.wastereuse.eu

Action 7 – LCA and Risk Analysis

Deliverable "Methodology for identification of carbon footprint (through evaluation of existing methodologies)"

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Contents

Executive summary

In the line of Action 7, a complete Life Cycle Aanalysis (LCA) in terms of raw materials consumption, energy use and emissions, as well as a Risk Analysis (mapping and modelling) by considering the use of a well established risk assessment methodology (DRASTIC approach) are carried out, regarding the options considered in Actions 3-6. Treated and untreated wastes have been characterized to assess the potential effects on soil properties as well as their suitability to improve crop production and quality (Actions 3 and 4) and the most suitable, environment friendly, low cost technologies are used for the development of alternative cultivation practices for the main water and nutrient consuming crops in Spain and Italy, in open field and greenhouse cultivations (Actions 5 and 6).

In the present deliverable, a methodology for the identification of carbon footprint (CF) of various anthropogenic activities, is discussed; emphasis is given on waste production and management. In order to assess the CF, the methodology and assumptions followed are similar to LCA which is a valuable tool for various applications, but inputs provided are related only to the greenhouse gas emissions generated and can adversely affect the environmental sustainability of a process.

The contents of the deliverable are:

1. Introduction

In the line of Action 7, a complete life cycle analysis (LCA) in terms of raw materials consumption, energy use and emissions, as well as a Risk Analysis (mapping and modelling) by considering the use of a well established risk assessment methodology (DRASTIC approach) are carried out, regarding the options considered in Actions 3-6. Treated and untreated wastes have been characterized to assess the potential effects on soil properties as well as their suitability to improve crop production and quality (Actions 3 and 4) and the most suitable, environment friendly, low cost technologies are used for the development of alternative cultivation practices for the main water and nutrient consuming crops in Spain and Italy, in open field and greenhouse cultivations (Actions 5 and 6).

In the present deliverable, a methodology for the identification of carbon footprint (CF) of various anthropogenic activities, is discussed; emphasis is given on waste production and management. In order to assess the CF, the methodology and assumptions followed are similar to LCA which is a valuable tool for various applications, but inputs provided are related only to the greenhouse gas emissions generated and can adversely affect the environmental sustainability of a process.

2. GHG emissions

2.1 General issues

The significant increase in the concentration of carbon dioxide (CO_2) and other greenhouse gases (GHGs) such as methane, nitrous oxide, hydroflurocarbons, hydrochlorofluorocarbons, perfluoro-carbons and sulphur hexafluoride in the atmosphere, has been caused mainly by human activities such as the burning of fossil fuels (coal, oil and natural gas). These activities may cause significant adverse effects on humans, ecosystems and biological organisms and the resulting changes will not be easily reversed for many decades or even centuries because of the long atmospheric lifetime of GHGs and the inertia of the climate system (US EPA, 2006).

GHGs are also emitted during a material life cycle, for example during raw materials transport and processing, manufacturing and various other activities involved. Figure 1 shows the steps in the material life cycle at which GHGs are emitted and carbon sequestration is affected.

Total GHG emissions (without including land use, land-use change and forestry (LULUCF) activities which are covered in the Kyoto Protocol) in the EU-27 for the period 1990–2010 are seen in Figure 2. It is seen that GHG emissions decreased by 15.4% between 1990 and 2010 (862 million tones CO_2eq) and increased by 2.4% (111 million tones CO_2eq) between 2009 and 2010 (EEA, 2012).

Figure 3 shows GHG emissions in the EU‑27 by gas and by sector, in 2008. CO_2 is the predominant GHG emitted, accounting for 82% of total GHG emissions (excluding LULUCF and international bunkers). About 93% of this CO_2 originates from the combustion of fossil fuels and the remaining 7% from specific industrial processes (eg. production of cement, chemicals, iron and steel). Methane (CH_4) and nitrous oxide (N_2O), are generated mainly due to agricultural and waste management activities and account for about 9% and 7% of total emissions respectively, while fluorinated gases (F-gases) from industrial processes represent 2% of total emissions (EEA, 2011).

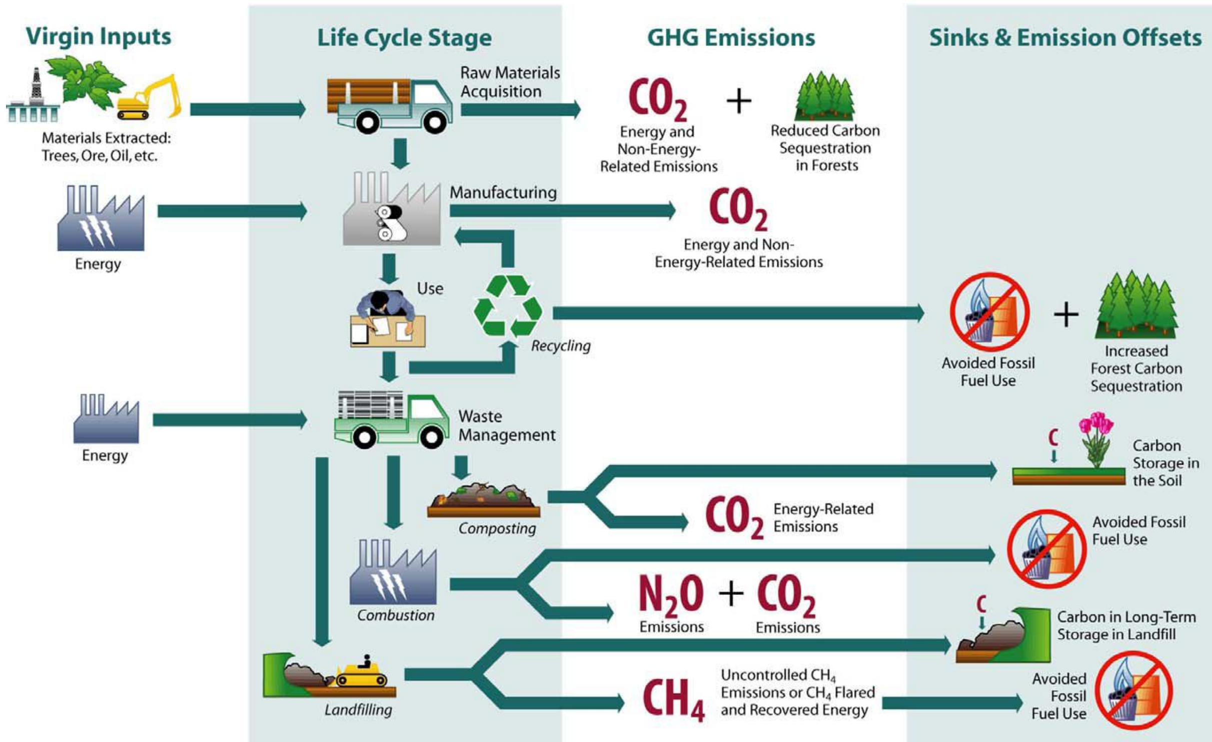

Figure 1. GHG sources and sinks associated with the materials life cycle (US EPA, 2006)

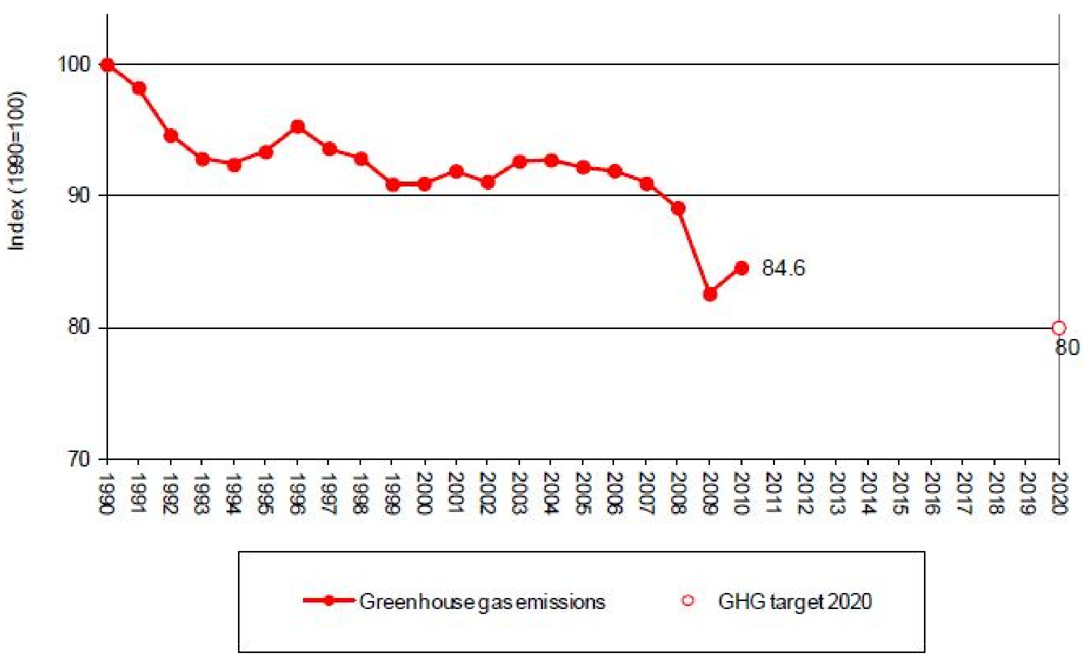

Figure 2. GHG emissions in the EU-27 for the period 1990–2010

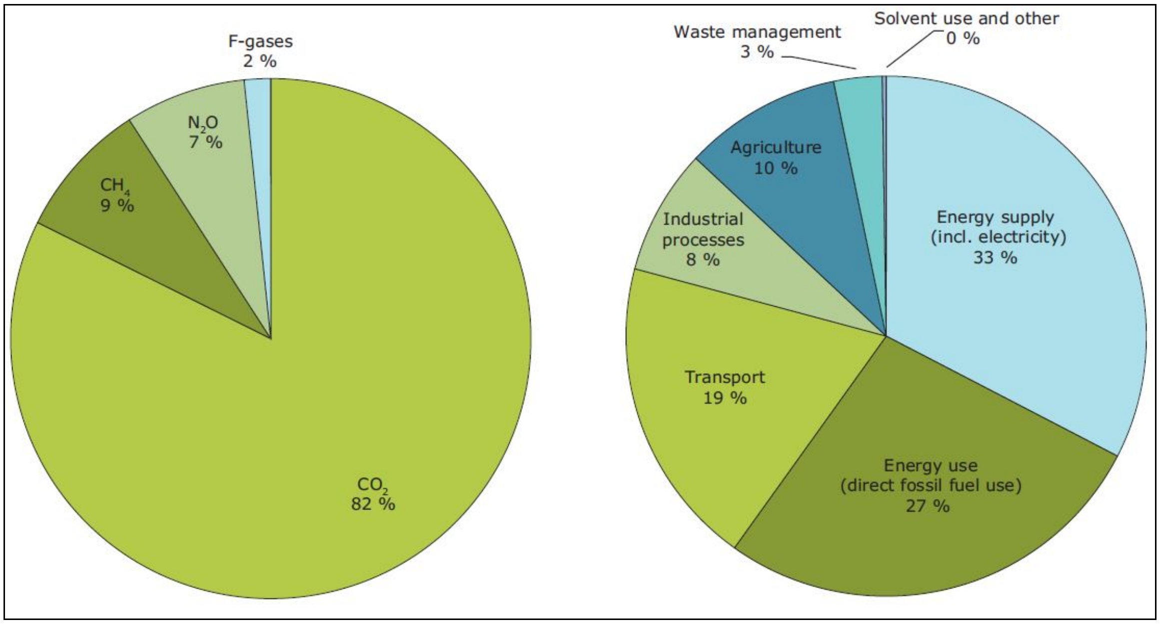

Figure 3. GHG emissions in the EU-27 by gas and by sector, in 2008 (EEA, 2011)

2.2 Direct, indirect and avoided GHG emissions

GHG emissions are categorized as direct, indirect and avoided, as seen in the following sections.

- Direct GHG emissions

Direct GHG emissions are generated from processes or equipment that are owned or controlled by the reporting entity, such as emissions from combustion installations (CO_2, N_2O), landfills (CO_2, CH_4), vehicles (CO_2, N_2O) and may be categorized as gross and net direct emissions. Gross direct emissions are generated by waste management activities, taking into account emissions from biomass, such as CO_2 from landfill gas flaring. Net direct emissions are taken into account in the inventory and reporting of emissions, after applying conventions concerning biomass, whereby the GHG emissions originating from biomass combustion are accounted for zero.

- Indirect GHG emissions

Indirect GHG emissions are generated from the activities of the reporting entity, but occur at sources owned or controlled by another entity, such as those generated during electricity production or waste transport (CO_2, N_2O). Indirect emissions are categorized as a) emissions from imports of electricity, heat or steam that are not self-produced and b) other indirect emissions, for instance during equipment construction and reagent consumption (EPE, 2010).

- Avoided emissions

In the case of energy generation or re-use of waste through various waste management technologies GHG emissions are avoided, as in the following cases and usually correspond to CO_2 emissions that are generated to produce an equivalent quantity of energy:

- Electric and thermal energy production from waste incineration
- Electric and thermal energy production from landfill gas and biogas from anaerobic digestion
- Recycling of materials such as paper, glass, steel, aluminium, plastics

Table 1 shows the emissions generated from various waste management processes as well as that actions that need to be taken for their decrease.

Table 1. Emissions generated from various waste management processes and actions that need to be taken for their decrease (EPE, 2010)

Activity	*Direct emissions*		*Indirect emissions*	*Avoided emissions*	*Actions to decrease emissions*
	Gross emissions	*Net emissions*			
Collection and transporta-tion	CO_2 from fuel consumption	CO_2 from fuel consumption	CO_2 from electric vehicles and outsourced transport	-	Use of electric vehicles and of alternatives fuels (eg. biofuels); development of alternative means of transportation (rail and waterway transport)
Physico-chemical waste treatment	CO_2 from on-site fuel consumption	CO_2 from on-site fuel consumption	CO_2 from purchased electricity consumption	CO_2 avoided through potential production of alternative fuels	Actions to optimize alternative fuel production
Biological treatment (composting -anaerobic digestion)	CO_2 from biomass and on-site fuel consumption; CH_4 and N_2O	CO_2 from on-site fuel consumption; CH_4 and N_2O	CO_2 from purchased electricity consumption	CO_2 avoided through i) energy production, ii) compost use in agriculture, iii) recovery of the heat produced by the composting process	Optimization of aerobic conditions for composting; optimization of energy and/or material recovery
Landfilling	CH_4 and CO_2 from landfill gas; CO_2 from on-site fuel consumption	CH_4 from landfill gas; CO_2 from on-site fuel consumption	CO_2 from purchased electricity consumption	CO_2 avoided through energy production	Optimization of CH_4 oxidation, capture and combustion; optimization of energy recovery

2.3 GHG emissions in composting and landfilling

In biological treatment such as composting or anaerobic digestion, a treated organic amendment to be used in agriculture is recovered through aerobic/anaerobic fermentation of waste (agricultural waste, biowaste, sewage sludge). During waste degradation CO_2 is mainly generated (not taken into account in the final balance since it comes from biomass). However methane (CH_4) and nitrous oxide (N_2O) emissions can occur and should be taken into consideration. It is mentioned that home and industrial composting differ in terms of CH_4 and N_2O emissions (Hermann et al., 2011).

In the case of anaerobic digestion along with the production of digestate, biogas (mainly consisting of CH_4) is also produced and is captured and combusted in flares or recovered for thermal or electric energy. As in composting, CO_2 from combustion is not taken into account in the final balance; in this case as well, CH_4 and N_2O emissions might occur (leakage at digester).

During landfilling, waste is disposed of in sites which should be environmentally isolated and natural degradation takes place during time. If best practices are considered, emissions produced by degradation of waste (gas and leachate) may be recovered through the use of drainage systems and treated. This landfill gas is mainly composed of CO_2 and CH_4 in nearly equal amounts and its quality depends on the composition of the waste; trace elements such as N_2, O_2, H_2S, CO, NH_3, H_2 and volatile organic compounds (VOC) are also generated.

Part of this landfill gas can be captured and destroyed through flares or recovered to produce energy. Captured CH_4 is converted through combustion into CO_2, which has an impact on the greenhouse effect that is 25 times less than CO_2 and also comes from biomass and is therefore not taken into account in the final balance. However, all of the produced landfill gas cannot be captured and part of it is emitted to the atmosphere (diffuse emissions); the quantity of biogas cannot be easily determined and is therefore estimated using modeling methods (EPE, 2010).

The models used to estimate GHG emissions also take into account the local climatic conditions which have a high impact on the overall process. A simple model may take into consideration the following issues (Eurostat, 2011):

1. During the initial active phase, the degradable portion of the waste landfilled undergoes both aerobic and anaerobic degradation; as the landfill is not sealed during this phase both CH_4 and biogenic CO_2 are emitted.
2. By sealing the landfill the “methanogenic” phase takes place and the landfill gas contains greater quantities of CH_4 than in the first phase. However, a key measure to mitigate CH_4 emissions is by CH_4 capture and subsequent combustion for energy production.
3. As different types of carbon degrade at different rates (sugars and fat degrade relatively quickly, cellulose degrades more slowly) and lignin products (contained in wood) are slightly degraded in landfill, these materials may not degrade appreciably even over much longer time.

3. Carbon footprint definition

A carbon footprint (CF) analysis is a form of life cycle analysis (LCA) limited to assessing the impact of emissions that affect climate change. CF is a more publicly understood and widely used measure of environmental impact. The impact categories used in LCA include, among others global warming; acidification; eutrophication; human health; ecosystem toxicity; ozone depletion; smog formation; habitat alteration; resource and water depletion.

The definitions and measurement units for the CF both vary as can be seen in Table 2 (EC, 2007; Wiedmann and Minx, 2008; De Benedetto and Klemeš, 2009; Čuček et al., 2012).

Table 2. Definitions and units for CF

Definition for CF	*Unit*
Amount of CO_2 and other GHGs emitted over the full life cycle of a process or product	mu CO_2eq/FU
Result of life cycle thinking applied to global warming	mu CO_2eq/FU
Land area required for the sequestration of fossil-fuel CO_2 emissions from the atmosphere through afforestation	au CO_2eq/FU
Measurement of the exclusive direct and indirect CO_2 emissions over a life cycle	mu CO_2/FU
Measurement of the imbalance within the carbon cycle	mu C/FU

FU: functional unit, mu: mass unit, au: area unit

The CF is quantified using indicators such as the Global Warming Potential (GWP), which reflects the relative effect of GHGs in terms of climate change considering a fixed time period, such as 100 years (GWP_{100}). The GHGs are converted to CO_2 equivalents (CO_2eq - a normalization of all the gases to the global warming potential of CO_2 over a 100-year time frame) taking into consideration their relative contributions to global warming. Table 3 shows the GWPs and common sources from some of the most important GHGs (EC, 2007; SKM Enviros, 2011). The GWP coefficients for all GHGs are shown in Table I of Annex I (Forster et al., 2007).

CO_2 has an assigned GWP of 1 and is used as the reference gas to which all other GHGs are compared. For example, the GWP of CH_4 is 25 meaning that one tone of CH_4 will cause the same amount of warming as 25 tones of CO_2.

Table 3. GWP and common sources of some of the most important GHGs in a 100-year time horizon (Forster et al., 2007)

GHG	GWP	Key source
Carbon dioxide (CO_2)	1	Combustion of fuels, cement production
Methane (CH_4)	25	Agriculture, landfilling, wastewater and sludge treatment, oil and gas extraction and processing, mining activities
Nitrous oxide (N_2O)	298	Agriculture, waste water treatment, combustion processes, nitric acid and adipic acid (a precursor of nylon) production
Hydroflurocarbons (HFCs) and hydrochlorofluoro-carbons (HCFCs)	77–14,800	Refrigerant manufacture and use
Perfluorocarbons (PFCs)	7,390–17,700	Refrigerant manufacture and use, aluminium and magnesium smelting
Sulphur hexafluoride (SF6)	22,800	Aluminium and magnesium smelting, high-voltage switching equipment

For the determination of the impacts of various processes on the climate change, numerous models have been developed, but none of these provide specific guidelines for monitoring and management of single-product GHG emissions over time. Scipioni et al. (2012) have developed such a model based on the ISO standards for GHG emissions that involves the following steps: i) definition of the objective of the research, the organizational and operational boundaries, ii) quantification of the product's CF by calculating the emission factors using the equation [1] and iii) CF monitoring.

$$\textit{Emission factor} = GWP_{100,x} * g_x \qquad [1]$$

where $GWP_{100,x}$ is the Global Warming Potential (see Table I of Annex I), as specified by the Intergovernmental Panel on Climate Change (IPCC) and g_x is the amount of GHGs produced by process x.

4. Methodology in LCA and carbon footprint analysis

In order to assess the CF, the methodology and assumptions followed are similar to LCA, but instead of collecting a wide range of inputs and outputs for each process during the life cycle, only the emissions of GHGs are considered. The outputs of a CF analysis are typically much less complex than LCA and usually a spreadsheet format is used to produce graphical representation of the results. For example, pie charts illustrating CO_{2eq} emissions by source (landfilling, incineration, use for fuel or electricity production etc.) in a waste management scenario assist in the identification of the major source contributor to the CF and also show the relative importance of the emissions by comparing sources.

4.1 Life Cycle analysis (LCA)

An LCA study is a valuable tool for various applications, such as the design or improvement of products and processes and the development of business plans and policy strategies. LCA is based primarily on the ISO 14040 and 14044 standards (http://www.iso.org/iso/home.html) and on the Handbook "General guide for Life Cycle Assessment – Detailed guidance" by JRC-IES (2010). It is important to mention that LCA is an iterative process and allows for revision of the initial definition of goal and scope based on the findings of the inventory analysis; for example, a system boundary may be modified to include a process that was initially disregarded. The key methodological aspects of an LCA are summarized in the five-phase procedure discussed below (Finnveden et al., 2000; JRC-IES, 2011).

Phase I: Goal definition

Identifies the followings:

- Intended applications
- Proposed study methods, important assumptions and impact limitations
- Reasons for conducting the study and the decision context
- Target audience
- Comparisons to be disclosed to the public
- Commissioner of the study and other influential actors
- Whether the study is interested in the potential consequences of this decision

Phase II: Scope definition

Identifies the followings:

- Function of the product for both qualitative and quantitative aspects
- Reference unit for measurement and analysis
- Life Cycle Inventory (LCI) modeling approach according to the decision context
- System boundaries
- Relevant impact categories
- Whether data quality is sufficient (in terms of data accuracy, uncertainty and completeness of the inventory)
- Check whether all foreground and background data used in a LCI/LCA study are methodologically consistent
- Whether this study includes comparative assertions
- If the study includes comparisons and whether additional requirements are needed
- Proper review and report type according to target audience and final deliverable

Phase III: Life Cycle Inventory (LCI)

- Identify foreground and background data
- Design data collection format
- Collection of inventory data (typically required only for the foreground system)
- Describe what the modeled unit process represents
- Collect relevant inputs and outputs of the unit process
- Select secondary LCI data sets
- Fill initial data gaps
- Solve multi-functionality of process
- Calculate and aggregate inventory data of a system

Phase IV: Life Cycle Impact Assessment (LCIA)

- Assign LCI results to the selected impact categories
- Calculate category indicator results
- Provide a basis for comparing different types of environmental impact categories (all impacts get the same unit) (optional)
- Assign a weighting factor to each impact category depending on the relative importance (optional)

Phase V: Interpretation of results, reporting and critical review

- Identify significant issues
- Perform completeness, sensitivity and consistency check
- Derive conclusions, limitations and recommendations
- Check if the LCA results fulfill the goal and scope of the study
- Define if the quality is sufficient
- Define if there is potential for improvements

4.2 Carbon footprint analysis

A CF management strategy should focus on the following targets:

- Define and measure an initial baseline CF of the process studied (eg. waste treatment technology), known as a reference footprint.
- Develop measures and means to reduce the CF by reducing emissions and substituting conventional systems with lower carbon technologies.
- Focus on best practices/innovative approaches and inspire behaviour change.
- Implement climate adaptation strategies so that the legacy development may be appropriate in the long term basis (LOCOG, 2007).

In order to assess the CF of a product or process, no official internationally approved standard methodology exists. However, a CF analysis is typically completed in five phases which are briefly presented in the following lines (BSI, 2011a; SKM Enviros, 2011):

Phase I: Identify sources

GHG emissions typically occur from the following source categories: (1) stationary combustion i.e. combustion of fuels in stationary equipment such as boilers, furnaces, burners, turbines, heaters, incinerators, engines, flares etc; (2) mobile combustion i.e. combustion of fuels in transportation devices such as automobiles, trucks, buses etc; (3) process emissions from physical or chemical processes; (4) releases from the energy required to power incinerators; (5) fugitive emissions i.e. intentional and unintentional releases such as equipment leaks from joints, seals and landfills.

As a first step, it is important to identify the emissions produced by the product, system or organisation for each source category. These are effectively the sum of all the emissions from the above categories and are related to the production of each product or service. It is important not to exclude activities that could have higher than usual emission. In Table 4 some common examples of high- and low- intensity materials and processes are shown.

Phase II: Select calculation approach

The CF is generally calculated based on a set of principles, known as the GHG Protocol, that are consistent with those proposed by the Intergovernmental Panel on Climate Change (IPCC) for compilation of emissions at national level. Although strong international standards are emerging, they are not mandatory and some companies may develop their own calculation methods.

Phase III: Collect data

Once the sources and calculation approach have been decided, data regarding all activities (or proposed activities if a future footprint is being assessed) must be collected. Collection and collation of data is the most effort-consuming step in order to build the life cycle inventory. Direct and indirect emissions for all Kyoto Protocol GHGs should be considered and all results should be reported (eg. in tons of CO_2eq). Usually in this step information regarding fuel consumption, transport data and raw material consumption is obtained. These are then combined with the appropriate emission factors within the next stage.

Phase IV: Apply calculation tools

In order to simplify the process of CF assessment various software tools are available (discussed in the following section 6).

Phase V: Analysis of results

In the final phase, the results of the study are analyzed. Key indicators are also established to allow comparison eg. of various treatment technologies in waste management, so that the overall effect of specific reduction measures can be quantified.

Table 4. Examples of high- and low- intensity materials and processes

Very high (>5 kg CO_2eq/kg)	High (1-3 kg CO_2eq/kg)	Medium (<1 kg CO_2eq/kg)	Low (<0.1 kg CO_2eq/kg)
Refrigerants	Plastics	UK/EU field crops	Unprocessed minerals, eg. gravel, sand
Electronic components	Most chemicals	Glass	By-products eg. straw, woodchips, animal feeds
Meat products	Fuels	Paper and cardboard	Water production and processing
Aluminium	Dairy products	Plastics processing	Landfilling of non biodegradable materials
Pigments/dyes	Greenhouse crops	Landfilling of biodegradable materials	Transport <1,000 km by articulated lorry or <20,000 km by sea
Concentrated foodstuffs	Rice		
Laundry/hot water treatment	Peat		
	Freezing		
	Cooking		

5. System boundaries in carbon footprint analysis

The boundaries for the assessment of the CF are used to define which parts and processes of the life cycle belong to the analyzed system, i.e. are required to provide its function as defined by the functional unit. A precise definition of the system boundaries is important to ensure that all attributable or consequential processes are actually included in the modeled system. When system boundaries are determined: (a) the results include all environmental impacts which are relevant to the system being studied, (b) fair comparisons can be drawn between different studies and (c) the reader of the study can understand what has been included or excluded (JRS-IES, 2010).

According to BSI (2011a) two standard types of assessment (cradle-to-gate and cradle-to-grave) are used for the definition of system boundaries, as shown in Figure 4. The cradle-to-gate assessment takes into account the life cycle stages from raw material extraction up to distribution of the final product, while the cradle-to-grave assessment takes into account all life cycle stages from raw material extraction up to disposal at end of life. It is noted that cradle-to-gate boundaries can vary according to the position of the 'gate'.

Cradle-to-gate assessment is commonly used when suppliers are asked to provide information on the CF of the final product. In this case, emissions that occur only up to the point at which the product is transferred to the end user are reported. However, some impacts may not be calculated; for example, for energy-using products the overall CF is due to electricity use and this impact would only be included in a cradle-to-grave assessment.

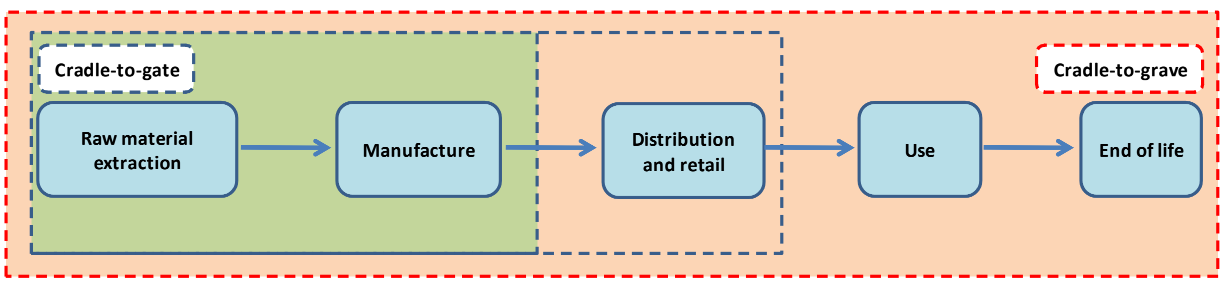

Figure 4. Boundaries determined in cradle-to-gate and cradle-to-grave assessment

In terms of waste management, a number of companies determine CFs at both operational and organizational level to highlight their commitment to reduce environmental impacts in the life cycle of a product or a process, as well as to develop more environment friendly technologies. In order to assess a waste treatment technology as well as the relative environmental impact of the different options proposed, footprint boundaries should be defined. Thereafter, a CF analysis is carried out and the results are reviewed to assess which treatment technology has a better environmental life, by comparing for example waste treatment/disposal options such as landfilling or energy generation from waste Figure 5 shows system boundaries that can be determined during waste management (SKM Enviros, 2011).

The system boundary of the product life cycle shall exclude the GHG emissions associated with (a) human energy inputs for processing (e.g. if fruit is picked by hand rather than by machinery); (b) transport of consumers to and from the point of retail purchase; (c) transport of employees to and from the working area. Furthermore, emissions from capital goods (trucks, airplanes and buildings) are usually not included in the CF of a product or process since it is difficult to allocate the production of these capital goods to a certain product and the relative impact on the total CF is estimated as small (BSI, 2011b).

6. Tools for carbon footprint assessment

Many tools have been developed for CF evaluation (CF calculators) to estimate CO_2 emissions, promote public awareness of carbon emissions as well as identify methods for their mitigation. CF calculators generally use input characteristics of individual behavior and return an amount of CO_2 emitted as a direct result of such behavior. These calculators may be provided by government agencies, non-governmental organizations and private companies. CF calculators that have become more prevalent on the Internet can generate varying results (by as much as several metric tons per year per individual activity) even when similar inputs are used. The variations in calculator outputs may be due to different calculating methodologies or conversion factors. Thus, there is a need for improved consistency and transparency in the calculators used for CF analysis (Padgett et al., 2008).

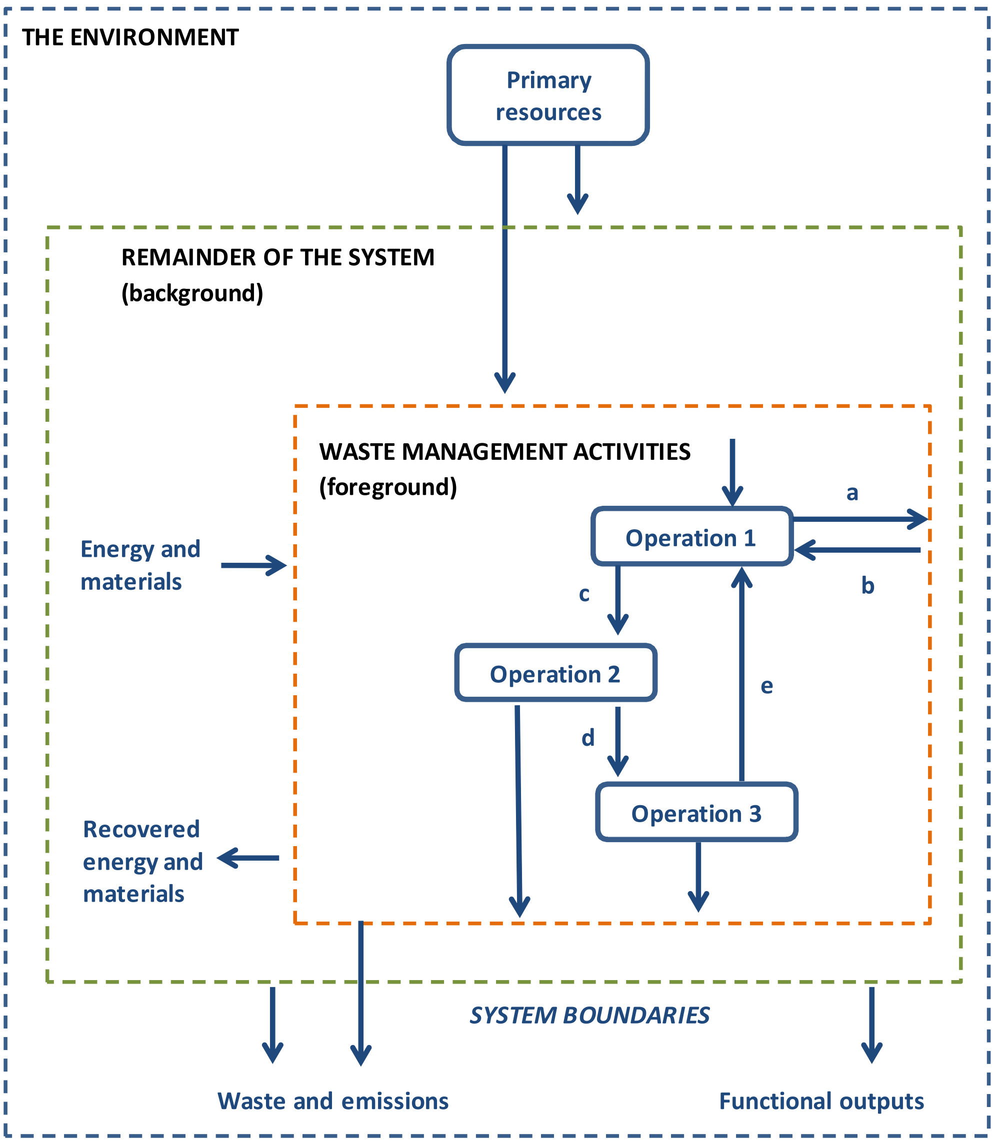

Figure 5. System boundaries in waste management activities (material flows “a” and “b” are open-loop, while “c”, “d” and “e” are closed-loop) (Barton et al., 1996)

The international standards ISO 14040 and 14044 which are the globally recognized standards for life cycle based environmental assessments, provide robust guidelines for performing transparent and reliable CF calculations. It is mentioned that many organizations create their own CF models using basic spreadsheet software. An advantage of such models is that they can be created relatively cheaply, often using software already owned and operated by the organization (EC, 2007).

Some of the tools developed for CF analysis regarding waste management, include (SKM Enviros, 2011; http://epa.gov/):

- Waste Reduction Model (WARM), http://www.epa.gov/climatechange/waste/calculators/Warm_home.html, assists in tracking and reporting GHG emission reductions from several different waste management practices. WARM calculates and totals GHG emissions of baseline and alternative waste management practices (recycling, combustion, composting and landfilling).
- WATER9, http://www.epa.gov/ttn/chief/software/water/water9_3/index.html, is a wastewater treatment model used for the estimation of air emissions of individual waste constituents in wastewater collection, storage, treatment and disposal facilities.
- MSW-DST (Municipal Solid Waste Decision Support Tool), http://www.epa.gov/ordntrnt/ORD/NRMRL/appcd/combustion/cec_models_dbases.html, is used for evaluating the life cycle environmental tradeoffs and full cost of solid waste management. It can be used for all waste management activities including collection, transportation, material recovery facilities, transfer stations, composting, remanufacturing (of recovered materials), landfilling and combustion, as well as off-sets for the potential benefits from conservation of energy and materials.
- Greenhouse Gas Equivalencies Calculator, http://www.epa.gov/cleanenergy/energy-resources/calculator.html, is used to calculate and communicate GHG reduction strategy, reduction targets or other initiatives aimed at reducing GHG emissions.
- TRACI model (Tool for the Reduction and Assessment of Chemical and Other Environmental Impacts), http://www.epa.gov/nrmrl/std/traci/traci.html, has been developed to assist in impact assessment for sustainability metrics, LCA, industrial ecology, process design and pollution prevention.
- Landfill Gas (LFG) Energy Benefits Calculator, http://www.epa.gov/lmop/projects-candidates/lfge-calculator.html, estimates direct, avoided and total GHG reductions as well as environmental and energy benefits, for the current year in a landfill. The LFG Energy Benefits Calculator expresses reductions of CH_4 and CO_2 in equivalent environmental and energy benefits.
- LandGEM (Landfill Gas Emissions) model, http://www.epa.gov/ttn/catc/products.html#software, is used to estimate emission rates of landfill gas. LandGEM is an automated estimation tool with a Microsoft Excel interface that can be used to estimate emission rates for total landfill gas, methane, carbon dioxide, non-methane organic compounds and individual air pollutants from municipal solid waste landfills.
- Waste and Resources Assessment Tool for the Environment (WRATE), http://lca.jrc.ec.europa.eu/lcainfohub/tool2.vm?tid=197, can be used to evaluate the environmental impacts from waste management activities over the life cycle of the materials involved. Various parameters such as release of GHG to the atmosphere, resource depletion, freshwater ecotoxicity, air acidification, eutrophication and human toxicity are taken into consideration.
- Entreprises pour l' environnement (EPE), http://www.epe-asso.org/, is a simple tool focusing on waste management. Its main function is to model GHG emissions from waste collection to disposal and calculate (where relevant) the avoided emissions through recycling.
- MEBCalc model (Measuring the Environmental Benefits Calculator), http://www.zerowaste.com/pages/MEBCalc.htm, is a software used for computing the environmental footprint of a community's municipal solid waste (MSW) management system, from collection through final disposition of each discarded product or packaging material.

- Bespoke Tools. A number of these tools are available on the market, are directly applicable to waste management systems and simple to use.
- Footprint Expert, http://www.footprintexpert.com/, is an extensively used tool which is mainly used for assessing CF from product rather than waste management. However, it does include a comprehensive 'end of life' calculator for assessing the emissions from waste management.
- CCalc, http://www.ccalc.org.uk/, is a tool that enables quick and easy estimations of the CF of products, processes or supply chains. It is designed for assessing industrial activities and product footprints not focusing specifically on waste management.

7. Identification of carbon footprint in Wastereuse

In the line of Wastereuse, an LCA is carried out for all processes considered in Italy and Spain to enable an accurate assessment of the carbon footprint of the proposed alternative cultivation practices. LCA is carried out to evaluate the consumption of raw materials (agricultural waste, energy, water etc.) and emissions of pollutants (CO_2, CH_4, SO_2 to air etc.) as well as improve and optimize the application of treated or untreated AW on crop land in open field and in protected cultivations in Mediterranean countries.

The leading standards for LCA (international standards ISO 14040 and ISO 14044) as well as the key methodological five-phase aspects of an LCA, as discussed in detail previously, are followed. LCA includes a CF analysis and is implemented by assessing the impacts of the emissions that affect climate change. Therefore, the impact categories which are defined according to CML 2001 methodology (developed by the Institute of Environmental Sciences at the University of Leiden in the Netherlands) (Guinée, 2001) and calculated in the present LCA study are listed in Table 5.

The five impact categories and cumulative energy demand (Frischknecht and Jungbluth, 2003), as an energy flow indicator, are calculated. These impact categories were selected because of their relevance with agricultural production and related energy processes (Torellas et al., 2012). Furthermore, these categories are selected due to their similarities with LCA studies for open field and greenhouse production for other similar crops in Spain and Italy (Antón et al., 2005; Martinez-Blanco et al., 2011). Owing to the lack of reliable data, toxicity categories are not assessed.

Table 5. Environmental impact categories and measurement units for each category

Impact category	Acronym	Units
Acidification potential	GWP	kg $SO_{2eq}\cdot y^{-1}$
Eutrophication potential	EP	kg $PO_{4eq}\cdot y^{-1}$
Global warming potential (100 years)	GWP	kg $CO_{2eq}\cdot y^{-1}$
Ozone depletion potential	ODP	kg $CFC11_{eq}\cdot y^{-1}$
Photochemical oxidation potential	POP	kg $C_2H_{4eq}\cdot y^{-1}$
Cumulative energy demand	CED	MJ eq$\cdot FU^{-1}$

LCA is carried out by compiling an inventory of relevant inputs and outputs of a system (the inventory analysis), evaluating the potential impacts of those inputs and outputs (the impact assessment) and interpreting the results (the interpretation) in relation to the objectives of the study.

Many commercial software tools have been developed for LCA studies to estimate emissions, promote public awareness of emissions as well as identify methods for their mitigation. These calculators may be provided by government agencies, non-governmental organizations and private companies. GaBi and SimaPro, developed by the PE International and SimaPro UK, respectively, are the most popular software for LCA (Laurent et al., 2014). In the present study GaBi 6 software, is used to model the system and evaluate its environmental impact.

GaBi software models every element of a product or system from a life cycle perspective, so that the best informed decisions on the manufacture and lifecycle of any product can be made. It also provides an easily accessible content database detailing the energy and environmental impact of sourcing and refining every raw or processed element of a manufactured item. In addition, it looks at the impact on the environment and presents alternative options for manufacturing, distribution, recyclability, pollution and sustainability (http://www.gabi-software.com).

The present study focus on four cultivation cases representative of the actual crop/horticulture production in three different demonstration areas in Italy and Spain:

- Scenario 1: implementation of agricultural cultivation practices in open field production of lettuce in Italy (Albenga, Savona province, Liguria region)
- Scenario 2: implementation of agricultural cultivation practices in greenhouse production of lettuce in Italy (Albenga, Savona province, Liguria region)
- Scenario 3: implementation of agricultural cultivation practices in open field production of barley in Spain (Barrax, province of Albacete)
- Scenario 4: implementation of agricultural cultivation practices in greenhouse production of lettuce in Spain (Santomera, region of Murcia)

Agricultural waste management scenarios using both AW and conventional fertilizers were modelled and compared in all studied cases. All the environmental impacts are normalized and compared according the functional unit. In the present study, the functional unit is 1 kg of each crop produced.

Based on the system boundaries, different phases are created using GaBi software within each studied case. The main phases include: AW/compost production and transport, nursery phase and transport, waste transport and utilization and full production of each crop. This latter includes the sub-phases of cultivation in field operations, fertilizers production and transport, pesticides production and transport, the agricultural machinery and the irrigation system. For greenhouse cultivation of the studied crops, the greenhouse phase is also considered. All transport processes are considered to be by road for all the different phases and sub-phases. In fact, the issue of return transport is extensively evaluated in the present study, even though it is recognized that return transport plays a major role in cost but a rather minor role in environmental comparisons when short-distances are considered.

8. Conclusion

In the present deliverable, a methodology for the assessment of CF generated from various anthropogenic activities with emphasis on waste production and management is discussed. CF is a widely used measure of environmental impacts of GHGs such as CO_2, CH_4, N_2O and others in the atmosphere and is quantified using the Global Warming Potential (GWP) and considering a fixed time period, such as 100 years. In order to assess the CF, the methodology and assumptions followed are similar to LCA, but inputs used are related only to the GHG emissions. A CF analysis is typically completed in the following five phases I) Identify sources, II) Select calculation approach, III) Collect data, IV) Apply calculation tools and V) Analyze results. Fair comparisons of the results can be drawn when the system boundaries are precisely defined through cradle-to-gate or cradle-to-grave assessment and CF calculators based on globally accepted standards are used.

In the line of Wastereuse, an LCA is carried out for all processes considered in demonstration actions in Italy and Spain to assess the carbon footprint of the proposed alternative cultivation practices, evaluate the consumption of raw materials and emissions of pollutants. LCA includes a CF analysis and is implemented by calculating the emissions of the following impact categories: acidification potential, eutrophication potential, global warming potential (100 years), ozone depletion potential, photochemical oxidation potential and cumulative energy demand. It is anticipated that the alternative cultivation practices developed in demonstration actions in the project will result in a substantial reduction of the carbon footprint compared to current practices, by reusing AW and minimizing the use of fertilizers.

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Annex I

Table I. Direct (except for CH_4) global warming potential (GWP) relative to CO_2, by the Intergovernmental Panel on Climate Change (Forster et al., 2007)

Industrial designation or common name, chemical formula	*GWP for 100-year time horizon (2007)*
Carbon dioxide, CO_2	1
Methane, CH_4	25
Nitrous oxide, N_2O	298
Substances controlled by the Montreal Protocol	
CFC-11, CCl_3F	4,750
CFC-12, CCl_2F_2	10,900
CFC-13, $CClF_3$	14,400
CFC-113, CCl_2FCClF_2	6,130
CFC-114, $CClF_2CClF_2$	10,000
CFC-115, $CClF_2CF_3$	7,370
Halon-1301, $CBrF_3$	7,140
Halon-1211, $CBrClF_2$	1,890
Halon-2402, $CBrF_2CBrF_2$	1,640
Carbon tetrachloride, CCl_4	1,400
Methyl bromide, CH_3Br	5
Methyl chloroform, CH_3CCl_3	146
HCFC-22, $CHClF_2$	1,810
HCFC-123, $CHCl_2CF_3$	77
HCFC-124, $CHClFCF_3$	609
HCFC-141b, CH_3CCl_2F	725
HCFC-225ca, $CHCl_2CF_2CF_3$	122
HCFC-225cb, $CHClFCF_2CClF_2$	595
Hydrofluorocarbons	
HFC-23, CHF_3	14,800
HFC-32, CH_2F_2	675
HFC-125, CHF_2CF_3	3,500
HFC-134a, CH_2FCF_3	1,430
HFC-143a, CH_3CF_3	4,470
HFC-152a, CH_3CHF_2	124
HFC-227ea, CF_3CHFCF_3	3,220
HFC-236fa, $CF_3CH_2CF_3$	9,810
HFC-245fa, $CHF_2CH_2CF_3$	1,030
HFC-365mfc, $CH_3CF_2CH_2CF_3$	794
HFC-43-10mee, $CF_3CHFCHFCF_2CF_3$	1,640

Perfluorinated compounds	
Sulfur hexafluoride, SF_6	22,800
Nitrogen trifluoride, NF_3	17,200
PFC-14, CF_4	7,390
PFC-116, C_2F_6	12,200
PFC-218, C_3F_8	8,830
PFC-318, c-C_4F_8	10,300
PFC-3-1-10, C_4F_{10}	8,860
PFC-4-1-12, C_5F_{12}	9,160
PFC-5-1-14, C_6F_{14}	9,300
PFC-9-1-18, $C_{10}F_{18}$	>7,500
Trifluoromethyl sulfur pentafluoride, SF_5CF_3	17,700
Fluorinated ethers	
HFE-125, CHF_2OCF_3	14,900
HFE-134, CHF_2OCHF_2	6,320
HFE-143a, CH_3OCF_3	756
HCFE-235da2, $CHF_2OCHClCF_3$	350
HFE-245cb2, $CH_3OCF_2CHF_2$	708
HFE-245fa2, $CHF_2OCH_2CF_3$	659
HFE-254cb2, $CH_3OCF_2CHF_2$	359
HFE-347mcc3, $CH_3OCF_2CF_2CF_3$	575
HFE-347pcf2, $CHF_2CF_2OCH_2CF_3$	580
HFE-356pcc3, $CH_3OCF_2CF_2CHF_2$	110
HFE-449sl (HFE-7100), $C_4F_9OCH_3$	297
HFE-569sf2 (HFE-7200), $C_4F_9OC_2H_5$	59
HFE-43-10-pccc124 (H-Galden 1040x), $CHF_2OCF_2OC_2F_4OCHF_2$	1,870
HFE-236ca12 (HG-10), $CH_2OCF_2OCHF_2$	2,800
HFE-338pcc13 (HG-01), $CHF_2OCF_2CF_2OCHF_2$	1,500
Perfluoropolyethers	
PFPMIE, $CF_3OCF(CF_3)$ $CF_2OCF_2OCF_3$	10,300
Hydrocarbons and other compounds–direct effects	
Dimethylether, CH_3OCH_3	1
Methylene chloride, CH_2Cl_2	8.7
Methyl chloride, CH_3Cl	13