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A life cycle assessment of a standard Irish composting process and agricultural use of compost

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markets for recycled materials

Comhshaol, Pobal agus Rialtas Áitiúil
Environment, Community and Local Government

Life Cycle Assessment of Irish compost production and agricultural use

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Life Cycle Assessment of Irish compost production and agricultural use

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1 INTRODUCTION

1.1 BACKGROUND

Composting is the breakdown of organic material such as food or garden waste in a controlled aerobic environment. Compost can be used in agriculture as a soil conditioner and as a source of nutrients.

In order to increase the awareness and potential of compost, one must obtain information and data regarding its quality. The environmental impact of products and processes is becoming an increasingly important quality metric. The life cycle assessment methodology will be employed in this study to determine the environmental impacts of organic waste derived compost. The potential of this compost to be used as an organic fertiliser has been assessed and compared to conventional artificial fertiliser.

Thus, by conducting this LCA, detailed information regarding composts environmental impacts will be made available which may then be used to improve the marketability of the compost.

1.2 LIFE CYCLE ASSESSMENT

The environmental impacts of the composting system were quantified using the life cycle assessment methodology regulated by the ISO 14040 series international standards. The LCA method enables the environmental impact of a product or service to be determined in terms of the consumption of resources and emissions into the atmosphere, as well as the production of waste during the entire life cycle (“from the cradle to the grave”).

The goal of the study is to quantify the environmental impacts of the composting process in order to assess its potential as an effective organic waste management and fertiliser production method. The composting system will then be compared to artificial fertilisers in order to determine which option has the least impact on the environment.

The primary audience for this work will be the organic waste management and fertiliser industry. The results of the study will also be of benefit to Acorn Recycling. The LCA is based on their technology so the results and conclusions drawn from the analysis should provide further insights into the overall process and its environmental impacts.

The results will allow one to conclude on the most suitable management option. The results should provide a comprehensive analysis on the potential advantages/disadvantages of using compost as an organic fertiliser as compared to more conventional methods.

2 SYSTEM BOUNDARIES

The aim of the LCA is to compare compost and artificial fertilisers. When comparing two systems in a life cycle assessment, one must ensure that they carry out equal functions.

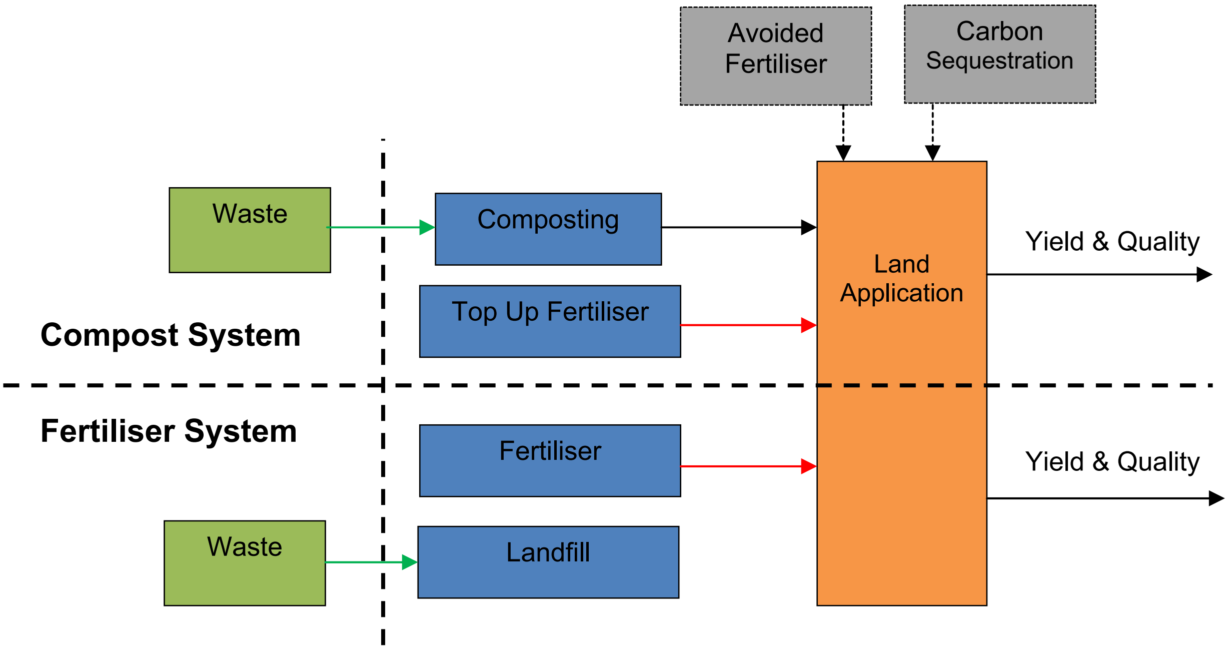
The composting process not only produces an organic fertiliser, but also acts as a waste management technique for dealing with biodegradable waste. So, the composting system carries out two functions:

- Manages a given quantity of organic waste
- Produces a compost which can act as a fertiliser

However, the fertiliser system only carries out the function of producing fertiliser. Therefore, the fertiliser system must be expanded to incorporate an organic waste management step. By using system expansion, the systems now carry out equal functions and thus can be considered equivalent. The system expansion method is widely employed in LCA studies, particularly when dealing with waste management systems.

Figure 1 displays the expanded system. Both the composting system and the fertiliser system now carry out equal functions, namely, fertiliser production and organic waste management.

Figure 1. System Boundaries



The land application step receives an equivalent amount of nutrients from both systems. The composting system uses an amount of artificial fertiliser to "top up" the nutrients available in the compost.

The study assumes that an equivalent yield and quality are obtained from both systems. These assumptions have been verified by land application field trials conducted in association with rx3. Thus one can conclude that the systems are identical, as given quantities (of acceptable quality) of crops are produced and a given amount of organic waste is treated/managed.

The following components of the life cycle have been excluded from the system:

- **Capital Equipment.** The production and maintenance of capital equipment is not included due to a severe lack of data associated with this part of the life cycle.
- **Waste Collection:** Household organic waste collection is not modelled in this study. It is assumed that the organic waste collected from a single point and is then transported to composting facility.
- **Post Application Emissions:** Once the compost/artificial fertilisers have been applied to the soil, certain emissions may be released. The primary emission of interest is nitrous oxide (N_2O), but other emissions such as NO_X, NH_3 and N_2 may also be prevalent. Most LCA studies do not include these post application emissions due to lack of data and uncertainty (ROU, 2003; Blengini, 2008; Butler and Hooper, 2010). However, according to Boldrin *et al*. (2009), the amount of Nitrous oxide emitted is proportional to the amount of N applied with the compost. Boldrin sites a range of studies which suggest between 1.0-2.2% of the nitrogen applied with the compost are emitted as N_2O. Martinez-Blanco (2009) also considered the emissions of these nitrogen based pollutants. Due to the lack of certainty about the post application emissions for the artificial fertilisers, these have been excluded from the life cycle assessment. One may argue that the emissions from both systems may be considered equivalent and thus may be legitimately excluded from the analysis. Either way, these emissions are not included in this report.

2.1 LIFE CYCLE IMPACTS

In order to quantify the environmental impacts of the composting system, the environmental impact category of global warming potential (GWP) was selected.

Global warming potential (GWP): GWP is calculated in carbon dioxide equivalents (CO_2-Eq.). This means that the green-house potential of an emission is given in relation to CO_2. Since the residence time of the gases in the atmosphere is incorporated into the calculation; a 100 year time period is considered.

3 LIFE CYCLE INVENTORY

The life cycle inventory will account for activity data within the system boundaries of the study. Each unit process (displayed in the boxes in Figure 1) must be included in the life cycle inventory. This will include accounting for all emission to air, water and land as well as the materials and energy used in the system. The inventory of the unit processes are now discussed in more detail.

3.1 TRANSPORTATION

The organic waste must first be transported from its point of origin to the location of final treatment. A standards European 27 tonne payload capacity truck is modelled in the transportation system. The transportation stage is run on standard EU diesel. Table 1 displays the characteristics of this standard transportation phase. This is considered the default transportation phase and will be used as the transportation stage for all of the scenarios.

Table 1. Transport characteristics

Parameter	Value
Distance	100 km
Percentage on motorway (average speed 82 km/h)	27%
Percentage outside of town (average speed 70 km/h)	43%
Percentage within town (average speed 27 km/h)	30%

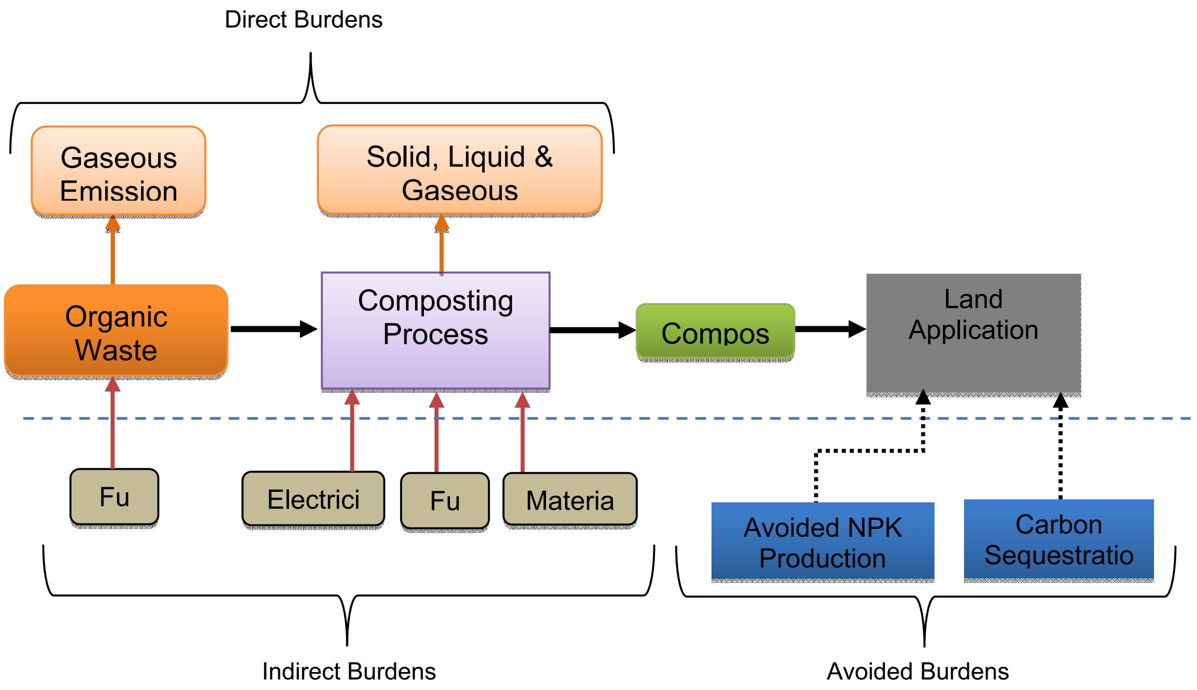
3.2 COMPOSTING PROCESS

An important methodological assumption is taken in waste management LCAs. This is in relation to the upstream system boundary, which is usually assumed to begin at the point of waste generation (Ekvall *et al.,* 2007). This simplification is sometimes called the *zero burden assumption*, suggesting that the waste carries none of the upstream burdens into the waste management system (Ekvall *et al.,* 2007).

Thus the cradle of the system begins when the organic material becomes waste. The production and use phase of this organic material is not considered in the lifecycle. This is considered within the organic material e.g. food production, lifecycle.

A detailed diagram of the composting system is shown in Figure 2. The system begins with the transportation of the organic waste to the composting facility and is completed with the application of the compost on land. The benefits of applying compost to land are also accounted for.

Figure 2. Composting Life Cycle



The life cycle inventory consisted of direct, indirect and avoided burdens:

- *Direct Burdens*: The direct impacts will include emissions from fuel combustion and gaseous emissions due to the degradation/mineralisation of the organic material.
- *Indirect Burdens*: Impacts from producing materials and energy/fuels that are used throughout the composting life cycle. The indirect burdens will be calculated using the life cycle inventory databases such as European life cycle database (ELCD) and U.S. Life Cycle Inventory Database (USLCI).
- *Avoided Burdens*: The avoided burdens are the environmental benefits derived by replacing the need to produce artificial fertilisers and the use of landfill as a deposit for the organic wastes. The compost that is produced can be used as an organic fertiliser and thus replace a given quantity of artificial fertilisers. Thus the impacts of producing the conventional fertilisers are avoided. The carbon sequestered by the application of compost is also accounted for in the analysis.

The basic formula to calculate the environmental performance is:

Direct Burdens + Indirect Burdens – Avoided Burdens = Environmental Performance

The composting inventory data was obtained from the Acorn Recycling facility in Tipperary, Ireland. The following inventory data was for the period March-June 2012. The input-output data has been adjusted to account for season variation. Table 2 presents the life cycle inventory of the Acorn composting facility over the March – June period.

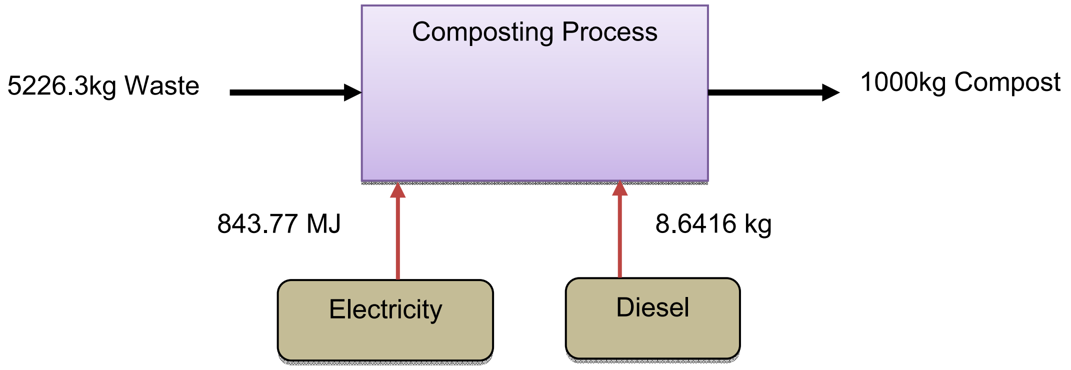
Table 2. Acorn Composting Inventory (Bowden, 2012)

Type of Flow	Value	Units
Input		
Electricity	341,040	kWh
Diesel Oil Consumption	15,113	litres
Organic Waste	7,604.48	tonnes
Wood chips	428.84	tonnes
Output		
Compost Production	1,455.05	tonnes
Solid Waste Dumped	282.06	tonnes
Leachate	272.27	tonnes
Emissions		
CO2 Biogenic	1,415.14	tonnes

Limited emission data from the Acorn site was available. However, the emissions data is similar to that present in several European studies. The leachate produced is sent for further processing at a wastewater treatment plant. The solid waste that is produced mainly consists of plastic waste materials and is sent to landfill.

A streamlined inventory of the Acorn facility is shown in Figure 3 below. The production of 1000 kg of compost is used as the reference quantity. This will allow the Acorn facility to be compared to other European composting systems.

Figure 3. Acorn streamlined process



3.3 EUROPEAN COMPOSTING INVENTORIES

In order to enhance the credibility of the analysis, two European composting studies have been considered. The composting facilities are in-vessel systems and thus can be accurately compared to the Acorn site. The European facilities are located in Italy (Blengini (2009)) and Spain (Martinez-Blanco *et al.* (2010)). The composting life cycle inventories outlined by Blengini (2009) and Martinez – Blanco *et al*. (2010) are presented in Tables 3 and 4 respectively.

3.3.1 Italian Facility

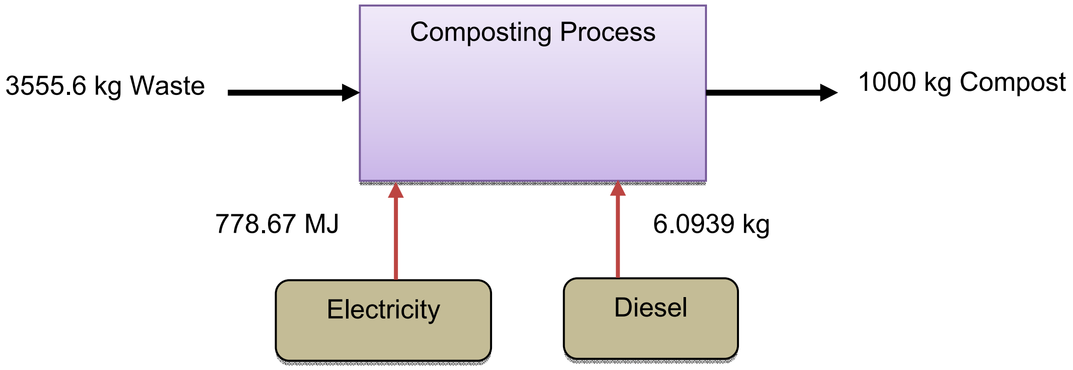
During the year 2004, 16,000 tonnes of moist bio-waste consisting of organic waste and green and wooden waste was used in the composting process. The 16,000 tonnes was converted into 4500 tonnes of high quality compost. The mass yield is relatively low (0.28 tonnes of mature compost per tonne of input bio-waste). However, as stated in the study, the intensive maturation and screening "allowed for better compost quality". The inventory analysis of the facility is outlined in Table 3. The data presented in Table 3 is given per input tonne of organic waste.

Table 3. Italian Composting Inventory

Type of Flow	Value	Units
Input		
Electricity	219	MJ/tonne organic waste
Diesel Oil Consumption	2.06	Litres/tonne organic waste
Organic Waste	16,000	Tonnes
Water	89	Litres/tonne organic waste
Output		
Compost Production	4500	Tonnes
Solid Waste Dumped	-	
Leachate	-	
Emissions		
CO_2 Biogenic	156	Kg/tonne organic waste
NH3	0.6	Kg/tonne organic waste

The streamlined inventory for the Italian composting process is displayed in Figure 4.

Figure 4. Italian (Blengini (2008)) Streamlined Process



3.3.2 Spanish Facility

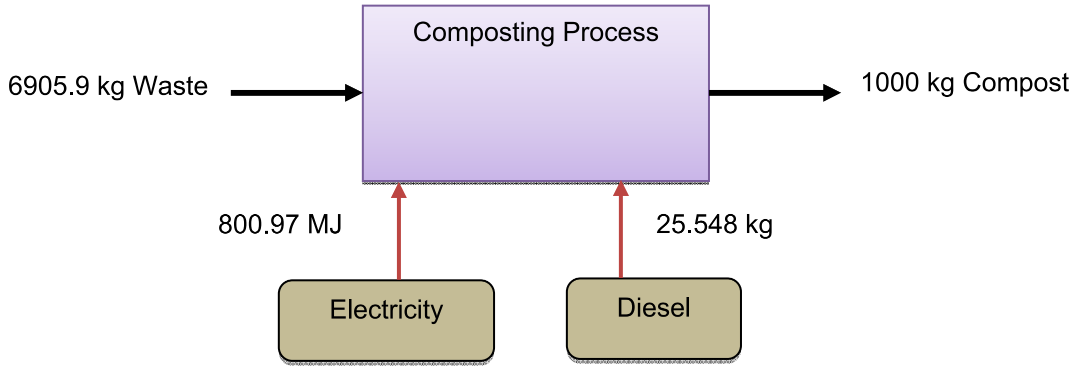
The inventory average for the years 2003-2006 is presented by Martinez-Blanco *et al.* (2009). A total waste input of 14,461 tonnes is converted into 2,094 tonnes of compost. A total of 2,823 tonnes of waste is also produced. The typical inventory for the composting facility, averaged over the three years is presented in Table 4 below.

Table 4. Spanish Composting Inventory

Type of Flow	Value	Units
Input		
Electricity	465.9	MWh/year
Diesel Oil Consumption	64.3	M3/year
Organic Waste	14461	tonnes
Water	426.778	Litres/tonne
Output		
Compost Production	2094	Tonnes
Solid Waste Dumped	2823	Tonnes
Leachate		
Emissions		
CO_2 Biogenic	2385.89	tonnes/year
NH3	1.59	tonnes/year
CH4	5.45	tonnes/year
VOC	17.5	tonnes/year
N2O	0.3	kg/year

The streamlined inventory for the Spanish composting process is displayed in Figure 5.

Figure 5. Spanish (Martinez-Blanco et al. (2009)) Streamlined Process



3.4 FERTILISER PRODUCTION

The basic lifecycle for fertiliser production is represented in the schematic displayed in Figure 6.
The artificial fertiliser that is applied to the land is made up of the NPK nutrients. The exact constituents of the fertiliser are as follows:

Nitrogen: **Calcium ammonium nitrate (CAN)**
Phosphorus: **Superphosphate**
Potassium: **Muriate of potash**

The production of mineral fertilisers implies the use of energy and other materials which result in a release of greenhouse gases.

Average European data on fertiliser production was assumed for this study. A wide range of values exists for fertiliser production GWP. The variability between the different sources of data is partially due to the energy mix considered for electricity production. Boldrin *et al.* (2009) outlines the range of values for fertiliser production GWP.

Each of the values used in this study lie within the range of values outlined in Boldrin *et al.* (2009)

The life cycle inventory of the fertiliser production is presented in Table 5 below. The GWP of the fertilisers is given in CO_2-Eq. The GWP figures are presented per kg of elemental nutrient.

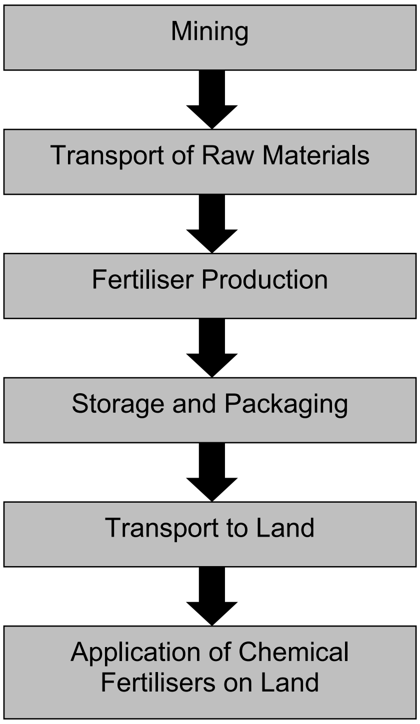


Figure 6. Fertiliser Life Cycle (Adapted from Zeijts *et al.* (1999))

Table 5. Fertiliser Production GWP

Nutrient	Value	Units	Reference
Nitrogen	8.76	kg CO_2-Eq.	Hermann *et al.* (2011)
Phosphorus	1.28	kg CO_2-Eq.	Boldrin *et al.* (2009)
Potassium	0.7	kg CO_2-Eq.	Hansen *et al.* 2006

The GWP figures included in Table 5 accounts for the cradle to gate production of the fertilisers. The possible post application emissions after fertiliser production are not considered in this study.

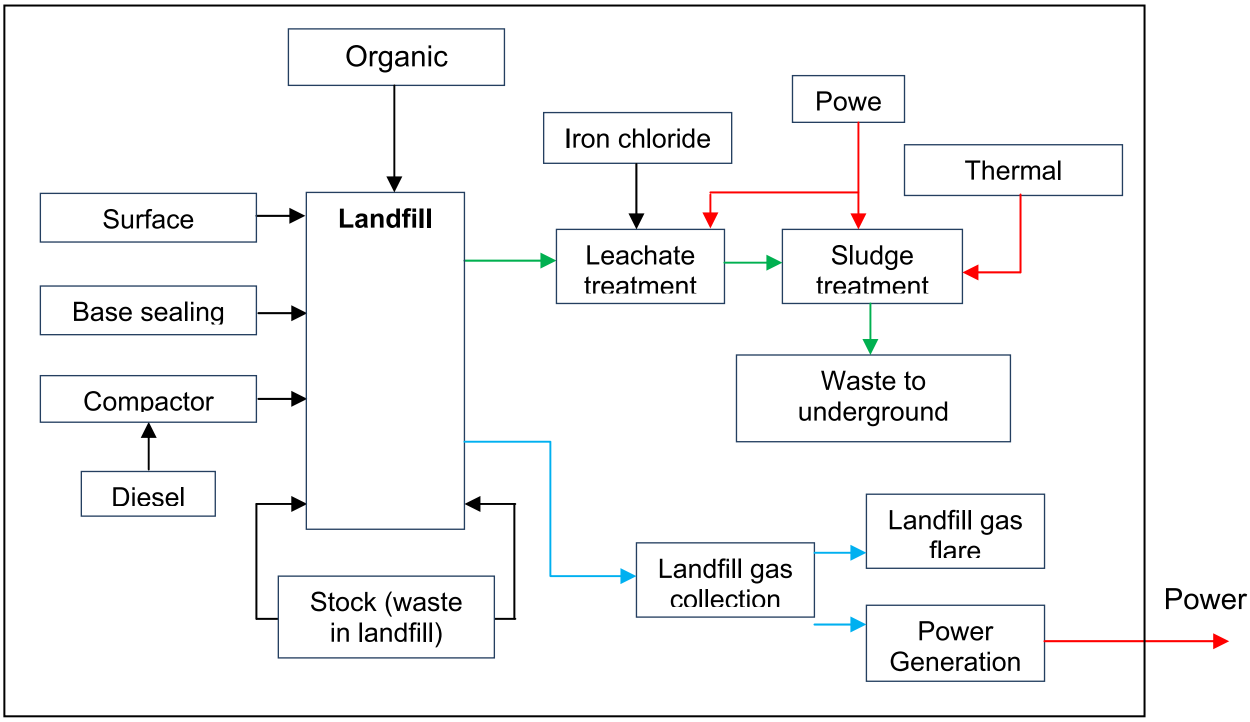
3.5 LANDFILL

The landfill is modelled as a typical municipal waste landfill with surface and basic sealing meeting European limits for emissions.

The landfill system is modelled over a 100 year time frame. The environmental impacts of the landfill process that are considered are those occurring within 100 years. The environmental burdens resulting from the emissions of the landfill gas to the atmosphere and from the treatment of landfill leachate in a waste water treatment plant are considered.

The electricity produced from the landfill gas is modelled as replacing conventional Irish grid electricity. The European Life Cycle Database landfill model, which is used in the assessment, is shown in Figure 7.

Figure 7. Municipal landfill model, system boundary (ELCD, 2010)



3.6 AVOIDED BURDENS

Applying compost to land may yield positive effects that are not achieved by the utilisation of artificial fertiliser alone. These include: reduced water use; improved soil properties including structure and drainage; higher organic matter content in the soil; replacement of artificial fertilisers; sequestration of carbon in the soil

These benefits all have the potential to increase greenhouse gas savings. However, it is not possible to quantify all of the impacts because of a lack of data and the high uncertainty associated with available data. The important benefits that are accounted for are the avoided artificial fertiliser and carbon sequestration. However, one must note that the un-quantified benefits offer significant improvements to the soil and thus are a driving factor in the use of compost as an organic fertiliser. The two benefits of applying compost to land that have been quantified are now discussed in more detail.

3.6.1 Avoided artificial fertiliser

The compost that is applied to the land contains within it a certain amount of nutrients (NPK). The availability of these nutrients to the plants is outlined in Table 6.

Table 6. Compost Nutrient Availability

Nutrient	Nitrogen	Phosphorus	Potassium
Nutrient Availability	10%	75%	80%
Nutrient Availability (kg/wet tonne)	1.9	3.3	5.2

This study assumes that the available nutrients in the compost replace the synthetic nutrients on a 1:1 basis. Thus the artificial fertiliser does not have to be produced because it will be replaced by an equivalent amount of organic fertiliser in the form of compost. The avoidance of the artificial fertiliser production means avoiding the GHGs that are emitted during its life cycle.

3.6.2 Carbon Sequestration

The application of compost as organic fertiliser promotes over time, a build-up of carbon in the soil, which could prove to be a powerful sink for the carbon sequestered in the soil (Blengini, 2008). The carbon sequestration process is highly complex and depends on many factors outlined by the US EPA (2002), including application rate, climate factors, soil type etc. Butler and

Hooper (2010) outline the limitations and difficulties with quantifying the carbon sequestration of compost application to agricultural land. Due to the complexity and uncertainty involved in quantifying carbon sequestration, a wide range of sequestration data is available.

Blengini (2008) outlines the potential carbon sequestering ability of compost. He states that the sequestration abilities can vary from 133-213 kg CO_2-Eq. per tonne of mature compost.

Based on the US EPA (2002) study, Butler and Hooper (2010) calculated the net potential carbon sequestration from the application of 1 tonne of compost to be 75kg of carbon. The ROU (2003) also uses the US EPA (2002) sequestration data to conclude a figure of 70.56 kg of carbon equivalent is stored per metric tonne of compost applied. When these values are converted to CO2-Eq they come to 275 kg CO_2-Eq and 258.7 kg CO_2-Eq/tonne of compost respectively.

Due to the wide range of values and the uncertainties associated with them, a conservative estimate is employed for this analysis. The average value given by Blengini (2008) of 173 kg CO_2-Eq/tonne of compost is also used in this study.

4 ENVIRONMENTAL PERFORMANCE

The life cycle impact assessment is now presented. The performance indicator used in the study is global warming potential (GWP) measured in kg CO_2-Eq. Thus the results are presented in relation to their GWP.

4.1 BIOGENIC CARBON EMISSIONS

An important point to note on the GWP is the inclusion of biogenic CO_2. This is a controversial issue in LCA studies. The US EPA (2002) study states that "composting also results in biogenic CO_2 emissions associated with decomposition, both during the composting process and after the compost is added to the soil. Because this CO_2 is biogenic in origin, however, it is not counted as a GHG (greenhouse gas) in the Inventory of U.S. Greenhouse Gas Emissions and Sinks and is not included in our accounting of emissions and sinks." The ROU (2003) study also excluded the biogenic carbon emissions.

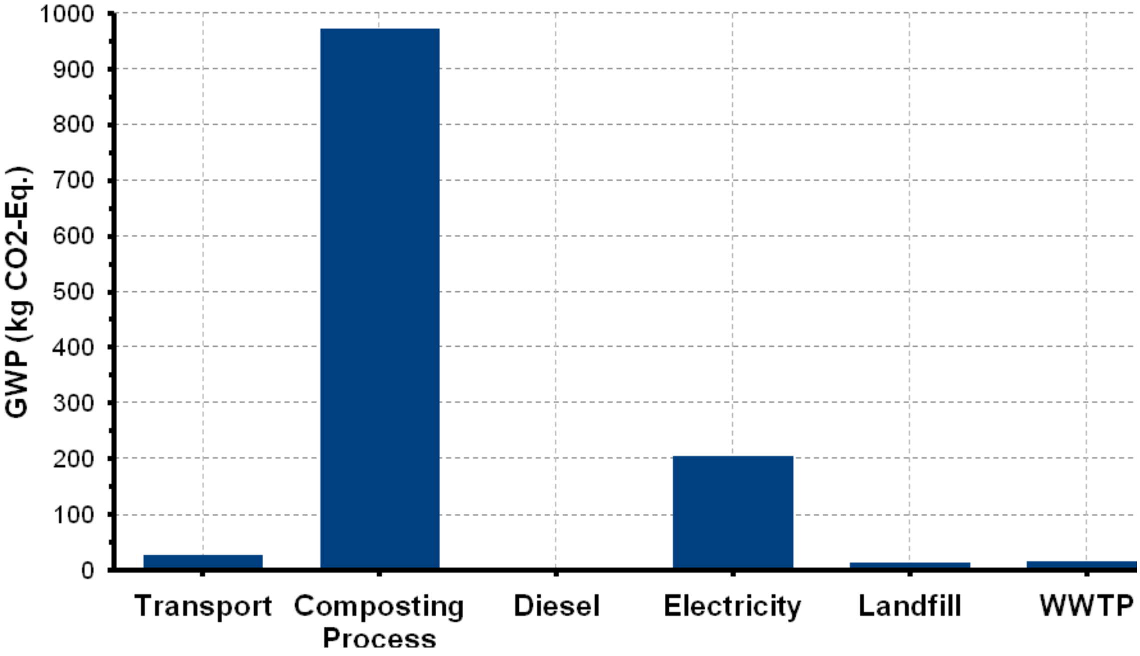
Composting can be regarded as a dramatic acceleration of the carbon cycle and the composting process will greatly accelerate carbon emissions compared to the normal carbon cycle. Thus as Butler and Hooper (2010) note, "within the timescale used to assess benefits from application of composted material, biogenic emissions are significantly greater than would be the case if material were left to die and decompose unaided in a natural state". Blengini (2008) also notes that the "exclusion can heavily distort the results".

Thus, both these studies included the biogenic carbon emissions in their analysis. The same approach is followed in this study, so one must note that the biogenic carbon emissions are included.

4.2 COMPOSTING SYSTEM

The Acorn composting facility was first analysed and its GWP calculated. The Acorn facility generates 1235.9 kg CO_2-Eq per tonne of compost produced. Figure 8 displays the primary contributions to the GWP within the composting system.

Figure 8. Composting System GWP



The major contributions to the GWP are from the direct emissions from the composting process itself. These emissions account for approximately 79% of the overall GWP. The electricity used within the facility also adds a substantial amount to the GWP. The transportation, diesel input and liquid and solid waste treatments produce an insignificant contribution to the overall GWP.

4.3 COMPOSTING COMPARISON

As noted earlier, the Acorn composting facility is compared against other European composting systems in order to improve the reliability of the results. The systems are compared in terms of the GWP per tonne of organic waste treated at the facilities. The landfill option is also present in the comparison to highlight its impact. Table 7 outlines the GWP for managing 1 tonne of organic waste.

Table 7. Waste Management GWP over entire life cycle

Waste Management System	GWP (kg CO_2-Eq.)
Composting (Ireland)	236.48
Composting (Italy)	214.03
Composting (Spain)	241.53
Landfill (EU average)	434.73

Table 7 clearly displays the similarity of the composting systems in terms of their GWP. To further prove the credibility of the results, a review of the data present in LCA literature regarding this topic was conducted.

As stated above, the direct emissions from the composting process account for 79% of the overall GWP. Thus approximately 182 kg CO_2-Eq is released directly from the Acorn composting facility. Butler and Hooper (2010) reviewed 5 studies outlining the kg of CO_2 emissions per kg of feedstock. They range from 165 to 217, with the average being 190 kg CO_2-Eq. Thus one can be confident that the inventory analysis conducted on the Acorn Facility is accurate, reliable and conforms to EU averages.

Table 7 also presents the GWP for landfilling one tonne of organic waste. This value of 434.73 kg CO2-Eq., is almost double that of the composting options. By composting organic waste in the Acorn facility rather than depositing it in a landfill, up to 200 kg CO2-Eq. per tonne of organic waste can be saved. Therefore landfill plays a very important role in the outcome of this LCA. By treating organic waste in a composting process, one avoids the use of landfill, and thus saves a significant amount of GHG from being emitted.

4.4 COMPOST APPLICATION TO LAND

In order to display the primary contributors to the GWP of both systems, Figure 9 shows the GWP of the systems when one tonne of compost is applied to land. The nutrients that are contained within the compost are then available for crop uptake. An equivalent amount of synthetic nutrients must also be applied in the fertiliser system. The quantity of waste required to produce the 1 tonne of compost must also be managed. For the fertiliser system, this is achieved by landfilling an equivalent amount of organic waste.

Figure 9 shows that the composting process produces the highest amount of GWP for the composting system. This GWP is only partially offset by the carbon sequestering ability of the compost. The avoided production of fertiliser has an almost negligible affect on the overall GWP.

Observing the fertiliser system, it is clear to see the effect of the landfilling process. The GWP produced when landfilling the organic waste completely swamps the GWP of the fertiliser production.

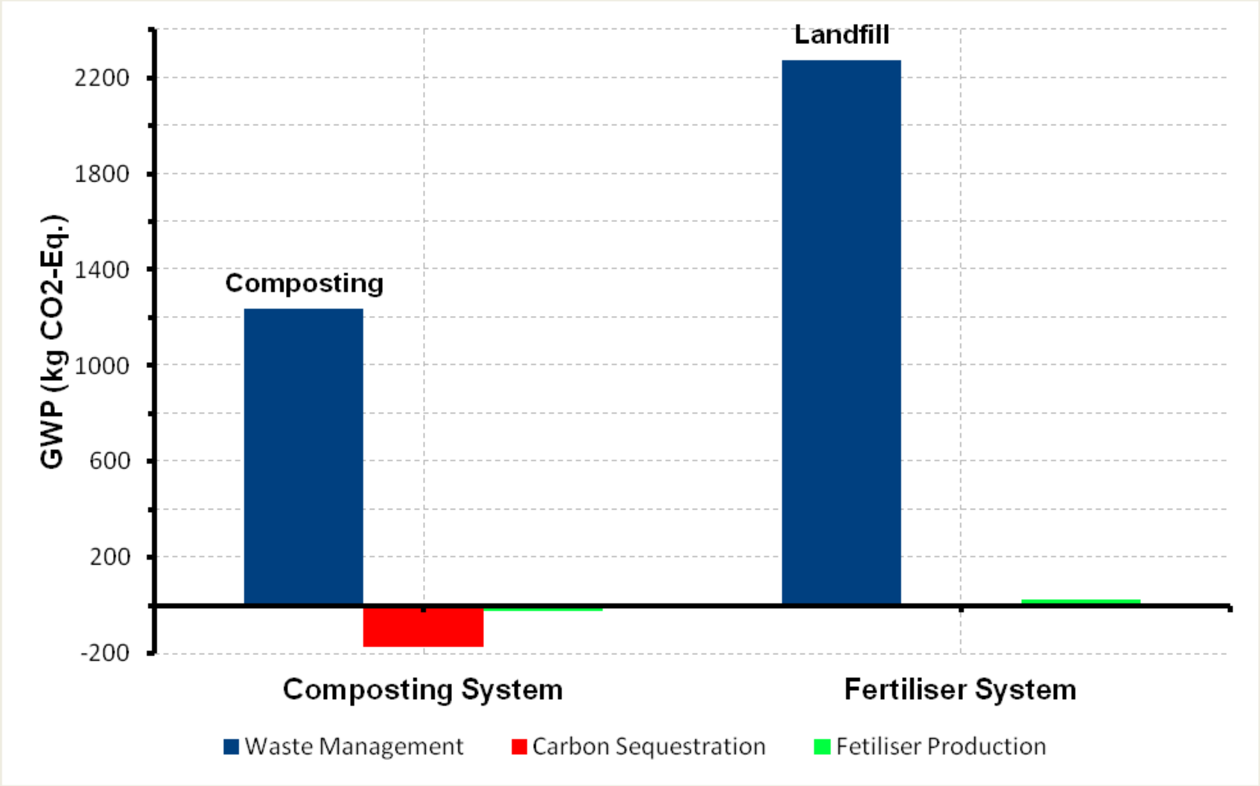


Figure 9. System Comparison for the application of 1 tonne of compost

The clear benefits of using the composting system now become evident. The composting system carries out the two functions of waste management and fertiliser production. One can see from Figure 9, that this option produces a much lower GWP than carrying out these operations separately i.e. by landfilling waste and producing artificial fertilisers.

By utilising the composting system, one avoids the use of landfill. The avoidance of the landfill GWP by composting the waste far outweighs the GWP produced during the composting process. This is the primary reason why the composting has a lower environmental impact in terms of GWP.

5 LAND APPLICATION ANALYSIS

The compost/fertiliser system was tested on five farms using different crops, during a separate rx3 project. The system boundaries for the field trials are the same as that displayed in Figure 1. The field trials data show that an equivalent yield and quality for the crops was obtained using both systems.

Therefore the functionality of both the composting and the fertiliser system can be considered equivalent and thus the LCA can be conducted accurately. The environmental impact from each of the farming systems is displayed in the following tables.

5.1 FARM A - SPRING BARLEY

Farm A grows spring barley using minimum tillage in both 2010 and 2011. Fertiliser application rates for Farm A are displayed in Table 8. The GWP of both systems is presented in Table 9.

Table 8. Farm A fertiliser Application Rates

	Natural Fertiliser				Artificial Fertiliser		
	t/ha	N	P	K	N	P	K
Compost	12	16	35	24	119	0	51
Artificial	n/a	0	0	0	135	35	70

Table 9. Farm A GWP

Life Cycle Stage	Quantity (kg)	GWP Factor	GWP (kg CO2-Eq)
Composting System			
Compost	12 tonnes	1235.9 kg CO_2-Eq/tonne	14,831
Avoided Fertiliser			
Nitrogen	16 kg	-8.76 kg CO_2-Eq/ kg N	-140.16
Phosphorus	35 kg	-1.28 kg CO_2-Eq/ kg P	-44.8
Potassium	24 kg	-0.7 kg CO_2-Eq/ kg K	-16.8
Top Up Fertiliser			
Nitrogen	119 kg	8.76 kg CO_2-Eq/ kg N	1,042.44
Phosphorus	0 kg	1.28 kg CO_2-Eq/ kg P	0
Potassium	51 kg	0.7 kg CO_2-Eq/ kg K	35.7
Carbon Sequestration	12 tonnes of compost	-173 kg CO_2-Eq/ tonne compost	-2076
Total			**13,631**
Fertiliser System			
Fertiliser Production			
Nitrogen	135 kg	8.76 kg CO_2-Eq/ kg N	1,182.6
Phosphorus	35 kg	1.28 kg CO_2-Eq/ kg P	44.8
Potassium	70 kg	0.7 kg CO_2-Eq/ kg K	49
Landfill	62.715 tonnes of waste	434.73 kg CO_2-Eq/ tonne of waste landfilled	27,264
Total			**28,540.4**

Therefore, the GWP savings (C02 eq.) from displacing synthetic fertiliser with compost, on this farm in this situation are;

28,540 – 13,631 = 14,909 kg /ha.

5.2 FARM B – WINTER WHEAT

The fertiliser application rates for Farm B are shown in Figure 10. The GWP of both systems is presented in Table 11.

Table 10. Farm B fertiliser application rates

	Natural Fertiliser				Artificial Fertiliser		
	t/ha	N	P	K	N	P	K
Compost	15.5	20	45	30	90	0	60
Artificial	n/a	0	0	0	110	45	90

Table 11. Farm B GWP

Life Cycle Stage	Amount	Factor (kg CO2-Eq.)	GWP (kg CO2-Eq)
Composting System			
Compost	15.5 tonnes	1235.9 kg CO_2-Eq/tonne	1,9157
Avoided Fertiliser			
Nitrogen	20 kg	-8.76 kg CO_2-Eq/ kg N	-175.2
Phosphorus	45 kg	-1.28 kg CO_2-Eq/ kg P	-57.6
Potassium	30 kg	-0.7 kg CO_2-Eq/ kg K	-21
Top Up Fertiliser			
Nitrogen	90 kg	8.76 kg CO_2-Eq/ kg N	788.4
Phosphorus	0 kg	1.28 kg CO_2-Eq/ kg P	0
Potassium	60 kg	0.7 kg CO_2-Eq/ kg K	42
Carbon Sequestration	15.5 tonnes of compost	-173 kg CO_2-Eq/ tonne compost	-2681.5
Total			**17,052.1**
Fertiliser System			
Fertiliser Production			
Nitrogen	110 kg	8.76 kg CO_2-Eq/ kg N	963.6
Phosphorus	45 kg	1.28 kg CO_2-Eq/ kg P	57.6
Potassium	90 kg	0.7 kg CO_2-Eq/ kg K	63
Landfill	81.007 tonnes of waste	434.73 kg CO_2-Eq/ tonne of waste landfilled	35,216
Total			**36,300.2**

Therefore, the GWP savings (C02 eq.) from displacing synthetic fertiliser with compost, on this farm in this situation are;

36,300 – 17,052 = 19,248 kg /ha.

5.3 FARM C – GRASS CLOVER

The fertiliser application rates for Farm C are shown in Figure 12. The GWP of both systems is presented in Table 13.

Table 12. Farm C fertiliser application rates

	Natural Fertiliser				Artificial Fertiliser		
	t/ha	N	P	K	N	P	K
Compost	9.2	18	30	48	98	0	98
Artificial	n/a	0	0	0	136	30	145

Table 13. Farm C GWP

Life Cycle Stage	Amount	Factor (kg CO2-Eq.)	GWP (kg CO2-Eq)
Composting System			
Compost	9.2 tonnes	1235.9 kg CO_2-Eq/tonne	1,1370
Avoided Fertiliser			
Nitrogen	18 kg	-8.76 kg CO_2-Eq/ kg N	-157.68
Phosphorus	30 kg	-1.28 kg CO_2-Eq/ kg P	-38.4
Potassium	48 kg	-0.7 kg CO_2-Eq/ kg K	-33.6
Top Up Fertiliser			
Nitrogen	98 kg	8.76 kg CO_2-Eq/ kg N	858.48
Phosphorus	0 kg	1.28 kg CO_2-Eq/ kg P	0
Potassium	98 kg	0.7 kg CO_2-Eq/ kg K	68.6
Carbon Sequestration	9.2 tonnes of compost	-173 kg CO_2-Eq/ tonne compost	-1591.6
Total			**10,475.8**
Fertiliser System			
Fertiliser Production			
Nitrogen	136 kg	8.76 kg CO_2-Eq/ kg N	1,191.36
Phosphorus	30 kg	1.28 kg CO_2-Eq/ kg P	38.4
Potassium	145 kg	0.7 kg CO_2-Eq/ kg K	101.5
Landfill	48.082 tonnes of waste	434.73 kg CO_2-Eq/ tonne of waste landfilled	20,903
Total			**22,234.26**

Therefore, the GWP savings (C02 eq.) from displacing synthetic fertiliser with compost, on this farm in this situation are;

22,234 – 10,475 = 11,759 kg /ha.

5.4 FARM D – SPRING BARLEY

The fertiliser application rates for Farm D are shown in Figure 14. The GWP of both systems is presented in Table 15.

Table 14. Farm D fertiliser application rates

	Natural Fertiliser				Artificial Fertiliser		
	t/ha	N	P	K	N	P	K
Compost	10.7	21	35	56	104	0	9
Artificial	n/a	0	0	0	135	35	70

Table 15. Farm D GWP

Life Cycle Stage	Amount	Factor (kg CO2-Eq.)	GWP (kg CO2-Eq)
Composting System			
Compost	10.7 tonnes	1235.9 kg CO_2-Eq/tonne	13,224
Avoided Fertiliser			
Nitrogen	21	-8.76 kg CO_2-Eq/ kg N	-183.96
Phosphorus	35	-1.28 kg CO_2-Eq/ kg P	-44.8
Potassium	56	-0.7 kg CO_2-Eq/ kg K	-39.2
Top Up Fertiliser			
Nitrogen	104	8.76 kg CO_2-Eq/ kg N	911.04
Phosphorus	0	1.28 kg CO_2-Eq/ kg P	0
Potassium	9	0.7 kg CO_2-Eq/ kg K	6.3
Carbon Sequestration	10.7 tonnes of compost	-173 kg CO_2-Eq/ tonne compost	-1851.1
Total			**12,022.28**
Fertiliser System			
Fertiliser Production			
Nitrogen	135	8.76 kg CO_2-Eq/ kg N	1,182.6
Phosphorus	35	1.28 kg CO_2-Eq/ kg P	44.8
Potassium	70	0.7 kg CO_2-Eq/ kg K	49
Landfill	55.921 tonnes of waste	434.73 kg CO_2-Eq/ tonne of waste landfilled	24,310
Total			**25,582.9**

Therefore, the GWP savings (C02 eq.) from displacing synthetic fertiliser with compost, on this farm in this situation are;

25,582 – 12,022 = 13,560 kg /ha.

5.5 FARM E – WINTER WHEAT

The fertiliser application rates for Farm E are shown in Figure 16. The GWP of both systems is presented in Table 17.

Table 16. Farm E fertiliser application rates

	Natural Fertiliser				Artificial Fertiliser		
	t/ha	N	P	K	N	P	K
Compost	8.6	11	25	17	129	0	33
Artificial	n/a	0	0	0	140	25	50

Table 17. Farm E GWP

Life Cycle Stage	Amount	Factor (kg CO2-Eq.)	GWP (kg CO2-Eq)
Composting System			
Compost	8.6 tonnes	1235.9 kg CO_2-Eq/tonne	10,629
Avoided Fertiliser			
Nitrogen	11	-8.76 kg CO_2-Eq/ kg N	-96.36
Phosphorus	25	-1.28 kg CO_2-Eq/ kg P	-32
Potassium	17	-0.7 kg CO_2-Eq/ kg K	-11.9
Top Up Fertiliser			
Nitrogen	129	8.76 kg CO_2-Eq/ kg N	1,130.04
Phosphorus	0	1.28 kg CO_2-Eq/ kg P	0
Potassium	33	0.7 kg CO_2-Eq/ kg K	23.1
Carbon Sequestration	8.6 tonnes of compost	-173 kg CO_2-Eq/ tonne compost	-1487.8
Total			**10,154.08**
Fertiliser System			
Fertiliser Production			
Nitrogen	140	8.76 kg CO_2-Eq/ kg N	1,226.4
Phosphorus	25	1.28 kg CO_2-Eq/ kg P	32
Potassium	50	0.7 kg CO_2-Eq/ kg K	35
Landfill	44.95 tonnes of waste	434.73 kg CO_2-Eq/ tonne of waste landfilled	19,541.1
Total			**20,834.5**

Therefore, the GWP savings (C02 eq.) from displacing synthetic fertiliser with compost, on this farm in this situation are;

20,834 – 10,154 = 10,680 kg /ha.

5.6 LAND APPLICATION CONCLUSIONS

The data indicates that the displacement of artificial fertiliser with compost on each farm halves the GWP associated with fertilising the crop.

On all five farms, the composting system preformed significantly better than the artificial fertiliser system. This is primarily due to the avoided burdens one produces when utilising composting technologies over landfill. By processing the organic waste in a composting system, one avoids the significant GWP that is associated with depositing organic waste in a landfill.

The GWP associated with fertiliser production is not significant when compared to the waste management components in the life cycle.

6 CONCLUSIONS

The methodology used in this study has followed the guidance in the ISO BSI standards 14040 and 14041. This has been supplemented by good practise identified during an extensive literature review. Primary plant data has been used where possible and this has been complimented with information from other peer reviewed LCA reports and life cycle inventory databases.

The composting inventory obtained in accordance with Acorn Recycling was similar to that of other European studies. Thus, the author is confident of the accuracy and reliability of the inventory data employed.

The results of the LCA model have shown that, in a life cycle perspective, the system of composting organic waste has a clear environmental benefit over using artificial fertilisers with landfill as a waste management option.

From this LCA, one can confidently conclude that using a composting system to manage organic waste and produce organic fertiliser is a much more effective system than conducting these functions separately.

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