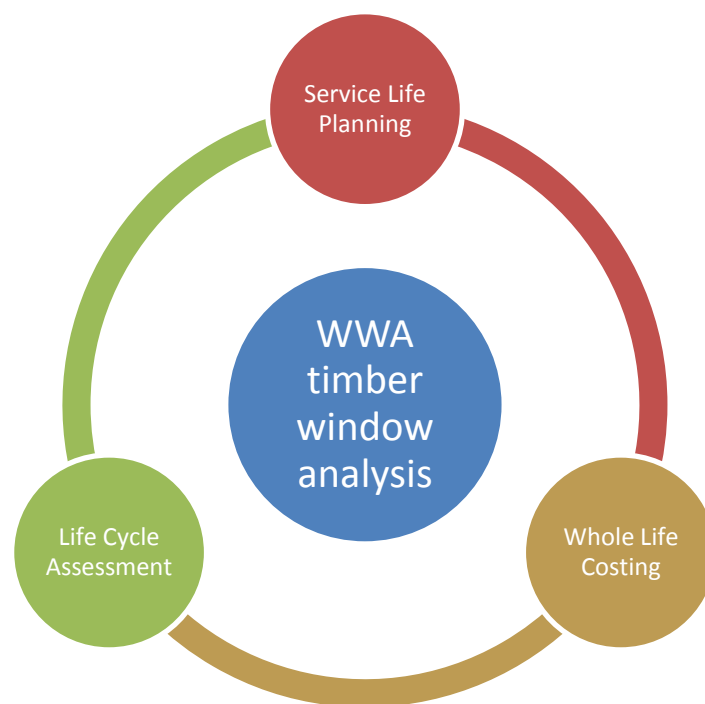


# Life Cycle Assessment of timber, modified timber and aluminium-clad timber windows



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## Executive Summary

This report is the second part of a fuller study on the whole life assessment of timber, modified timber, aluminium-clad timber, and PVC-U windows. The first report considered Service Life Planning (SLP) and Whole Life Costing (WLC). This report considers the Life Cycle Assessment (LCA) of these alternative window frame materials. This work will allow a complete like-for-like longevity, cost and environmental impact comparison of timber, modified timber, aluminium-clad timber and PVC-U frame materials.

LCA is an internationally recognised tool for assessing the environmental impact of products, processes and activities. It is a methodology for evaluating the environmental load of processes and products during their whole lifecycle and is one of various environmental management tools currently available for assessing impact and sustainability. LCA is used to assess the environmental impact of processing raw materials, manufacture of finished products and components, during construction, to transport materials and products to site, to maintain components, and to process materials at their end-of-life to recycle and/or dispose of materials.

This report is conducted within ISO 14040 and PAS2050 guidelines and sets a new standard for the whole life cycle appraisal of timber windows. It considers a base case scenario plus 6 alternative scenarios which test the sensitivity of inventory data and boundary inclusions on Global Warming Potential (GWP) of the frame materials considered.

Major findings are captured under consideration of boundary conditions, end of life treatment, service life impact, the reducing intensity of grid electricity, the sustainable sourcing of timber, and the recycling of construction materials.

This report finds that all timber based window frame materials are preferable to PVC-U alternatives in every scenario considered.

Using the methods adopted in this report, recycling is found to be the optimum end of life treatment for timber based window frames. The report conclusions lean to supporting the aims of WRAP in pursuing greater waste segregation, and possible tighter restrictions on timber waste entering landfill sites. This report also demonstrates the significant sensitivity of GWP outputs to the sustainable and ethical sourcing of timber under FSC or equivalent standards.

It concludes that there is no single or optimal timber based window frame material; there is not a one-size-fits-all solution. For various exposure conditions and applications one timber based product may be preferable over another in service life terms, while others may prevail in cost or global warming potential terms. It is clear that PVC-U windows are not comparable with wood alternatives in GWP terms.

The results of the first parts of this study (Service Life Planning, SLP and Whole Life Costing, WLC) are summarised here as follows:

Applying a factor analysis, as set out in ISO 15686:8, predicts an expected service life for timber windows of between 56 and 65 years; for modified timber windows between 68 and 80 years; and

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for aluminium-clad timber windows 71 and 83 years. These are set against a base case for PVC-U of between 25 and 35 years.

Using NPV analysis, the whole life cost comparison for each option can be evaluated. With PVC-U windows indexed at 100, all timber based window options were indexed at less than 100: demonstrating that capital, installation, maintenance and replacement costs are lower for all building life options of 60, 80 and 100 years, and for all timber window alternatives. For mild exposures, timber windows offered the lowest lifetime cost option, while for moderate and severe exposures the more durable modified timber and aluminium-clad windows gave more favourable lifetime cost outcomes.

In practice, if initial capital cost is the only criterion, PVC-U windows are the least expensive short term option. If, however, total lifetime cost is the primary concern, the analysis suggests timber offers the lowest cost option for properties in a typical urban/suburban setting, aluminium-clad timber options would be favoured on high-rise or multi-storey buildings, benefitting from their extended service life and low access requirement, while in coastal or moderately exposed locations modified timber or aluminium-clad timber windows may be optimal.

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## 1.0 Introduction

This report provides the final part of a three-part research project to assess the whole lifecycle of materials used in window frame manufacture, use and end-of-life. This report concerns the Life Cycle Assessment (LCA) of four commonly used materials in window frame manufacture: timber; modified timber, aluminium-clad timber and PVC-U. This report accompanies analyses completed on Service Life Planning (SLP) and Whole Life Costing (WLC) of the same frame materials, completed in June 2012. The work was commissioned by the Wood Window Alliance and completes work started at Imperial College London in 2010. The findings within this report are the work of Dr. Gillian Menzies at Heriot Watt University. Used together both reports provide a comprehensive comparative tool for window frame material evaluation.

Timber windows referred to in this report are constructed from high quality, preservative treated softwood to BS EN 942, BS EN 599 and BS 817; constructed from a defect free enhanced substrate (heartwood); and with endgrain and construction joint sealing. Although the analysis here is limited to frame materials only, all window units are factory glazed and assumed to be installed in a recess.

In this report, modified timber is defined as timber which has undergone acetylation. This technique creates a high performing wood which can be used in demanding outdoor applications, including windows, doors, decking, cladding, and bridges. Wood contains hydroxyl groups that interact with water according to changes in climatic conditions - the main reason wood swells and shrinks. Acetylation converts these hydroxyl groups to acetyl groups by reaction with acetic anhydride. Naturally grown timbers already contain a proportion of acetyl groups, but the acetylation process increases this proportion significantly and the resulting timber is more dimensionally stable, indigestible (rot resistant) and durable.

Aluminium-clad timber windows, as referred to here, are timber windows with a full aluminium profile clad to the exterior of the window. The aluminium is commonly protected with a powder coating, typically guaranteed for around 25 years. The interior of the window appears as a timber window. The aluminium can be repainted after 20-30 years to maintain good aesthetic appeal, or left untreated with no loss of functional performance. The aluminium profile can also be removed, recycled, and a replacement clipped into place. This last option is assumed to be the preferred option in all scenarios evaluated within this report.

PVC-U windows are constructed from 70mm extruded PVC-U extrusions with mild steel reinforcement.

The LCA analysis has been carried out using SimaPro 7.3.2 software and the Ecoinvent 2.2 database which accompanies the software. ISO 14040: Environmental Management – Life Cycle Assessment – Principles and Framework has been used as the guiding framework for the analysis contained within this report. All assumptions made throughout the analysis are stated. Any deviations from the Ecoinvent 2.2 database have been justified.

## 2.0 Life Cycle Assessment

The construction industry is the highest consumer of materials globally, consuming around 6 tonnes of material per person per year. Energy is needed to create buildings through extraction and processing of raw materials, manufacture of finished products and components, during construction, to transport materials and products to site, to maintain components and to process materials at their end-of-life to recycle and/or dispose of materials (Consoli et al., 1993). If a boundary is drawn around this lifecycle and an assessment of inputs and outputs which cross this boundary is made, some attempt is given at assessing a building's Life Cycle Assessment (LCA). Figure 1 illustrates the lifecycle of window materials. Sometimes whole buildings are assessed in LCA terms, but more commonly individual materials and components are subject to detailed analysis.

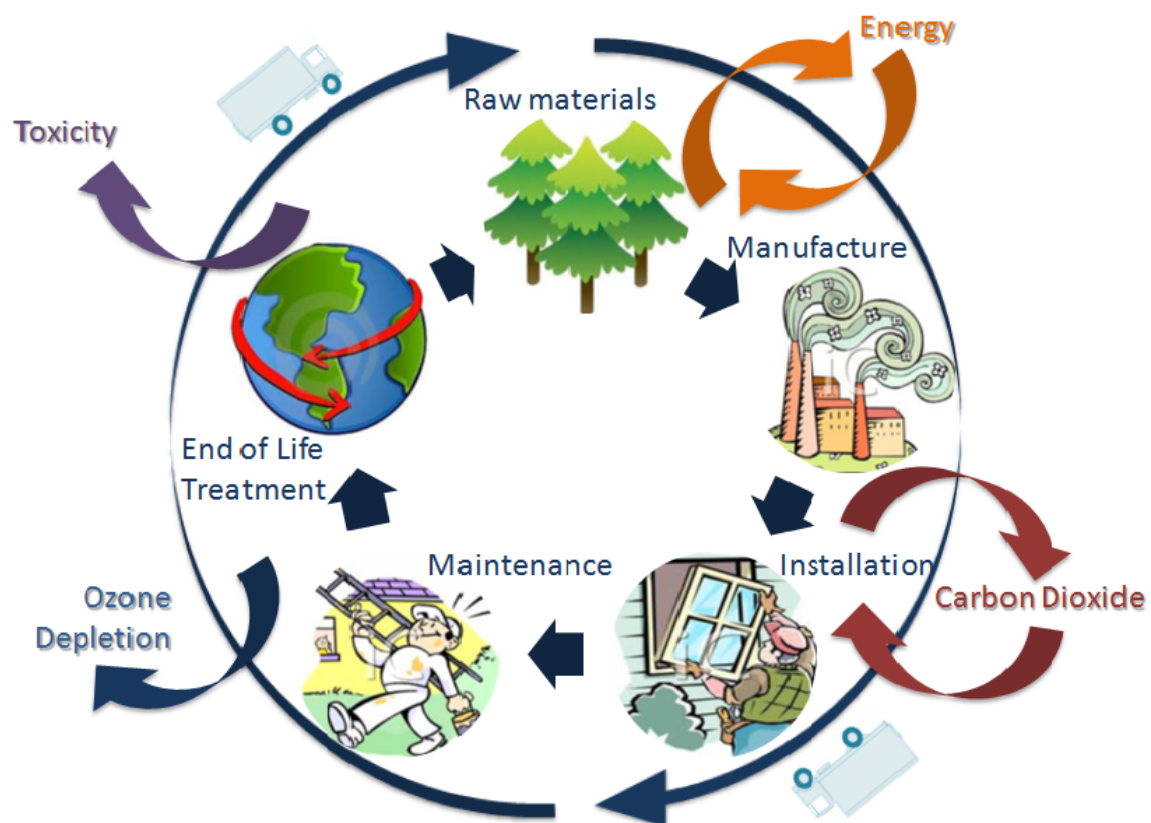


Figure 1 : Life Cycle Assessment of Window Materials

There are many methods available for assessing the environmental impacts of materials and components. LCA is a methodology for evaluating the environmental load of processes and products during their whole lifecycle and is one of various environmental management tools currently available for justifying environmental concerns (Sonnemann et al., 2003). With its origins in the 1960s (Selmes, 2005) LCA has become a widely used methodology over the last two decades for understanding better the impact which product lifecycles have on local and global communities.

LCA is an internationally recognised tool for assessing the environmental impact of products, processes and activities, using indicators described in Table 1.

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**Table 1 SimaPro Environmental Impacts Measures**

Abiotic Depletion	Ozone Layer Depletion	Terrestrial Ecotoxicity
Acidification	Human toxicity	Photochemical Oxidation
Eutrophication	Fresh Water Aquatic Ecotoxicity	Global Warming Potential
Marine Aquatic Ecotoxicity		

**Life Cycle Energy Analysis (LCEA)** emerged in the late 1970s and focuses on energy as the only measure of environmental impact of buildings or products. The purpose of LCEA is to present a more detailed analysis of energy attributable to products, systems or buildings; it is not developed to replace LCA but to compare and evaluate the initial (capital) and recurrent (operational) energy in materials and components. **Life Cycle Carbon Assessment (LCCA)** is likened to LCEA, and relies on prevailing energy structures to convert mega joules of energy to kilograms of CO<sub>2</sub>. This report will focus on LCCA. Other terms commonly used when discussing lifecycle definitions, energy and carbon issues are shown in Table 2.

**Table 2: Commonly used lifecycle terms**

Cradle to Grave	Describes all the processes which a product or component goes through from raw material extraction to obsolescence and final disposal. It assumes no EoL residual value.
Cradle to Gate	Describes the impacts associated with products, materials or processes up to the point at which they are packaged and ready for delivery to site.
Cradle to Site	Describes the impacts associated with suppliers (raw materials), transportation to manufacturing centre, manufacturing, packaging, and transportation to site. In the case of construction impacts, this would also include any processing required on site to make use of the product or component.
Cradle to Cradle	Similar to Cradle to Grave, but assumes that an obsolete component has a residual value at the end of its <i>first</i> life. It assumes that construction waste can be recycled and used to provide raw materials for re-manufacture of the same product, or new and different products.
Embodied Energy (EE)	A Cradle to Gate or Cradle to Site analysis based on energy inputs only. i.e. those energy inputs relating to raw material extraction, transportation, processing, manufacturing, and packaging.
Embodied Carbon (EC)	Converts this embodied energy from MJ to tonnes of CO <sub>2</sub> . Frequently embodied CO <sub>2</sub> is given as CO <sub>2</sub> e
Equivalent Carbon Dioxide (CO <sub>2</sub> e)	A way of describing how much global warming a given type and amount of greenhouse gas may cause, using the functionally equivalent amount or concentration of carbon dioxide (CO <sub>2</sub> ). Put simply, if CO <sub>2</sub> has a Global Warming Potential (GWP) of 1, then Methane has a GWP of 25, and Nitrous Oxide a GWP of 298.

Generally speaking a material, product or component has three main stages to its cradle to grave carbon lifecycle; Embodied Carbon (EC), Operational Carbon (OC) and End of Life carbon (EoL). In the case of windows, maintenance is captured under the operational energy stage. A full dynamic LCCA of windows may also include the glazing and thermal insulation qualities (the U-value) and give some indication of the energy expended to heat a home or building. This analysis will consider only the lifecycle of the window frame materials.

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A comprehensive LCCA study has four main stages:

1. Scope and boundary setting;
2. Inventory analysis;
3. Impact assessment; and
4. Improvement analysis.

A fifth and important element of LCCA includes an analysis of data sensitivity to the overall results. This may include an analysis of the quality of inventory data used, a test of the sensitivity of assumptions made, and/or a number of scenario analyses.

Before considering the specific issues relating to these LCCA stages, some points to note include:

**Boundary definitions** The accuracy of carbon calculations is directly related to, and profoundly influenced by, boundary definitions. Naturally, more comprehensive boundary assumptions result in more precise calculations. The direct carbon requirement for manufacturing processes is generally less than 50% of the total embodied carbon of a product, but can be up to 80%, while the indirect carbon requirement for extracting raw materials is generally less than 40%, and the carbon emitted to make the capital equipment less than 10%. In general, the carbon requirement to make the machines that make the capital equipment is very low. Inclusion/exclusion of indirect processes like raw material extraction, embodied carbon of manufacturing machinery, transportation, reoccurring embodied carbon of materials, or the feasibility of recycling and reuse, can have a significant effect on overall results.

**Completeness of study** The more processes which are included in a study the more complete and accurate the results become. Indirect carbon contributions depend upon many factors, including raw material sources. The Inventory of Carbon and Energy (ICE) database commonly reports data sensitivities of 30% due to varying boundary inclusions and completeness of studies [ICE, 2011].

**Energy supply assumptions** These assumptions can produce significant variations in embodied carbon evaluations; whether primary or secondary (delivered or end use). If primary energy is reported instead of delivered or end-use energy, the value may be 30 to 40% higher for common building materials. Lack of information regarding these factors is one of the main obstacles in comparing life cycle inventory results.

**Energy source assumptions** Energy sources inherently have varying carbon coefficients. Generation of electricity from hydroelectric power or other renewable sources have significantly different impacts than conventional, hydrocarbon based, fossil fuel sources. For example in Canada and Norway, aluminium is produced solely using hydroelectric power. Brick production in Nottinghamshire uses methane from landfill [Smith, 2005] rather than traditional (generally coal fired) energy supplies. Variations in energy source and distribution will impact both embodied energy values (due to cycle efficiencies), and carbon emissions resulting from energy use. Buchanan and Honey [1994] found that carbon emissions relating to material production could differ by a factor of three depending on assumptions made over energy supply.



**Product specification** Differences in processing and application also generate large variances. Virgin steel consumes significantly more energy than recycled steel, and different processes within the steel manufacturing industry affect embodied carbon values.

**Manufacturing differences** Processing efficiency levels improve over time as a result of technological advances, and can vary depending on the geographical location. Studies following Buchanan and Honey's findings [1994] in construction materials (summarised by Alcorn and Wood, 1998) indicate a continuing downward trend in processing energy for many materials. Conversely, however, there is a trend to make more technical specifications for construction projects, increasing in some cases, the length of supply chains and processing steps to final product completion.

## Methodologies

There are a number of recognised approaches to LCA, LCEA and LCCA, including process analysis, Input-Output analysis, and hybrid analyses.

### Process Analysis Method

This is the oldest and still most commonly used method, involving the evaluation of direct and indirect energy inputs to each product stage. It usually begins with the final product and works backwards to the point of raw material extraction. The main disadvantages centre on the difficulties in obtaining data, not understanding the full process thoroughly, and extreme time and labour intensity. These result in compromises to system boundary selections (which are generally drawn around the inputs where data is available). Furthermore it is likely to ignore some of the processes such as services (banking and insurance, finance), inputs of small items, and ancillary activities (administration, storage). The magnitude of the incompleteness varies with the type of product or process, and depth of the study, but can be 50% or more [Lenzen and Treloar, 2002]. For these reasons results are found to be consistently lower than the findings of other methodologies. Process LCA is best used to assess or compare specific options within one particular sector. This report is an example of such a method. The major advantage is the ability to define individual product life stages and material inputs, enabling in-depth sensitivity or scenario analyses to be performed.

### Input Output Analysis

Originally developed as a technique to represent financial interactions between the industries of a nation, this method can be used in inventory analysis to overcome the limitations of process analysis. The method is based on tables which represent monetary flows between sectors, and which can be transformed to physical flows to capture environmental fluxes between economic sectors. The number of sectors and their definition vary within each country. The great advantage of this method is data completeness of system boundaries; the entire economic activities of a nation are represented. However despite the comprehensive framework and complete data analysis, I/O analysis is subject to many uncertainties, due mainly to the high level of aggregation of products. Many dissimilar commodities, or sectors containing much dissimilarity, are put into the same category and assumed identical; assumptions are based on proportionality between monetary and

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physical flows. In some countries I/O tables are not updated frequently, resulting in temporal differences with irrelevant or unrepresentative data. Unsurprisingly, LCAs based on process analysis and I/O analysis yield considerably different results. I/O-LCA is suitable for strategic policy making decisions (comparing sectors) as well as providing complementary data on sectors not easily covered by process LCA. This method would be impractical for the current study.

### Hybrid Energy Analyses

The disadvantages of previous methods can be reduced if a hybrid method, combining both P-LCA and I/O-LCA methodologies, is employed. In this model some of the requirements are assessed by process analysis, while the remaining requirements are covered by input–output analysis. The main disadvantage of these techniques is the risk of double counting.

For the analysis contained in this report a process-LCA approach is adopted, using SimaPro 7.3.2 software modelling tools and the Ecoinvent 2.2 database. Deviations from the Ecoinvent 2.2 database are made in justified cases and are identified throughout the analysis. For simplicity the results are reported for Global Warming Potential (GWP) only. A number of scenario analyses are included and results are reported with potential error bars.

### 3.0 Boundaries, Scope and Functional Unit

The aim of this study was to define an approach for the fair and “apples for apples” comparison of various window frame materials in terms of their lifecycle environmental impact.

A lifecycle is defined as a period of 60 years for this study. This period of time is in-keeping with other analyses of building components (for example the BRE Green Guide to Specification).

The purpose of the study is to provide a comparison of materials used in contemporary window frames. The purpose is not to define absolute values for the GWP or EC of materials over their lifecycles. The results should be interpreted in terms of their relative magnitude, rather than their absolute value.

The findings of this report are to be used in conjunction with the Service Life Planning (SLP) and Whole Life Cost (WLC) report issued in June 2012, and are intended to provide information to specifiers concerned with selecting windows with a whole life appraisal approach e.g housing associations and clients/owners with a long term investment view.

The LCCA contained here adopts a process-LCA approach which includes the frame materials of the window. The boundary includes all raw material extraction, transportation and processing, manufacturing energy, finishing, site construction, maintenance over 60 years, transportation and End-of-Life (EoL) processes. It excludes the energy and impact of manufacturing the machinery required to make the windows, the glazing unit for the windows, the window ironmongery, and the dynamic differences in thermal performance of the windows (U-value factors).

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The study is a Cradle to Grave analysis, although one scenario considers the Cradle to Cradle impacts of processing materials for use as recycled content in future products.

The study also assumes that timber used in windows acts as a carbon store, according to the UK PAS2050 standard [BSI, 2011]. It assumes that all timber is sustainably sourced and managed according to FSC (Forest Stewardship Council) or equivalent specification. The FSC was founded in response to public concern about deforestation and demand for a trustworthy wood-labelling scheme. FSC certification is focused on forest management and a chain of custody.

The functional unit of the study is kgCO<sub>2</sub>e per window. The window size is consistent for all options and scenarios in the study: a standard window unit measuring 1230mm wide by 1480mm high.

#### 4.0 Inventory Analysis

A base case scenario was developed to describe as closely as possible the current assumptions, processes, transportation, locations, energy mix, disposal and other prevailing factors. Later in Section 6.0 a number of alternative scenarios are described and assessed.

The basic process, materials, waste, energy, heat and transportation needed over the lifecycle of a basic timber window is described and quantified in Figure 2.

Appendix A details the full inventory of data used in this study.

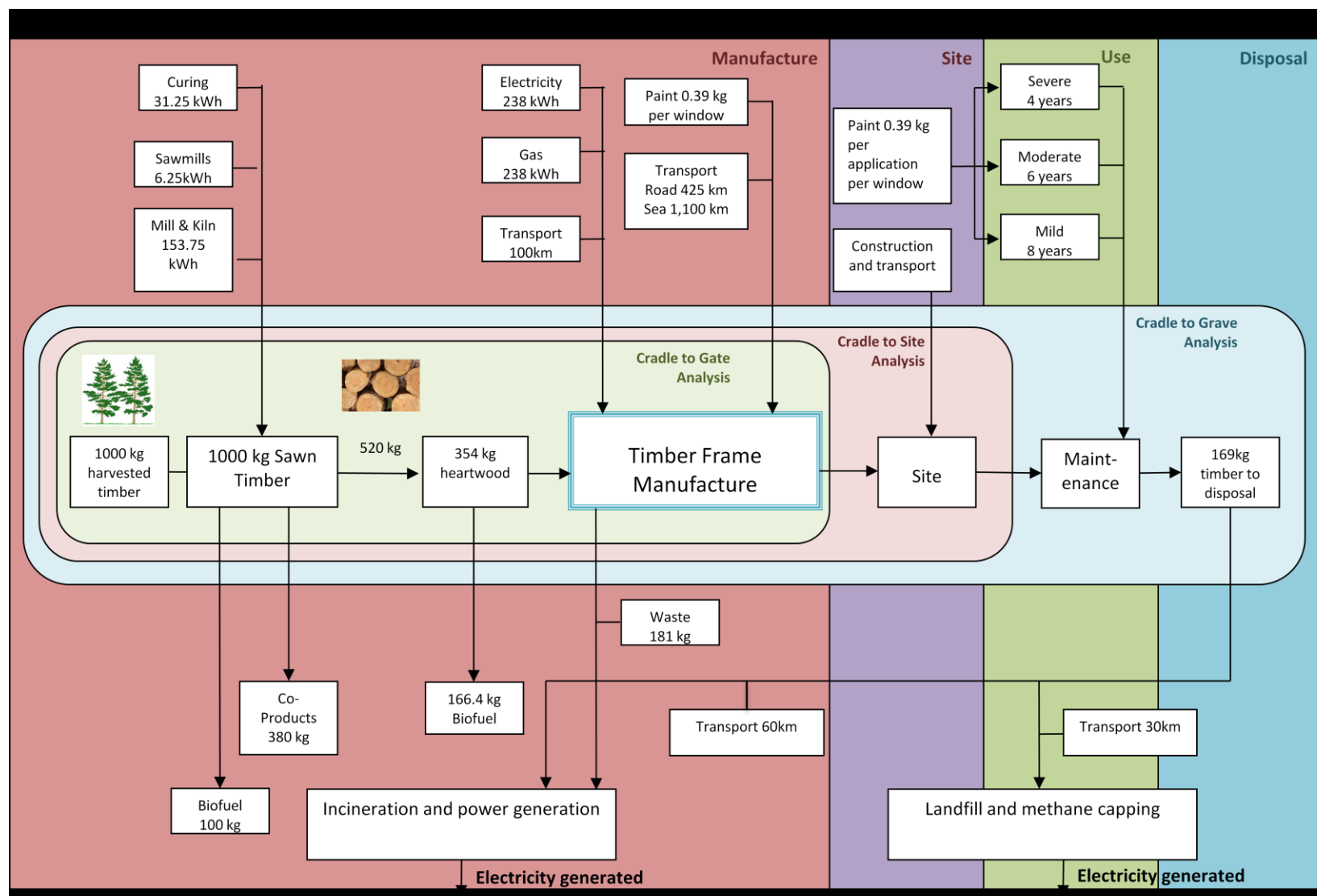


Figure 2: Cradle to Grave Inventory of inputs and outputs for a base case timber window frame (quantities stated are per 12 windows)

#### Inventory notes for frame materials

For aluminium-clad (Al-clad) timber windows a mass of 5.4kg of aluminium is accounted for, including 5% waste. Over a 60 year lifecycle it is assumed that the aluminium profile is replaced once in mild and moderate exposure scenarios, and twice in a severe exposure scenario. All aluminium is recycled.

For modified timber wood is sourced from the Radiata pine species in New Zealand. The transportation requirement via sea freight is accounted for in addition to the requirements for the wood acetylation process. This requires acetic anhydride as a raw material and produces high performance, durable timber as a product, and acetic acid as a by-product of the acetylation process. The LCA simulation is based on the Halcon process and a new database entry made in SimaPro to provide inventory information using data from Accsys Technologies, and provided by Imperial College London [Hillier & Murphy, 2002]. A major consideration of the Halcon process is the large credit given for the avoided production of acetic acid. An adjustment was also made to the quantity of wood required for the frame manufacture stage. Radiata pine undergoes acetylation in a range of set dimensions. Based on the size of window frame for this study, an inventory of acetylated timber sections was compiled, and the associated quantity of waste calculated.

For timber and modified timber frame options 0.39kg of paint is factory applied to the finished windows. At each maintenance event, based on a mild, moderate or severe exposure scenario a further 0.39kg of paint is applied.

For PVC-U windows a mass of 17.45kg of Polyvinylchloride and 4kg of reinforcing steel is accounted for. PVC-U windows are produced in many locations throughout the UK and EU. With no specific data on transportation from factory to site, this is excluded from the study at present. The mass of PVC-U is based on a 70mm A-rated window. The mass of steel is taken from a BRE client report on Generic Environmental Profiles of Timber Windows, cited in Davis Langdon [2010].

#### Co-products and biofuel

Co-products of the life cycle (used as skirting boards and architraves) are removed from the system in the same way as cradle to grave elements, assuming no residual EoL value, but also implying no impact on the current lifecycle.

Biofuel in the LCA system refers to offcuts and sawdust which are used to provide heat and/or power within the lifecycle. E.g. biofuel at the sawn timber stage is used to dry timber in the kiln. Biofuel produced while selecting heartwood may be used to heat the factory and offices on the processing site. Other waste can be used for animal bedding or as raw material to the particleboard industry. This type of waste is assumed to have no residual EoL value or impact.

#### Timber carbon storage and forest stewardship

It is assumed that all timber used in the production of timber and timber based window frames are sustainably sourced. On 3 March 2013, the European Union (EU) Timber Regulation entered into

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force, making it a crime to introduce illegally harvested timber and products into the EU market. Importing companies are required to have a **due diligence system** to avoid this. According to the British Standard, PAS2050, biogenic carbon storage must be fully accounted up to a period of 100 years. Any emission occurring after 100 years is not considered. In this study, the building life is taken to be 60 years and therefore all carbon sequestered during the growing phase of the trees, and the subsequent known release of this carbon through combustion or rotting in landfill are accounted for. Any carbon stored in wood products which are recycled at EoL remains; no residual value is assumed.

For 1000kg of felled timber, the sequestered carbon dioxide stored is assumed to be 1600kg. The carbon content of dried wood is approximately 50%. Using an assumed 12.5% retained moisture level and 50% of the dry weight as carbon, the carbon in 1000kg of wood weighs 436kg. The molecular mass of carbon is 12, while for oxygen is 16. This means that each kg of carbon in the timber has been drawn from 3.67kgCO<sub>2</sub>. For sustainably sourced timber this leads to a carbon store of 436 x -3.67 = -1600kgCO<sub>2</sub>. This value has been entered into the SimaPro model in a simulated opening balance manner.

#### Base Case End of Life Scenario

The base case EoL scenario is based on a recent update publication by WRAP [WRAP 2012]. For timber the baseline recycling rate for construction and demolition in 2008 was 78%. The remaining 22% is divided equally between incineration with electricity production (avoided electricity at UK grid production), and landfill with methane capping and electricity production. By 2015 WRAP makes recommendations under two policy options. The first is a restriction from landfill for different types of waste which would results in 86% of construction and demolition waste being recycled by 2015 and 50% of the remainder diverted to combustion; the second is to place a ban on unsorted waste which would results in 88% of construction and demolition waste being recycled by 2015 and 70% of the remainder diverted to combustion.

Current practice for PVC-U suggests that 12% of windows are crumbed and recycled (re-extruded for possible use in new PVC-U windows), 12% are incinerated, and 76% are landfilled [Davis Langdon, 2010]. According to the Ecoinvent database the degradability of PVC-U in landfill over 100 years is 1%. While the release of carbon and methane is therefore very small, the loss of fossil fuel based materials should be considered. Also, the capacity of landfill sites to “hide” all our refuse is of considerable ongoing concern. Reported by the Environment Agency in Zglobisz et al [2010], the landfill capacity in England and Wales is sufficient only until 2015.

## 5.0 Impact Assessment

SimaPro 7.3.2 gives a number of environmental impact categories and a full LCA appraisal, as listed in Table 2. In order to make a simplified basis for comparison across frame material choices and the various scenarios considered in Section 6.0 a focus is made on the Global Warming Potential (GWP) of each permutation, measured in  $\text{KgCO}_2\text{e}/\text{window}$ . A focus on GWP only for the base case reveals the graph shown in Figure 5.

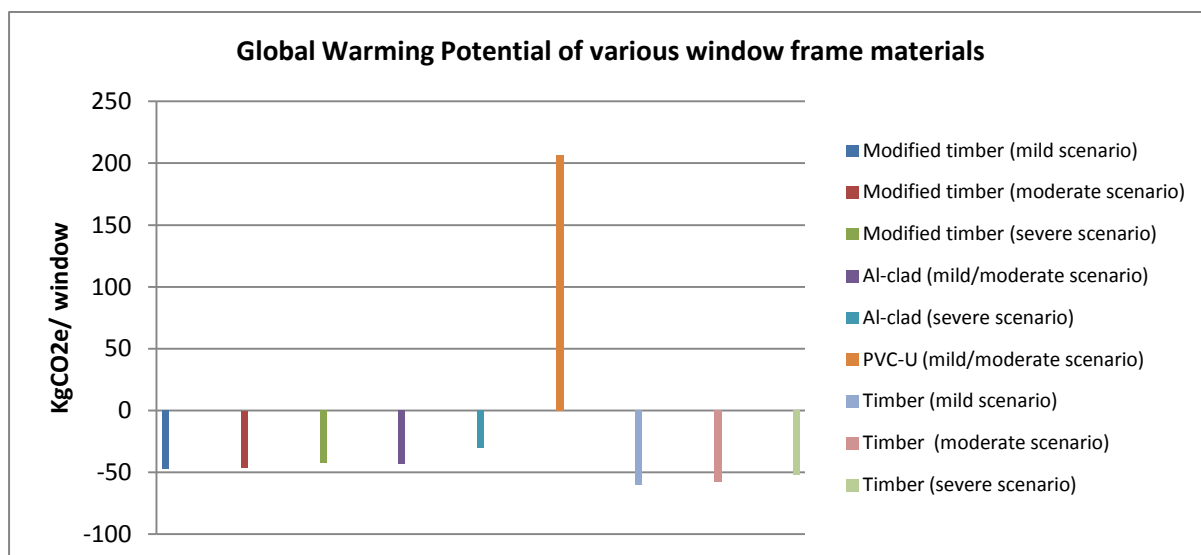


Figure 5: GWP for base case scenario

It is immediately noticeable that all timber based window options have negative values while the PVC-U option has a strongly positive impact. This is due to the carbon storage effect of timber during its growth phase. In the scenario analysis below it is shown how this negative impact is affected positively or negatively in relation to EoL assumptions and treatment, and whether timber is sustainably sourced.

It is also worth noting that the graph above represents the impact over a 60 year period. Each of the timber based options has a minimum service life which would service a 60 year building design life. The various exposure scenarios considered demonstrate the application of paint in maintenance events of timber and modified timber, and the replacement of aluminium cladding in Al-clad window frames over 60 years. According to the service life planning part of this study only PVC-U windows would require complete replacement within a 60 year building life. In a mild/moderate exposure scenario there would be one complete window replacement over a 60 year building life, while in a severe exposure scenario there may be two complete window replacements.

It is stressed that rather than focussing on the absolute values of GWP for each frame type and scenario that the results are used comparatively. For the reasons emphasised in the methodology section above it is rare for one LCA study to be directly comparable with another.

## 6.0 Waste Scenario Analysis and sensitivity

Using the SimaPro model for the base case described above, six scenarios were considered which test the sensitivity of assumptions made about timber sourcing and the end of life treatment of all materials. These scenarios are as follows:

1. Timber is not sustainably sourced and therefore cannot act as a carbon store since no replacement tree is planted when the raw materials are felled.
2. All materials are recycled at EoL on a Cradle to Grave basis, i.e. no residual value is given for materials which will enter a future product lifecycle.
3. All materials are recycled at EoL on a Cradle to Cradle basis, i.e. construction waste can be recycled and used to provide raw materials for re-manufacture of the same product, or new and different products. The benefit of providing reduced impact raw materials to a future lifecycle is counted in this lifecycle as a positive impact. This is outwith the recommendation of ISO 14040 but is included here to investigate if there are any strongly influencing benefits from the onward use of recycled materials.
4. All materials are incinerated at EoL and electricity produced is fully offset against the emissions generated, i.e. electricity is generated as an avoided product. This is an unlikely scenario given the recommendations set out by WRAP [2012], but is investigated to determine any strongly influencing results.
5. The outcomes in Scenario 4 are heavily dependent on the assumptions used to determine the carbon intensity of grid electricity in the UK. The current intensity factor published by Defra is 0.547 KgCo2e/kWh. As we move forward with the UK Government's aims to decarbonise grid electricity, this value is assumed to drop. The benefit to the lifecycle of avoided electricity production through waste incineration is therefore reduced as we progress towards a lower carbon intensity grid. Scenario 5 therefore includes avoided electricity from EoL incineration at 50% of the current grid carbon intensity.
6. Scenario 6 is similar to Scenario 5, but assumes a purely hypothetical analysis of a zero carbon intensity electricity grid in the UK.

Figures 6-11 show the GWP results for each of these six scenarios.



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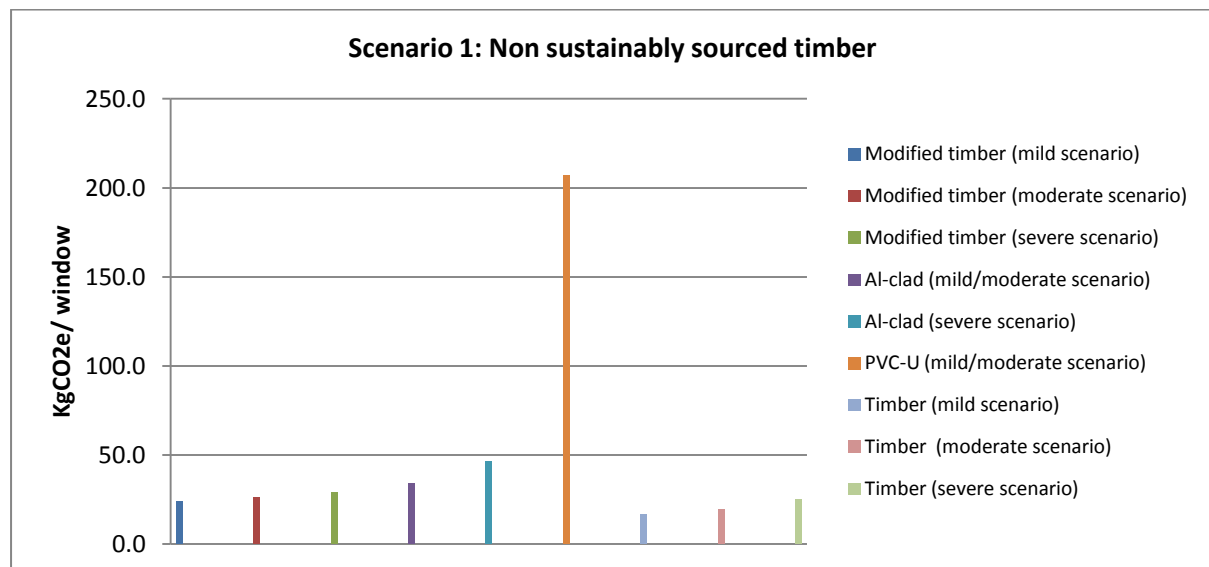


Figure 6: Scenario 1 GWP of unsustainably sourced timber (no carbon sequestered during growth)

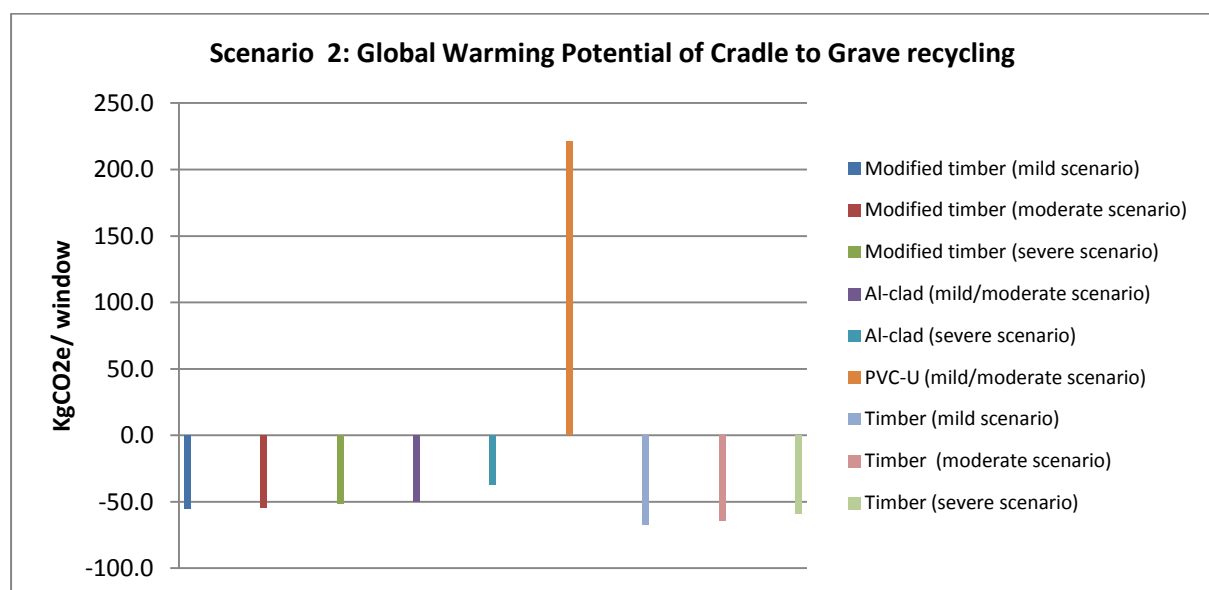


Figure 7: Scenario 2 GWP of Cradle to Grave recycling

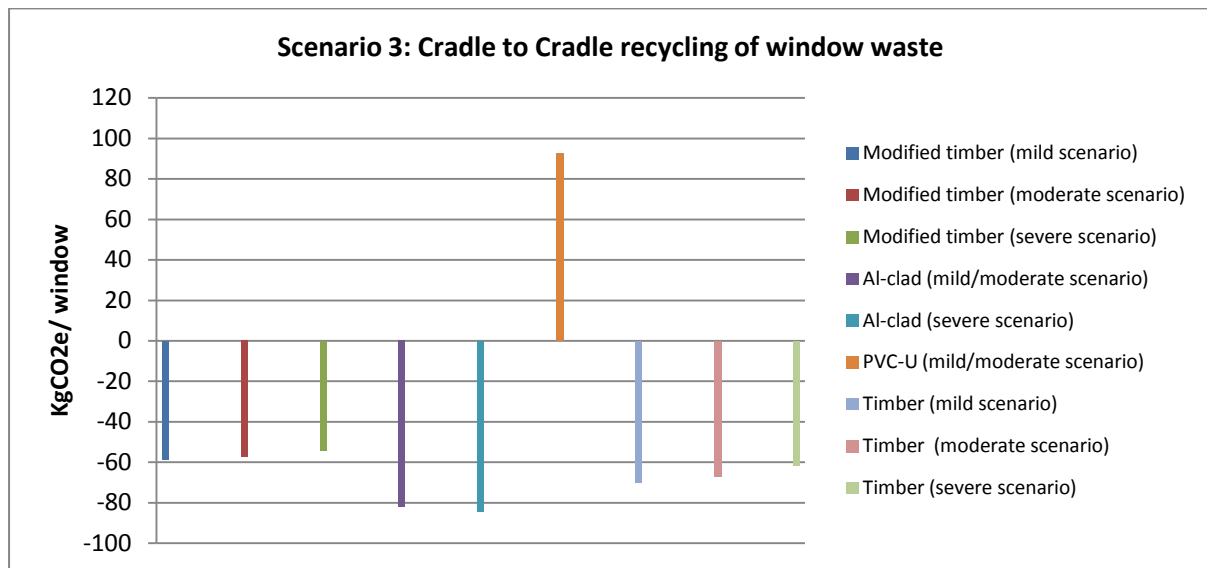


Figure 8: Scenario 3 Cradle to Cradle recycling of waste (includes benefit to next lifecycle)

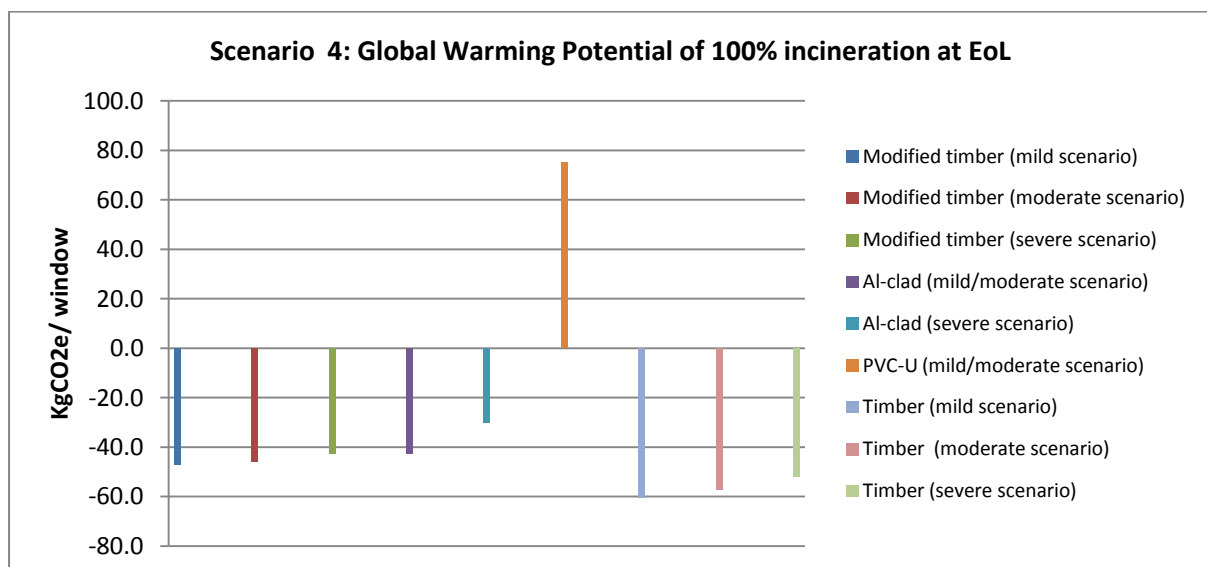
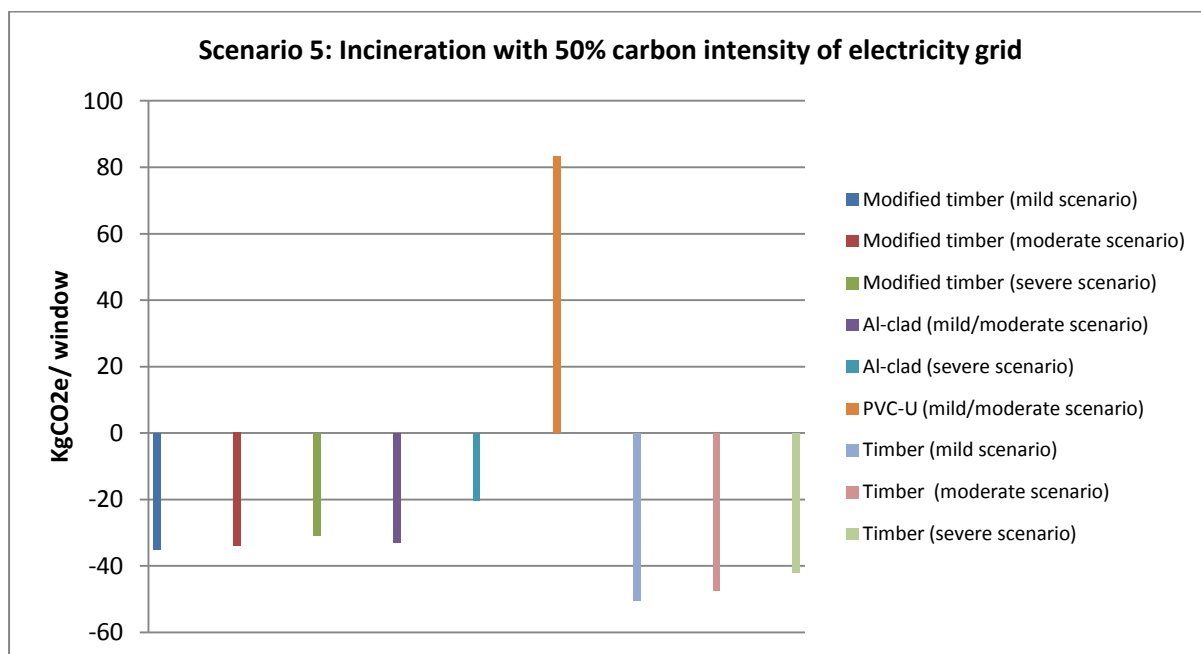
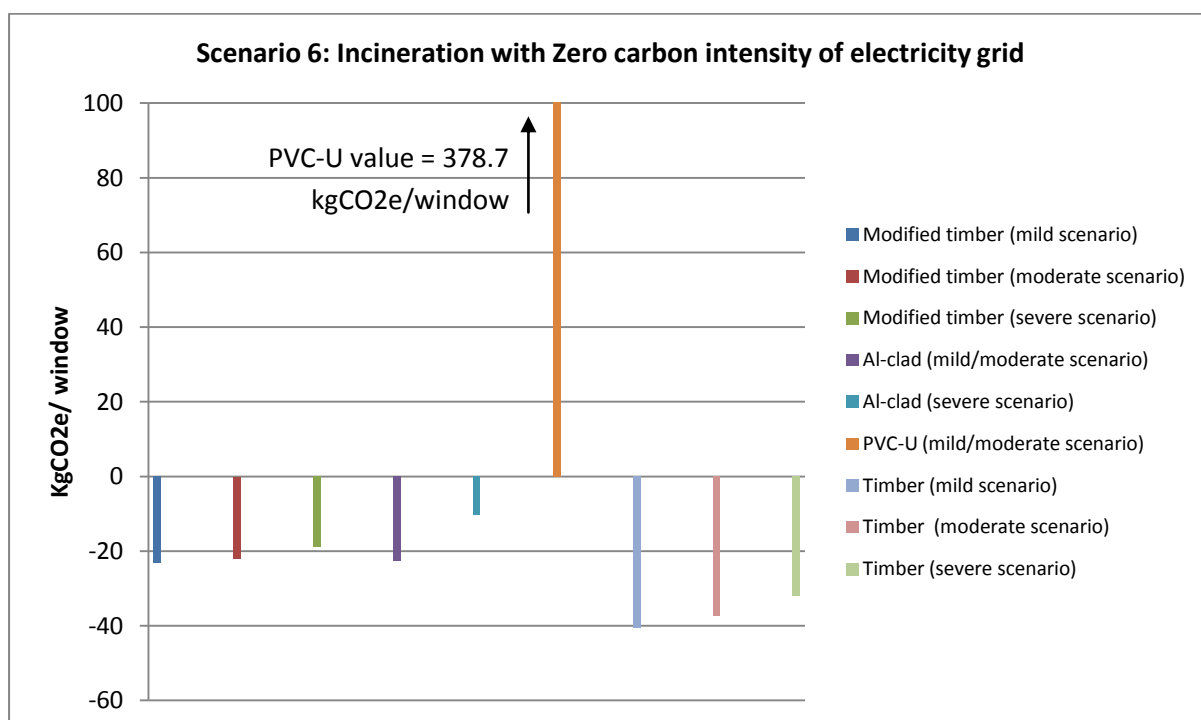


Figure 9: Scenario 4 All materials incinerated at EoL (current UK grid carbon-intensity)



**Figure 10: Scenario 5 All materials incinerated at EoL (50% UK grid carbon-intensity)**



**Figure 11: Scenario 6 All materials incinerated at EoL (Zero UK grid carbon-intensity)**

Figure 12 attempts to capture these variances in one graph to show the potential shift in GWP results according to these scenario assumptions and investigations. Note that Figure 12 omits the effect of non-sustainably sourced timber (as this is now illegal under EU law), and the scenario for Cradle to Cradle analysis (as this is outwith ISO 14040 guidance).

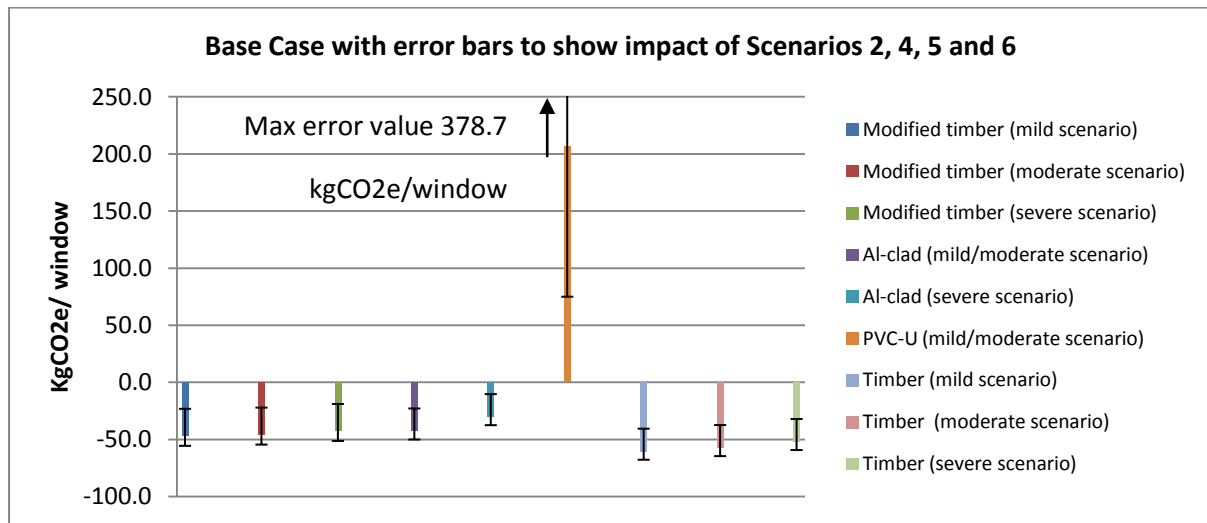


Figure 12: Base Case with error bars to show impact of Scenarios 2 and 4-6

## 7.0 Discussion and Conclusions

Seven main discussions result from the above analysis. These include issues of:

- Sustainable sourcing of timber
- Recycling of materials
- End of life treatment
- Boundary inclusion
- Reducing intensity of grid electricity
- Service life impact
- Comparison of timber frame options

### Sustainable sourcing of materials

The impact on the GWP of all timber based window frames which are sustainably sourced is clearly evident. The only scenario for which the GWP is positive for timber based options is seen when no carbon sequestration can be accounted for in the growing phase of the trees. New EU regulations from March 2013 ensure the legal obligation of timber users to source raw materials responsibly and ethically. This scenario is therefore purely hypothetical, but shows the sensitivity of the study to PAS2050 guidelines. The topic of carbon sequestration and its accounting is a subject of strong debate amongst researchers [Ostle et al, 2009]. This study highlights the importance of getting this right.

### Recycling of materials

The optimum scenario for EoL treatment for timber products is shown to be recycling, with the largest negative GWP values seen in Scenarios 2 and 3. This is because the carbon remains stored in the timber and is not released through incineration or landfill decay.

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In Scenario 2 (Cradle to Grave recycling) no significant benefit is seen for PVC-U windows over the base case scenario (largely landfill for PVC-U). This is because SimaPro deals with these processes in essentially the same way. Cradle to Grave analysis assumes no EoL residual value for PVC-U, while landfill assumes minimal biodegrading of PVC-U in landfill. Clearly it would be better to recycle PVC-U windows than landfill them, but as the lifecycle for the window has ended under Cradle to Grave analysis, this cannot be accounted in this lifecycle.

Scenario 3 (Cradle to Cradle recycling) is very different. The positive benefit to timber and PVC-U disposal is clearly evident with the best GWP values for all windows. This is a question of LCA boundary setting which must be consistent within a comparative LCA study. It is still seen, however, that timber based window frames perform better in GWP terms than PVC-U even when Cradle to Cradle boundaries are set.

#### End of Life Treatment

Clearly the EoL assumptions made are critical to the outcome of the study. Perhaps the best, and fairest, comparison which can be made at present is based on current EoL treatments for the various frame materials. In all scenarios, in terms of GWP, timber based window frames outperform PVC-U alternatives.

It is also seen that the optimum EoL treatment for timber is to recycle it. Initiatives like WRAP should therefore press on with their aims to improve recycling rates of timber, ensure waste segregation and continue steps to reduce landfilling of timber.

#### Boundary inclusion

LCA boundary inclusion/exclusion is well known to have significant impact on LCA results. This is particularly true when using a Process-LCA methodology, as in this report. The important factor is to ensure that boundaries are consistent within a comparative LCA. Treatment of avoided products and positive accounting of by-products can have significant effects on the overall results.

#### Reducing Intensity of Grid Electricity

Any analysis based on the “payback” of energy generated or carbon emitted either as a part of the use phase of a product (e.g. the installation of loft insulation or the manufacture of renewable technologies like photovoltaic panels) are sensitive to the long-term intensity of electricity supplies. Defra/Decc [2012] applies a five year rolling average of grid carbon dioxide equivalent intensity. The current value of 0.589 kgCO<sub>2</sub>e/kWh has dropped from 0.884 kgCO<sub>2</sub>e/kWh in 1990 due to efficiency of production and transmission, and use of alternative fuels. As part of the UK renewable energy strategy the CO<sub>2</sub> intensity of future electricity supplies should reflect a continuing downward trend.

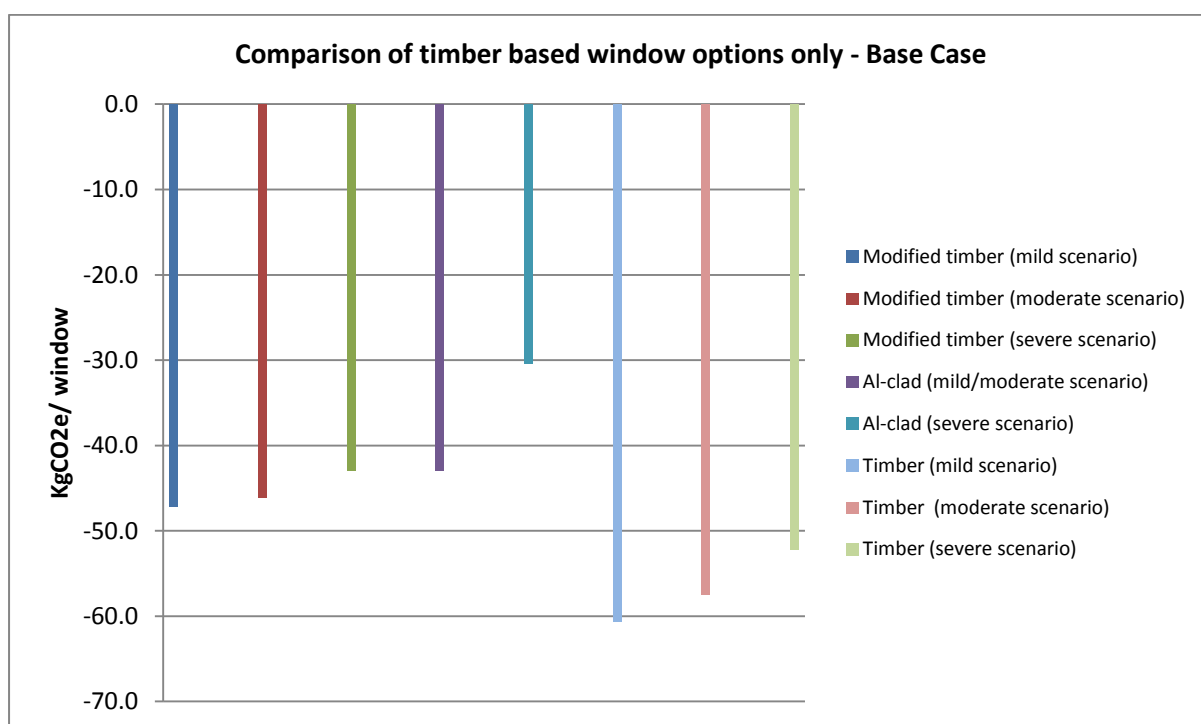
It is seen in this study that if we were to achieve a hypothetical zero carbon grid intensity that all timber frame options would still be GWP negative. However it is noted that the UK is very unlikely to move towards a policy of wide scale incineration of wood waste.

## Service Life Impact

The results of this LCA report are to be read in conjunction with the earlier work on Service Life Planning and Whole Life Costing. It was shown that PVC-U windows, even in a mild exposure scenario are unlikely to be serviceable beyond 35 years. This means that for a 60 year building life the GWP for the PVC-U scenarios considered above should be doubled. This further emphasises the environmental impact of fossil fuel based raw materials in construction.

## Comparison of timber frame options

Removing PVC-U from the base case scenario reveals the results shown in Figure 13.



**Figure 13: Base Case - comparison of timber based window options only**

It can be seen that basic timber windows offer improved GWP values over 60 years for all exposure scenarios. Modified timber options for all exposure scenarios and Al-clad timber windows used in mild or moderate exposure scenarios are roughly equivalent. Al-clad timber windows used in severe exposure locations may have a higher GWP than alternatives, but this outcome is largely based on the assumption that the aluminium cladding will require replacement after 20 years of in-situ use. It is argued that the performance of the aluminium will not have been altered detrimentally after this time, but that replacement is deemed necessary for aesthetic reasons, i.e. perceived obsolescence.

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## 9.0 Appendices