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The challenge of specifying a low carbon insulation: Comparing linear and circular supply chains in the manufacture of insulation

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Abstract

In the last decade, ‘green’ and sustainable supply chain management practices have been developed in efforts to try and reduce the negative consequences of production and consumption processes on the environment. In parallel to this, the circular economy discourse has been propagated in the industrial ecology and production economic literature and in business and practice. The ideals of the circular economy principles suggests that the frontiers of environmental sustainability can be pushed by emphasising the idea of transforming the supply chains in the manufacture of products in such a way that there are workable relationships between ecological systems and economic growth.

The Life Cycle Analysis [LCA] framework is deployed and based on ISO 14040 published international standards. In addition scenario analysis is integrated into the framework to model potential impacts of various recommendations that could be generated from the result of the LCA. By using LCA, the main aim is to assess the environmental impacts associated with the supply chain in the manufacture of insulation materials, also understanding the market dynamics, policy and societal implications that could arise by the implementation of circular production systems.

By arguing for these ideas to be integrated into supply chain management theory and practice, the paper uses building thermal and acoustic insulation case study. Insulation is a crucial component in the construction of new buildings and ‘eco’ refurbishment projects. The case study demonstrates the environmental gains in terms of carbon emissions that can be achieved through some circular economy principles as against traditional linear production systems. The paper therefore asserts that an integration of circular economy principles within sustainable supply chain management can provide clear advantages from an environmental point view despite some external supply chain influences and scenarios. Further to this, emerging supply chain management challenges and market dynamics were researched by a team and are also highlighted and discussed.

Keywords: Circular Economy, Linear Supply Chain, Construction, Carbon Emissions, Low Carbon, LCA

1. Introduction

Energy efficient and renewable building technologies are key in humanity's efforts to tackle global challenges (James Martin, Jan. 2007) such as, climate change policy makers are facing choices over how to balance support for energy efficiency and renewables, while keeping fuel prices down. The challenge in the construction of new build and in domestic and commercial refurbishment projects is in the specifying a low-carbon insulation, while providing adequate energy saving performance and services critical components for low carbon buildings.

The case study asserts that the integration of environmental gains in terms of carbon emissions that can be achieved through the following of some circular economy principles within the sustainable supply chain management in the manufacture of insulation as against conventional linear production systems can provide clear advantages from an environmental point view despite some external supply chain influences and scenarios.

In addition the case study will present results of Life Cycle Assessments (LCA) to propose changes to the manufacturing process, supply chain and the product to assess the possible impacts of these on the overall carbon footprint of the a low carbon insulation. Along with emerging supply chain management challenges and market dynamics discussed.

The case study presented is also used to create evaluation criteria for insulation materials in order to devise a methodology to establish a monitory value for what is normally considered a non-monitory value of low carbon insulation.

In addition, to evaluate insulation materials to create a simple energy rating index which compares the carbon footprint of a conventional and a low carbon insulation product in their manufacturing supply chains. Much like the European label that provides an A-G rating required for all electrical items – showing their environmental impact. This label will indicate that the product has been independently assessed and found to meet strict environmental criteria, considering more than just energy consumption and putting the insulation product among the best in its class.

2. Circular Economy

The circular economy is defined as an economic paradigm where resources are kept in use as long as possible, with maximum value extracted from them while in use. The paradigm has its conceptual root in industrial ecology, emphasising the benefits of recycling waste materials and by-products (Jacobsen, 2006). The principles of circular economy thus extend the boundary of green supply chain management by devising methodologies to continuously sustaining the circulation of resources and energy within a quasi-closed system. This consequently reduces the need for new material inputs into production systems as well as minimising the use of virgin materials for economic activity (Andersen, 2006; Genovese *et al.*, 2015). The Ellen Macarthur Foundation in 2015 concluded that the European economy operates in a linear take-make-dispose resource model that generates significant waste.

In the European Union (EU), the European Commission had recently launched a consultation to determine measures that could be taken at EU level to overcome barriers in development of circular economy during manufacture and consumption of products (Early, 2015a). In essence, the concept of circular economy pushes for a closed-loop supply chain design, enabling any products at the end of their life cycle to re-enter the supply chain as a production input.

3. Life Cycle Assessment [LCA]

Sanders in 2012 defines Life Cycle Assessment as an approach that considers environmental stewardship by analysing the environmental aspects and potential impacts associated with a product, process, or service. Hence, the use of LCA enables the estimation of the cumulative environmental impacts resulting from all stages in the product life cycle. This has been emphasied by Murphy and Norton in 2008 and Acquaye *et al.* in 2012, who state that management strategies increasingly include usage of LCA for identifying environmental impacts and inefficiencies in resource use throughout the lifecycle of a product.

The LCA methodology has been described as incomplete, primarily because it is not possible to account for the theoretically infinite number of inputs of every complex product supply chains into the LCA system (Acquaye *et al*., 2011; Genovese *et al*., 2015). However, LCA remains a useful indicator of the environmental impacts associated with a product's life cycle and can be a basis for eco-labeling requested by consumers, non-governmental organizations (NGOs) and national as well as international authorities (Jensen *et al*., 1997). In addition, if LCA is used optimally, it can be a decision support tool that helps businesses to ensure that their choices are environmentally sound.

4. The Construction Insulation Materials Industry

Several recent studies have shown that greenhouse gas mitigation is now a central policy of almost all developed economies (Acquaye *et al*., 2011). It is also stated by that buildings, in particular, account for approximately 40% to 50% of total emissions in these countries. In the United Kingdom, the UK Green Building Council has identified construction as the most emission-intensive industry. It is responsible for around 50 % of greenhouse gas production in the country (Dadhich *et al*., 2015). Fraunhofer in 2009 highlighted that more attention should be given to the environmental impact of the construction industry as the industry is responsible for 40 percent of overall waste production in the European Union.

The Code for Sustainable Homes (Department for Communities and Local Government, 2006) states that the construction of buildings should emphasize optimum energy efficiency and the use of natural, reclaimed and recycled materials. EU policies, such as the Construction Products Regulation, Eco Design Directive and Green Public Procurement are steering the construction industry towards more sustainable production and operation (Paroc, 2014). Insulation of buildings is a major element in providing an economical route to achieving the requirements of these various regulations. The Code for Sustainable Homes has been officially scrapped by the UK government as part of its 'bonfire of red tape' in the house-building sector. The changes are the culmination of the Housing Standards Review, published 27th March 2015 housing-standards-review-final-implementation-impact-assessment, which aims to reduce the cost and complexity of building homes in England and stop the 'pick and mix' approach to housing standards by different local authorities in England.

There are many different types of insulation materials available in the market, each produced from different resources such as sheep wool, stone wool, glass wool, and recycled cotton / denim. Regardless of the type of insulation material, the levels of thermal insulation required either for new buildings or building regulations sets refurbishment projects. These are mainly expressed as a U-value, which is a measure of heat loss. Although of the same type (i.e., stone wool), different brands of insulation may exhibit different thermal insulation performance and require different amount of material to achieve the required U-value. Therefore, the U-value often becomes a useful indicator for customers to select their preferred insulation product. However, a value is normally not considered of a low carbon insulation. With the introduction of regulations such as the Landfill Tax (Gov.uk, 2015), there are economic benefits that can be gained in addition to environmental benefits of rerouting these building materials to other avenues such as reuse or recycling.

5. **Importance of the Case Study**

It is important to understand the environmental implications of utilising sustainable insulation alternatives in various contexts and applications. The increasing understanding and adoption of environmental paradigms such as the circular economy requires a holistic assessment approach in which environmental impacts are brought into one consistent framework, regardless of whether these impacts have occurred or will occur (Genovese *et al.*, 2015).

The availability of LCA on insulation products will enable well-informed decisions to be made by key stakeholders in the construction industry, taking into account the full consequences and benefits of their construction material selection. Producers of insulation products and other construction materials need to re-evaluate their supply chain and place greater emphasis on the sustainability of their products and supply chains.

This case study will therefore seek to understand the potential impact of switching from conventional insulation materials to insulation materials produced using recycled sources and in the implementation of circular economy production systems.

6. Methodology

The main aim of this research is to evaluate and compare the environmental impacts associated with the supply chain of building insulation projects obtained from recycled materials using a circular supply chain to those associated with traditionally manufactured products using a linear supply chain. Both products considered in this research generally serve the same function, which is mainly to contain heat within a building.

A Life Cycle Assessment (LCA) provides a good understanding of the environmental impacts of supply chains. A comprehensive LCA enables the identification of production paths associated with high energy and resource usage, as well as pollution and emission of greenhouse gases (Genovese *et al*., 2015). Therefore, the LCA will form the foundation of the research, supported by the presentation of results through various means.

6.1 Life Cycle Assessment

The life cycle assessment framework deployed for this study is based on ISO 14040 published international standards (Finkbeiner *et al*., 2006).

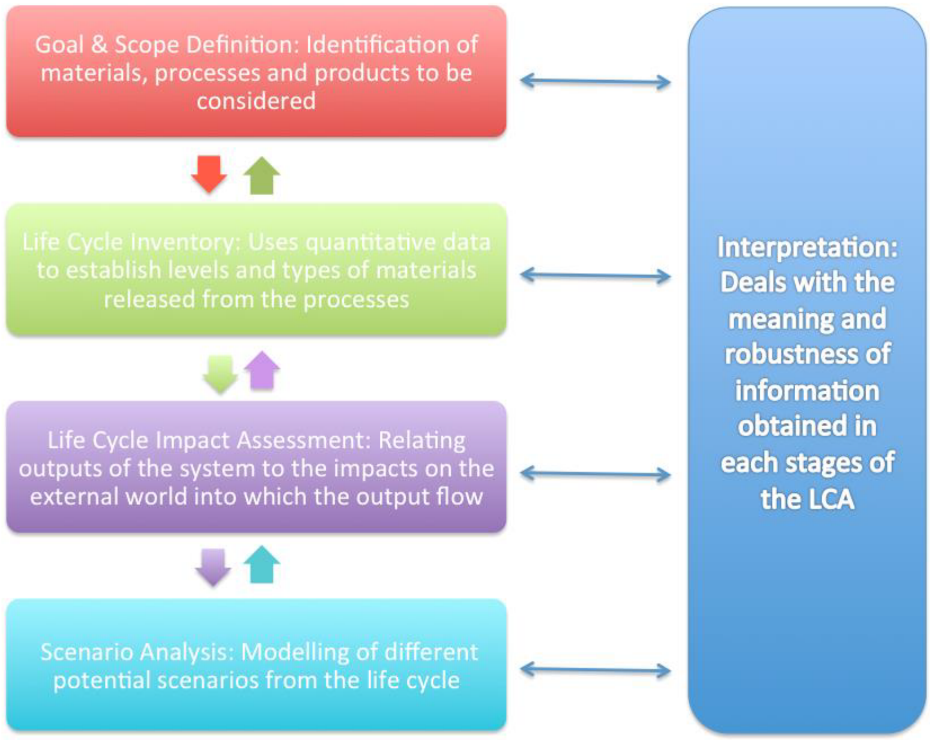


Figure 1: Adaptation of LCA standards according to ISO14040

The environmental impact can be measured in many different ways depending on the chosen life cycle impact assessment (LCIA) method (Teehan and Kandlikar, 2012). One of the categories within the method as per the Intergovernmental Panel on Climate Change (IPCC) standard is the global warming potential over 100 years (GWP100) in kilograms of carbon dioxide equivalent (kgCO2-eq). This method is adopted for this case study due to the availability of data and because it has been used effectively in a large number of similar studies (Dadhich *et al.,* 2015; Genovese *et al*., 2015; Acquaye *et al.,* 2014). It has to be noted that the study deploys cradle-to-grave analysis, where the assessment involves a partial product LCA from resource extraction (cradle) until it is packed at the factory, before it is transported to the customer (grave) (Guinee, 2002).

6.2 The Functional Unit

The Functional Unit (FU) of the LCA is a measure of the function of the studied system and provides a reference to which the inputs and outputs can be related. According to ISO 14040 standards, the FU is defined as ‘the quantified performance of a product system for use as a reference unit in a life cycle assessment study.

In studies of thermal insulation products, the thermal resistance R, measured in m2K/W, has been generally accepted as a meaningful and operational functional unit (Schmidt *et al*., 2004). The R-value is the measure of resistance to heat flow through a given thickness of material. Therefore, the higher the R-value, the more thermal resistance the material has and the better its insulating properties (Schmidt *et al*., 2004). In addition, it also gives information about the amount of insulation material that is required to achieve a certain thermal resistance within the product’s lifetime. This consequently enables the comparison of two different products. This is arguably a very simplistic method to compare the performance of two insulating materials when the available information is the thickness of the material and the thermal conductivity.

Heat moves in a number of different methods and the R-value only takes into account conduction. The U-value provides a more robust representation of the thermal insulation property of an insulation product. The calculation of U-value takes into account the three major ways in which heat loss occurs: conduction, convection and radiation. Nevertheless, the R-value is selected as the functional unit due to the availability of information for analysis and its adequate robustness as a meaningful and operational functional unit (Schmidt *et al*., 2004).

6.3 Supply Chain Mapping

The output of the LCA will be organised and presented in graphs reporting the total carbon emissions and the breakdown of the emission hotspots. Supply chain maps will visually represent the interaction between different entities (Dadhich *et al*., 2015).

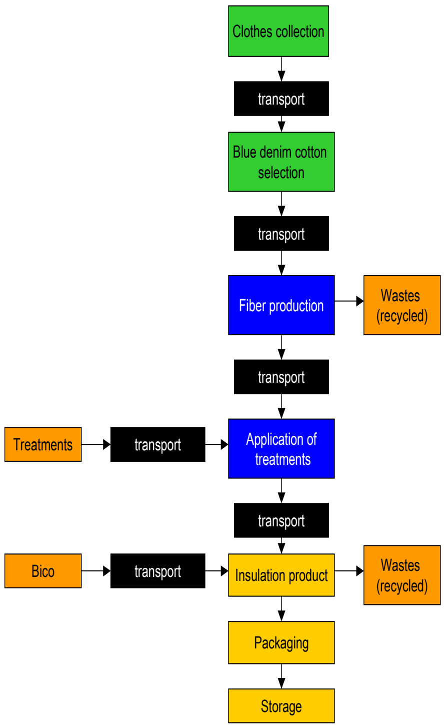
According to Koh *et al.* (2013), a supply chain map can be used to provide clear understanding of the flow of materials and the environmental impacts along the supply chain. This will then form the basis for benchmarking the environmental performance of the supply chains for both products and identify ways to manage the impacts.

7. Case study of insulation materials

Thermal and acoustics insulation materials represent one of the crucial components in the construction of new buildings and in renovation projects. In the United Kingdom (UK), the insulation market exceeding £1 billion in 2008 forms a significant component of the construction industry (Murphy and Norton, 2008). With increasing emphasis on sustainable construction and green building, insulation plays a fundamental role in contributing to the environmental credentials of any construction projects, from how the insulation products are manufactured and its supply chain, to the energy saving capability of the products through preventions of heat loss in buildings. One of the most commonly used insulation material within the construction industry is stone wool, which is produced using virgin raw materials from volcanic rock such as database or basalt, together with limestone and dolomite (Väntsi and Kärki, 2013); recently, alternative products, based on the recycling of used materials, have been proposed as an alternative to traditional materials.

This case study focuses on the environmental implications and performance of two insulation products that directly compete with each other in the same market segment. Commercial names of the products will not be disclosed for confidentiality reasons. The first product, resulting from a circular supply chain, is produced using recycled cottons (in the following, it will be indicated as **P1**); the second product – based on stone wool - is a common insulation type in the construction industry and produced from molten rock (in the following, it will be indicated as **P2**).

Data for the supply chain of P1 has been obtained from the UK distributor and French manufacturer of the product, and are complemented with secondary data from Ecoinvent (2010). Similarly, Ecoinvent (2010) database was utilized to extract data related to the supply chain of P2. Due to the potentially diverse end-of-life scenarios for both types of insulation products, making direct comparison is very difficult. Even more so, the expected service life of many insulation products is relatively long, which is around 50 years (Murphy and Norton, 2008). Thus, the results from the LCA are considered for the ‘cradle to grave’ part of the supply chain only. This includes the input of raw material, the production process, and up to but not including the distribution to customer. The case study also did not include the emissions associated with the installation of product, its usage and disposal. The stages within the manufacturing of P1 up until the packaging is shown in the process map.



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Figures 2: Supply chain process flow chart/map for P1

As a direct comparison, the typical production process of P2 is shown in Figure 3.

Figure 3: Typical supply chain process flow map for P2

The electricity source used in the manufacturing supply chain process for P2 is based on the medium voltage electricity generated and transmitted for industrial use in the UK; for P1, the medium voltage electricity mix for France where the product is manufactured is considered.

8. Data Collection

As mentioned, the carbon emissions implications of the supply chain of the two types of insulation products being studied are obtained from both primary and secondary sources. The primary data is collected through direct communication with the social enterprise manufacturing and distribution and companies for P1 via face-to-face meetings, interviews, company reports and emails, while secondary data are sourced directly from Ecoinvent (2010) database. Ecoinvent is an online database with comprehensive Life Cycle Inventory (LCI) datasets, which have been used in a number of academic studies and corporate reports (Wiedmann *et al*., 2011).

The manufacturing and distribution companies provided the following specific information for P1:

- The quantity of collected clothes for recycling and its proportion in terms of collection methods;
- The distance of transportation and types of transportation used for movement of materials in the supply chain;
- The quantity of energy consumption (electricity and gas) within the supply chain;
- Types and quantity of chemicals used in product treatment, and
- The process map of P1 production, from raw material to final product.

From Ecoinvent (2010), the cumulative effects of emissions are presented using kilogram CO2 equivalents (kgCO2-eq) of the unit input over a 100-year period. For the stone wool (P2) insulation product, the quantity of materials for each Functional Unit (FU) is derived from Ecoinvent (2010) database. As for P1, the data given by the manufacturing and distribution companies allows the quantity of each materials and processes required for the FU to be calculated. These quantities are multiplied with the emissions intensity per unit obtained from Ecoinvent (2010) and the total is summed up to give the total emissions of each product's supply chains.

The quantitative and environmental analysis was complemented by an LCA completed by the manufacturing company of P1. The main purpose of the analysis was to dissect the cost elements of the manufacturing circular (P1) and linear (P2) supply chains and product alternatives, as well as identifying the market challenges associated with the implementation of circular economy practices in the insulation materials industry.

8. Preliminary findings of data analysis

The functional unit [FU] used in research conducted for the case study was defined according to a proposal from the Council for European Producers of Materials for Construction (CEPMC, 2000). The product lifespan is considered to be 50 years and an R-value of 1 m2K/W. The same unit is used in the criteria for EU eco-labeling of insulation materials (Schmidt et al., 2004). It has to be noted however, that stone wool insulation materials come in a variety of brands and produced by different manufacturers. P1 chosen has a thermal conductivity of 0.039 W/mK while the P2 stone wool insulation product chosen for this study has a thermal conductivity of 0.035 W/mK. Accordingly, the FU is defined as:

$FU = R * \lambda * d * A$

Where:

R is the thermal resistance to be obtained, assumed equal to 1 m2K/W,
λ is the thermal conductivity, which is 0.039 W/mK for P1 and 0.035 W/mK for P2 ·
d is the density of the insulation products = 20 kg/m3 for P1, 38 kg/m3 for P2
A is the area of the insulation material to be considered (assumed equal to1 m2)

The resulting unit in kilograms necessary to provide a thermal resistance of 1 m2K/W for a use period of 50 years (Schmidt *et al*., 2004) is therefore shown in Table 3.

Material	**Thermal conductivity,(W/mK)**	**Density (kg/m3)**	**Functional Unit (kg)**	**Corresponding insulation thickness (mm)**
P1 (Circular)	0.039	20	0.78	39
P2 (Linear)	0.035	38	1.33	35

Table 3: The functional unit in kg necessary to provide a thermal resistance of 1m2K/W for a use period of 50 years. (Schmidt *et al.*, 2004)

The preliminary data supplied by the manufacturing and distribution companies for P1 provided a comprehensive overview of the entire supply chain of the product, from collection of denim cottons to the packing process of the finished products. Each year an average of 11,000 tonnes of clothes are collected to be processed in France as inputs for the production of P1. The clothes are collected using various methods in two types of sacks.

The clothes are collected using three different methods. These are identified as:

- Door-to-door collection – sacks are distributed to individuals and later collected from door to door
- Collection in container – individuals deposit the clothes in different containers located in various locations in France, and
- Collection among local groups – Annually, 730 tonnes out of the 11 000 tonnes of clothes used in the production of P1 are collected from local groups.

The main methods of transportation used in transporting materials between the main production locations are lorries ranging from 3 tonnes up to 24 tonnes. In some cases, small vans are also utilised, specifically in the collection of clothes as input material. Another means of transport utilized in the production of P1 is sea freight, where the bi-composite polyester binder manufactured in South Korea are transported 19 663 km from Busan port to Le Havre in France.

The electricity used in the manufacturing process is supplied by the Électricité de France (EDF) grid, converted to medium voltage for use in the manufacturing facilities. The electricity consumption in different stages of the manufacturing process ranges from 0.0018 kWh to 0.3787 kWh for each FU of insulation material produced.

8.1 Supply Chain Mapping

The results of the analysis directly compare the carbon emission implications of producing insulation material using recycled sources (P1) through a circular open-loop supply chain compared to the production of stone wool insulation material (P2) through a linear production system. Results are summarised in Figure 4.

Using the methodology discussed, the analysis shows that the emissions from the supply chain of stone wool (1.5090 kgCO2-eq) is 64 % higher than that from the production of P1 (0.9200 kgCO2-eq). This preliminarily analysis indicates that the emissions of P1, the insulation product produced from a circular open-loop supply chain,are significantly lower than insulation produced from a linear supply chain. In addition, as P1 is produced mainly from waste cottons, the emissions that would have been generated from waste disposal are also avoided.

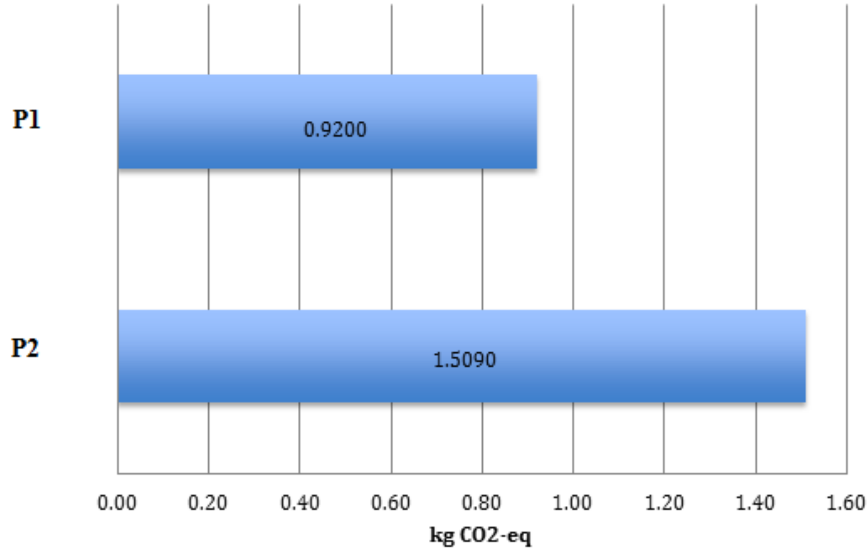

Figure 4: Comparative levels of emissions by P1 and P2 supply chains

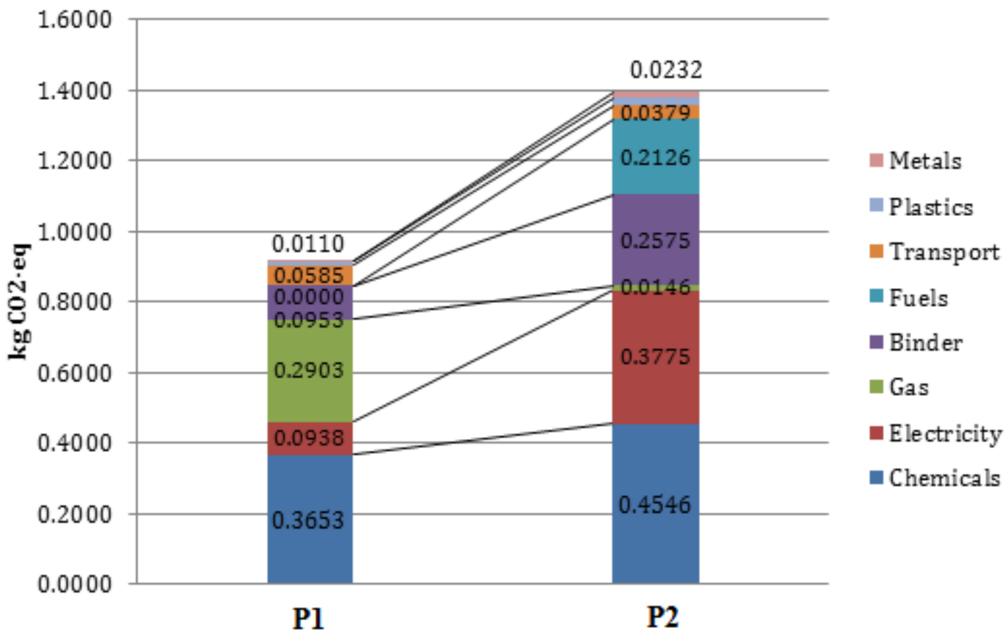

Figure 5: Breakdown of carbon emissions hotspots in P1 and P2 supply chains

It can be observed from the graph that within both supply chains, chemicals are the main 'hotspots' for both P1 and P2 as there are a number of different chemicals used for product treatments. For P1, this contributes to 39.7% of the total emissions, which are caused by the chemicals used as treatment to add fire retardant properties and parasite resistance to the insulation materials. As for P2, the proportion of emissions contributed by chemicals is also significant at 30%; with phenol, urea and formaldehyde combining to a total of 27.9%; these are mainly the components for the binder (Pilato, 2010).

The environmental benefits from adopting circular supply chains can therefore be investigated in terms of the types of chemicals required for product treatment to produce insulation materials of identical thermal performances. The total emissions from chemicals required for treatment in the production of P1 is 0.3653 kgCO2-eq, which is 19.6% lower than the emissions due to the chemicals used in product treatment for P2. This implies that the use of recycled cotton in the circular supply chain for P1 enables the input material to be treated with chemicals with lower environmental impact, compared to the linear supply chain.

Electricity is also a significant hotspot for both products' supply chains although it is much more prominent for P2 supply chain at 25% while the electricity emissions from P1 supply chain is 75.2% lower than P2 at 0.0938 kgCO2-eq. This is due to the French electricity mix used in the production of P1. Transport is another major hotspot in P1 supply chain, forming 6% of the total carbon emissions. This is significantly higher than P2, in which case transport constitutes only 2.5% of the total emissions. The main proportion of the carbon emissions from the transport element of the P1 supply chain is from the clothing collection stage. As stated earlier, for P1, cotton clothing is collected from around France using various methods with collection from containers forming 70% of the total annual input of clothes and consequently contributing 4% of the total emission of P1. The average distance for collection from each container is 180 km, using 3 tonne lorries at an average fill rate of 70%.

The identification of carbon hotspots enables the impact of each phase of the materials' supply chain to be translated visually in supply chain carbon maps as seen in Figures 6 and 7.

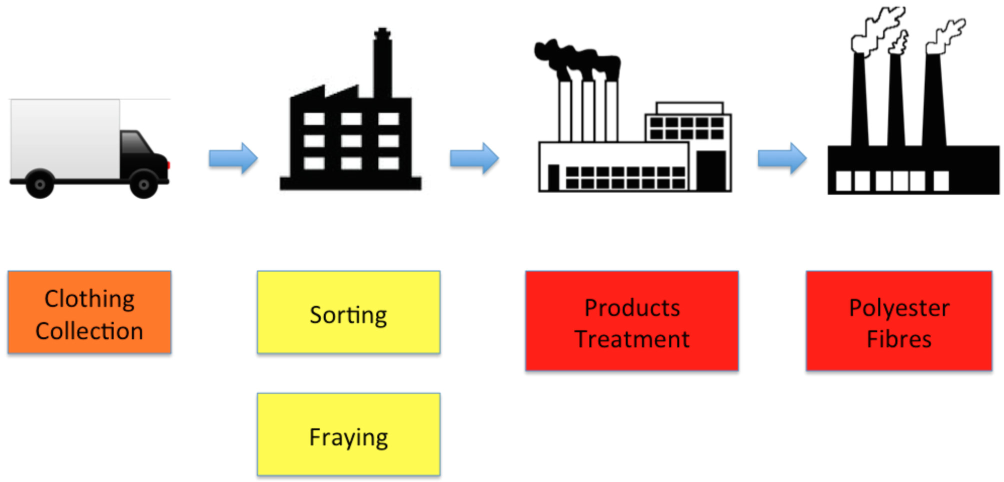

Figure 6: Supply chain Carbon Map for P1

The supply chain carbon map of P1 in Figure 6 presents the upstream and downstream carbon emissions of the product supply chain obtained using process LCA methodology. The main activities in the supply chain are the collection of clothing for recycling, sorting and fraying of the clothing, chemical treatment of the product and the manufacturing of the polyester fibres, which are used as a binder for the material. Figure 6 reiterate the finding that product treatment activities, and the manufacturing of bi-composite polyester binder are the main hotspots within the supply chain. This analysis estimates that product treatment activities contribute to 68.2% of the total lifecycle emissions while the manufacturing and transportation of binder accounts for 21.1% of the emissions. It has to be noted, however, that in both of these elements, the electricity used in the processes is also taken into account.

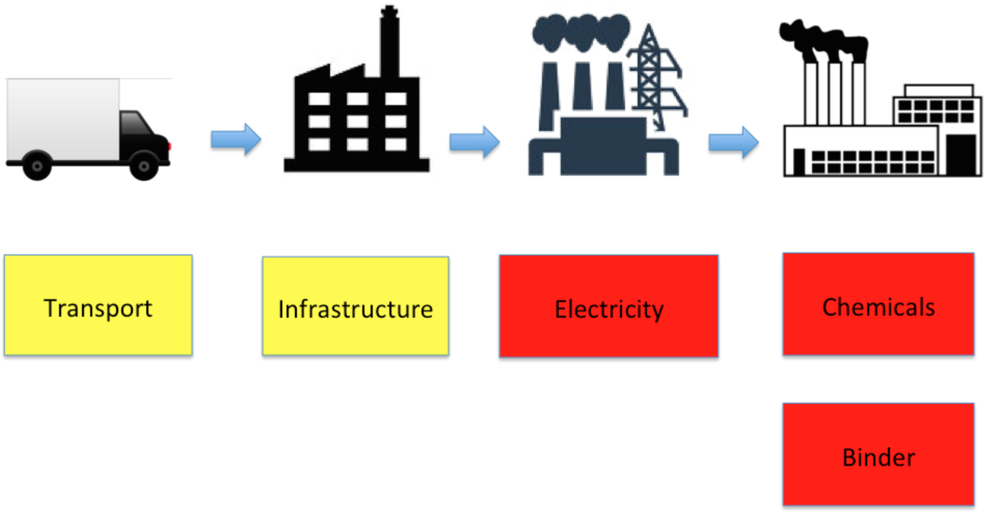

Figure 7: Supply chain Carbon Map for P2

A slightly different approach was taken for the linear alternative, P2, where the electricity element is accounted separately. As shown in Figure 7, for P2, product treatment chemicals and binder material are the major carbon hotspots in the supply chain with each respectively responsible for 30.1% and 17.1% of the supply chain carbon emissions. As it turns out, electricity is another major carbon hotspot, contributing to 25% of the carbon emissions. This is mainly attributed to the UK electricity grid, which still generates a major proportion of its electricity from non-renewable sources such as coal and natural gas.

The manufacturing and distribution companies of P1 have been identified changing the bi-composite polyester binder to a biological binder will further reduce the total emissions of the product. This is effectively corroborated with the findings of the analysis using supply chain mapping which identified the manufacturing of the binder as one of the major hotspots in the supply chain. The company believes that finding a binder that can provide optimum product performance while at the same time reducing the total carbon emissions from its life cycle will be the key to improving the environmental credentials of P1.

9. Market condition

Stone wool is the main product for conventional insulation. In the green segment, sheep wool has been introduced. Customers for P1 are low carbon building project, DIY home owners, musicians setting up studios and customers who want green product and who have some understanding with respect to what makes an insulation product sustainable.

Marketing a product manufactured through a circular supply chain presents major challenges in the industry, as customers within the industry are more concerned with the price and performance of the insulation product, rather than the environmental credentials of its supply chain. They rarely look for carbon emissions of a product.

In addition, in the UK, many conventional insulation products receive subsidies from the government through energy efficiency schemes operated by central and local government. These findings are consistent with results from Genovese *et al*. in 2015, who stated that, in the current free-market economy, products resulting from circular supply chains may not be an economical alternative. Existing P1 customers already have some understanding and the general public should be better informed on the environmental credentials of the insulation products that they are using. This awareness can be cultivated from the provision of greater incentive from the government to encourage the purchase of products that can reduce the environmental impacts from activities such as new construction or renovation projects.

10. Discussion

Different scenarios are modeled and potential strategies are identified to reduce the environmental impacts of the insulation materials supply chain. Two main scenarios are considered for the analysis: The electricity mix, and the configuration of the clothing collection methods for product P1.

10.1 Scenario 1: The electricity mix

The worldwide energy demand is currently rising, with some estimating that energy consumption will rise by 50% from 2005 to 2030; mainly due to rising population sizes and increased energy requirements of developing nations (U.S. Energy Information Administration, 2008). In many countries, the current energy demand is met mainly by using fossil fuels, which are in limited supply. The sources of energy, specifically electricity are therefore an important driver of environmental impacts that have to be considered when performing LCA (Bousquin *et al*., 2012 and Teehan and Kandlikar, 2012).

In the data presented, the scenarios considered in terms of electricity generation are based on the actual situation for production of both types of insulation products. P1 is manufactured and packed in France. Therefore, the emissions intensity figures considered for the electricity generation and transmission in the life cycle of P1 are based on France's energy mix (0.0946 kgCO2-eq). Meanwhile, the production facilities of P2 are located in the United Kingdom, where the emission intensity for electricity is 0.60 kgCO2-eq. This is 538.9% percent higher than the emissions figure for France (Ecoinvent, 2010). In France, 77% of the electricity produced in 2014 was from nuclear power while 17.7% was from renewable energy sources such as hydropower, wind and solar (Le réseau de l'intelligence électrique, 2015). This explains the very low level of carbon emissions associated with grid-connected electricity in France.

10.2 Micro Renewable Generation Schemes

As insulation material manufacturers have little or no control on the country's electricity mix, another potentially feasible approach that can be considered in efforts to reduce carbon emissions from the electricity is by commissioning micro-renewable generation schemes. Based on the assumption that the micro-renewable generation scheme caters for 100% of the production facility's electricity demand. The total carbon emission for production of both P1 and P2 is calculated. According to the Department of Energy and Climate Change (2011), there are a range of micro generation technologies available for commercial scale applications. These include solar photovoltaic (PV) panels, wind turbines, hydroelectric and bio energy.

The scenario is modeled by using emissions intensity values from Ecoinvent (2010) database of a range of renewable electricity generation schemes. These values are incorporated in the process LCA, replacing the emissions intensity of medium voltage electricity obtained from the grid of the country where the products are produced and assuming that all other elements such as power consumption remain constant. The results of this analysis are shown in the graph in Figure 9.

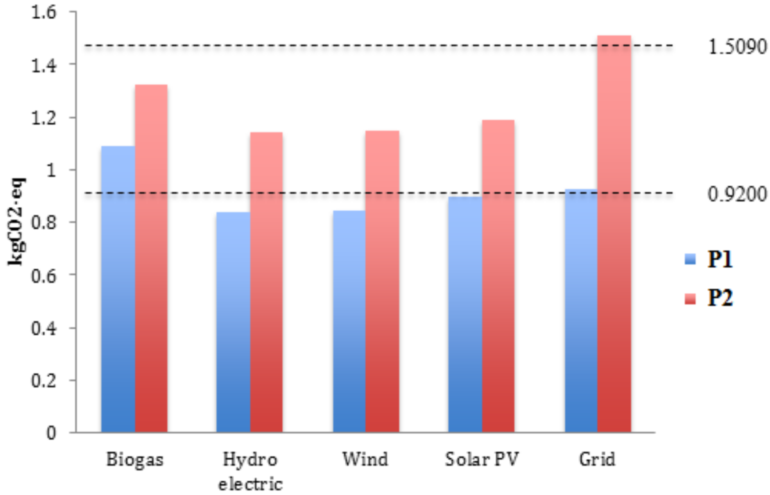

Figure 9: Total carbon emissions of supply chains of insulation materials produced with renewable electricity source

The result of the analysis indicates that switching to renewable energy sources in the production of both P1 and P2 generally reduces the total carbon emissions from the supply chain. The only exception is switching to electricity generated using biogas for P1, where the total emissions will actually increase by 16.11%. This is opposed to P2 case, where switching to biogas will reduce the total emissions by 18.6% to 1.32 kg CO2-eq. This is mainly attributed to the UK grid in which stone wool production facilities are connected to, which exhibits high emissions intensity level.

The renewable energy scheme that gives the highest amount of reduction in emissions for both P1 and P2 supply chains is hydroelectricity with reductions of 9.0% and 36.7% respectively. Although the findings imply that hydro electricity generation may help to significantly reduce the supply chain carbon emissions of both products, the feasibility of commissioning such scheme at a micro-level needs to be investigated further, for example, the impact to the local environment, particularly fish and the river ecosystem need to be carefully assessed prior to any construction of such schemes.

The next type of renewable generation scheme that can help reduce the lifecycle emissions of both types of insulation products is wind energy, with potential reductions of 8.3% for P1 and 36.09% for P2, resulting in total emissions of 0.81 kg CO2-eq and 1.15 kg CO2-eq respectively.

Micro wind generation schemes are growing in Europe with good progress being seen in the development of standards for such schemes (Department of Energy and Climate Change, 2011). The Committee on Climate Change (2011)identified that wind energy is a feasible replacement solution to non-reliable energy sources, as a great percentage of geographical locations in Europe have access to stable and reliable wind sources. Just with any other renewable generation schemes, the energy generated from wind turbines are intermittent and might not be able to match peak or off peak demand. Therefore, reliable electricity storage systems should also be put in place. Alternatively, the manufacturing facility may also utilise a mix of both wind generation scheme and grid connected electricity to address this problem.

The use of solar photovoltaic (PV) schemes is also another example of how the total emissions from the supply chain can be reduced by utilisation of the renewable sources rather than depending on grid connected electricity. However, similar issues to both hydroelectric and wind power generation schemes need to be addressed in order to adopt solar PV as a feasible alternative to grid connected electricity. Nevertheless, continuous research and development have now resulted in more efficient and reliable solar PV technology being available commercially (Department of Energy and Climate Change, 2011).

10.3 Scenario 2: Configuration of clothing collection methods

This analysis will focus solely on P1, as the process involved, which is the collection of clothing, is only applicable to this circular supply chain. The supply chain map shown in Figure 6 implies that transport, which forms the main element in the clothing collection process, is also a major carbon hotspot in the supply chain and categorised as a high impact element, which contributes to 6.3% of the total emissions. A significant proportion of this is attributed to the transport during the clothing collection phase, with 5.8% of the overall emissions, where 4% of the total emission is from the collection of clothes in containers. Collections from containers also form 70% of the total clothing collection.

Therefore, this analysis will model different scenarios of clothing collection in containers to identify the configuration that will be able to reduce the existing carbon emissions. At present, clothes are collected from containers twice a week using 3 tonne lorries with a fill rate of 70 percent. This configuration results in 0.037 kgCO2-eq of emissions per functional unit. The analysis is conducted by changing the frequency of collection from the containers from twice a week, to a number of different frequencies. The types of vehicles used are also adjusted according to the frequency of collection, based on the assumption that the fill rate for each collection remains at an average of 70%.

The analysis shows that changing the type of collection vehicle from 3.5T to 7.5T lorry to a bigger 7.5T to 16T lorry without changing the frequency of collection reduces the total emissions by 2.1%. However, noting that the current average fill rate is 70 percent, switching to a bigger vehicle without changing the frequency of collection means that the fill rate will be significantly reduced. Although the bigger capacity lorries exhibits less carbon emission, the economics of using a bigger collection vehicle needs to be investigated further in terms of its fuel consumption and maintenance.

The analysis also shows that reducing the frequency of collection from containers will reduce the total emissions from the life cycle of P1. The result of the analysis shows that reducing the frequency of collection to once in a week reduces the total emissions by 3.07% compared to the base scenario and reducing the collection frequency to once in two weeks reduces the total emissions by 3.5% from the base scenario. This is achieved through reduced total transport distance, as well as the utilisation of lorries with bigger capacity, which evidently exhibits lower emissions intensity. Reducing the frequency of collection from containers located all over the country means that the manufacturer of P1 will need to allocate bigger storage facilities to store a bigger amount of clothes for a longer period. This will ensure a steady supply of material input for the next stages of manufacturing of P1.

10.4 Further Opportunities

The potential of adopting a more closed-loop supply chain through the recycling of end-of-life P1 insulation materials can also be explored. This can initially complement the existing input of waste cotton material before potentially being developed further to become another major source of input material. As regards the P2 supply chain, some major stone wool insulation manufacturers are already exploring the potential of adopting a closed-loop circular supply chain by utilising their own waste insulation material as production inputs for new materials (Rockwool, 2013; Parco, 2014). Some of these companies have even developed reverse logistics mechanisms to propel the concept forward within their organisations.

11. Conclusions

During the last decades, green and sustainable supply chain management practices have been developed, trying to reduce negative consequences of production and consumption processes on the environment. In parallel to this, the circular economy discourse has been propagated in the industrial ecology literature and practice. Circular economy pushes the frontiers of environmental sustainability by emphasizing the idea of transforming products in such a way that there are workable relationships between ecological systems and economic growth.

In this paper, through a case study from the construction industry, the performances of traditional and circular production systems have been compared. Specifically, the research has compared the environmental impacts of the supply chains of two different types of insulation materials. The study aimed to identify whether the circular supply chain of the insulation material P1, which is made from recycled materials, exhibits lower carbon emissions than P2, which is produced through a traditional linear supply chain from virgin raw materials. The analysis was conducted using traditional process LCA methodology, utilising a combination of data provided by the industry and a reliable database, which is utilised by worldwide practitioners of LCA methodology. This has allowed the calculation and analysis of the total lifecycle emissions of the products being studied. In addition, supply chain carbon maps were derived, hence providing a greater visibility of the supply chain. The modeling of different scenarios enables the identification of potential strategies to reduce the environmental impacts of the two products.

The results from this research indicated that P1, which is the insulation material produced within a circular supply chain exhibits lower total carbon emissions within its production life cycle compared to stone wool insulation material which typically follows a linear supply chain route in its production life cycle. Supply chain carbon mapping showed that the use of chemicals in the treatment of both types of insulation products contributed to significant proportions of the total life cycle carbon emissions of both products. The results also show that transport elements dominate a larger proportion of the total emissions of the circular supply chain compared to the linear one This is mainly due to the clothing collection phase further upstream of P1 supply chain, which is transport intensive. Qualitative discussion resulting from an interview with industry stakeholders however questioned the economic viability of the circular supply chain.

One of the limitations of the research is the reliance on secondary data for the undertaking of the process LCA exercise. Another limitation in this study lies in the traditional process LCA methodology itself. Its restricted system boundary is an issue that needs to be addressed in order to increase the accuracy of the environmental impact assessment.

In terms of future researches, more environmental indicators should be considered in order to perform a much more robust comparison between a linear and circular supply chain system. Apart from the Global Warming Potential (GWP), the measurement of other categories such as land and water usage and ozone depletion may provide more holistic overviews of the environmental impact associated with the supply chains. In addition, the bottom-up process LCA methodology used in this research could be integrated together with the top-down environmental input-output methodology to develop a hybrid LCA framework (Genovese *et al*., 2015). This will effectively resolve the complexity issue associated with LCA.

Also, attention will be devoted to the cited simple economic implications, in many cases representing the main challenge for the implementation of circular economy initiatives. For example, the research can assist to evaluate insulation materials to create a simple energy rating index which compares the carbon footprint of a conventional and a low carbon insulation product in their manufacturing supply chains. Much like the European Eco label that provides an A-G rating required for all electrical items – showing their environmental impact. The criteria devised in the evaluation of insulation materials to create the energy rating index will include, but not limited to: LCA completed, thermal conductivity value, R and U-values, density, follow circular economy principles, energy used in manufacturing process, energy use in transport and size of trucks, binder used and source, fire retardant chemical used and source, recycled components of insulation, can the insulation be recycled at end of life,

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