Identifying Potential Resource and Embodied Energy Savings within the UK Building Sector

- Through Implementation of Reduction measures –

MSc Thesis – 30 ECTS

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ECTS : 30

Acknowledgements

As a final reflection on what has been a rewarding experience I would like to acknowledge that the analytical and reporting skills required during this research have been acquired from the excellent teaching curriculum and staff as part of the Sustainable Development MSc course at Utrecht University. Without the support of this programme this research would not have been possible and has allowed me to contribute to a topic of upmost interest to myself, for which I would like to express my absolute appreciation and recognition of the great work carried out by the faculty.

I would like to extend a personal thank you to

DR Robert Harmsen, my leading supervisor whom provided a wealth of advice and always ensured that feedback was received in an effective and encouraging manner during the whole process. Your willingness to have an open door policy to questions was of huge benefit during the final weeks of the study and was extremely helpful. Additionally I would like to thank you for your initial interest in the project from our very first meeting. Most notably for the help and direction which lead to the combination of this research with a truly interesting internship with Triple E consulting working on the on-going EC project Sustainable Buildings.

Dr Katarina Svatokova, my supervisor at Triple E Consulting who helped to guide the research topic and provided access to crucial data.

Family and friends, who provided constant support through the more challenging times encountered. A special thank you to my Granddad who passed away during the writing of this report, a figure that both inspired and encouraged me to target my maximum potential.

Executive Summary

The topic and current problem

With resource and energy consumption in the UK vital components to tackle for ambitions to reduce the nations CO_2 emissions and achieve energy efficiency targets. Are current reduction efforts in the UK building sector truly pursuing all routes possible to effectively decouple the resource and energy requirements from the likely increased building production needed to satisfy future demand?

Resource efficiency is an increasingly important global challenge especially for economically developed regions such as the EU where many resources are already been overexploited. Advancing economic development including increased international trade and rapid population growth are placing further pressures onto the availability of resource requirement via increasing demand. The improvement of efficiency and reducing the absolute consumption of resources is a logical approach to tackling the problems that renewable resources are currently not able to address, especially for construction materials.

The importance of this is acknowledged in the European Commission's 2020 strategy released in 2010. This recent plan prioritises policy promoting resource efficiency as one of the seven flagship initiative towards creating a more sustainable Europe. The Roadmap for a Resource Efficient Europe released in 2011 builds upon the initiative outlined in the 2020 strategy and highlights the perceived most effective approaches to achieving the defined targets. Tackling Key sectors is recognised as the most important method, with the building sector identified as one of the 3 most central, with the following statement taken from the document

"Better construction and use of buildings in the EU would influence 42% of our final energy consumption, about 35% of our greenhouse gas emissions and more than 50% of all extracted materials"

However to date firm legislation in place to reduce total resource use is absent in all major EU policy.

Energy efficiency improvements in the sector are better understood with targets relating to the building sectors energy use more defined than those for resource use. These are observed as overarching EU wide energy reduction targets. Following the Kyoto protocol the European Commission set the Euro 2020 targets which include reductions of 20% in primary energy consumption by the year 2020 from projections of the 2005 base year levels. The European Commission's Energy Efficiency Action Plan acknowledges the building sector as the largest total energy use in EU member states representing ~40% of the primary energy consumption and holds the most potential for reductions. The energy performance of buildings directive has effectively ensured that efficiency improvements have been implemented onto all new UK buildings over recent years with a commitment that by 2021 all new buildings constructed will be "nearly energy zero". This has resulted in a broad range of reduction measures and policy's focusing on reducing energy consumption in the operational phase of a buildings lifecycle. With these improvements in place, the average UK building has now moved from a total lifecycle energy use of 80:20 to 60:40(operational: embodied). This embodied energy is expected to become the dominating factor in the near future. However, current legislation and policy are not viewing energy use from a holistic perspective. With the building sector identified as a primary target for European ambitions to decrease resource and energy consumption, a deep understanding of how this can be 1 implemented for resource savings and 2 expanded for additional energy savings is required whereby a holistic life cycle perspective is taken.

The current problem acknowledged by this research is that similar levels of actions as those seen for energy in the operational phase of a building are not being taken to reduce the embodied energy and resources used for new building production. There exists substantial yet unknown potential to further reduce resource and energy use in the sector via implementing innovative best practice examples across the EU through implementation of reduction measures that focus on the lifecycle stages outside of the operational phase. This is a result of the quantitative consumption of both resources and associated embodied energy for new building production currently remaining unknown.

Few studies on the quantitative savings potential of these reduction measures in the building sector exist with non-providing projections into future potentials and consumption trends (EP, 2012). Instead the current body of literature is comprised of a scattering of small scale demonstration projects which only serve to show what reduction measures are available and what savings can be produced at a local level. There are also no projections for large scale application of embodied energy reductions with the scarce current body of research focusing on what reductions can be made at individual building scale through the application of commercially available low energy building materials. There is however a wealth of data for the amounts of embodied energy that can be reduced within material manufacture but no connection has been made thus far for what this means for the building sector.

Methods of Analysis

In order to unlock the resource savings potential and additional energy savings available to the UK building sector a number of analytical steps were taken.

A quantitative understanding of the resource and associated embodied energy use in the sector is vital for calculations surrounding any reductions that may be achieved. No database exists for resource consumption within the sector, therefore extensive desk based research was carried out for the key materials used for building production, enabling a frim data set to be created from known consumption in the sector over the period 2000-2010 for the UK.

This consumption was then analysed against recorded building activity per annum over the period for both residential and commercial properties, which allowed the intensity of use of each key material to be tracked over the previous decade. This was developed to record the average amounts of each material required to construct a theoretical 100m^2 new floor space (combination of both residential and commercial). The trend in material intensity was the extrapolated for future projections in building activity (amount of 100m^2) constructed in future years, so that material requirement could be projected alongside building activity for three varying scenarios.

The three future scenarios explored varying levels of UK building activity in terms of both construction and demolition and are modelled primarily around the demand for buildings from population growth and housing shortage.

The embodied energy demand for the building production was identified for all time period assessed using a fixed reference average value for energy required to produce each key material in the UK in 2008 as reported by the Inventory of Carbon and Energy 2008 (ICE, 2008). This was simply multiplied by projected material quantity used for future projections with the energy intensity needed for building material production held static throughout the analysis.

The use of this method allowed for the total embodied energy and resource requirements for the period (2000-2010) and for future projections in varying levels of building activity over the periods (2013-2020) & (2013-2030) to be identified if no reduction measures were implemented.

Comparative analysis of the key material contribution to overall energy and resource use provided much needed insight into where the major issues of embodied energy and resource use are located for new building production by highlighting the key materials with the largest contributions. A brief assessment of each materials supply chain and of building production from a lifecycle perspective identified specific points where reduction measures are most effective.

Desk based research into available levels of best practice and currently available reduction measures provided a range of reduction measures able to tackle the most important areas of concern deemed by this research to be those that tackle materials with the largest contribution to overall consumption during the period 2000-2010.

The range of reduction measures proposed were assessed to identify what savings they held at local level through literature review of studies investigating their potential at project level or small scale operation i.e. in one production plant.

No sufficient indicators were identified to track the cumulative savings potential or efficiency gains brought about by the reduction measures thus a range of suitable indicators were developed.

The reduction capability was then scaled up to sector wide level assessing the reduction potential when applied to the relative consumption needed for new building production in the UK over the time periods investigated. This potential was assumed to be limited by the supply side market to an extent thus a high and medium maximum deployment potential was developed for each measure in an attempt to model the implications of a moderate and aggressive policy strategy to support uptake. The amounts of resource and embodied energy needed for new building production after implementation of each measure are calculated to identify the total savings potential available over the time periods assessed and within future target years 2020 and 2030, which allows for efficiency gains against the no implementation projections to be tracked.

The savings potential available for all periods and in the target years was then assessed for the deployment of all measures simultaneously as part of a package. This allowed for the absolute savings and efficiency improvement in resource and embodied energy needed for new building production in the UK to be identified.

The results obtained provided a much needed quantitative potential permitting the proposal of quantitative time bound reduction targets to be set for the sector.

Findings

The results obtained indicate significant resource savings can be achieved over the short to mid term future and that an even greater proportion of the embodied energy used for new building production can be reduced within the time periods investigated. In the wider context of national consumption the savings identified per annum appeared insignificant for both resource and energy use representing saving of <1% of the projected national consumption. However, it must be acknowledged that savings identified are only achievable in new building production of which represents <1% of the existing building stock (which accounts for ~40% of national energy use).

The analysis of the historical period allowed for insight into what the largest contributors to overall energy and resource consumption were in the sector identified as:

- Resources: Aggregates, Cementious material, Bricks
- Embodied Energy: Steel, Aluminium, Bricks, Cementious material

The reduction measures proposed to tackle these areas were identified as

- **Measure 1** – Timber frame and clad walls (as a substitute for conventional masonry)
- **Measure 2** – Best available technology to lower the embodied energy of metal
- **Measure 3** – Best available technology and fly ash replacement for cement production
- **Measure 4** – Waste management at the construction phase

The absolute savings potentials were identified for each time period investigated for these measures at local level, national scale and when combined as a package. These results are displayed below

The savings potential held by each measure at local and sector wide scale, also presented combined savings for implementation as a package for the time periods investigated.

Measure	Local level		National level					
			2000-2010		2013-2020		2013-2030	
	Resource	EE	Resource [Mt]	EE [PJ}	Resource [Mt]	EE [PJ}	Resource [Mt]	EE [PJ}
1	26.55 [tonne/100m2]	247 [GJ/100m2]	3.3-4.7	31-44	1.9-4.1Mtonne	18-39	11-23.4 Mtonne	103-217
2		36 [GJ/tonne of Aluminium] 13.45 [GJ/tonne of Steel]		32-62		16-45		102-308
3		0.37 [GJ/tonne of ready mixed concrete] 0.24 [GJ/tonne of concrete block]		4-10		2.4-9.3		19.7-79.4
4	14.1 [tonne/100m2]		7.6-17.9		3.7-14.6		26.1-57.8	
		Combined savings	10.9-22.6	66-116	5.6-18.8	35-93	37.5-81.2	224-605

The measures are considered to be technically feasible at the scale required to bring about the identified savings owing largely to the fact that they are already commercially viable at project level or in at least in one production plant for measures that require reductions in the manufacturing stage.

From the development of a new indicator set it was possible to track how these absolute quantitative savings could improve the levels of efficiency observed for projections under no implementation these improvements are displayed below.

The efficiency gains brought about by implementation of the reduction measures for new building production

Efficiency improvement possible through measures		
	Target year 2020	**Target year 2030**
Resource Efficiency improvements	4.70%	9.30%
Energy Efficiency improvements	6.40%	28.60%

The tracking of these improvements allowed for provisional time bound quantitative targets to be set that include the incorporation of other reduction measures identified but not explored in this report. These are

- 5% resource efficiency gains by 2020
- 10% resource efficiency gains by 2030
- 7% embodied energy efficiency gains by 2020
- 30% embodied energy efficiency gains by 2030

Whilst the importance of these savings for a new buildings construction are subject to change considering efforts in the operational phase are likely to increase, especially considering the role of renewable energy such as PV panels and wind turbines for individual buildings. The fact remains no house will be "nearly energy zero" when a whole life cycle perspective is taken and that the reductions identified in this report offer further absolute savings then tackling the operational phase alone. These savings should not be over looked no matter how energy efficient the use phase becomes.

Conclusion and recommendations

The UK building sector holds significant further savings potentials for both resource and energy consumption. This requires a whole lifecycle perspective to be taken to realise the full potential available with identified savings able to significantly improve the prospect of sustainable buildings and contribute to national consumption reduction ambitions. The findings from this study hold implications for other EU member states where these opportunities are also being missed.

There is a wide and varied resource use and performance level throughout regions in the EU with average resource intensity per m^2 floor space observing drastic differences. Thus by identifying the resource savings that can be achieved for the UK serves only as a proxy for the levels that may be achieved across the EU with nations likely excelling or underperforming for individual measures. Additionally, it is extremely complex to determine what contribution the identified measures play into absolute savings for the EU as they only address 1 (perhaps 2 including industrial) sector, thus at a EU wide or even national level this will ultimately depend on the makeup of the economy

Key recommendation formed from the completion of this research include

- Further research into a broader range of reduction measures where likely less but unknown potential still remains
- Creation of a sector wide resource consumption database and future projections for energy requirement for the production of major building products
- A thorough policy analysis into how these measures would be best supported and an ex ante impact assessment carried out for the implications on stakeholders, society, environment and economic implications
- Similar studies carried out for other major sectors such as food and transport to provide a greater quantitative understanding of resource savings at national level.

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1. Introduction

1.1 Background

Resource efficiency is an increasingly important global challenge especially for economically developed regions such as the EU where many resources are already been overexploited. Advancing economic development including increased international trade and rapid population growth are placing further pressures onto the availability of resource requirement via increasing demand. The European quality of life, societal development and environmental concerns are under pressure from the current over exploitation of the natural resource base. Whilst renewable resources provide a widely accepted solution to this issue, under practical circumstances a transition to sustainable materials is at least decades away (Kubba, 2012), especially for cases such as the construction sector where requirements such as physical strength play a pivotal role in the selection of materials used. The improvement of efficiency and reducing the absolute consumption of resources is a logical approach to tackling the problems that renewable resources are currently not able to address.

Although current issues surrounding resource consumption, efficiency, environmental impacts and domestic security have gained political involvement over the past decade, from a sustainable development perspective the major problems are not appropriately addressed. This is highlighted by firm legislation in place to reduce total resource use being absent in all major EU policy, instead tending to focus on the related impacts (SERI, 2009). (Giljum and Lutz, 2009) state that without effective policy intervention global resource extraction could reach in excess of 100 billion tonnes per annum in 2030. In 2012, ~3 billion tonnes of raw material were used in the manufacturing of building products at a global scale which translates to ~40-50% of the total flow (Dodd et al, 2012).

EU Policy statements reflecting the importance of decreasing resource consumption towards long standing targets such as those defined in the Kyoto protocol can be seen in the form of the EU sustainable development strategy adopted by the European council in June 2006, documenting how the EU plans to uphold its future commitments to sustainable development (Council of the European Union, 2006). This strategy includes the conservation and management of natural resources with broad objectives and targets. These targets provide an outline of the EU ambitions without attached approaches to achieve them. This policy has since been reinforced by the introduction of the European Commission's 2020 strategy (EC, 2011) released in 2010. This recent plan prioritises policy promoting resource efficiency as one of the seven flagship initiative towards creating a more sustainable Europe and generating sustainable growth, thus bringing efforts to decrease resource consumption to the forefront of current debate.

The 2020 strategy acknowledges the need to make technological improvements and ensure levels of best practice are implemented whilst changing production and consumption habits. Successful demonstrations of resource efficiency such as the vast improvements in recycling rates over the past decade have stimulated the belief and demand that larger reductions can be achieved (EC, 2011). The Roadmap for a Resource Efficient Europe released in 2011 builds upon the initiative outlined in the 2020 strategy and highlights the perceived most effective approaches to achieving the defined targets. Tackling Key sectors is recognised as the most important method, with the building sector identified as one of the 3 most central alongside food and transport, collectively accountable for 70-80% of all environmental impacts (EC, 2011b). The Roadmap for a Resource Efficient Europe states "*Better construction and use of buildings in the EU would influence 42% of our final energy consumption, about 35% of our greenhouse gas emissions and more than 50% of all extracted materials; it could also help us save up to 30% water*."(EC, 2011b). The construction sector is then of vital interest when assessing the potential savings that can be implemented up to 2020 and paves the way for longer term goals for 2050.

The building sector then also contributes heavily to the energy consumption at national and EU level. Efforts to reduce resource consumption in new building production should then also focus on reductions of embodied energy within the building sector. Targets relating to the building sectors energy use are more defined than those for resource use. Seen as overarching EU wide energy reduction targets. Following the Kyoto protocol the European Commission set the Euro 2020 targets, which include reductions of 20% in primary energy consumption by the year 2020 from projections of the 2005 base year levels (EC, 2013b). Within this target the building sector is acknowledged as a major contributor the total energy use in EU member states representing ~40% of the primary energy consumption (EC, 2013b), with further predictions that this sector is expanding hence a likely future increase in consumption. However, under current performance the projections for meeting this target are rapidly slipping away.

Resource efficiency understanding is not consistent throughout the member states with the European commission recognising that a mutual harmonisation of the various existing assessment methods is needed in order to realise deeper reductions (BRE, 2007). Furthermore, there is a widely varied resource and energy efficiency performance level throughout regions of the EU and within individual nations with average resource intensity per m^2 floor space observing drastic differences for some of the key building materials (WI, 2009) and energy required for the production of building materials fluctuating between manufacturers.

There currently exists a range of best practices throughout the lifecycle phases of a building that operate at a decreased resource and energy use compared to the EU average. These best practices almost exclusively remain at small scale. These measures if scaled up to a sector wide level provide the opportunity to contribute the EU ambitions in both resource and energy efficiency within one of the acknowledged key sectors.

1.2 Problem definition

The World Business Council for Sustainable Development projections state that current effort for resource efficiency require a 4-10 fold increase in order to sustainably meet growing demands, with significant improvements by 2020 essential (WBCSD, 2010). This increased efficiency is needed across the complete lifecycle of buildings to provide the maximum reductions possible. Resource efficient construction provides a systemic approach that adds to the potential of other ambitions such as building related energy and emissions reductions via looking at material and energy flows over the lifetime of a building.

With the building sector identified as a primary target for European ambitions to decrease resource and energy consumption, a deep understanding of how this can be 1 implemented for resource savings and 2 expanded for additional energy savings required. Although energy use in the operational phase of a buildings life cycle is the most important factor to tackle, there are currently a broad range of specific policies designed with the primary purpose of reducing this and the potential savings are under deep investigation (UNEP 2007). Recent improvements by implementation of reduction measures have successfully decreased the energy demand for heating and lighting largely driven through technological advancements and building regulation for measurements such as insulation. As a consequence of this increased pressure for a greener use phase, the ratio of total energy use over a buildings life cycle has decrease from 80:20 to 60:40 within the UK, with predictions that embodied energy is likely to become the dominating factor in the near future (EIO, 2011)

The current problem acknowledged by this research is that similar levels of actions as those seen for energy in the operational phase of a building are not being taken to reduce the embodied energy and resources used for new building production. There exists substantial yet unknown potential to further reduce resource and energy use in the sector via implementing innovative best practice examples across the EU through implementation of reduction measures that focus on the lifecycle stages outside of the operational phase (EC, 2012).

1.3 Targeted Knowledge Gap

The most significant barriers to realising resource and embodied energy efficiency within the sector are due to associated deficiencies within the knowledge base, followed by a lack of demand for sustainable buildings, costs involved with changing process's and materials (EC, 2012). If these challenges are to be met by the harmonisation of currently varied levels of performance by the implementation of reduction measures as seen for the operational phase, the associated levels on resource consumption and embedded energy should be identified at national scale.

Whilst energy use in the building sector is widely recorded at national level and are in most instances readily available the same cannot be said for resource use and associated embodied energy. During a review of the sector reporting, no quantitative data on the amounts of raw and manufactured building material specifically entering the building sector was identified. For individual materials these levels are occasionally available at national level through common industry databases that track annual sales by volume, but there is certainly no database exclusively for the building sector. This is presumably due to energy in the use phase only requiring the monitoring of mainly gas and electricity use (a common) measurement between buildings. However, for the material input during construction and the varying embodied energy required to produce this material is far more complex and not standard.

This presents a problem as if the sectors material use is not known and recorded on an annual basis then trends in the efficiency cannot be established. Furthermore, it is impossible to project a savings potential if the current total use is unknown. Whilst research has been carried out onto identifying hotspots of concern and identification of the barriers to resource efficiency with corresponding policy suggestion such as that carried out by the Building Research establishment on behalf of the Environment Agency (EA, 2008), there still exists a need to identify the related quantitative potential to these adaptations. This includes the need for a database of the exact resource and associated embodied energy consumptions at a national scale within the sector.

Although there are large amounts of indicators available in the EU for tracking resource use only a handful are developed to set quantitative targets, which currently are observed to be very general in their formulation and driven by EU legislation (EC, 2012b). These include targets such as waste generation. However, there is a complete absence of sector specific resource consumption targets (EC, 2012b).

As mentioned energy consumption does have the 20% by 2020 target. However, this target is not suitable for the assessment of embodied energy reductions because the efforts will only decrease energy requirements of new buildings thus dwarfing its contribution to absolute energy use in the sector due to a large existing building stock in its operational phase.

It is evident then that appropriate indicators and targets are not available to fairly assess the contributions from reduction measures aiming at lifecycle stages outside of the operational phase. Lacking both the quantitative measurements of the consumption within the sector and no time bound targets has resulted in no meaningful assessment of the savings potential available.

The construction sector has the largest total material consumption and direct material input. With OECD projections that the EU economy will grow at an average ~2.4% per annum to 2030 an increasing demand of infrastructure will be required translating to an additional ~10% of the existing building stock (OECD, 2012). Additionally, old buildings at the end of their life span will be demolished. This provides enormous opportunity for savings at both construction and reclamation/recycling stages, as even the smallest improvements at this scale would amount to significant reductions. The Importance of these potential savings are echoed within the differences in levels of performance in resource use that can be noted throughout the EU, e.g., sand and gravel intensity per m^2 varies with about a factor 6 and the iron intensity per m^2 with about a factor 3 between Member States, not including the extremes (Meyer, 2011). In regards to recycling rates, some Member States reach over 90% while the majority are far from reaching the 70% target outlined in the waste framework directive (EP, 2008). Thus there is an evidently a large scope for reductions.

There exist a range of best practices available to bring about much needed reductions in resource consumption and the associated embodied energy of building production. There is a body of research available that identifies these opportunities and the physical reduction they bring about. These include approaches to reduce the resource intensity of key building materials via substitution to less intensive materials or use of less intensive production methods. This includes measures such as the increased use of Ultra-high performance concrete (EP, 2012). Reducing overall consumption by implementing building techniques that utilise less material with a more detailed assessment of the specific needs of the building a prerequisite, this is often termed resource-light construction (EA, 2008). Implementation of a more industrialised process, as the construction sector remains one of the few industries in which the resource use is largely governed by the experience and competency of labourers (Vrijhoef and Koskela, 2008). This involves the incorporation of pre-assembled and fabricated modular components within a factory like process thus inevitably leads to minimized waste streams and higher embedded energy efficiency. Improved reclamation/resource use can dramatically reduce the amount of material needed to be extracted and thus the energy required, especially for energy intensive materials such as common metals, with the stocks of Copper in buildings comparable to the virgin resource levels (Gerst and Graedel, 2008).

Few studies on the quantitative savings potential of these reduction measures in the building sector exist with non-providing projections into future potentials and consumption trends (EP, 2012). Instead the current body of literature is comprised of a scattering of small-scale demonstration projects, which only serve to show what reduction measures are available and what savings can be produced at a local level. There are also no projections for large scale application of embodied energy reductions with the scarce current body of research focusing on what reductions can be made at individual building scale through the application of commercially available low energy building materials. There is however a wealth of data for the amounts of embodied energy that can be reduced within material manufacture but no connection has been made thus far for what this means for the building sector.

This lack of related research is highlighted when visiting some of the more renowned scientific research databases. When searching information regarding the savings potential in buildings the results lists produced are almost exclusively filled with articles and journals detailing what energy reductions are possible within the operational phase of a building.

When considering that the sectoral composition of countries is crucial to the structural composition of economies, it is suffice to state that improved understanding of resource efficiency in specific sectors is vital in the transformation to a resource efficient Europe. Many of the studies looking into resource efficiency within the building sector investigate case studies of measures which may be scaled up to show potential at sector or regional level (EP, 2012). Surveys are also a commonly used method for identifying the savings potential and only one study (Meyer, 2011) bases potential on a modelling approach.

In conclusion there is a clear knowledge gap relating to the following areas of interest

- The absolute level of resource consumption and associated embodied energy used annually for building production
- No method developed for tracking efficiency in this resource and embodied energy consumption (including no indicators or targets)
- No understanding of the potential current levels of best practice in resource use and energy used in building production can have at a sector wide scale.

1.4 Objectives

With these current knowledge gaps present the problem identified cannot currently be addressed which is therefore leaving the building sector in a situation where reductions in resource and energy use for new building production are known to be available. However, due to a lack of information surrounding consumption levels within the sector and the scope in which reduction measures can be applied to, there is currently an unknown opportunity passing by.

This research aims to provide a comprehensive overview of the potential savings of natural resources and embodied energy associated with UK building sector. The study focuses on determining the total reductions in terms of the maximum potential possible, that can be achieved through the implementation of a range of identified resource and energy reduction measures aimed at the opportunities within the lifecycle stages currently underexplored within the sector. To achieve this, major knowledge gaps identified above must be filled which provokes the need for sub objectives.

A quantitative data base identifying the recent levels and trends in resource and energy use for new building production will be created for the UK building sector for the period 2000-2010. These trends may then be projected forward so that future savings potentials can be explored.

Identification of the absolute savings potentials that are held by reduction measures currently assessed only at local level. The, potential of these measures will be explored if they were ramped up to sector wide scale within the UK. Taking the examples of best practice and ramping them up to a sector wide level provides a realistic way of contributing to reductions in resource consumption.

The development of a range of indicators to accurately assess the efficiency gains in resource and energy consumption in new building production, brought about by implementation of identified reduction measures. Due to the apparent lack of suitable resource and embodied energy targets a major objective of this study is to develop a range of indicators specifically geared for this purpose in new building production. Such indicators should provide quantitative data on the reduction potential available and furthermore allow for increases in efficiency to be tracked.

The overall objective is then to identify the total quantitative savings potential in resource use and energy within new building production over a future period. Aiming to be able to be able to project what efficiency gains can be realised in target years from implementation of proposed reduction measures alone. This allows for the informed proposal of quantitative time bound reduction targets and to unlock the savings potential within areas of this sector that are currently missed opportunities.

It is expected that the yielded results from this research will provide invaluable information for EU policy makers with regards to directing the strategies of infrastructure design and building processes throughout the supply chain of the EU building sector. The study intends to support the EU commission's targets in relation to resource efficiency via highlighting the importance of tackling resource consumption within the dominant consuming sector.

The construction sector within the EU varies between nations in regards to aspects such as the volume of construction and building techniques used and the introduction of harmonised EU wide standards will affect all member states. For this reason the research will focus onto the effects of introducing these improvements onto one member state, identified as the UK, in which the future reduction potentials are explored over 3 varying degrees of building activity.

1.5 Connection to Internship

In spite of the extent of the resource use and the significance of the related environmental impact, there is no existing policy at the EU level addressing resource use in the building sector and there are only a limited number of Member State and business initiatives addressing the issues (EC, 2012). Therefore, it is not expected that significant improvements will be achieved in resource efficiency with the current policy context in the short to medium term. Recognising this, the EC DG Enterprise Action plan (EC, 2007) states proposed policy options, calling for an EU Assessment Framework for the environmental performance of buildings. These policy options include; Establishment of an EU wide scheme, allowing for benchmarking applied on a mandatory or voluntary basis. Development of European harmonised standards, through EU standardisation platforms such as Eurocodes. Guidance to schemes used in MS on resource use areas to include and possible indicators to use for that purpose.

With the impact assessment of these policy implications being investigated through the on-going project of EC DG Environment "Sustainable Buildings" under Framework contract ENV.F.1/FRA/2010/0044. It is the intention of this study to identify the associated quantitative savings potential that could be realised through implementation of reduction measures that can be translated as EU wide harmonised building standards and is the primary basis for undertaking this research in tandem to an internship with Triple E Consulting, Rotterdam.

2. Research Question

The Research will focus on addressing the following questions and all though not necessarily exhaustive of the study, provides the basic framework for the research.

The focus of the research revolves around the main research question

Main Question

What are the quantitative potential savings in resource use and associated embodied energy available in new building construction that can be brought about through the implementation of currently available reduction measures at sector wide scale for the UK?

Since it is not possible to answer this question from all facets this research aims to take initial steps into answering this question and the investigation will be split into key sub questions which are described below.

Sub questions

What are the main resources used within the UK building sector?

What is the average intensity of use for each of these materials between 2000-2010 in UK building production in terms of Kg/m^2 and the associated embodied energy KJ/m^2?

What are the largest contributors to resource and energy consumption during building production?

What are the reduction measures available to tackle the areas of concern in excess consumption and what potential do they hold at local level (tonnes/100m^2) [MJ/100m^2]?

What are the hypothetical savings at National level in terms of resource use and embodied energy for each of the identified reduction measures for the period 2000-2010?

What is the potential for these identified savings if translated into actual future savings that can be realised at national level over the periods 2013-2020 and 2013-2030?

Are these identified reduction measures feasible at national scale?

Can Resource and embodied energy efficiency improvements for new building production be tracked? If so 1) what levels of improvement can be projected up to 2020 & 2030, 2) Can suitable quantitative time bound targets be created?

2.2 Scope of research (study boundaries)

For clarification at this point, in the context of this report

Embodied energy refers to energy consumed during all phases throughout the construction process except for the operational phase. This includes extraction of raw materials, manufacturing/processing of materials and equipment, transport, construction, demolition and recycling/waste. A focus of sustainable manufacturing is to incorporate targets towards resource and embedded energy efficiency into all product life cycle stages, improving the materials environmental performance. Efforts to reduce resource consumption can also decrease the embedded energy within the construction process, with a range of options and levels of best practices available throughout the complete supply chain (Karra & Ibbotson, 2011).

Resource efficiency is assumed as the concept of utilising natural resources at a decreased level whilst providing a similar level of service present before reductions are implemented. Therefore, resource efficiency is not solely the apparent increase in efficiency that may unwillingly result in hiding actual depletion due to increased total consumption, but also incorporated overall changes in resource use conforming to the Jevons Paradox (Alcott et al, 2008). In the context of this research resources are seen as the direct material inputs into a buildings production

In essence the study's main purpose is to highlight the possibilities for reducing resource consumption into the building sector whereby the existing body of research focuses on the energy savings that can be acquired during the operational phase of the lifecycle. Therefore, savings that can be achieved within this phase, most commonly associated to heating and lighting shall not be included within this potential analysis. Other notable established boundaries include

- A physical assessment of the UK building sector only. Which is assumed act as a representative for the purpose of highlighting the potential available in all member states
- This study focuses specifically on buildings rather than the whole construction sector and furthermore relates only to residential and commercial properties, choosing to neglect industrial buildings which contribute <1% of the EU's building stock
- -A selection of commonly used materials for building envelopes will be used during the assessment process due to individual buildings often containing a wealth of material in small quantities that are not representative of the average EU building. i.e. marble flooring

Reduction measures explored and the potential savings they possess shall be limited to

- Measures that can be applied to LCA stages outside of the operational phase
- Measures that can be applied widely across the EU
- Measures specifically relating to the building envelope

*Note this is not the selection criteria incorporated for the reduction measures but founding principles base on what this research hopes to achieve (namely focusing on new building production only [not operational phase] and measures that can be applied throughout the EU)

In regards to the feasibility of the measures no economic constraints will be considered and also future development scenarios do not incorporate sector wide policy that has not been enforced before the production of this report.

2.3 Outline of Thesis

As a quick reference for what each chapter entails and to provide a framework for how the sections of this research interlink. The proceeding chapters of this paper are structured as follows:

(Chapter 3) Research Concepts – Outlines the theoretical and practical concepts that will be deployed throughout this study, used to answer the research questions. This section describes how each tool will be incorporated into the study and provides argumentation into why this approach has been adopted

(Chapter 4) Methodology – Provides a step-by-step account of the process carried out during the subsequent sections of this Report. This section provides the calculations used to assess consumption and potentials. Data inputs, sources and assumptions are first recorded within this section, however where applicable may be duplicated within the analysis section i.e. for discussion into why a data source requires further assumptions. This chapter explains where and how each of the theoretical concepts introduced in chapter 3 are integrated into the research.

(Chapter 5) Historical UK building sector activity – Provides an overview on the UK building sectors composition. Presents the activity in the sector (new building production) over the period 2000-2010 to identify recent trends and the total target available for reduction measures. This information provides a basis for the construction of the scenarios used in this report.

(Chapter 6) Material selection & Identification of resource and embodied energy consumption (2000-2010)

This chapter serves to

- Explains the common characteristics and reasoning behind selection of the materials.
- Provide insight into where reduction measures may effectively target through a brief analysis of each materials supply chain and incorporation into a building alongside the specific possible opportunities for reduction where applicable
- Identify the total amounts of each material used in the UK building sector per annum (2000-2010) and provides the basis for future projections. This is needed to fill the current gap where no such database exists.
- Identify the amounts of associated embodied energy used in the UK building sector per annum (2000-2010)

(Chapter 7) Analysis of trends in resource consumption and associated embodied energy for the UK building sector (2000-2010)

- Used to compare the trends in resource and energy use for individual materials identified in chapter 6.
- Aims to provide insight into how total resource consumption is developing within the sector to identify any underlying efficiency gains or material substitution.
- This comparative analysis also allows for provisional insight into the materials creating the largest issues, therefore highlighting the most important areas to tackle for reduction measures and the founding criteria for their selection

(Chapter 8) Scenario Construction – A range of Scenarios are developed with underlying assumptions explained in a transparent fashion. This range of scenarios allows for sensitivity analysis along two main parameters, activity in the sector and take up rate of reduction measures. For each future scenario the total projected resource and embodied energy consumption under no implementation is presented. This assumes the extrapolation of resource intensity trends observed over the historical period but for embodied energy assumes a frozen efficiency.

(Chapter 9) The reduction measures

- A summary of the areas of concern identified by analysing the resource and embodied energy consumption trends over the historical period (2000-2010) (Chapter 7) and the opportunities for reductions within each materials supply chain (chapter 6) are used as criteria for selection of the proposed reduction measures.
- Each measure is described and the savings potential at a local level (i.e. per tonne of material) are identified.
- The deployment rate for each measure at national level across the UK building sector is developed based on a review of transitional periods for similar measures and practical considerations surrounding the current commercial position of the measure such as supply side constraints. (*The supply side constraints are assumed to be interlinked with building activity – this is discussed in further detail where relevant)

(Chapter 10) Identification of suitable quantitative reduction indicators

As expressed in the problem definition there are no appropriate indicators to

- Track absolute reductions for resource and energy consumption in new building production brought about by implementation of reduction measures
- Track increase in efficiency as a result of these reductions
- This also includes no means to compare reductions achieved in a target year compared to baseline projections under no implementation

This chapter develops suitable indicators for this purpose which are used in chapters 11 & 12

(Chapter 11) Analysis of reduction potential at national scale for individual measures

The hypothetical savings potentials over the period 2000-2010 is explored due to building activity and resource consumption being known under a higher degree of confidence for this period due to findings from chapter 6.

The practical savings potential is then explored for each individual measure and for future projections into building activity (scenarios created in chapter 8) with the base year 2013 and future target year 2020 &2030. This is performed to allow the research to be of practical use to policy makers seeking reductions in the short to midterm.

The feasibility of each measures implementation at national scale is also assessed within this chapter.

(Chapter 12) Analysis of reduction potentials at national scale for combined measures

The chapter is essential a carbon copy of chapter 11 but for the combined savings of the reduction measures if implemented simultaneously as a package. Additionally a comparison of the potentials between measures is performed to allow for priority should such an approach be taken.

(Chapter 13) Discussion of results – Analysis of findings will be discussed and reviewed to identify how the savings potential identified can contribute towards the ambitions of the European Commission. This includes a discussion into where to go from here in terms of setting future targets related to the identified potentials. A reflection on the importance of this research and further recommendations incorporating a critical assessment of the research and potential improvements.

(Chapter 14) Conclusion – General conclusive remarks into the degree of success obtained when aiming to answer the encompassing research questions.

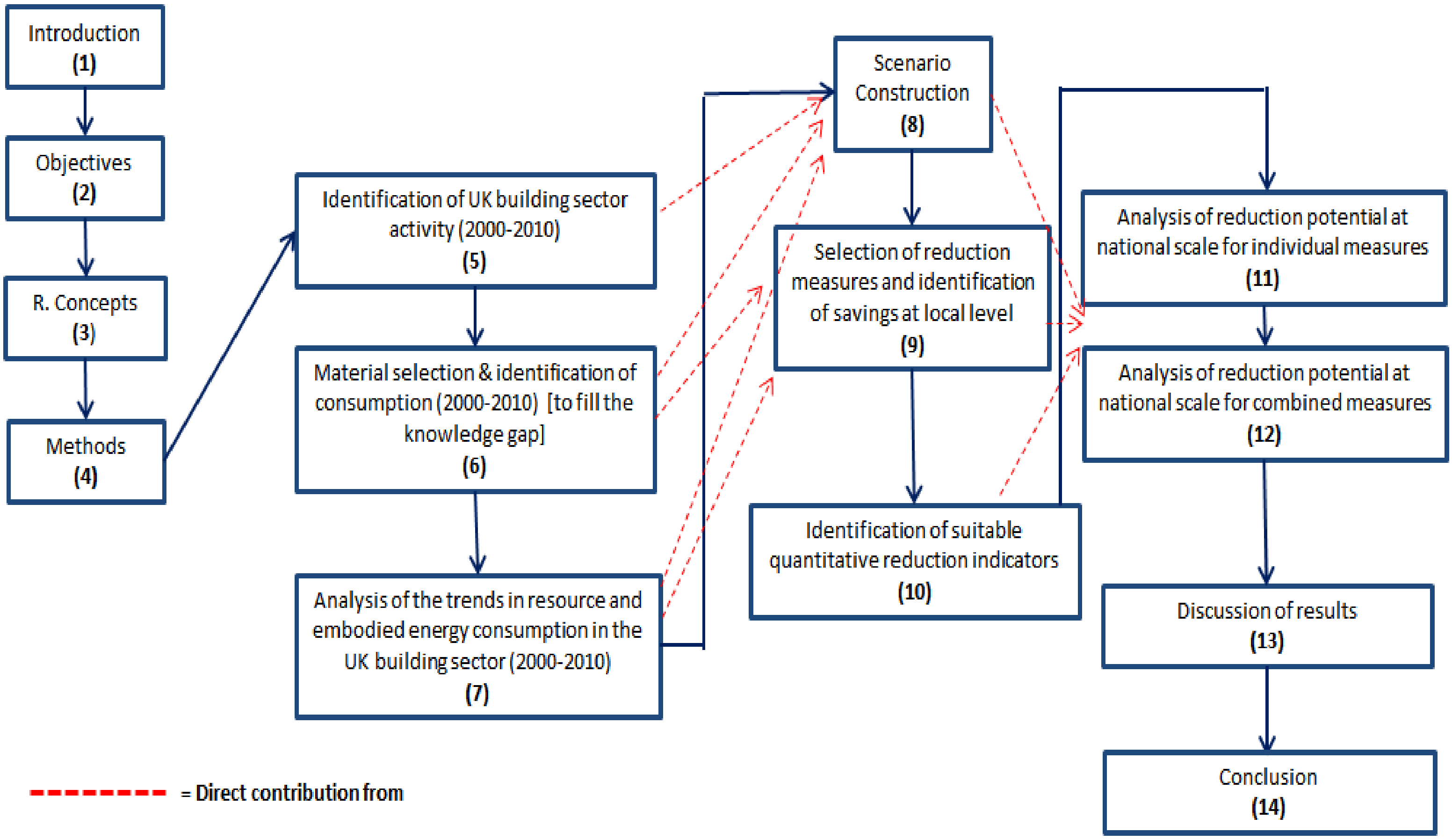


Figure 2A: ***Schematic representation of the research Framework***

3. Research Concepts

3.1 Life Cycle Perspective

The most appropriate method for a holistic assessment is the LCA method which provides a systematic study of the key stages within a buildings life span and supply chain effects of products, processes and services (Ortiz, Castells and Sonnemann, 2009). This methodology can be used to assess material consumption and related inflows of embedded energy from cradle to grave and has been used in the building sector since 1990 (Ortiz, Castells and Sonnemann, 2009). Consequently a Life cycle perspective is required for identifying effective areas to tackle when investigating the methods of best practice available for improving resource use. The application of LCA is fundamental to sustainability and improvement within the building sector and has a broad international acceptance for improving resource efficiency (Nielsen, and Wenzel, 2002). As options to realise improvement exist throughout the buildings life this LCA perspective will be adopted for the purposes of this research with the phases being assessed including;

1. Raw material Extraction and Processing
2. Manufacturing of Building materials — Upstream
3. Construction and assembly
4. Operation and Maintenance
5. Demolition and Removal — Downstream

At each of these stages resource consumption occurs along with influxes of associated embodied energy. Reduction measures imposed at one stage may have effects at another i.e. the construction phase may use a material that saves thermal energy requirements in the use phase. However, the effects and measures that can be incorporated into improvements at the operational phase have no effect on the reductions that can be achieved in any other stage. It should be noted that transportation of the materials across the supply chain is also important from an LCA perspective, however is not included in this report as this varies extremely between building projects and also has no direct effect on material consumption. The design stage will be assessed which is commonly not included in LCA studies, however from a literature review this function can play a pivotal role in resource use. It is important to assess measures relating to all of these phases to determine the possible saving potential and it is possible that one phase might present more opportunity than others.

It is also necessary to investigate process along the supply chain, particularly in the manufacturing industry, where techniques may be adjusted so that less energy is needed for production whilst the resource consumption remains at the same quantity. This research aims to incorporate this type of energy saving into the analysis however in its broadest terms the actually savings may once more be translated into resource savings in view of the primary fuel used for production. Furthermore, where saving measures include recycling techniques the overall savings in energy will be established based on the difference between embodied energy acquired by the product after demolition to produce a construction worthy product and the embodied energy to produce the identical product from virgin/commonly used sources.

In order for an LCA to provide meaningful insight it is of crucial importance to use reliable and exact input data from published sources whilst identifying an accurate inventory of the mass inputs of the investigated system (Ulgiati et al, 2005), which in the context of this study is seen as the UK building sector including residential and commercial buildings. It is important to establish at this stage of the study for the transparency of results occurring from the analysis that commonly LCA's are used to assess the multifaceted problem of the environmental impacts arising from a system. However, this study elects to focus on a limited set of parameters namely resource consumption and embodied energy brought about from processes connected to the sector, thus gravitating towards the aim of the research. This thesis then acknowledges that the characterised flexibility of choices in assessment methods when performing an LCA which allow the approach to focus on the specified elements of assessment, do not aim to produce an oversimplified indicator of the overall environmental soundness and sustainability. Therefore, do not intend to be interpreted as such, but rather as direct implications for the aforementioned EC ambitions.

3.2 Case Study Analysis of Material Input – Output (MFA)

There are a range of commonly used materials throughout the EU construction sector which may be targeted for EU wide resource efficiency measures. The major resources include Concrete, Aggregates, Stone, Brick, Clay, Gravel, Steel, Aluminium, Copper, and Wood (BPIE, 2011). In order to identify where the largest impact can be achieved by the implementation of reduction measures it is crucial to first identify the volumes of these materials being used throughout the building sector within the case study nation and assess the embedded energy attributed to each on an annual basis. This will be accounted for using a material input output method largely based on material flow analysis which is translated into associated embodied energy using a fixed average value needed to produce the building materials. This analysis will also reveal which significant resources used are not subjected to sufficient policy initiatives to limit consumption trends at present. The waste production for each material from the sector per annum will also heavily influence which materials will be targeted by this research. Whilst analysis of total consumption may provide initial insight into the areas of concern and certainly build the basis for the reference scenario a thorough investigation into the cradle to grave process from each material is needed to identify if savings are possible and how. The material flow analysis is detailed to the purpose of the report recording the key materials by quantity as they enter the building stock through new construction and as they leave through demolition, additionally recycling and reuse are tracked for downstream measures.

3.3 Construction of scenarios

The production of scenarios provides policy makers with a view of the implications from adopting or expanding investigated measures in the future. Scenario construction offers a useful mode to establish insight into how much potential a measure holds, which can be accurately developed further by incorporating a series of underlying assumptions which may provide a more likely projection of future states. In order to assess the difference in relation to the implementation of a certain measure, a reference state must first be established. This reference is often represented as BAU approach whereby the projection continues under the existing circumstances with built in future assumptions of what influencing factors are likely to occur but leaving the measure in question emitted. In this research this is referred to as the (No implementation scenario).

3.3.1 A Historical Scenario (2000-2010)

A historical scenario will be deployed to identify what levels of resource consumption and associated embodied energy that are used within the building sector when no reduction measures are applied and building activity in known. It is beneficial to the research to incorporate a past analysis to create the data inputs needed such as newly constructed building and material consumption being readily available and reliable data, rather than estimated projections which should allow for a more accurate assessment of the total savings potential.

3.3.2 Future scenarios (2013-2020) (2013-2030)

Target years of 2020 and 2030 have been selected for this research into future savings potential as it coincides with the ambitions of the EC and provides an adequate timeframe to realise longer term saving that may be achieved by the identified measures. Key Intervals will be assessed within this target period to provide policy makers with useful insight into the shorter-term savings available through each measure and give indication of the level of reduction that can be achieved at time steps throughout the period of investigation taking into account the roll out rate of the identified reduction measures. A series of three future scenarios are developed to provide sensitivity analysis for future reduction potentials, these alternative scenarios are subjected to the following concepts.

3.3.3 Variations in building activity

Decomposition top-down analysis can be used to project trends such as rate of new build construction up to a specified target year (EC, 2011). This method incorporates a combination of extrapolation from previous trends and future projections of GDP/economic/population growth, which are used to create 3 varying scenarios for building activity.

3.3.4 Extrapolation of material intensity

All alternative scenarios to predict future trends 2013-2030 use extrapolated material intensity of use data from the 2000-2010 period to create as accurately as possible the future targets for reduction measures. This intensity of use is then multiplied by the building activity (100m^2 built) to create a fixed projection of what resource consumption would occur in future years if no reduction measures were to be implemented. These trends are labelled (no implementation).

Using this technique provides the average intensity of material use within new builds per 100m^2 to be projected up to the target years. This means that although amount of construction/demolition changes between the scenarios the mix of materials used per 100m^2 of newly constructed floor space whilst fluctuating annually will be the same throughout all three scenarios in any specific year. Reductions identified from measures will therefore be subtracted from these projections.

3.3.5 Frozen Technology Reference

Resource consumption indicators provide information of resource use for the materials being investigated. These may be combined into aggregated consumption indicators.

There are no detailed assessments of the likely future reductions in embodied energy needed to produce the key building materials assessed. It is proposed that to create a reference scenario (labelled no implementation) up to 2020 and 2030 a frozen technology baseline approach must be incorporated. This can be categorised as a bottom up approach because it assumes no changes to the level of energy efficiency in terms of intensity of use per kg of material created. However, the approach still allows for expected fluctuations in the production of new buildings to be accounted for. The energy efficiency of the material manufacturing can be frozen at base year values (or in this research for 2008 UK values (ICE, 2008) which provides the most complete up to date data. The application of this method ascribes that reductions up to the target year that could potentially be brought about by autonomous technological/operational improvement within the construction process including beneficial forthcoming policy are not represented.

However, considering that there is no regulation currently in place for resource consumption within this sector and the wide use of traditional building techniques that are still deployed this approach appears to be very apt.

3.3.6 Varying Deployment Potential

Traditionally the construction industry is slow in the take up of new technologies and this phenomenon is universal. New technologies most notably involving new materials take on average 10-20 years before they are widely accepted (Kua and Lee, 2001) .The maximum deployment potential is the part of the technical potential that can be realised once limiting factors to deployment of the measure have been factored in. This potential provides a more realistic projection into the savings potential as it takes into consideration the limitations of the supply side of the market including aspects such as training needed to expand new techniques involved with consumption decrease. This deployment potential will also take into account the amount of new builds within the target period but at this stage of the analysis limitations surrounding the costs of implementation will be neglected. As deployment potential is characterised by the maximum installed capacity, the maturity of the supply side market is of significant influence and the growth of the ability to meet demand, which will at least initially not be viable. This must be logically estimated over the period of investigation to provide a more reliable assessment of total potential (WB, 2010). It is important to distinguish that the deployment potential of measures relating to the demolition and reclamation phases of a buildings life cycle will depend heavily on the demolition rate of buildings instead of amount of new construction. Under this concept medium and high deployment potentials for each reduction measure will be assessed where a 0% deployment rate is business as usual (no implementation).

This results in each measure having a medium penetration rate and a high take up rate throughout the sector. As each measure has a varying degree of abatement potential due to their intended targets these rates will be established on an individual basis also taking current practices into account. To clarify the significance of this method (measure 1 may have a take up rate of medium 20%, high 40% but measure 2 may only be applicable to 10% of the total material used so its take up rate would be much lower i.e. med 3% high 8%).

The absolute savings brought about by the deployment potential are linked directly to building activity in this research. Meaning that the demand caused by building activity directly stimulates the ability of the supply side of the reduction measures.

Delinking the deployment potential from the demand for buildings is extremely complex. This is due to some of the measures requiring high %ages of import. E.g.

i.e. if world aluminium production is 100 tonnes in year 5 (5 years after the base year) UK consumption is 10 tonnes in year 5 10 tonnes of aluminium production in year 5 can be produced with half the energy The problem is how much of this 10 tonnes is then sent to the UK.

Thus, using a fixed percentage of the buildings production that the reduction measure can impact provides a better method for these projections.

3.3.6 Combined potential scenario

A collective scenario incorporating all of the identified reduction measures will also be developed. This allows for total reductions under the developed deployment rates to be identified over the future target periods and what may have been hypothetically saved during the historical period.

3.4 Identification and analysis of Resource saving measures

The design of this research includes the identification of levels of best practice currently being performed within the construction sector that may be applied throughout European building sites and the attached supply chain.

This includes practices that bring about significant decreases in resource consumption/ embedded energy in any of the investigated materials and at any stage of the building supply chain. The identification and evaluation of the best practices to be further analysed for potential contributions to saving potential will be performed via desk based research of existing project- scale case studies. It is postulated that analysis of a broad range of best practice measures applied to specific projects will allow the researcher to identify a selection of options that provide the greatest potential savings in line with the EC's Resource efficient initiative.

This research into existing case studies focuses on empirical data collection that can ideally be measured against what could be termed 'the normal practice" i.e. not best practice but the average rate of consumption for a particular process across the sector for the nation. The data collection will primarily derive from building authority and private building company databases alongside technical reports for individual projects

Additionally it is important to seek information from recent reduction techniques and to select measures that can be applied to the construction of the majority of new builds. Once identified the potential for this range of options when applied as building standards will be explored by ramping them up to national level to see how they contribute to a comprehensive strategy to lower resource/energy consumption.

3.5 Comparative studies

3.5.1 Selecting the most appropriate measures

The measures selected for investigation will aim at the largest areas of use for resource and embodied energy identified during the 2000-2010 consumption analysis.

Selection of the reduction measures is based on specified criteria relating to significant savings i.e. percentage reductions compared to the projected consumption. Selection of which of the identified reduction measures to further analyse via scenario development will require assessment of each measures possible contribution and also if they tackle areas of concern identified during the analysis of the material supply chains and sector wide consumption levels of resource and embodied energy during the period 2000-2010.

3.5.2 Comparison of Options

Options will be ranked on a quantitative basis for savings potential in order to provide insight in terms of priority for policy makers. This will enable indications into which measures should be explored within a political context in regards to implementation as EU-wide building standards. This comparison will include analysis of the total potential savings that can be achieved from the maximum deployment of each option for total savings over the future periods investigated and target years.

3.6 Feasibility studies

A brief feasibility study for the implementation of each reduction measure explored onto the UK building sector will be performed. This includes a literature review of the associated industry's ability to improve performance. Where appropriate acknowledgements of the barriers and benefits of achieving national scale implementation and the technical viability of this over the future periods investigated.

4. Methods

This section describes how the research concepts in the previous chapter are applied to answer the research questions acknowledged. The section aims to incorporate all of the mentioned concepts into a logical step-by-step approach.

The following general layout Key has been created to enhance the logical sequence of proposed research steps and follows the order in which they appear within this report:

KEY:

Main Research Step (1,2,3)

Sub Research Step (A,B,C)

Data and Assumptions used

Calculations Performed

4.1 Historical Analysis 2000-2010 (Chapters 5-7)

In order to assess future savings potentials the period 2000-2010 is first investigated to identify what impact the proposed saving measures may have attained during the past decade. The prime reason for the inclusion of this time period is to provide an accurate foundation for future savings projections that is based on recent trends within the UK building sectors absolute resource consumption and resource efficiency. Embodied energy required for the building production is also identified using a fixed efficiency for each material.

As data availability for new construction is not as holistic as desired a series of literature based assumptions have been factored in to calculations. Where possible the most up to date data has been selected with national databases chosen as the preferred data source. For all calculations, assumptions referring to construction, demolition and material use have been provided within the corresponding data sheets located in the Annex section to allow for the highest degree of transparency for the reader.

A. Identifying the trend in building activity (2000-2010) (Chapter 5)

By analysing previous years it is possible to incorporate accurate data sets regarding the trends in construction/demolition of buildings and the common material consumption used for their production. This serves the purpose of identifying how much building production was achieved for the resource and energy consumption per annum and allows for efficiency to be identified.

Data used (sources)

- The number of new residential buildings constructed per annum, sourced from UK national statistics data base estimates (ONS, 2013)
- The average size of a residential Property (UK). In 2008 – 90.62m^2 according to the Odyssee database (Enerdata, 2013)
- The % split of newly constructed floor space in the UK attributed to residential or commercial buildings in 2012 (BRE, 2013)
  Residential buildings = 74.67% of the UK floor space
  Commercial buildings = 25.33% of the UK floor space

Assumptions used

- The average floor area of a new residential property remained static at 90.62m^2
- The % split of floor space for residential and commercial buildings remained static

Calculations

The find the total newly constructed floor area per annum

1. ***(Number of new residential buildings$_{2000}$ x Average floor space (90.62m^2))* = Total new residential floor space$_{2000}$**
2. ***(Total new residential floor space$_{2000}$ / % of floor space for residential properties (0.747))* = Total new residential and commercial floor space$_{2000}$**

To identify the amount of commercial floor space $_{2000}$ = (2-1). (This is repeated for each year)

B. Identifying the demolition of buildings 2000-2010 (Chapter 5)

The demolition rate of building activities needs to be identified to establish what amount of materials is available for downstream reduction measures per annum. This trend in recycling rate is also useful for future projections.

Data used

- The Demolition rate of UK residential buildings per annum
  The demolition rate in the UK 1996-2004 was 0.1% (around 20000 houses per annum) (Boardman, B et al, 2005)
  This rate is still consistent in the estimates of the English housing survey in 2010 (EHS, 2010)
- The total UK housing stock over the period
  in 2010 the total UK housing stock = 26.1 M showing an increase of 6.1% from 2000. (Halifax, 2010)
  Therefore 26.1/ 106.1 = 24.6M houses in 2000
- The average size of a residential Property
  In 2008 – 90.62m^2 according to the Odyssee database (Enerdata, 2013)

Assumptions Used

- The average floor area of a new residential property remained static at 90.62m^2
- The % split of floor space for residential and commercial buildings remained static

Calculations

To identify the total amount of residential and commercial floor space demolished per annum

As the demolition rate did not alter over the period

0.1% of 24. 6 M house stock$_{2000}$ = 24600 demolished$_{2000}$
0.1 % of 26.1 M house stock $_{2010}$= 26100 demolished$_{2010}$

((24600 + 26100)/ 2) = Average demolished$_{2000-2010}$ = 25350 houses per year annum constant

(25350 houses per year annum constant X Average household floor space [90.62m^2]) = 2297217m^2 of residential floor space floor space is demolished per annum$_{2000-2010}$

(Residential floor space demolished [m^2] / 0.7467) = Total floor space demolished [m^2]

total floor space demolished [m^2] - Residential floor space demolished [m^2] = commercial floor space demolished [m^2]

N.B As the average floor space of houses demolished is unknown due to the varied nature of selection and property sizes during this period the average house size for the period 2000-2010 was used

C. Selection of Materials to investigate 2000-2010 (Chapter 6)

The selection of materials used to identify resource consumption in the UK building sector are based on the following criteria.

- Only Key materials are assessed. These are the dominantly used materials by quantity for building production in the UK as reported by (OFNS, 2010b) Monthly statistics of building materials and components.
- The materials selected are used for the construction of the building envelope of buildings throughout the EU meaning reduction measures identified may be applied to building projects outside of the UK allowing for the greatest reductions at EU level.
- The selected materials are assumed to hold the largest contributions of resource/energy use within the sector due to their consistent use in large quantities and are established materials commonly used over the last decades, suggesting likely continued use in future projections.

Whilst some materials are used in smaller quantities across buildings such as plastics, they are seen to be not as constant in use. Also due to the large range of building materials used this selection has to be limited to avoid over complicating the data collection process due to no readily available database being present for the sector.

D. Identifying the consumption of major building materials (2000-2010) (Chapter 6.1-6.6)

The levels of consumption for each selected building material are investigated and recorded for the period 2000-2010 to identify the changes in resource use and extrapolation of the trends to create future projections.

As no sector specific database exists the resource consumption of each major material must be identified separately and collated. In order to maximise the potential of this report material data use is generated and classified in a manner that is consistent between materials and with methodologies of other generators of resource flow data.

For transparency of linked calculations and the exact sources for material consumption, data sheets have been created with a unified layout presenting all relevant assumptions, calculations, sources and raw data. These are located in the annex section. Furthermore, a mass balance approach is necessary to compare all resources fairly, which meant raw data in the form of alternative units; area, length etc. are converted into a mass value.

Data used

The annual consumption for each material will be identified using desk-based research. These consumption rates will be formed from sector specific reports and databases such as the (Eurofer, 2011) report "European steel in Figures and the EuroStat Prodcom Data base for concrete consumption.

Assumptions

Factored in to most material consumption trends are literature-based assumptions regarding the percentage of the material consumption actually used in the building sector. This is needed as often the material flow is recorded for the UK as a whole or for the construction sector as a whole.

E. Identifying the associated Embodied energy for each material (Chapter 6.1-6.6)

Once the quantity of material use has been identified using the previous step, the associated embodied energy can be calculated. The inventory of Carbon and Energy (ICE, 2008) provides the recorded amount of embodied energy for each of the materials investigated in (MJ/Kg) so

((The overall quantity of material used for new buildings X embodied energy (MJ/KG)) = Total embodied energy

The embodied energy for each material is held static (frozen) throughout the decade at levels reported in (ICE, 2008). This has been done due to only minor savings being realised in the energy intensity of the products being investigated over the period with no radical reductions occurring. Furthermore, this represents industry averages within the UK all complied within the same source for use of reference. This assumption whilst not precise is the most accurate method available when considering the practicalities of this study. This is due to reported embodied energy amount by industry officials being widely varied and almost always for 1 or 2 manufacturers only, whilst the ICE study provides an average standard with larger population sample. Due to the varied nature of the raw data collection in terms of metrics reported in, further conversion calculations were needed in some instances, therefore each corresponding data sheet aims to present these calculations in a unified clear style.

F. Comparative analysis of resources used during 2000-2010 (Chapter7)

The results for each individual material are compiled and compared along with manipulation of the data to identify how consumption trends over this period relate to the production and demolition of buildings. This will be performed in terms of complete volume and for 100m^2 floor space as to provide greater accuracy in projections of reduction measures savings in the future.

The creation of an average 100m^2 building provides the most accurate way to assess trends and reduction potentials in an unbiased manor considering the inclusion of both residential and commercial properties and these essentially form one entity. Additionally by using a relative measurement of (100m^2) fluxes and trends in individual material use can be analysed over the period allowing for comparison of an annual basis. This allows for projections into consumption trends per 100m^2 to be carried forward into projections to 2020 & 2030. This requires

Calculations

Identification of Resource intensity for each material in 100m^2 of new build in each year

(Total new floor space constructed in annum** $_{2000\text{-}2010}$ **[100m^2] / total individual material used for buildings in annum** $_{2000\text{-}2010}$ **[Ktonne]) / 1000 = tonne of material used per [100m^2] in annum ∑ = Total material used per annum

Tonne of material used per [100m^2] in annum * Embodied energy reported in (ICE,2008) = Embodied energy per [100m^2] [GJ]

Additionally these may further be expressed as % of individual materials contribution to total quantity or embodied energy per [100m^2] and will guide in the identification of important areas to tackle for reduction measures.

G. Review of the supply chain and current use in the sector (Chapter 6.1-6.6)

Alongside the data collection on quantity consumed and associated embodied energy a review of the supply chain for each material and the processes in which they pass through during manufacture is assessed. This also includes where relevant information surrounding waste streams and opportunities for material substitution plus insight into the likely occurrence of future use in the sector.

4.2 Scenario Construction (Chapter 8)

A. Developing the Historical scenario (2000-2010) (Chapter 8.1)

The historical scenario (2000-2010) is the culmination of the above tasks 4.1 A-E and serves the purpose to identify the level of resource and embodied energy use in the sector over the previous decade in relation to the exact amount of building activity that took place. This allows for variation in intensity of material use to be tracked and projected forward. The total material consumption over the period (identified from step 4.1 D) and the total associated embodied energy (identified in step 4.1 E) then represent the sectors total consumption before reduction measures are implemented.

B. Future alternative scenario (2013-2020) & (2013-2030) (Chapter 8.3)

A range of future scenarios are developed to show the potential of reduction measures up to 2020 and 2030. Reductions are measured against a frozen reference scenario whereby no reductions in material/energy efficiency are autonomously occurring over the period.

There are 3 scenarios developed (A,B,C) which represent change in the building production/demolition period over 2013-2030 all of which are again analysed further under a medium and high take up rate.

Data used

- Residential properties built (2013-2030) for each scenario

Scenario A – (based on extrapolation of 2000-2010 data an average 187,243 residential buildings are constructed per annum)
scenario B – (Based on self-calculation provided in scenario construction section and (OFNS, 2011a) population projection 229,517 houses needed to be built per annum to meet demand up to 2020 then production slows to 200,350 for the period 2020-2030
scenario C – (Based on Primes 2009 annual increase to building stock of 1% an average of 273,000 houses are constructed per annum up to 2020 then this slows down to 0.8% between 2020-3030)

- Residential Properties demolished per annum
- The average size of a residential Property (UK). In 2008 – 90.62m^2 according to the Odyssee database (Enerdata, 2013)
- The % split of newly constructed floor space in the UK attributed to residential or commercial buildings in 2012 (BRE, 2013)
  Residential buildings = 74.67% of the UK floor space
  Commercial buildings = 25.33% of the UK floor space

Thus total floor space added is calculated as in step 4.1A for the future projections

Assumptions used

- The average floor area of a new residential property remained static at 90.62m^2
- The % split of floor space for residential and commercial buildings remains static
- A linear trend in material composition of 100m^2 building occurs (from 2000-2010)
- Demolished buildings have the same composition as those constructed in the year 2000

Calculations

To find the Total new floor space built (2013-2030) for each scenario

1. ***(Number of new residential buildings $_{2013\text{-}2030}$ x Average floor space [90.62m^2]) =* Total new residential floor space$_{2013\text{-}2030}$**
2. ***(Total new residential floor space$_{2013\text{-}2030}$ / % of floor space for residential properties [0.747])* / 100 = Total new residential and commercial floor space$_{2013\text{-}2030}$[100m^2]**

This is then plotted into a graph into a realistic growth trend following the recession seen in 2000-2010, which generates **total new build [100m^2] per annum**. This includes the year 2011 and 2012 so that average build rates per annum used during the construction are also accounted for in these years and not increased within the ones being investigated.

To find annual demolition rate see calculation performed in step4.1.B for scenarios A&B this rate remains static across the whole period. For scenario C this demolition rate between (2010-2020) was an average x 4.

The composition of 100m^2 of new building in each year is calculated by following a linear trend from the consumption observed for 100m^2 in the period (2000-2010). This allows for embodied energy in 100m^2 to be calculated as before and also gives total quantity of material used per 100m^2

(Total new build [100m^2] in annum$_{2013\text{-}2030}$ X Total material quantity or Total Embodied energy [per 100m^2] in annum $_{2013\text{-}2030}$) = Total material quantity of embodied energy in that year.
$\sum_{2013\text{-}2030}$ = Total material quantity or Total embodied energy for 2013-2030

The quantity of material in demolished houses uses the material mixture per 100m^2 seen in 100m^2 of constructed building in the year 2000
Therefore material composition of 100m^2 $_{2000}$ X amount of floor space demolished = Total quantity of material demolished

4.3 Identification of Reduction measures (Chapter 9)

A. Identification of the areas of priority concern (Chapter 9.1)

The key areas of concern to tackle regarding the resource consumption and associated embodied energy are identified by close analysis of the results produced in step 4.1 F (chapter 7). This is under the assumption that the largest contributors to overall consumption for both resources and energy are the priority concern.

Furthermore, opportunities for reductions in these areas are put forward from the analysis of each key materials supply chain performed in step 4.1 G and include elements such as (identified excess waste streams and processes that require large energy inputs). These are then used to indicate where efforts would be most effective for reduction measures.

B. Identification of the corresponding reduction measures and their savings potential at local level (Chapter 9.4-9.7

The major aims of this step are to identify a set of levels of currently available reduction measures that may achieve reductions in resource consumption and embedded energy within the UK construction sector. This will be identified using desk based research and a review of the current case studies/literature identifying the possible reductions at a small/local scale level. The focus of this research will be to identify these crucial data inputs. For each measure

- How much resources are saved per (tonne of material produced) which is then translated into m^2 of floor space [Kg/m^2] by using the known amounts of materials used per 100m^2 (2000-2010) and projected amounts (2013-2030)
- How much embodied energy is saved per tonnes of material used [MJ/tonne]

C. Identifying the deployment potential (Chapter 9.4-9.7)

At this stage the Deployment scenarios will be developed and are done so in what may be considered as an unconventional style compared to other projection based studies. It is vital for the reader to understand this methodology. Thus at this point it is elaborated in its simplest form and reiterated at the start of section 9.2 to serve as a reminder.

Explanation of deployment scenarios:

- The deployment scenarios for each measure are individually developed from literature review of the industry and similar transitional periods from similar technologies/strategies where appropriate.
- Each measure has what is classed as a high deployment rate and a medium deployment rate whereby 2 different degrees of implementation are explored.
- This high and medium deployment is extended to show what percentage of building production (or material production) the measure could effect over a **20 year time span**. (Not to be confused with actual calendar period)
- This is developed in such a way that the base year for implementation is irrelevant and does not influence the deployment rate. (Due to all measures having non or hardly any current implementation)
- Thus if implementation started in the (base year 2000 for the historical scenario) or (2013 for the future scenarios A-C) the percentage of production the measure effects would be identical for the 2 at every annual time interval) A worked example is provided below

> e.g.
>
> 5yrs of implementation 2004 in the historical scenario would have the same % as 2016 in the future scenarios) (e.g 5%)
>
> However, It must be emphasised that this does not mean the absolute amount of production effected and therefore savings is the same for this year as constructional activities are different.
>
> e.g.
>
> In the year 2004 100 buildings produced so 5% implementation in this year means 5 buildings subjected to the measure
>
> In the year 2016 200 building produced so 5% implementation in this year means 10 buildings subjected to the measure

Under this development it is presumed that the deployment rate for all measures in terms of absolute amount affected is driven by the demand of the sector (amount of building production). This may not be strictly the case for all measures but it is commonly observed that the supply side reacts quickly within the building sector to meet demand.

This technique was chosen because of two fundamental reasons.

1) As previously mentioned in the bullet points above the reduction measures explored are not implemented in either of the base years to any extent or at the same negligible extent I.e <2% of total production. The production capacity in both base years is assumed to be sufficient to meet the demand.
2) Delinking the deployment potential from the demand for buildings is extremely complex. This is due to some of the measures requiring high %ages of import.

> i.e if world aluminium production is 100 tonnes in year 5 (5 years after the base year)
> UK consumption is 10 tonnes in year 5
> 10 tonnes of aluminium production in year 5 can be produced with half the energy
> The problem is how much of this 10 tonnes is then sent to the UK.

D. Feasibility Studies of the reduction measures implementation at national scale (Chapter 9.4 -9.7)

The feasibility of achieving the identified savings potentials at national scale is assessed from a qualitative perspective using desk-based research. Where appropriate identifying recent industrial developments, drivers and issues which where applicable include possible policy option to support implementation.

4.4 Analysis of the Savings potential held by reduction measures at national level (Chapters 10-12)

A. Development of a range of appropriate indicators (Chapter 10)

A literature review of the current sector wide EU targets for resource and energy reductions identifies no suitable current targets exist.

New proposed indicators that will allow for the reduction potential of proposed measures in resource efficiency and embodied energy efficiency for new building production are created. Embedded within these indicators are fixed time spans (2013-2020) (2013-2030) which allow for the cumulative reduction to be tracked and what reductions can be achieved in the target years.

This is achieved through adapting similar indicators within the field of energy analysis to specifically focus on the improvements available within the sector (new building production occurring over the time periods investigated)

B. Analysis of the Reduction potential at national scale for individual measures (Chapter 11)

The reduction potential is calculated from the known consumption rates for the period 2000-2010 and projected consumption 2013-2030 under no implementation calculated in chapter 8 (steps 4.2 A & B above). They are calculated at national level to see each measures potential when applied at national scale.

This involves the incorporation of

Data needed

- The deployment potentials (High and medium) (developed in step 4.3 C)
- Reduction potential at local level (identified in step 4.3B)
- The building activity (developed during scenario creation in Chapter 8, Step 4.2)

The reductions at national scale over each of the scenarios and time periods investigated are then calculated as follows:

Calculations

(Reduction per 100m^2 building achieved by reduction measure X [kg/100m^2] or [MJ/100m^2] * (building activity per annum *deployment rate for measure X in that annum)

= The total reductions that can be achieved per annum
∑ The total reductions that can be achieved per annum = Total cumulative reductions over a period

Total consumption (no implementation) - Total cumulative reductions over a period = Total new consumption after implementation at high or medium deployment.

*This is performed for each of the 3 time periods investigated separately and for each measure.

This also allows for individual target years to be assessed and also for reductions to be expressed as a % of which consumption is reduced compared to no implementation

C. Analysis of the Reduction potential at national scale for combined measures (Chapter 12)

The results obtained from the previous step will be combined so that all measures saving Resource use will be assessed together and the same for embodied energy to identify total savings as a package of options. This will once again be performed under medium and high deployment. A comparison of each reduction measures contribution to the total saving is then made. Additionally side calculations are performed to provide insight into what efforts are needed during the operational phase of the building for identical energy savings identified. There is no such current effort for resource reduction thus the amount of new buildings that could be produced using the identical amount of quantity savings are provided.

5. UK building sector 2000-2010

5.1 Composition of the UK building sector

While environmental statistics are well documented for the UK construction industry as a whole there exists a clear lack of sector specific data indicating the precise contribution from the residential and commercial building sectors. However, information on the UK construction industry as a whole still provides integral insight into the flows of materials, waste and associated embodied energy by the building sector. The UK construction sector can be divided into several sectors which include; construction of residential and commercial buildings also including service buildings such as healthcare and education, Industrial buildings and national infrastructure such as roads, bridges etc. This UK construction sector as a whole extracts around 380 Mtonnes of minerals per annum (CRW, 2008) and furthermore generates 120 Mtonnes of waste (WRAP, 2011).

There is currently a lack of quantitative understanding of the impact the UK building sector contributes to natural resource use. It is vital that this impact is well documented and understood if the industry is to achieve a sustainable status. This report focuses on the residential and commercial building production/demolition. A breakdown of how these general building types contribute to the total UK building stock can be seen in figure 5A.

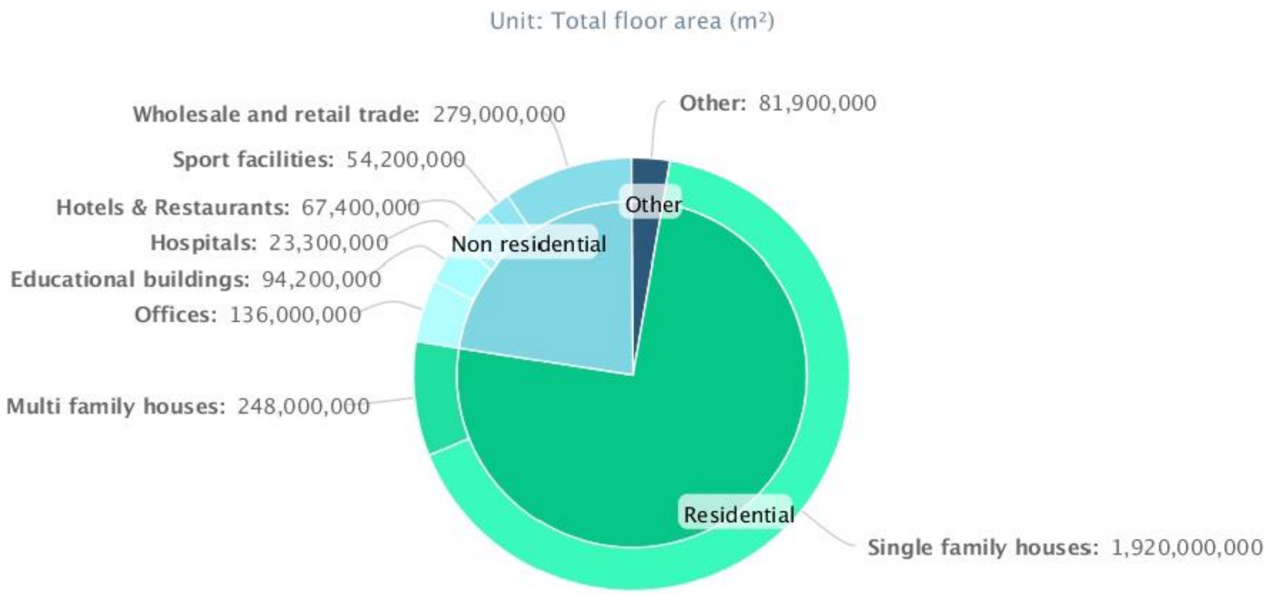


Fig 5A: *Breakdown of the UK building sector into general classifications in 2012. Source* (BPIE, 2013)
Residential buildings = 74.67% of the UK floor space
Commercial buildings = 25.33% of the UK floor space

As no available information was located on the amount of commercial floor space added per annum the percentage share of floor space for building seen in figure 5A for 2012 is adopted and assumed to be a static split throughout the time period investigated.

5.2 Historical levels of UK building Activity (2000-2010)

Houses built per annum reached record level during the 1960s, in 1968 record levels of 425,800 residential units were built (Halifax, 2010) .The number of residential properties built in the UK between 2000-2010 averaged at 187,243 per annum. This means that annual construction during this period is equivalent to <1% of the total housing stock. This decline in annual building production has been driven largely by population increase slowing and economic downturn. The average UK residential household floor space in 2008 was 90.62m^2 (Enerdata, 2013). It is assumed that this floor space area per residential property was static throughout 2000-2010. This is a fairly reliable assumption considering the 2000 estimates were at 91m^2 and new build houses are generally slightly smaller partly due to the increasing trend in capita per household decreasing, thus smaller houses are in demand (OFNS, 2000).

The trend in total floor space per annum constructed during 2000-2010 can be seen in figure 5B. This includes both residential and commercial floor space. Step by step calculations for this are provided in the methods section whilst raw data is available in the annex "build rate data sheet".

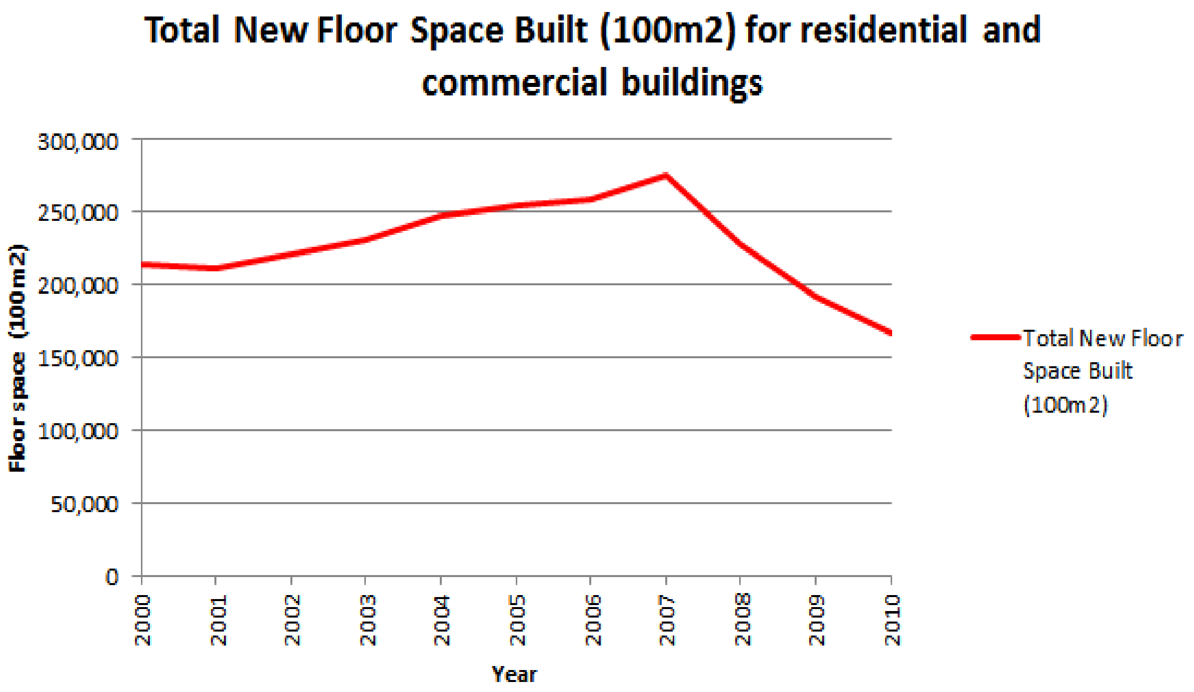


Figure 5B: *Annual new floor space built for both residential and commercial buildings in the UK (2000-2010)*

The annual building construction between 2000-20007 appears as a slight stable increase which is following the national population trend through the period. However, the notable alteration in seen in a sharp decline after 2007 which is a direct result of the 2007/2008 economic crisis with the market demand rapidly decreasing due to banks increasing interest rates and mortgages becoming less accessible (UOL, 2011). This trend is also true for commercial properties with companies unable to lease or buy retail space, offices etc due to maturity defaults whereby the borrower is unable to pay off existing debt leading to lower financial availability of capital (Marsh, 2011)

The overall building stock is however still growing during this period due to low demolition rates and refurbishment of older properties. The growth of the housing stock has been governed partly by thermal regulations as part of the UK building regulations meaning demolition tends to be of the older poorly insulated buildings (Uttley & Shorrock, 2008). It is important to understand the demolition rates present over the period as they directly affect the opportunities present for resource savings downstream of the operational phase. The demolition rate of residential properties in 2003 was reported at 0.1% of the total housing stock (Boardman et al, 2005). In 2010 the identical demolition rate was reported by (EHS, 2010). This has led to the assumption that over the decade the demolition rate remained at 0.1% and with no precise data to suggest otherwise this was averaged for the total housing stock over the period to produce a frozen annual demolition = 3,076,493m^2 including commercial property. The calculations, assumptions and raw data can once again be found within the methods section and "demolition data sheet". The total new floor space added to the building stock is then (new construction – demolition) and can be seen as the red area below in figure 5C.

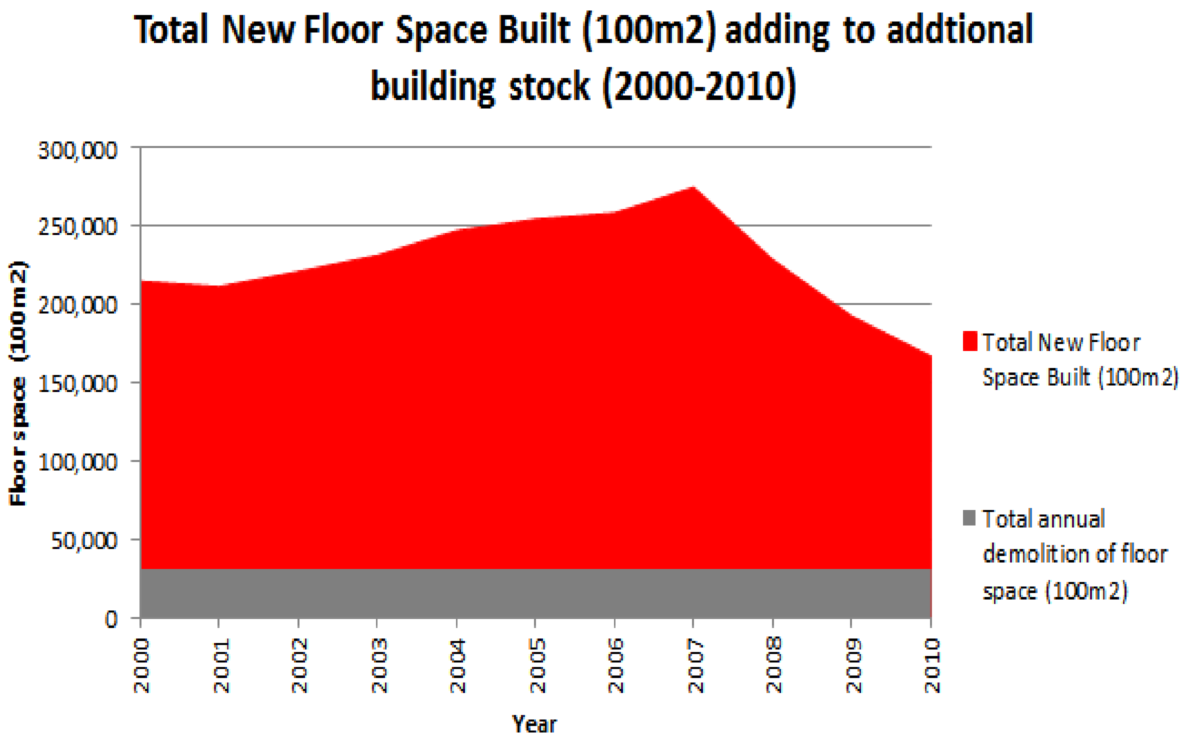


Figure 5C: *Total new floor space constructed contributing to existing housing stock after deductions of averaged static demolition rate (2000-2010).*

total Construction during the period = 2,499,629 (100m^2)

total demolition during the period = 338,414 (100m^2)

total addition to the building stock = 2,161,215 (100m^2)

From figure 5C it can at least initially be hypothesised that the life cycle stages upstream of the operational phase hold a greater opportunity for savings potentials due to a suggested larger material flow however this will become more apparent after analysis of reduction measures available.

It is necessary to highlight that 100m^2 of newly constructed floor space represents a theoretical mixture of both residential and commercial buildings and thus further calculations relating to material consumption per 100m^2 represents an average which is the most precise way of projecting possible reductions when considering buildings as a whole sector at national scale.

* A summary of assumption carried forward for future calculations used for scenario construction are provided below

- The % split of newly constructed floor space in the UK attributed to residential or commercial buildings in 2012 (BRE, 2013)
  - Residential buildings = 74.67% of the UK floor space
  - Commercial buildings = 25.33% of the UK floor space
- The average floor area of a new residential property remains static at 90.62m^2
- The % split of floor space for residential and commercial buildings remains static

6. Material selection & Identification of resource and embodied energy consumption trends (2000-2010

One of the major difficulties in reducing resource consumption within the sector is that it is currently unclear where the main challenges lie and how the industry can address them. Assessment of the common material flows through the UK construction sector is of fundamental importance for realising future saving potentials. The following materials have been selected for a number of crucial reasons following the criteria:

- Only Key materials are assessed. These are the dominantly used materials by quantity for building production in the UK as reported by (OFNS, 2010b) Monthly statistics of building materials and components.
- The materials selected are used for the construction of the building envelope of buildings throughout the EU meaning reduction measures identified may be applied to building projects outside of the UK allowing for the greatest reductions at EU level.
- The selected materials are assumed to hold the largest contributions of resource/energy use within the sector due to their consistent use in large quantities and are established materials commonly used over the last decades, suggesting likely continued use in future projections.

The vast majority of an average buildings structural shell is comprised of the materials selected within this investigation and although not exhaustive of all material found within a building, provides the greatest opportunity for overall resource and embodied energy saving due mainly to the quantity used within the sector but also accounts for the energy intensity needed for production such as that of aluminium. It is indeed true that there are buildings that totally contradict the above statement and use more radical material substitutes, however this collection of materials certainly constitutes the founding ingredients of the "average UK household/commercial building". The materials selected aim to target all of the key material classifications within the building envelope and furthermore focus on the dominant materials used within these categories. Where available a breakdown of their contribution to their category in term of quantity used in the UK building sector will be provided under the corresponding headings.

Due to the necessary calculations an accurate account of the UK's annual domestic material consumption for each investigated material must be identified and furthermore projected for future years. This data is mainly collected using national statistics that are recorded for the following materials at domestic production, import and export level but there does not exist an extensive database covering all building materials. Furthermore, there currently exists no database able to provide accurate quantities of material use in the building sector, with current attempts leading to inconsistent data series (Howard, 2000) this is especially true for the non-renewable resources investigated during this process. To overcome this problem a commonly used methodology below identifies the total amount of each material used per annum within the time period 2000-2010 and then applies a percentage of which is contributed to the building sector.

Material Investigated:

- Metals**: Aluminium, Cooper, Steel**
- Aggregates **(Sand, Gravel, Crushed Stone)**
- **Bricks**
- Cementious Materials**: Ready mixed concrete, Articles of cement**
- **Timber**
- **Glass**

The following sections provide a brief description of each material under investigation and aims to provide context for their inclusion whilst highlighting some of the processes involved during their addition into the built environment from a life cycle perspective. Each summary provides the reader with insight into the supply chain of a building and identifies critical evaluations of the quantities used within the UK, which are developed into the succeeding calculations.

*** Note during collection of data. The use of the Eurostat prodcom database data was deemed to be inaccurate before 2003 for the materials Aggregates, Ready mixed concrete and Glass. Subsequently these have been omitted from the results, this is reflected in figures 17, 25, 31, 33, and 36.**

6.1 The Metals

Metals are commonly used throughout the building industry within the building envelope for structural purposes and more recently aesthetics. This has surmounted in a wide range of metal based products commonly used in the building industry. They are a first choice material for structures, reinforcements, cladding, roofing, window frames and can be found in modern and historic buildings. They are generally energy intensive to manufacture from mineral ores hence large volumes of fuel consumption are required increasing the embodied energy (Smith, Kersey and Grifiths, 2002). Figure 6A below shows the commonly used metals in the construction sector as a whole for the UK in 1998. Whilst not precise for the building sector it reflects a similar insight into the more dominant metals used**.**

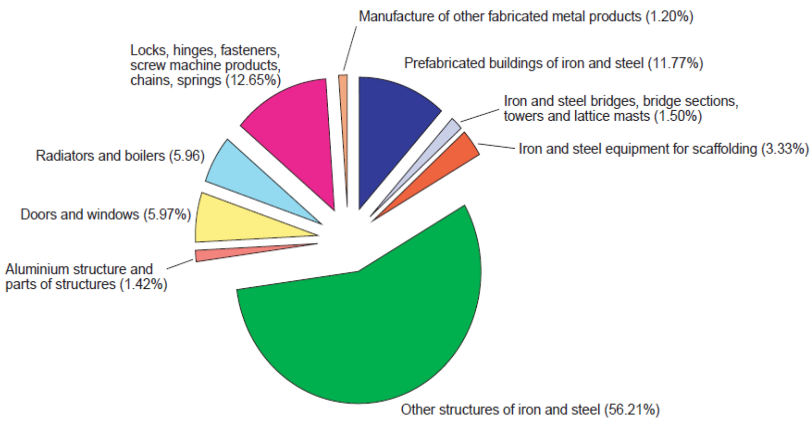


Figure 6A: *% of metal use in the UK construction Sector (1998) for metal types by weight. Source –* (Smith, Kersey and Grifiths, 2002)

As seen in figure 6A Steel is a popular metal used in the construction industry and used in large volumes in comparison to other metals. However, the relative small quantities of copper and aluminium also present opportunity within their associated embodied energy. These metals become increasingly important to this research when considering the primary production of steel requires approximately a quarter of the energy required to make the same quantity of copper and a sixth of that of aluminium (Smith, Kersey and Grifiths, 2002). An important factor to note is that metals can be recycled multiple times without loss of qualities as metallic bonds are restored upon melting and re-solidification. In contrast most other building materials degrade after recycling which is critical in structures that are governed by tight specifications.

Below a more detailed assessment of each metals inclusion into a building envelope and an overview of the lifecycle with associated energy inputs are discussed. At the end of each material section a graph representing the annual quantity used and associated embodied energy for the UK building sector 2000-2010 is displayed to provide context of the research.

6.1.1 Aluminium

Aluminium is utilised across the EU for a host of applications in the building and construction sectors, especially in the manufacturing of window frames. Other uses commonly associated to the metal include exterior cladding, doors, roofing, wall panels and partitions (EAA, 2012). The cradle-to-cradle cycle for aluminium used within the building sector can be seen below in figure 6B.

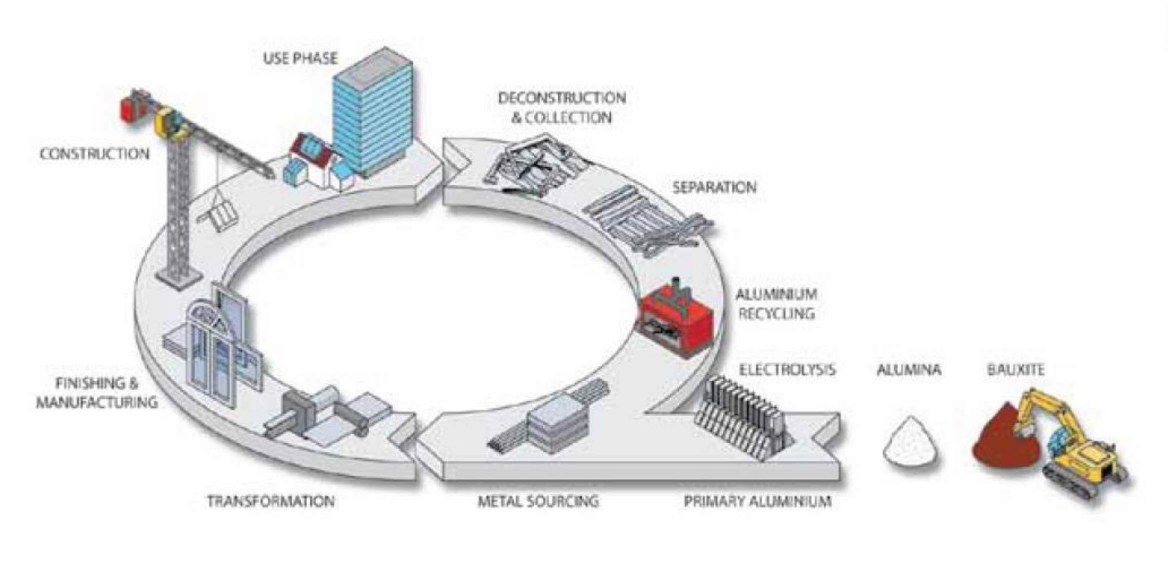


Figure 6B: *Schematic of Aluminium cradle-to-cradle life cycle*. *Source* – (EEA, 2012)

Approximately 50% of the aluminium currently being produced in the EU is derived from recycled raw materials with the energy required for manufacturing from recycled sources being ~5% of that needed for primary production (EAA, 2012). This large saving in energy requirements has economic benefits to manufacturers which spurs on greater recycling rates, with a study performed by the Delft University stating that 6 EU countries including the UK currently achieve >96% recovery rate (Delft University, 2004). However, due to the long life span of buildings, the amount of recoverable aluminium at demolition/ reclamation phase is limited thus much less than the current demand. Therefore, future demand will have to be met largely by primary production, which is of key importance to the embodied energy of the average UK building.

This primary process is extremely energy intense, which can be highlighted by a brief overview of some of the main manufacture steps. Bauxite, the ore for which aluminium is produced from is mainly found outside of Europe meaning that import into the member states is high with large transportation distances. The process of electrolysis which is vital in aluminium production, is highly energy intense, with no efficiency gains expected in the near future (HYDRO, 2012). Aluminium has the benefit of being one of a handful of metals that is able to be manipulated by using any casting method and can therefore be manufactured into virtually any shape and size, providing great flexibility to architects. Additionally to casting, when flat sheets are required rolling mills are used (Frees, 2008). Both processes require high energy inputs for the heating of the metal and the mechanical manipulation. This adaptability and multi-purpose use of the material means it is difficult to find an appropriate substitute.

With the energy intensive manufacturing process and acknowledged benefits the reduction of this aluminium use in the UK building sector will be further investigated especially considering its likely continued use due to unique properties such as its strength to weight ratio which are hugely significant to the compliance of structural regulations and seemingly lack of suitable substitute materials especially considering that it is the third most abundant element in the earth's crust. Even though bauxite is currently the only ore used for commercial aluminium production, known reserves are estimated to last for over 100 years (HYDRO, 2012). It is important to note that aluminium building components within a building shell may require more energy to construct than alternatives but also hold further functions such as reflective shading that will decrease the energy demands used for thermal control placed on the building during operational phase (HYDRO, 2012).

Aluminium has witnessed a vast increase in use over the past century with ~70% of all aluminium produced still being in use. This can essentially be classed as a stock and is due to the materials long life cycle of 50-80 years in buildings and 10-20 years in vehicles. An important factor needed in the following calculations within the next section of this report is that the building and construction sector account for ~26% of the EU aluminium end use market (EAA , 2010), this is displayed below in figure 6C. Although a number of studies and estimates provided by industry wide institutions promote the tracking of bauxite to estimate aluminium consumption the UK domestic production of aluminium is solely from alumina since 2000 (Dahlström, 2004) and it appears many of these studies neglect that bauxite has a conversion ratio of ~2-1 to alumina. Once aluminium has been formed into large slabs known as ingots it is then passed to third tier suppliers to produce mechanically worked products in the forms of wrought and cast components such as bars, tubes, sheets, fabrication etc. (Dahlström, 2004). These products are essentially what is used in buildings and cars. Tracking the consumption at this stage is possible and provides the strongest data point when assessing sector wide consumption,

The amounts of usable aluminium products entering each industry is unavailable due to the privatisation of the market with over 70% of the UK aluminium owned by stockholders (Dahlström, 2004). Due to the complicity of the aluminium flow the teaming of two statistics namely the consumed wrought and cast aluminium and the percentage share of the market used for building provides the most accurate estimation of actual quantity.

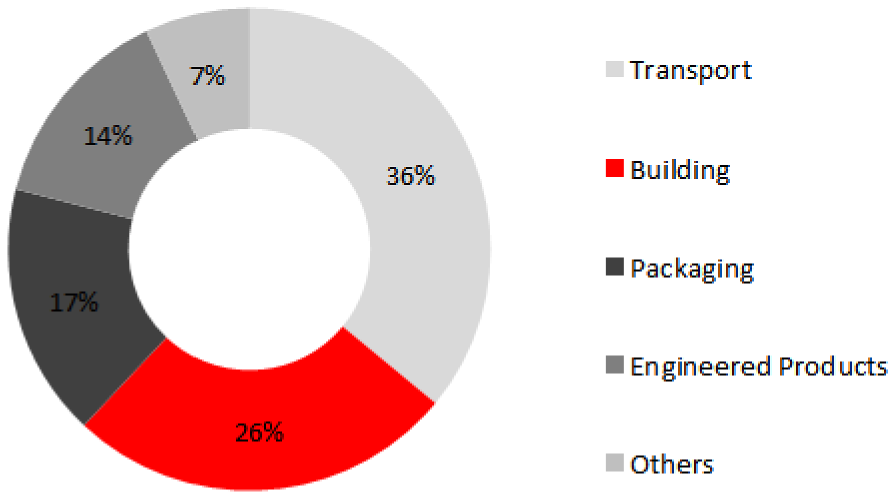


Figure 6C: *The proportion of Aluminium end uses within the EU*. *Source* – (EEA, 2010)

Aluminium Embodied Energy

The major energy use throughout aluminium manufacturing resides within the electrolysis stage, which requires 15000 KWh to produce 1 tonne. Furthermore, the total primary energy required to produce 1 tonne of cast aluminium to be 173 GJ (EAA, 2012), with this total factoring in the energy required for transportation of the ore. The inventory of carbon and Energy (ICE, 2008) estimates this Energy requirement at 155GJ for average tonne of aluminium excluding transportation which matches up reasonably well. Small variations are mainly due to the percentage of recycled content within the calculations. The ICE estimate is preferred in this instance due to figures being based on the UK aluminium trade with percentage of type of aluminium i.e. rolled, cast, extruded already factored in. The total quantity of aluminium used in the UK building sector and the associated embodied energy on an annual basis can be seen below in figure 6D.

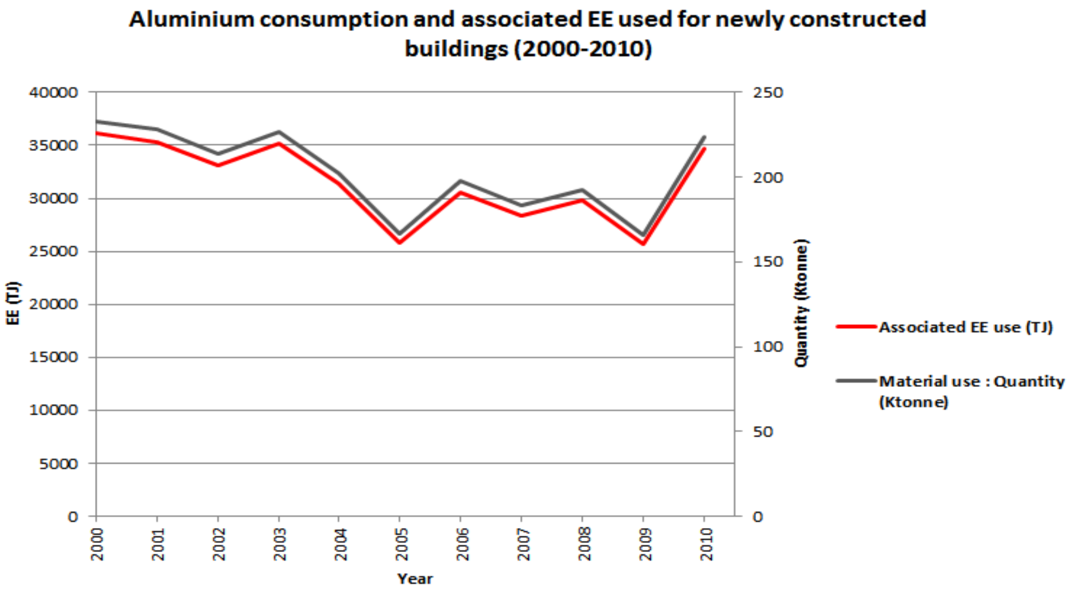


Figure 6D: *The Total consumption of Aluminium by the UK building sector and associated embodied energy (2000-2010)*

Fluctuations in aluminium use whilst not large are still evident. Unlike the other materials investigated within this report aluminium use within the building sector does not align with the construction rate of new buildings seen in figure 5B. This is partly due to the vast majority of aluminium use being attributed to commercial buildings, which is estimated at 97% of total aluminium used in the building sector for northern Europe (EEA, 2004). These commercial buildings are largely developed using current trends by architects, which may wish to include a higher proportion of aluminium. However, when compared to the historical price trend of aluminium constructed by the London Metal exchange there is clear correlation indicating when prices are high there is less use within the sector and vice-versa (LME, 2013). This partly explains the steep rise in aluminium use between 2009-2010 as aluminium prices reached a decade low (LME, 2013). However, this recent increase may also be partly explained by the introduction of more stringent thermal regulations to buildings that are completed in 2010 and onwards. These regulations can be seen in the form of L1A for new residential buildings (HM Government (A), 2010) and L2A for New commercial buildings (HM Government (B), 2010). These regulation demand increased insulation that is associated to a higher use of high quality window and door fittings which contain a greater proportion of aluminium.

6.1.2 Copper

Copper deposits are located globally in a variety of geological environments, with identified reserves estimated ~1.6 billion tonnes (USGS, 2003). Copper is used in many forms within the built environment including wires, electrical outlets, switches etc. However, this study focuses on its use within the buildings envelope including castings wrought sheeting and its major use for roofing applications and external cladding due to the materials desirable resistance to corrosion and durable life span (BGS, 2007). It may also be alloyed with other metals in order to acquire additional properties important to the building sector such as improved tensile strength and malleability for forming into specific measurements (BGS, 2007).

Due to its wide application and characteristics copper is the third most common metal used within industry behind Steel and aluminium in terms of absolute quantity consumed. Figure 6E displays the breakdown of this use into industrial sectors highlighting 29% of total copper consumption is used within the construction sector. Of this portion attributed to construction (75%) is directly used within buildings (ECI, 2011).

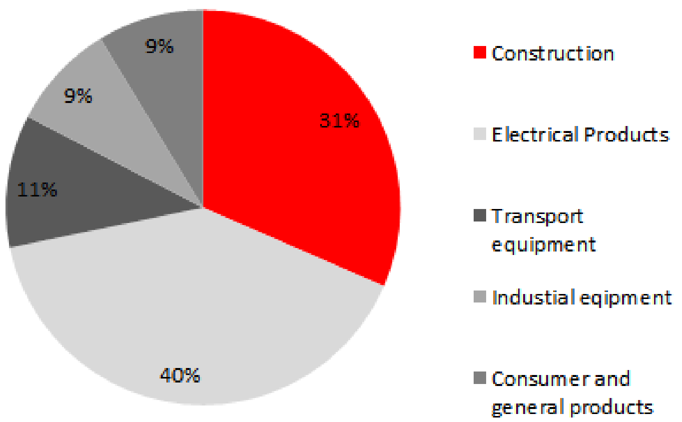


Figure 6E: *Copper consumption in industry breakdown by absolute quantity*. *Source* – (BGS, 2007)

The basic upstream Lifecycle of copper production can be seen in figure 6F and is separated into 3 main stages. ~90% of all copper is produced from sulphidic ores, with the remaining 10% from oxidic ores. This heavy use of sulphidic ores creates a specific advantage for copper manufacture whereby, during the smelting process there is no requirement for process fuel or for carbon as a reduction agent. So the additional energy needed for smelting and fire refining is fuelled by the energy within the ore. There is even an excess of energy, which is commonly used to melt recycled material within the same process, or to generate heat or power for other uses (IISD, 2010).

Once extracted the copper ore needs to be broken down and separated as much as possible. This is done using a process known as milling which involves the mechanical use of large equipment, first passing though cone crushers and latter mills (ECI, 2011). The crushed ore is then smelted in high temperature furnaces to remove impurities. The next step is electro-refining which removes remaining impurities in the raw metal, either from the ore or from secondary sources, to achieve the desired copper purity of >99.99%. The copper is then moulded into cathodes which are melted once more into profile, wire, tube products and also highlighted in red in figure 6F the wrought copper sheets and castings that are used in the building envelope.

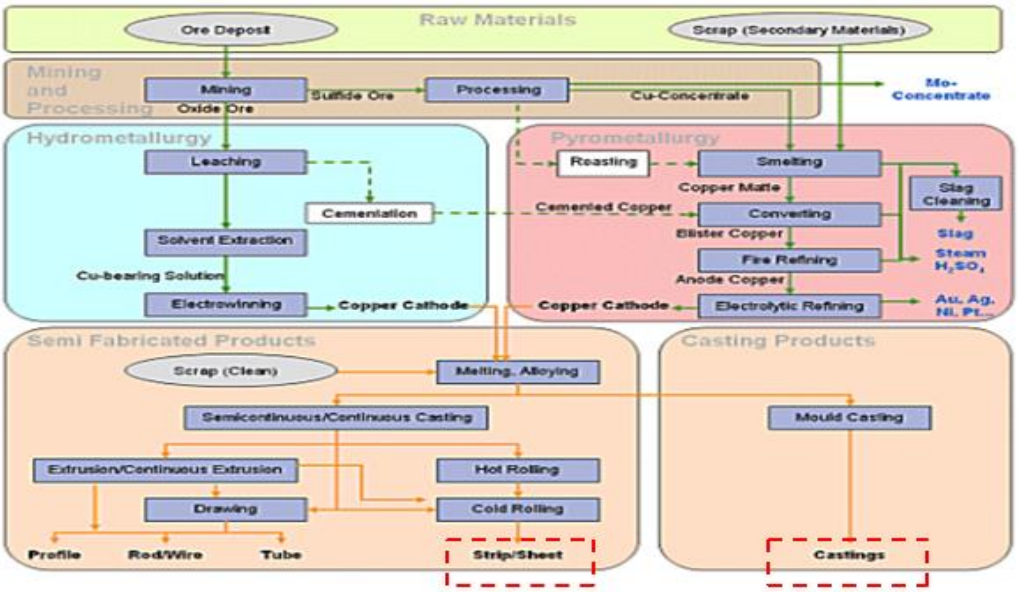
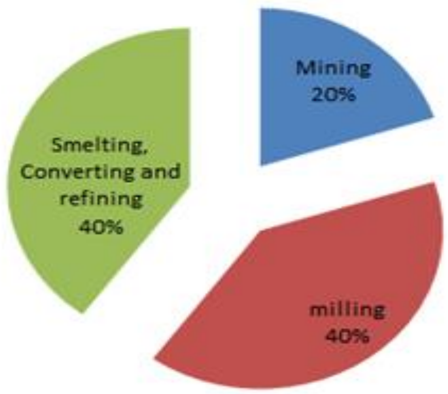


Figure 6F: *Schematic diagram of the upstream processes for production of Copper product. Source – (*Kupferinsititut, 2013*)*

Copper embodied energy

The energy used for copper production in these upstream lifecycle stages can be roughly split into the 3 major production steps highlighted above which include the extraction and manufacturing phases but little information is available on the energy used during construction of buildings, which is assumed to be only a fraction. This breakdown can be seen in figure 6G, which also includes a more in depth table providing average energy use in each specialised stage reported here in Btu.



Operation	10^6 Btu/ton	Total	Percent of total
Open-pit mining:		20.13	19-25
Drilling	0.61		
Blasting	3.90		
Loading	1.85		
Hauling	13.14		
Ancillary	0.64		
Milling:		42.73	40-52
Comminution	0.16		
Beneficiation	42.57		
Smelting: *		6.2-22.7	8-21
Electric furnace	22.68		
INCO flash	6.27		
Outokumpu flash	9.20		
Mitsubishi reactor	12.21		
Noranda reactor	10.41		
Converting:		0.9-6.5	1-6
Electric furnace	6.50		
INCO flash	0.94		
Outokumpu flash	2.13		
Mitsubishi reactor*	3.02		
Noranda reactor*	1.77		
Gas cleaning:		6.3-8.2	8
Electric furnace	7.73		
INCO flash	7.76		
Outokumpu flash	8.16		
Mitsubishi reactor	6.25		
Noranda reactor	7.36		
Electrorefining:		5.6-6.3	6-7
Electric furnace	5.61		
INCO flash	6.29		
Outokumpu flash	6.29		
Mitsubishi reactor	6.29		
Noranda reactor	6.29		
Total		81.9 -106.5	

Figure 6G: *The breakdown of EE used throughout Copper product production. Source* **–** (Pitt and Wadsworth, 2000)

From figure 6G the latter two processes appear to be the most energy intensive indicating efforts to reduce the embodied energy of Copper would benefit from targeting these stages in the products manufacturing phase.

In terms of downstream activity secondary Copper use is a growing industry especially considering the rising prices of the material. It is essentially 100% recyclable with no loss in properties. Due to this, recycling rates across Europe are high, with manufacturers who provide products to the building sector typically using ~50% of recycled copper and ~42% of EU Copper demand satisfied by recycled materials. Driven largely by schemes that provide high payment for scrap metals. In terms of energy this recycling uses 15% of the energy used to produce products compared to primary production, conserving fuel and reducing accompanying emissions. The long lifecycle of Copper has a positive impact on its embodied energy meaning its use in buildings will probably not need refurbishment. However, the limit of achievable end of life recycling today is governed by past production. The rapid growth of copper use means that demand must still be met largely by primary production, thus virgin material continues to enter the supply chain (EMA, 2011)

The total annual copper consumption used in the UK building sector has been identified along with the embodied energy associated with its use and is displayed below in figure 6H.

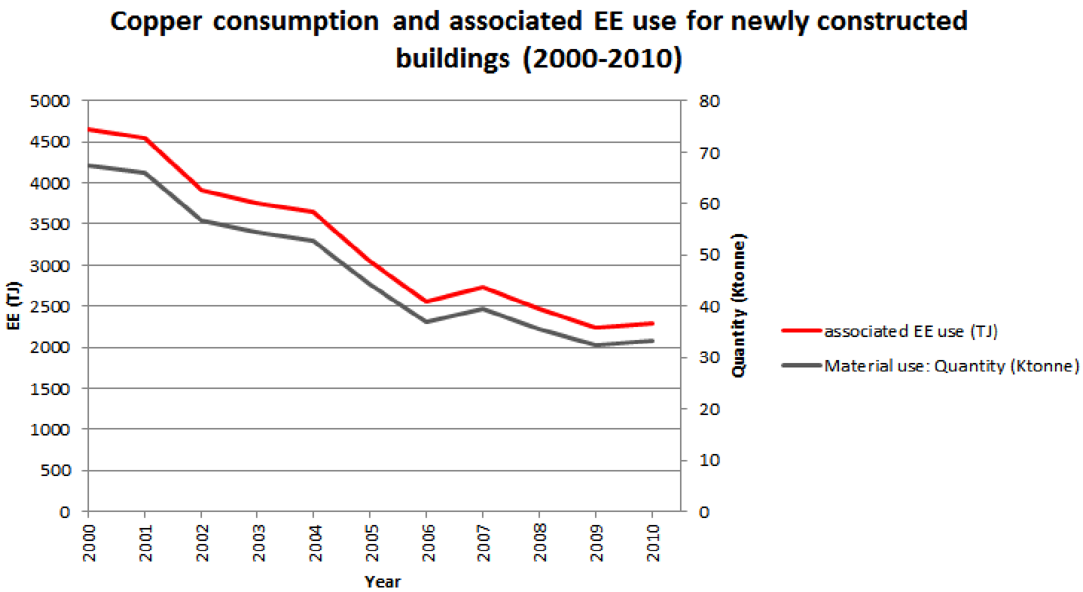


Figure 6H: *The Total consumption of Copper by the UK building sector and associated embodied energy (2000-2010)*

From figure 6H it is possible to conclude that the use of Copper within the UK building sector decreased over the decade with approximately half the amount consumed in 2000 recorded in 2010. When compared to the new build rate seen in figure 5B there is no obvious correlation, suggesting that copper consumption is not driven by build rate alone within this sector. However, when compared to the historical price trend this consumption pattern fits well. Copper prices increasing >300% from 2000 levels to an all-time high in 2006 (LME, 2013). Since 2006 Copper prices have stabilised which is also reflected in the metals use in the building sector seen in figure 6H as a fairly stable consumption level during this period

6.1.3 Steel

Steel use is ever increasing within the building sector with the UK a dominant user having a long history with the material. In buildings steel is often used to provide structural support in beams, rods, flooring etc. including framework which enables the reduction of required building size. Other uses include external cladding, joint work and trimming. The materials high strength to weight ratio allows it to span large areas of a building frame making it a perfect material for structural purposes especially in larger commercial buildings. The long life span of the material also renders it suitable for the building industry simultaneously reducing the need for refurbishment and demolition. Currently these desired qualities leave the option of substitution an extremely unlikely occurrence. Steel is used in products through a wide variety of sectors with 29% of all steel produced used in construction of this (75%) is consumed directly in the building sector with the majority integrated into structural design (EEF, 2010).

Iron ore is the primary resource for steel production. This ore is extracted from the natural environment and there exists a vast global supply rendering the material essentially unlimited as it is the most frequent metal in the earth's crust after aluminium (Dahlström et al, 2004).

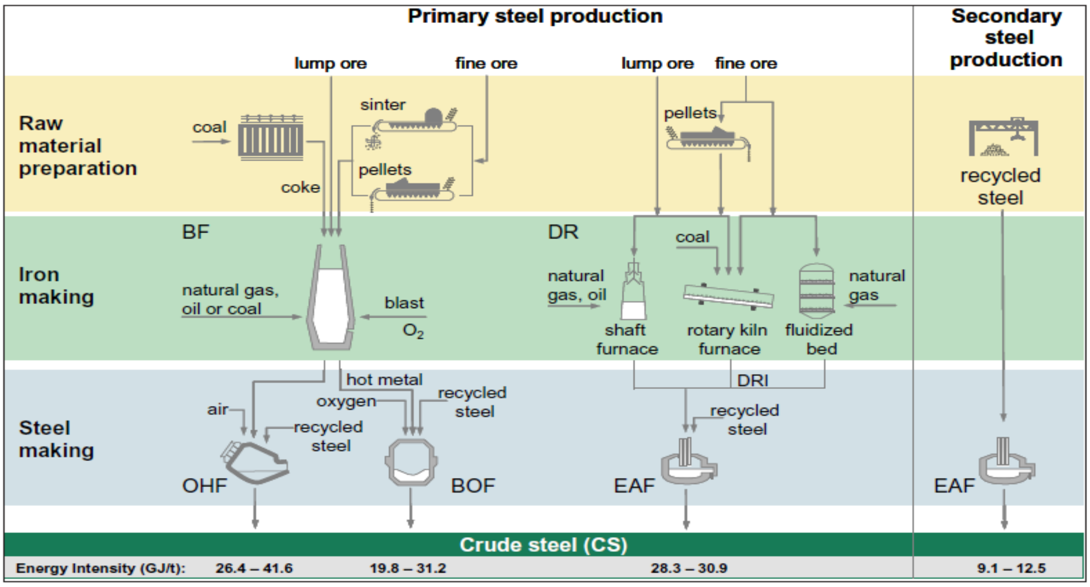


Figure 6l: *Schematic of Upstream steel production for primary and secondary sources*. *Source* – (WSA, 2008)

Primary steel production currently account for 75% of annual steel production on a global basis with the remaining 25% in the form of secondary production from scrap metal (WSA, 2008). There are 3 major process routes which are used to create primary Steel and can be seen in figure 6l. These include;

Blast furnace (BF) – basic oxygen furnace (BOF): 66%
BF – open hearth furnace (OHF): 3%
Direct reduction (DR) – electric arc furnace (EAF): 6%
all secondary steel production is produced using the EAF method.

Once crude steel has been produced it is then rolled, this can be done either by hot rolling or cold rolling machinery. The basic difference being that cold rolling takes higher energy as the steel is less malleable, however this is preferred as the steel cools it shrinks so in order to create the right measurements the cold rolling provides increased accuracy.

Embodied Energy of steel

The steel industry is the largest industrial user of energy but has improved the efficiency of steel production achieving ~50% reductions in energy needed to produce 1 tonne since 1975 (WSA, 2008). However, this current efficiency is largely dependent on the steel making facility and production route. Approximately 8% of the embodied energy is attributed to the mining, preparation and transportation of the raw materials to production facilities (UNEP, 1997). Within the steel production facilities ~95% of the energy used arrives in the form of solid fuel Coal, with gas (3-4%) oil (1-2%). Table 6A below provides the typical energy requirements for each major process in 2004 and the corresponding theoretical and practical minimum to provide insight into where reduction can be achieved.

Table 6A: *The typical energy use in each of the major processes relating to steel production*. *Source* – (USDE, 2004)

	Energy [GJ/tonne Steel]				
Process	**Absolute Energy Requirements**	**Absolute Minimum**	**% Difference**	**Practical Minimum**	**% Difference**
Iron ore to Pig iron Liquid hot metal (5%C)	13-14	9.8	25-30	10.4	20-26
Liquid Steel (BOF)	10.5-11.5	7.9	25-31	8.2	22-29
Liquid Steel (EAF)	2.1-2.4	1.3	38-46	1.6	24-33
Hot Rolling Flat	2.0-2.4	0.03	99	0.9	55-63
Cold Rolling Flat	1-1.4	0.02	98-99	0.02	98-99
18-8 stainless melting		1.2		1.5	

Table 6A identifies that the processes of converting iron ore into pig iron and the basic oxygen furnace process are the largest consumers of energy in steel production suggesting efforts to reduce resource use in terms of fuel and embodied energy in the upstream phases should focus into these stages of production.

As seen in figure 6I, secondary steel production uses far less energy than that of its primary counterpart and only incorporated the electric arc furnace method. Opportunities downstream of the buildings operational phase for steel have been investigated. In 2000 the steel construction institute compiled a survey of UK demolition contractors to report on end of use recycling rates of steel in buildings. This was later repeated in 2012 by Eurofer (SCI, 2013) the results for both surveys can be seen below in Table 6B

Table 6B: *The end of use recycling rates of steel in the UK construction sector reported by UK demolition contractors in (2000) & (2012) Source* - (SCI, 2013)

Product	% Reused		% Recycled		% Lost	
	2001	2012	2001	2012	2001	2012
Heavy structural sections/tubes	12	7	67	93	1	0
Rebar (in concrete super structure)	2	0	90	98	8	2
Light structural steel (supports)	10	5	89	93	1	2
Profiled sheet cladding (roof/façade)	15	10	79	89	6	1
Other non-structural steel used in buildings	2	4	85	96	13	1
Average across all products	8	5	85	91	7	4

Table 6B shows that the collection of steel from the downstream demolition phase remains high over the time period, ranging from 93-96%. These high recycling rates seen for all of the metals investigated in this report suggest there is little scope for resource reduction measures relating to metal recycling. Although the recycling allows for 100% recovery of the metal, reuse is still preferred as little/no extra energy is needed. This may present a reduction potential if the reuse of metal components could be improved. The total annual quantity and associated embodied energy for Steel use in the UK construction sector is displayed in figure 6J.

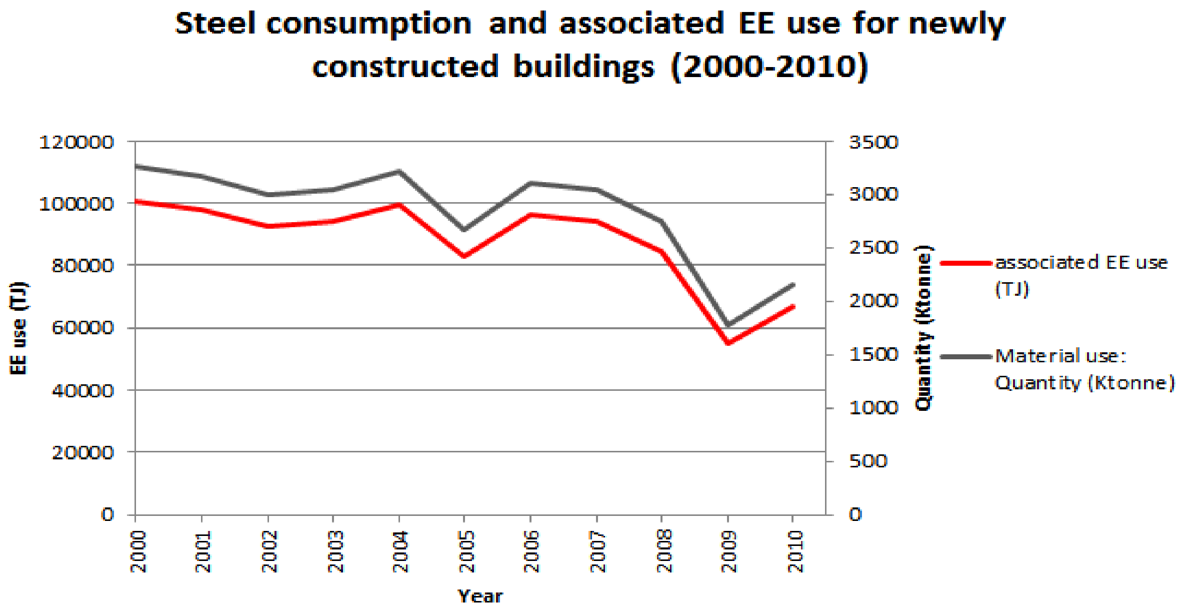


Figure 6J: *The Total consumption of Steel by the UK building sector and associated embodied energy (2000-2010)*

When compared the annual construction in figure 5B the steel consumption correlates well which was not observed for the other metals. This is presumed to be as steel is absolutely essential for modern building techniques with no suitable substitution and is heavily relied upon to meet structural specifications. Furthermore, the price of steel stayed fairly stable over the period (LME, 2013), which in contrast to the other metals investigated did not noticeably affect consumption trends. Due to its high correlation with buildings it is assumed steel as a material would be an excellent target for future reduction measures.

6.2 Aggregates

The Aggregates industry is by far the largest consumer in terms of extraction of natural materials that are not used for energy production. Within Europe 3 billion tonnes per annum are extracted from quarries and pits located in all of the member states (EEA, 2012). Aggregates commonly used within the building sector can be seen in figure 6K below. Of these aggregates crushed stone, gravel and sand account for ~ 70% of all quarried materials. These 3 materials have been chosen to represents the quarried products in this research due to their heavy use in terms of quantity within the building sector and available data in relation to material flow.

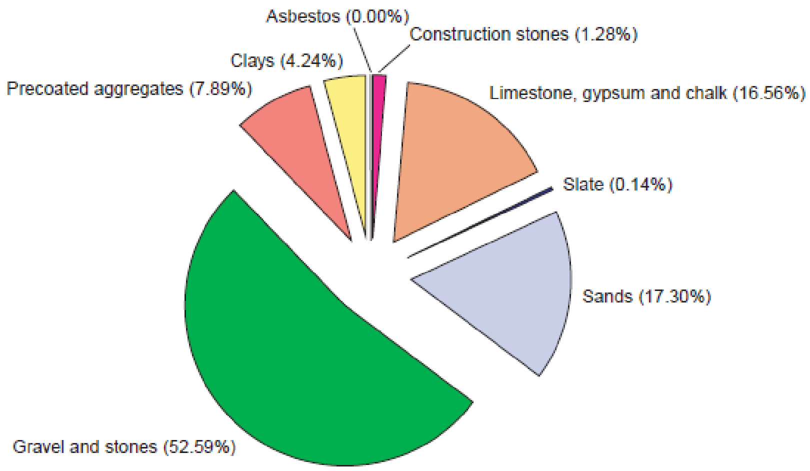


Figure 6K: *The breakdown of quarried products used in the UK construction sector in 1998, Source* (Smith, Kersey and Grifiths, 2002)

Aggregates are typically used in a vast range of products in the building sector most notably as a component of composite materials and are present in large quantities within ready mixed concrete, cement products and glass which are also analysed within this report. Careful assessment of the data is required to avoid double counting of this aggregate use within the building sector with data used excluding these uses and focusing of direct aggregate use in buildings.

Aggregates are very cheap to produce with a relatively simple processing chain. In large quantities they possess a stable uniform property whilst also allowing for improved draining compared to most soils due to a higher hydraulic conductivity value. For this reason these common aggregates are used in vast quantities across all EU building sites as base material for building foundations. This specific purpose of aggregates requires so much material that it alone accounts for 24% of all aggregate use (Smith, Kersey and Grifiths, 2002). As an example, the average U.S home construction requires about 400 tons of construction aggregates (National Stone, Sand and Gravel Association, 2012) and in 2012 the average U.S residential building floor area measured 221m^2 (United states Census Bureau, 2013). This equates to 181 tonnes of aggregate used for 100m^2 of building and is very close to the calculations performed in this report of 190.7 tonnes.

Aggregates used in the construction sector derive from one of three major sources, the percentage of total used in the building sector is presented alongside each source below;

Land won aggregates (76%)
Marine dredged aggregates (6%)
Recycled and secondary aggregates (18%)

For the first two primary sources once extracted from the earth's crust fairly simple processing stages are required which include mainly crushing and sieving the aggregates to desired size or in some instances, especially for sand no further processing is needed. The force needed to crush rock is directly proportional to the new area size achieved hence the smaller the desired size the more energy needed. Due to the extensive use of construction aggregates the series of crushing stages used has been optimised in the industry over the past century (Guimaraes et al 2007). This is highlighted in the associated embodied energy at 0.1 GJ/tonne (ICE, 2008), which is only a fraction of any of the other materials, investigated within this study. Additionally the most energy intense stage in aggregates used within the building sector is associated to their transport to site. Typically aggregates are consumed very close to their point of extractions. An interesting fact within the UK aggregates supply chain is that the transportation phase is the most expensive element to the end user and carrying the aggregate 40km is equal to doubling its price. As transport is neglected in this study and the embodied energy of aggregates is very low it is not seen as an important area to tackle within the context of this study.

The total quantity used however is still vast. The third option of recycling and use of secondary aggregates is primarily an ideal solution to reducing this. These are produced from construction wastes that are recycled and secondary products come from industrial wastes such as power station ash and blast furnace slag (BGS, 2008). These strategies not only reduce the need for primary extraction but also reduce the quantities of waste sent to landfill. These strategies can be performed on site but are usually done at a central plant. This involves further transport, mechanical sorting/separation and a greater degree of crushing than primary sources (BGS, 2008). Due to this the embodied energy in the recycled aggregates is actually higher than in the primary sources at 0.25GJ/tonne (ICE, 2008). To counteract this in 2002 an aggregate tax was placed onto virgin resources of an additional £1.60/tonne to stimulate demand for recycled aggregates with the reasons being these virgin resources are finite and their extraction brings about environmental degradation such as loss of land and pollution to watercourses (Lazarus, 2009)

Recycling and use of secondary aggregates then is not a preferred option in terms of reducing energy demands. However, it does provide a realistic ability to decrease total consumption of primary resources and is still very low in terms of embodied energy. This brief analysis leads to the conclusion that an ideal option would be one that reduces the overall quantities needed. This would presumably incorporate some type of change in the building design. Alternatively measures may focus on the reduction of waste in the upstream stages. Typical mineral waste constitutes 15-20% of the excavated rock and after processing may result in >50%. These estimates are currently not confirmed by any systematic quantification and waste amount vary depending on excavation sites and the resource been mined. However, some of this waste has the potential to be used as fill material for building foundations and if used would reduce overall demand for virgin extraction (BGS, 2007). Figure 6L below shows the total quantities of aggregates used as un bonded material (i.e. not in another product such as concrete) for the UK and the associated embodied energy.

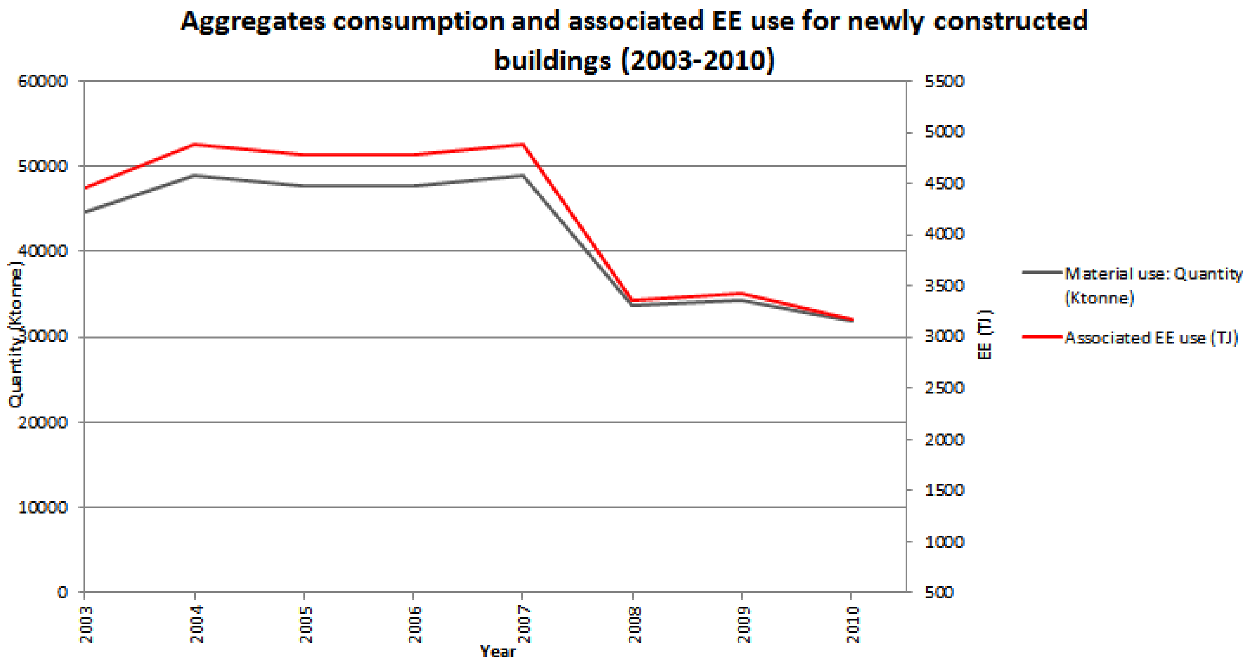


Figure 6L: *The Total consumption of Aggregates by the UK building sector and associated embodied energy (2003-2010)*

When comparing the total quantity of Aggregates used in the UK building sector with the amount of construction seen in figure 5B a tight trend is observed with annual levels remaining stable until the 2007-2008 recession where quantities severely dropped and have not recovered by the end of the decade. This tight correlation further suggests that aggregate use for building foundations has not changed over the decade with similar quantities used for structural support.

6.3 Brick

Bricks are a significant construction material in the EU and are one of the major components of a buildings outer skin. Clay resources provide a wide variety of products such as pipes and tiles that can be used within the built environment with bricks accounting for >95% as seen in figure 6M. They are dominantly responsible for the total quantities and associated embodied energy used in the building ceramics industry and therefore a primary focus of this report.

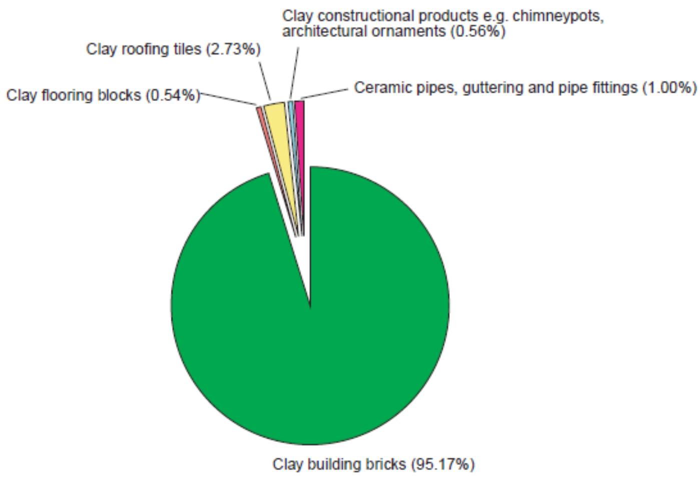


Figure 6M: *The breakdown of clay products used in the UK building sector by total quantity in 1998*, *Source* – (Smith, Kersey and Grifiths, 2002)

Bricks are a highly versatile and durable material with a long life span, making them an excellent choice for use in buildings. The majority of bricks used for UK buildings are for external walls with some also used for retaining walls. The bricks used for the construction of exposed walls are termed facing bricks and are of high quality providing weather resistant properties. These account for 88% of all bricks used in UK Buildings (ONS, 2013), they have an associated embodied energy of [8.2MJ/Kg] (ICE, 2008). The other 12% are known as common bricks which are of poorer quality and compressive strength and are typically used for internal walls, they have an associated embodied energy of [3MJ/Kg](ICE, 2008). As clay excavation and brick production is generally done at the same site the UK is almost entirely self-sufficient in meeting its brick demand.

A brief description of the upstream process of a bricks lifecycle allows insight into where intervention may provide opportunities for reduction measures. Clay is first extracted in quarries; this clay is then mechanically ground and crushed, blending with additives to achieve desired properties. The clay is then shaped into bricks using one of two common methods. This is most commonly achieved through extrusion of a single column that is subsequently cut into the required size accounting for 78% of UK brick production or alternatively the bricks are shaped using the soft mud process whereby the clay is mechanically pressed into moulds. The wet clay bricks then need to be dried in a dryer which is a very heat intensive process needing to reduce the moisture content of the clay to <1% however, heat recovered from the kilns used in the next process is utilised in this step. The dried bricks are then fired in a kiln at temperatures ranging from 900-1100°C. The most common type of kiln in the UK is the tunnel kiln that receives a constant flow of bricks during operation (Carbon Trust, 2010).

Embodied Energy of bricks

As bricks are delivered to the sight completed and handled manually the construction phase is negligible with the extraction phase also displaying small energy requirement. The manufacturing stage is then the most interesting upstream phase for reduction potential. Over the past decades the brick industry has managed to significantly reduce energy consumption in the upstream phases of brick production, however in recent years this has been slower to decrease the energy needed in best practice cases (BDA, 2012). In UK brick production there is a heavy use of natural fuel with gas predominantly consumed and 8% of total energy used is in the form of electricity for operating the mechanical equipment. Most of the energy consumed during brick production is within the firing stage, with drying being the second largest estimated at roughly 20% of fuel consumption which is considerably lower due to secondary heat typically recovered from the firing kilns. This energy consumption can be seen in table 6C below which shows the split between each phase for 3 UK plants investigated by the Carbon Trust (Carbon Trust, 2011). Note in this table power refers to the 8% electricity and fuel refers to gas use.

Table 6C: *The breakdown of energy use by each of the main manufacturing processes. Source* – (Carbon Trust, 2011)

Electricity (Power)	**Site 1**	**Site 2**	**Site 3**
Making and forming	25.9%	26.1%	22.7%
Setting	7.4%	1.4%	6.8%
Drying and Firing	41.2%	40.6%	32.0%
Dehacking	1.3%	2.8%	0.3%
Other - Compressors, lighting etc.	24.2%	29.2%	38.3%
Fuel			
Drying and Firing	100%	100%	96.7%
Other	0.0%	0.0%	3.0%

With current UK plants varying significantly in efficiency within the drying and firing stages energy use is often way above the theoretical minimum and the best practice observed in operational plants. This is illustrated in table 6D. The reduction of energy expenditure in upstream phases then centres around reduction measures aiming at reducing the fuel use in the drying and firing stages. There exists very limited potential for reduction in the overall clay resource use in these phases. Very little clay is wasted during the manufacturing process with plants fitting a belt that returns pre-fired waste to the beginning of the process. Waste post firing is broken down and used as aggregate. The recycling in this process is effectively 100%.

Table 6D: *The theoretical minimum energy of drying and firing bricks along with the mean of UK plants and the best practice. Source* (Carbon Trust, 2011)

Requirement	Estimated minimum energy use, KWh/tonne (assuming 40% flue and structural losses)
Drying extruded brick, 15% moisture content	194
Drying soft mud brick, 28% moisture content	330
Recoverable heat from dryer using current technology	0
Heating requirement in firing	416
Recoverable heat from a kiln using current technology	250
Minimum energy requirement for a extruded brick	360
Minimum energy requirement for a soft mud brick	496
Mean extruded plant	700
Mean soft mud plant	670
Best Extruded plant	370
Best soft mud plant	500

In terms of the downstream opportunities the use of materials from alternative recycled and secondary sources plays a large role in the current UK Brick industry. 11% of the brick over the last decade has been from recycled materials (Weinerberger, 2012). This strategy of adding additional waste from secondary sources reduces landfill and the need to excavate primary clay. However, any material added that is not virgin clay has to meet both the aesthetic and stringent technical requirements outlined in EU product standards (Weinerberger, 2012). This measure provides an opportunity for resources saving however does not realise any noticeable savings in the specific energy required for the production of the bricks. Furthermore reuse of bricks is declining as the majority of this was performed for aesthetic reasons and buildings being deconstructed now tend to have a higher quality of mortar binding the bricks making it very time consuming and difficult to clean for reuse, they too are usually crushed and used for aggregate.

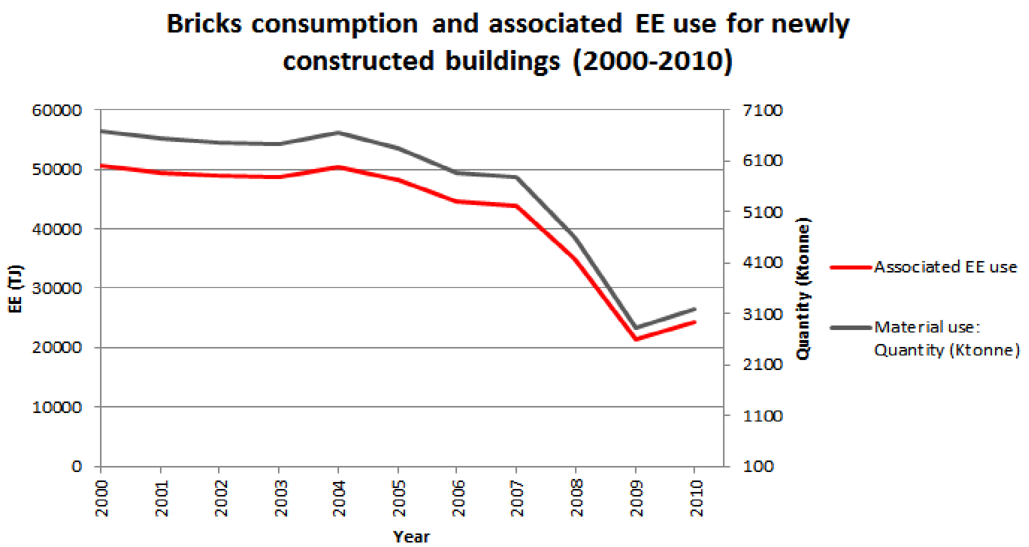


Figure 6N: The *Total consumption of Bricks by the UK building sector and associated embodied energy (2000-2010)*

The total annual consumption and embodied energy for bricks used in the UK building sector can be seen in figure 6N. The trend is corresponding to that seen in figure 5B representing new construction for the most part including the effects of the 2007-2008 recession and decrease in houses built. On closer inspection a slight decrease during the period 2000-2007 is observed which is converse to the increasing annual build rate during this period. This can be explained by the use of larger and cheaper concrete and breezeblocks used for some internal walls steadily increasing their market share and also becoming more prevalent in commercial buildings (BDA, 2012). This may also be partly explained by the increased use of other materials for exterior walls such as glass and timber, however the extent of this is not well documented. Additionally it is important to note that fixed embodied energy levels for brick production have been ascribed to the calculations used as seen in the Bricks data sheet. However, as the brick industry primarily supply to the building sector reductions in buildings may have led to the part time operation of plants. This non-continuous production is more energy intense as kilns have to achieve required temperatures (Carbon Trust, 2011).

6.4 Cementitious materials

Ready mixed concrete and cement articles are the two most dominantly used cement based products within the building sector seen in figure 6O.

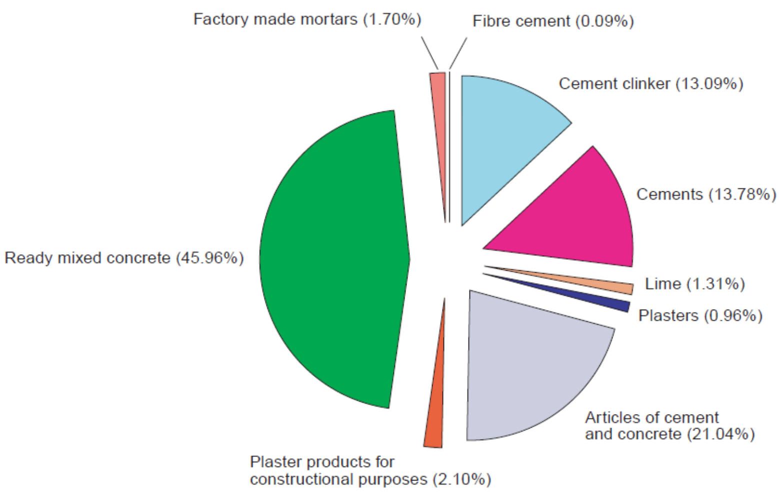


Figure 6O: *The breakdown of cement-based products used in the UK construction sector in 1998. Source* (Smith, Kersey and Grifiths, 2002)

As these two types of application are used in the highest quantity they have been selected for further investigation in this report. As in the previous sections each will be subject to a brief overview of the upstream and downstream lifecycle stages to provide insight into where reduction opportunities are present and the absolute amounts used per annum in the UK over the period 2000-2010 along with the associated embodied energy are identified.

6.4.1 Ready Mixed Concrete

Ready mixed concrete is a composite material made up of cement, aggregates and sand along with negligible amounts of additional additives such as retardants. The proportional mix of these materials is the determining factor for the final structural strength and also determines the embodied energy of the Concrete. The average ready mixed concrete used in the UK is a consistency of ratio 1:2:4 (cement, sand aggregate respectively) (CEMBUREAU, 2011) .At this mixture the embodied energy for Ready mixed concrete = (0.95 MJ/Kg) (ICE, 2008). Ready mixed concrete is used in large quantities for nearly all buildings, once the buildings designers have calculated the volume needed the mixture is simply transported to site, poured into the desired position and left to harden. Due to the precise mixtures that can be achieved within this process ready mixed concrete is preferred in the building sector opposed to mixing it on site. This is typically used in buildings for structural purposes including the foundation of load bearing walls and flooring.

A simplified diagram of ready mixed concrete production is displayed in figure 6P. The materials used for mixing are stored on the production site, which can be selected to ascertain specific specifications. As discussed earlier the aggregates used are excavated and processed using the identical processes observed for their direct use in buildings mainly as foundation fill. They are then transported to the concrete production plant and stored for later use. As noted earlier the embodied energy in their production is very low with the materials found in abundance. The cement is also produced off site and stored in silos ready for adding. As cement production is highly energy intensive this process is discussed in more detail below. Small amounts of additives are then added usually for the purpose of binding the concrete and improving hardening times and durability of the final product. Water is then added during the mixing phase, which acts to create the chemical reactions needed to form concrete when it comes into contact with the cement. These mixing times are performed to the optimum shortest duration in order to allow maximum production capacity to be realised (CISMA, 2010). Once the desired consistency has been reached it is then poured by chute to the Lorries. These Lorries are specially adapted with fitted mixers that rotate 2-6 times per minute to prevent the concrete from setting (CISMA, 2010).

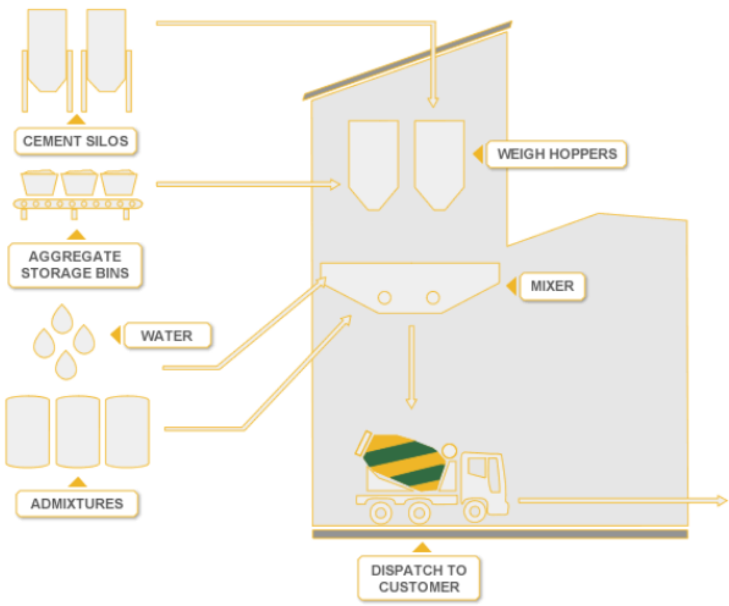


Figure 6P: *A simplified diagram of the ready mixed concrete manufacture process. Source* (Tarmac, 2012)

Embodied energy of Ready mixed concrete

In terms of the upstream cradle to gate life cycle of ready mixed concrete, the aggregates used contribute little to the energy requirements and processes such as the addition of water and mixing durations are critical to achieve prerequisite specifications, therefore savings here are very limited. Once again as seen with the other high quantity materials, transport of the concrete also contributes significantly to this. When looking for opportunities to reduce the energy needed one clear component arises. Cement production is by far the most energy intense element of concrete production. This is highlighted when comparing the reported embodied energy for the two materials which shows;

5.02 [MJ/kg] for cement production
0.95 [MJ/kg] for ready mixed concrete production (ICE, 2008)

The embodied energy for concrete is much lower as ~85% of the concrete is formed from aggregates with embodied energy content of [0.1MJ/Kg] (ICE, 2008). In terms of the whole upstream processes cement production constitutes ~75% of the total energy requirement (SCF, 2012) and represents ~15% of the quantity. The energy used during construction is negligible as concrete is simply poured into mould often relying on gravity alone.

6.4.2 Articles of cement and concrete

Despite the name articles of cement and concrete, concrete produced blocks and modules are often termed cement blocks, it should be established at this point for the confusing namesake that items termed cement blocks in literature are in their strictest terms actually concrete blocks. Concrete blocks are cheap to produce and can be easily moulded into required shapes. Furthermore, their design can include cavities that save on material use whilst maintaining absolute strength (Schierhom, 1996). Prefabricated concrete articles may be transported directly to site where they can be assembled rapidly saving on manual labour costs and build times. The ability to control the mixture and shape allow for aesthetic smooth finishes to be achieved popular within the building sector. Larger concrete blocks require less manual work for creating walls with less mortar needed, this combined with the materials thermoregulation properties means they are commonly used for the inner skin of modern buildings (Schierhom, 1996).

In terms of the upstream process cement blocks are very similar to that seen in ready mixed concrete in figure 6P. The main difference being after mixing, instead of being loaded into lorries and transported to site the concrete is poured into precast moulds to the required measurement and allowed to harden. These casts are most typically of uniform shape to the building sector with the vast majority forming a commonly found shape. Slight differences are seen in the composition of the concrete as a higher proportion of sand to aggregates is observed which produces a dryer and stiffer mixture suitable for casting (Schierhom, 1996).

Embodied Energy of Articles of Cement and concrete

Articles made out of the concrete such as blocks typically have a lower proportion of cement in their mixture and therefore a lower embodied energy per m^3 reported at an average of [0.67MJ/kg] (ICE, 2008). However, some precast products such as prefabricated modular components may require more energy especially if required in unusual shapes such as columns and wall panels. This is due to the urgency of drying the concrete into varies moulds for use on the constructions site. Extra energy is needed in this case for a process known as curing which is commonly done in kilns or by steam to dry the concrete more rapidly with average embodied energy content of [2MJ/kg] (ICE, 2008). However the vast majority of the energy requirements are still in the form of the cement used within the mixture.

Downstream phases of concrete

The Cement proportions in concrete cannot be viably separated or reused as cement. Once a building is demolished the concrete is typically recycled into aggregates using the recycling loop mentioned within the previous aggregates section and around 80-85% of recycled content is used for foundation fill in construction (WBCSD, 2011). The recycled aggregates may also enter back into the concrete production chain and quantities of 20% of total aggregates used can be from recycled sources in this process (WBCSD, 2011). So in quantitative savings the recycling of concrete brings about reduction in virgin aggregate demand or it can be recycled through the cement manufacturing process in controlled amounts, either as an alternative raw material to produce clinker or as an additional component when grinding clinker, gypsum and other additives to cement (MPA, 2013). Large sections of demolished concrete from buildings may also be reused for other purposes such a sea walls (MPA, 2013). However, reuse of concrete blocks in buildings is very limited. This is due partly to the damage sustained during life and destruction but mainly due to the specific measurements needed for new builds. A better design approach could incorporate this as seen in a handful of projects worldwide which have been deconstructed and placed elsewhere such as the 2012 Olympic stadium. Although this is not a realistic solution for wide scale application as the long life span of buildings makes this option difficult to foresee. There are seemingly no opportunities for energy savings in the downstream phase for concrete and recycling rates of aggregates are currently high in the UK however as previously mentioned this process does in fact have a higher energy intensity.

As cement products represents the major contribution of embodied energy in each of these product types, this process step is of key importance for reduction efforts as the processes in terms of embodied energy of concrete are indivertibly linked as seen in figure 6Q. A brief overview of the cement supply chain is discussed below.

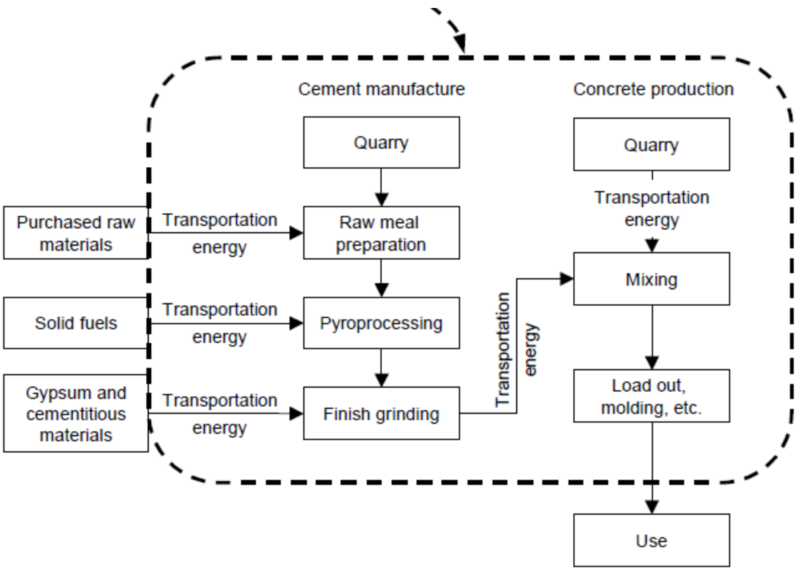


Figure 6Q: *The connection of the Cement and Concrete supply chain. Source* **–** (Nisbet et al, 2002)

6.4.3 Cement

The Most Common cement produced in the UK is Portland cement. Figure 6R shows the basic steps in cement production and its associated energy inputs.

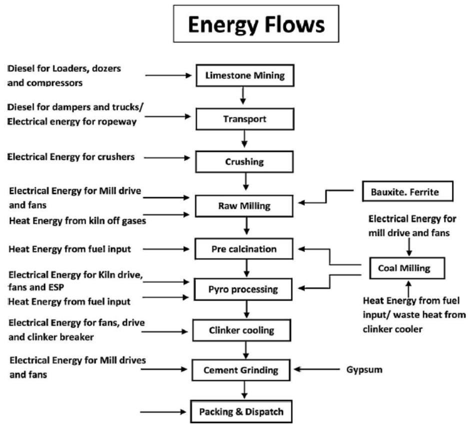


Figure 6R: *Schematic view of Portland cement manufacturing process and associated energy inputs. Source –* (Madlool et al, 2011)

The major raw material of cement is limestone of which clay, shale and aluminium and iron oxides are added. These materials are quarried and transported to the productions site. They first pass through the primary crusher and are milled together into a fine powder, they may additionally be pre homogenised into the correct quantities. The raw mixture then passes through the pre heater, which is powered by exhaust fumes from the kiln. The kiln which is typically heated to a temperature of 1400^{o}C is the most energy intensive step within the process which uses mostly gas and coal fuel in UK production (WBCSD, 2011b). The extreme temperature and rotation of the kiln allow the raw materials to be transformed into clinker. The widely adopted use of the dry production during these stages means energy saving in the industry has been improved compared to the wet production which needs to evaporate water (Zhu, 2011). The clinker is then mechanically cooled using cold air ventilation and grinded into Portland cement. This may then be grinded further with other materials such as gypsum to increase setting times.

There are large energy requirements throughout the process with mechanical operations and high temperature reactions. The breakdown of energy use during this process into 4 sub sections has been reported by (Madlool et al, 2011) and is displayed below in Figure 6S.

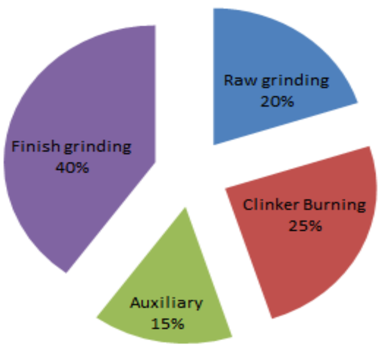


Figure 6S: *The breakdown of energy consumption by major process within cement manufacture. Source* (Madlool et al, 2011)

From figure 6S we can see that significant amount of energy are needed for all of the major processing steps indicating reduction measurement aiming at any of these steps would have a significant value and should be investigated further during the identification of best practice measurements.

The Ready mixed Concrete consumption and associated embodied energy for the UK has been analysed and is reported below in figure 6T. The corresponding information for articles made of concrete can be seen in figure 6U.

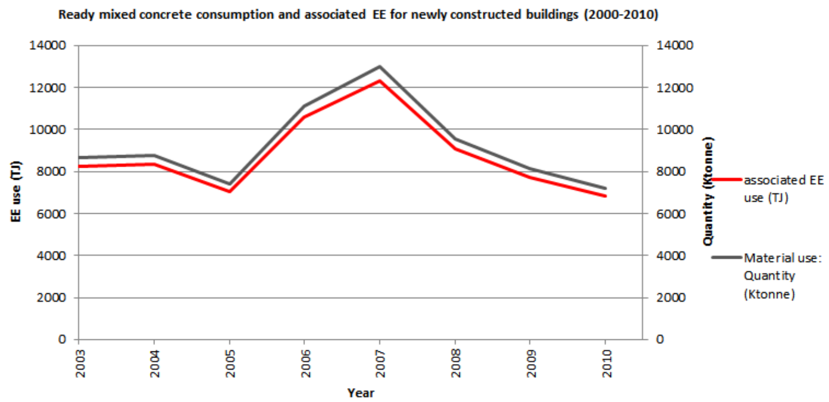


Figure 6T: *The Total consumption of Ready mixed concrete by the UK building sector and associated embodied energy (2003-2010)*

The consumption of concrete closely follows the newly built building trend seen in figure 5B after 2003 with 2007-2008 economic recession reducing the demand. This material has no real suitable substitute widely used at this scale and prices remain fairly constant meaning that use is not dictated by price as observed in the metals investigated. This material is constantly used in large quantities and has a medium embodied energy making it an ideal target for reduction measures.

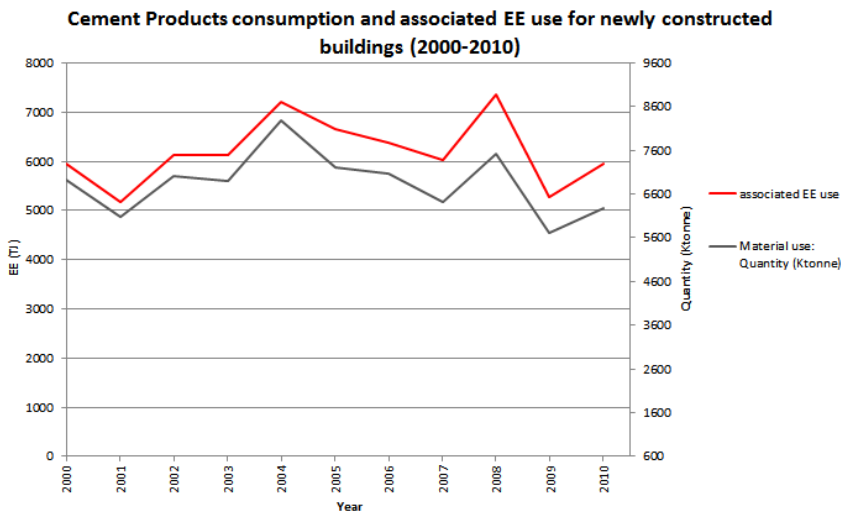


Figure 6U: *The Total consumption of Concrete articles by the UK building sector and associated embodied energy (2000-2010)*

The articles made of concrete appear to stay fairly stable during the time period. This may be driven by prices of other building materials in comparison especially in commercial buildings as during the economic recession consumption increased perhaps suggesting some building materials such as brick were substituted for this cheaper alternative.

6.5 Timber

Timber is the only material that truly represents renewable resources in this investigation and considering this study focuses on the materials most commonly used in buildings this speaks volumes about the current state of the sector. Whilst other materials such as metals can essentially achieve closed loop recycling, the increased demand for buildings still requires raw materials to enter the market. Timber has been used in buildings for centuries and offers a varying array of applications useful for the construction of a building envelope and indeed whole buildings can be constructed from this material. It offers lightweight and strength properties that can be ordered to specific measurements. Figure 6V below shows the approximate split of types of wood product used for construction in the UK.

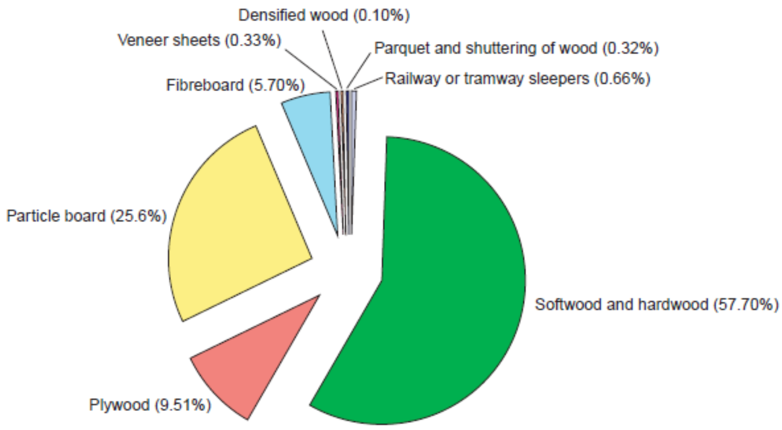


Figure 6V: *The Breakdown of Timber products used in the UK construction sector in 1998. Source -* (Smith, Kersey and Grifiths, 2002)

As seen in figure 6V softwood and hardwood products make up ~58% of the total timber use. These are sawn wood products such as beams and generally used for structural purposes including load bearing frames, roof and floor supports, floors, door and window frames etc. The other major product type is wood based panels. These include Plywood, particleboard, fibreboard and Veneer sheets and represent a further ~41%. These panels are increasingly used in the building sector for applications such as walls and floor panels, roofing and cladding of external walls. Of all sawn wood and wood based panels consumed, 52% are used in the building sector for the construction of the building shell (FAO, 2009). Furthermore, timber frame construction is a popular method of building in the developed world and is currently used in >25% of new houses in the UK, also becoming more widespread in commercial buildings (UKTFA, 2011). The timber provides a faster to construct and cheaper alternative to metal structural components. Typical load bearing components can be made of sawn wood instead of common steel and concrete work, with panels used for horizontal and vertical timber studs used to transfer the loads to the building foundations (UKTFA, 2011). The increasing use of prefabricated wood based panels is also of interest which can be substituted instead of common concrete and brick walls found in most building, serving to lower the embodied energy and overall quantity of materials used. This prefabricated method also saves time during the construction phase utilising work in factory environments and decreasing wastes produced at construction phase with estimates of ~20-40% reduction in waste generated (TREP, 2012).

Upstream resource use and embodied energy

Timber is only one product for designers to choose from with others promoted as environmentally viable options. However, few have production processes that are as simple and environmentally friendly as most timber products sourced from sustainable forests.

The first step of the lifecycle is the cutting down of the timber from forests located all over the globe and transporting it to the manufacturing site known as a mill. It is important to note that transportation is a significant factor when considering the embodied energy of timber. The logs are then cut into specified measurements and this is the sawn wood products, with 35% of hardwood and 45% of softwood converted into these products (FWPRCD, 2009). This is a low percentage as irregularities in the timber such as hollow cores and twists make large proportions unsuitable for strong uniform sections. The wood is then naturally dried and manipulated once more by sanding the wood into the desired shape.

Other wood based panel products such as Veneer panels are simply sheets of wood that are cut from the logs and stuck together using small amounts of glue. However, these commonly need mechanical drying which consumes more energy (FAO, 2009). As previously mentioned much of the original log is not used for these products but none is wasted. All of the off cuts and chips are converted into reconstituted products such as particle board with the flakes of waste wood bound together by synthetic resins and again cured in a heating process (FAO, 2009).

This amounts to no waste being generated in the upstream phases and an average embodied energy content for this range of products of [9.36MJ/Kg] (ICE, 2008). This is much lower than the alternatives investigated when considering the weight needed is much less. The extracting of the timber from the forest requires <1% of the total embodied energy with the manufacturing of the products the dominant phase for energy use (FWPRCD, 2009). However, in almost all cases the energy requirement is much less than the actual energy content of the timber if used for fuel. In the construction phase timber performs favourably in terms of energy use against the construction of brick and concrete walls with timber framework requiring comparable energy demands as steel frame in this phase (FWPRCD, 2009). There is subsequently a lack of areas to target for reductions in the upstream phases.

Downstream resource use and embodied energy

Timber reusability varies and is largely dependent on how well the timber has been maintained and the particular species it has been constructed from. In contrast to other materials investigated such as Aluminium, Steel and Glass, timber can often be reused without the need for complete remanufacture thus eliminating the energy needed in the upstream phases. This reused sawn timber is sourced from demolished buildings and furniture with timber not fit for reuse recycled into particle board although there is no accurate estimation of the amounts available. Sawn wood used in buildings very rarely contains recycled material, however wood based panels including particleboard and plywood can be 100% recycled. The embodied energy of these recycled products is similar to primary production

Both upstream and downstream phases of timber used in buildings lifecycle appear to be resource and energy efficient compared to other building materials. Therefore reduction measures should focus on increasing timber use as a substitute for other key materials investigated. This must be done from sustainable sources. Table 6E below shows the variations in fossil fuel use for timber when compared to other common structural materials it is able to substitute,

Table 6E: *Comparison of Embodied energy for Timber as a material substitute. Values from (ICE, 2008)*

Material	Embodied energy [MJ/Kg]
Timber	9.36
Steel	30.91
Aluminium	155
Brick	8.2
Concrete	0.95

Table 6E suggests large savings of embodied energy may be achieved using this substitution method also accounting for minimised quantity used. i.e. bricks and concrete may be less but the quantity used is far higher.

Figure 6W below displays the recorded quantities and associated embodied energy for timber used in the UK building sector for the previous decade.

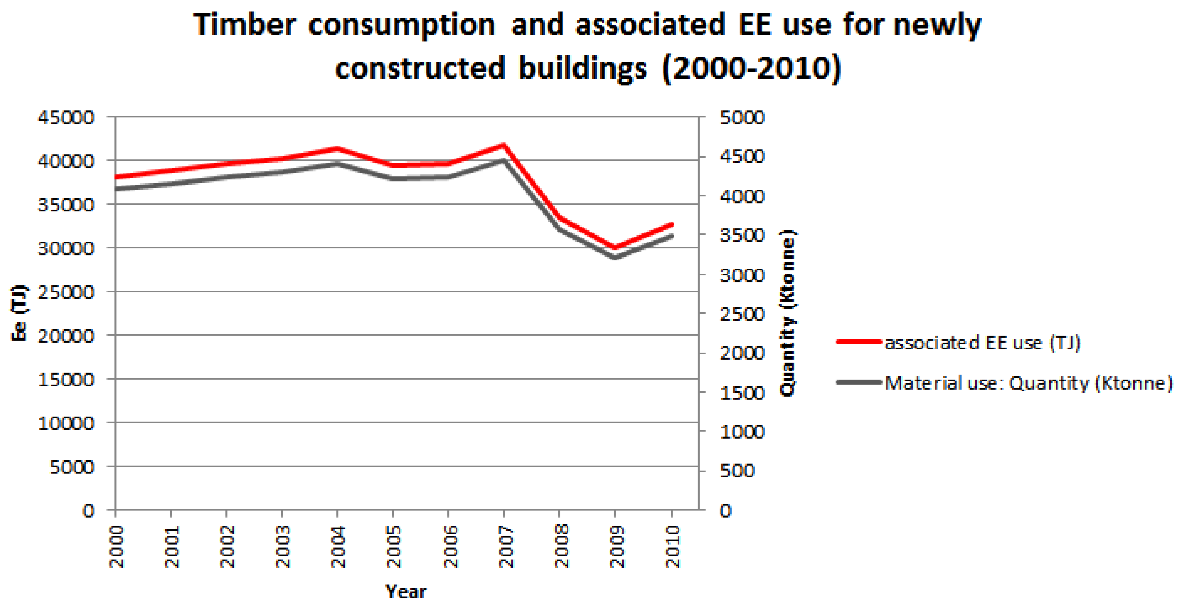


Figure 6W: *The Total consumption of Timber by the UK building sector and associated embodied energy (2000-2010)*

The trend is closely matching that of building production seen in figure 5B. What is noticeable is that there does not appear to be a disproportionate increase in use when compared to building production. This suggests that over this period the apparent increasing trend in use of timber has not actually made any noticeable difference meaning that this is probably over reported. This may provide a crucial area to target when identifying reduction measures.

6.6 Glass

Glass use in the construction sector has limited application as displayed in figure 6X. The main uses include glass fibre used for insulation of wall cavities, which is not necessarily used throughout Europe due to climate variations and shall be omitted from this study. The major application is flat glass used for windows in residential and commercial properties accounting for >86% of all glass used.

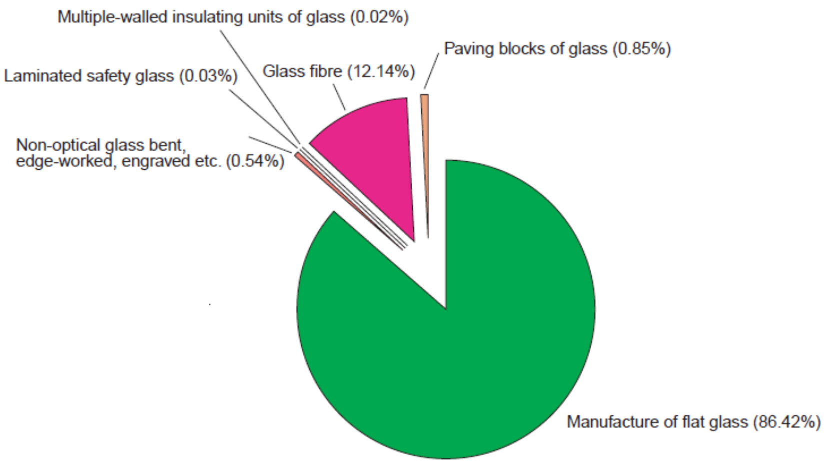


Figure 6X: *The Breakdown of Glass application within the UK construction sector 1998. Source* -(Smith, Kersey and Grifiths, 2002)

With no real commercially viable substitute for glass this market share is presumed to stay true for future consumption trends. An interesting development in glass use was observed when thermal building regulations were implemented initially meaning the size of window was reduced hence less glass produced. However, with the introduction of double-glazing production observed a significant increase over a short period of time (British Glass, 2010), this highlights the important role of building regulations onto material consumption within the sector.

Upstream phases of glass production

In European glass production, the average consistency is a mixture of

Silica Sand	51%
soda Ash	16%
Recycled Glass	15%
Dolomite	13%
Limestone	4%
Sodium Sulphate	1%

The sodium oxide acts as a flux for the silica lowering its melting point however this results in it being slightly water soluble, so calcium is added to make it insoluble(NGS, 2010) . Almost all-flat glass is produced using the float glass method in plants which operate continuously 24hrs a day. The raw materials are mixed together with an average of 15% recycled glass cullet, however this could be increased (NGS, 2010). The materials are blended and then enter a large furnace to be melted at temperatures >1600^{o}C to form molten glass. This molten glass is fed onto a bath of molten tin temp 1100^{o}C and floats on top allowing for a consistent thickness and smooth finish to be achieved. The glass is then lifted onto rollers to the annealing lehr to be cooled where it is then passed for cutting to desired measurements and transported to site.

Embodied energy of upstream glass phases

A lifecycle analysis of the EU float glass industry has been carried out by PE international (PE International, 2010). Figure 6Z below shows the breakdown of embodied energy into the two major upstream phases.

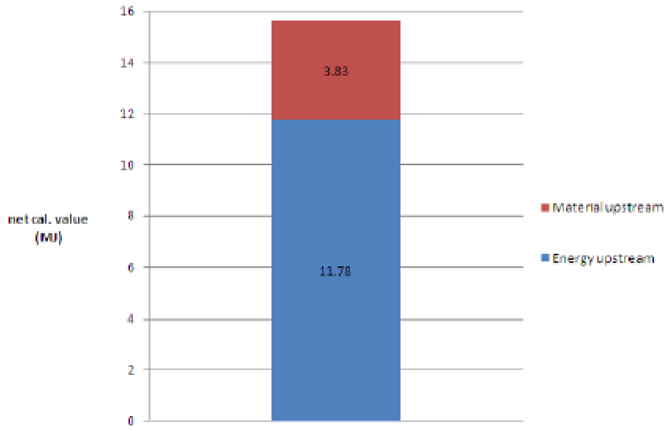


Figure 6Z: *Embodied energy of float glass per Kg split into extraction and manufacture stage. Source* (PE International, 2010)

The red section (3.83 [MJ/Kg]) represents the energy required to extract and process the materials ready to enter the manufacturing process. Of this ~80% is attributed to the production of Sodium carbonate making it the most energy intensive component of the first phase. The blue section represents the manufacturing phase where >70% of the [11.78MJ/Kg] required is demanded by the furnace used to produce the molten glass and the majority of the rest is electricity used to heat the tin bath (PE International, 2010).

Fuel	% of total	Process
Natural Gas	58%	Furnace
Oil	20%	Furnace
Electricity	22%	Tin bath

Downstream Glass

Glass can essentially be 100% recycled without any loss of properties however this requires energy due to recycled glass containing impurities that must first be removed. Also it must once again pass through the manufacturing process as cullet to be re-melted. The percentage of recycled glass in the UK is fairly low with an estimated 70% arriving at landfill (Glass for Europe, 2013). Reuse of glass in the building industry is next to non-existent with many developers considering it more economically viable to use primary produced sheets. This is due to the recovery costs and need to fit specific measurements of new builds. There are a handful of projects which have used large sections of commercial building glass cut into new size but opportunity seems limited.

In terms of embodied energy reduction measures should focus on the production of sodium carbonate for the 1st phase and the heating requirements used for manufacture including the furnace and tin batch. Downstream measures seem limited however the two can ultimately be connected. The use of 10% cullet in the glass mixture reduced fuel consumption in the furnace by 3% (Carbon Trust, 2004). There is scope to increase glass recycling and supply to upstream manufacturing process. However, saving of resources such as sand from the inclusion of this cullet are rather negligible due to the low associated embodied energy discussed previously and it large natural abundance.

The total quantity of glass used in the UK building sector and its associated embodied energy has been calculated and reported below.

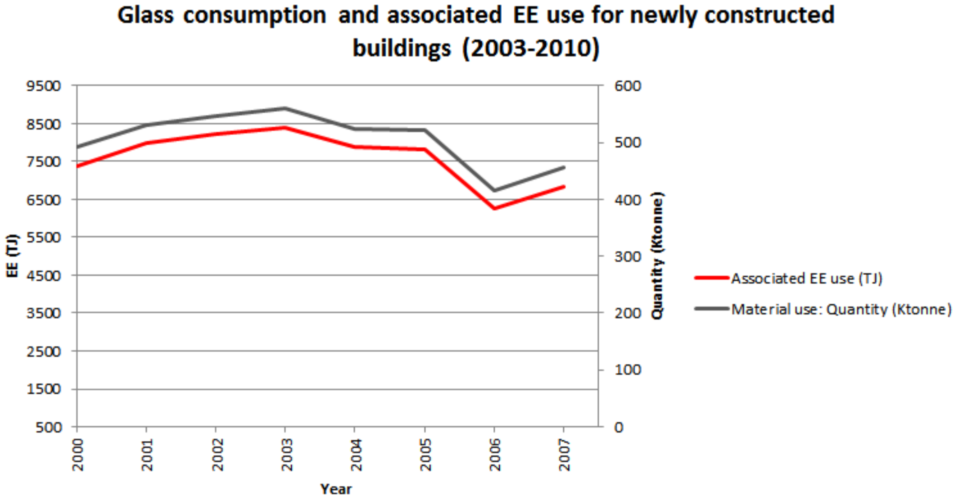


Figure 6AA: *The Total consumption of Glass by the UK building sector and associated embodied energy (2000-2010)*

From the period 2003 – 2010 the consumption of glass is seen to fluctuate in line with the numbers of new houses constructed seen in figure 5B. This is to be expected as window size has stayed fairly static over the period and is a consistent feature in all buildings.

6.7 Summary of the Embodied energy values used

Table 6F below provides a summary for reference of the associated values embodied energy required for each materials inclusion into a building and are all taken from the Inventory of Carbon and Energy, representative of average UK values (ICE, 2008). As previously mentioned all calculations performed and the corresponding data sources are thoroughly documented within the data sheets provided in the annex section.

Table 6F: *Summary of the Embodied energy for each material assessed. Source (ICE, 2008)*

Material	Embodied energy [MJ/Kg]
Aluminium	155
Copper	69.02
Steel	30.91
Aggregates	0.1
Facing Brick	8.2
Common Brick	3
Ready Mixed Concrete	0.95
Concrete blocks	0.67
Prefabricated Articles of Concrete	2
Timber	9.36
Glass	15

7. Comparative analysis of resource and energy consumption 2000-2010

To provide further understanding into the resource consumption trends over the period 2000-2010 and how they have developed alongside changes in build rate, this section aims to combine the individual results reported in chapter 6. This analysis allows such trends as resource efficiency, material preference/substitution and quantitative targets for reduction measures to become more apparent. This aids in the selection of scenarios for sensitivity analysis in the next section and highlights the knock-on effects of reduction measures implemented into an individual material supply chain may have on other materials and thus the building sector as a whole. Furthermore, these trends are analysed at a level of consumption per 100m^2 which allows greater insight into the developments in future building production.

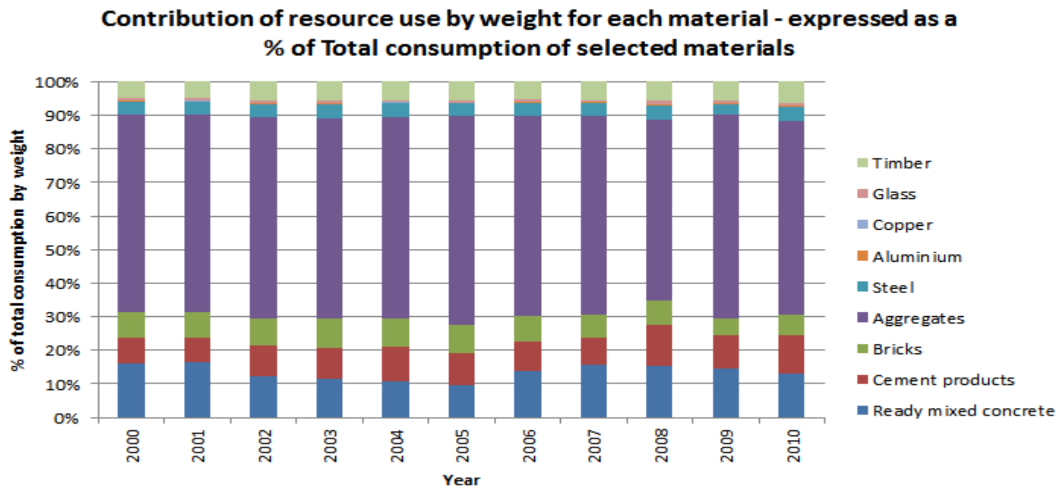


Figure 7A: *The quantity of individual materials used in the UK building Sector expressed as a % of the total (2000-2010)*

Figure 7A highlights the dominant use of aggregates within the sector which consistently represents over 50% of the total material use. As discussed in chapter 6 there are multiple opportunities to reduce the amount of virgin aggregates used directly in buildings. The opportunities exist in the downstream phase mainly through recycling techniques within the glass, concrete, cement, brick and aggregates industries. One major observation not immediately apparent from the graph is the reduction of bricks used after the economic recession of 2007. This results in an increase in concrete block work and is likely due to the relative cheaper cost to produce, showing substitution between these materials is not driven by environmental benefits but rather economic factors. Another substitution is seen in the slight increase of timber towards the end of the decade and a corresponding decrease in steel. These trends have also been identified for use in percentage use 100m^2 of new build per annum and remain true with the graph generated very similar to figure 7A, further indicating a constant use of common building techniques. In general the proportions of each of these key materials remains fairly static over the period suggesting building techniques and design have remained fairly constant, which is a prominent characteristic of the sector to minimise cost. More radical alternatives to common building construction tend to be privately funded projects and take place on small-scale meaning they will not significantly affect material fluxes at national level.

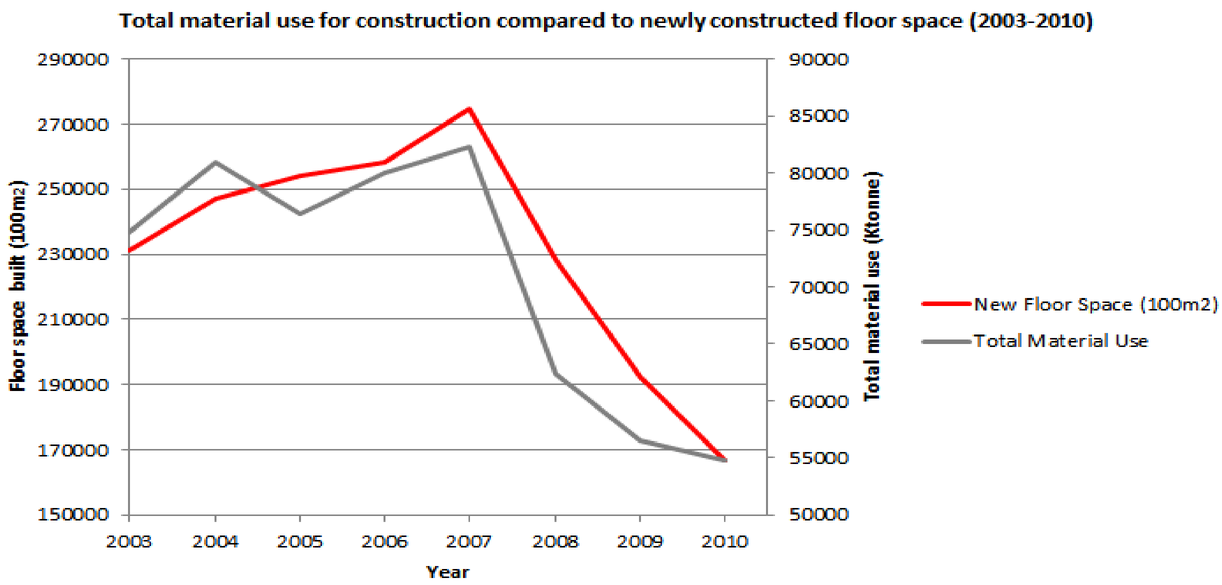


Figure 7B: *Comparison of Total annual material use with* m^2 *of new floor space constructed*

During the period 2003- 2010 the total material used generally fits the trend of the amount of new floor space created. There is a slight divergence between the two from 2005 -2009 suggesting a small amount of resource efficiency was observed during this period. In general the total material use for construction stayed in line with the amount of buildings produced suggesting little change to building practices to reduce material consumption over this period. Total use of building materials reduced significantly over this time period with 74,796Ktonne used in 2003 and 54,793Ktonne used in 2010. This reduction brought about by recession directly affects the total potential of reduction measures.

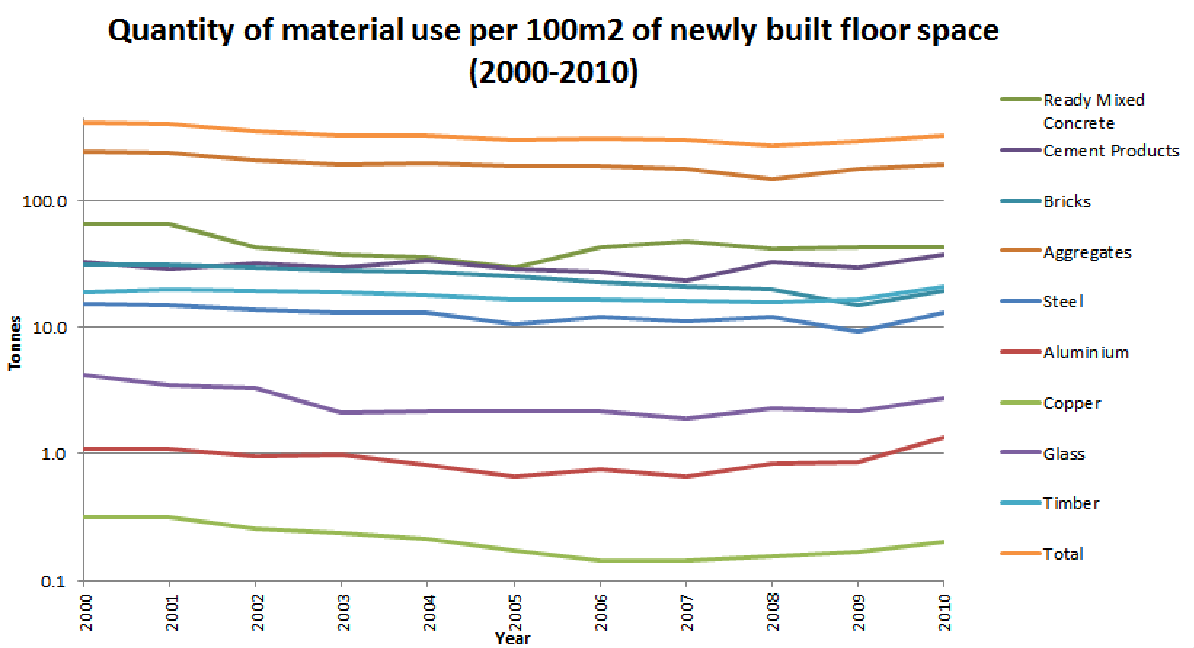


Figure 7C: *The quantity of individual materials used for construction of* $100m^2$ *floor space per annum.*

From figure 7C two main observations can be deduced. Firstly the use of resources to construct $100m^2$ of new floor space in the building sector significantly reduced over the period falling from a total of 323.5 tonnes in 2003 to a decade low of 273 tonnes in 2008. This then raised to 328 tonnes in 2010 this small increase seen as a kink at the end of the graph may be partly explained by economic pressure and the use of cheaper heavier materials such as concrete. However, the percentage split of the materials for 100m^2 stays fairly static suggesting that new building construction is underreported for this period. This may be due to the factored in split for commercial buildings which may have seen a larger production during the last two years assessed. The second finding is that the mixture of these materials in general stayed almost static over the period once again suggesting that material composition in buildings has remained largely unchanged considering residential properties are around 90m^2 and represent around 75% of buildings these quantities are fairly close to what can be found in the typical UK house.

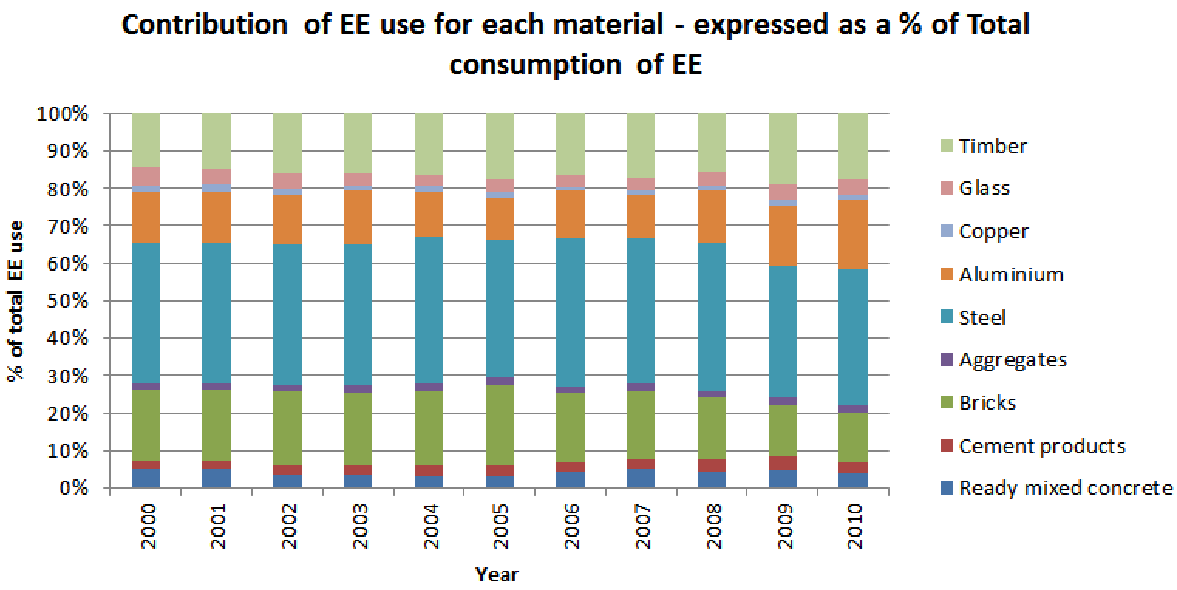


Figure 7D: *The Embodied energy of individual materials used in the UK building Sector expressed as a % of the total (2000-2010)*

Figure 7D clearly displays that considering quantity alone is not sufficient when proposing reduction measures and embodied energy must be taken into account. This is highlighted in the use of metals, which represent only a small fraction of the total material requirements in the UK building sector as seen in figure 7A. However, steel and aluminium alone account for >50% of the total embodied energy with copper's contribution also significant to an extent.

Specific observations of interest for best practices include the proportion of embodied energy relating to bricks. Cement products which actually hold a larger percentage share in quantity have relatively lower embodied energy and can be used as a substitute. Additionally the small quantities of aluminium and steel in comparison to timber account for a huge proportion of the embodied energy in buildings and may also be substituted in most instances. Aggregated and ready mixed concrete the two major material uses by weight represent on average only ~6% of the embodied energy and although after a brief analysis of each materials supply chain, performed in the previous subsections, provides the greatest opportunity for quantitative material savings offer little significance for reductions in the sectors energy demand.

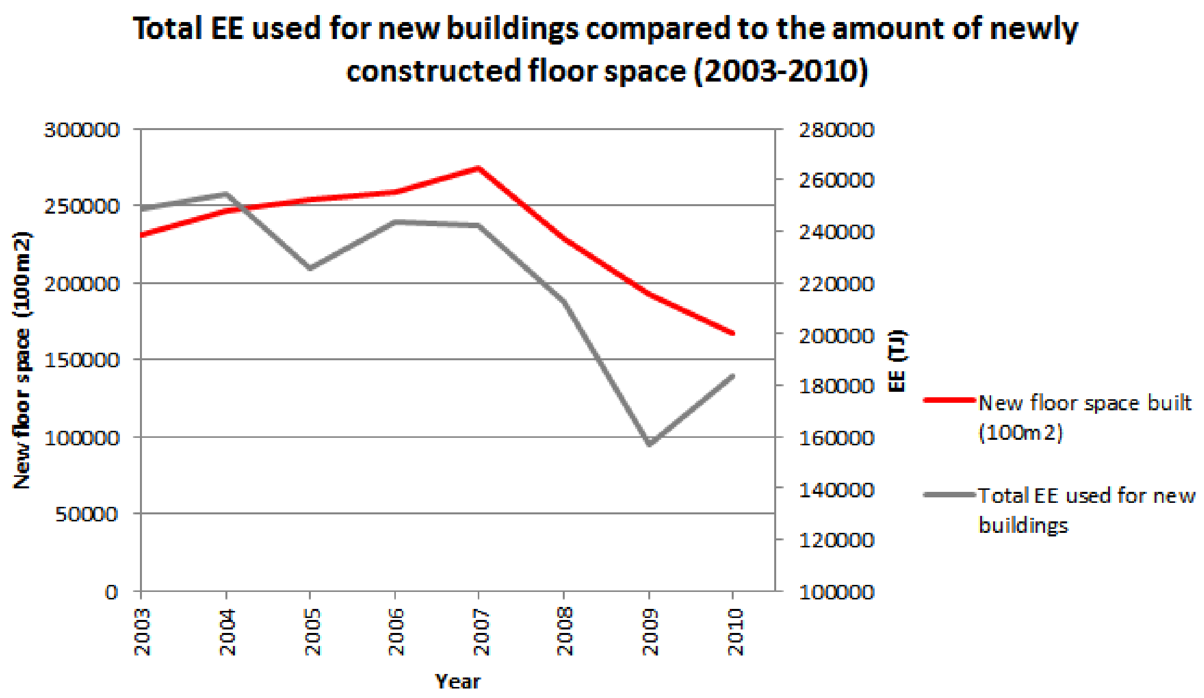


Figure 7E: *Comparison of Total annual Embodied energy use with 100m^2 of new floor space constructed*

The embodied energy use in the sector falls significantly over the decade from 268,302 TJ in 2003 to 157,066 TJ in 2009. This is similar to the trend displayed by the total quantity of resources used seen in figure 7B, because the mix of materials is fairly static over the period and energy efficiency within the industries remains fixed within this study. The increase displayed in 2009-2010 is likely due to the same reasons discussed for the identical findings in figure 7C. However, this may partly be explained by an increase in aluminium and steel use in this year shown below.

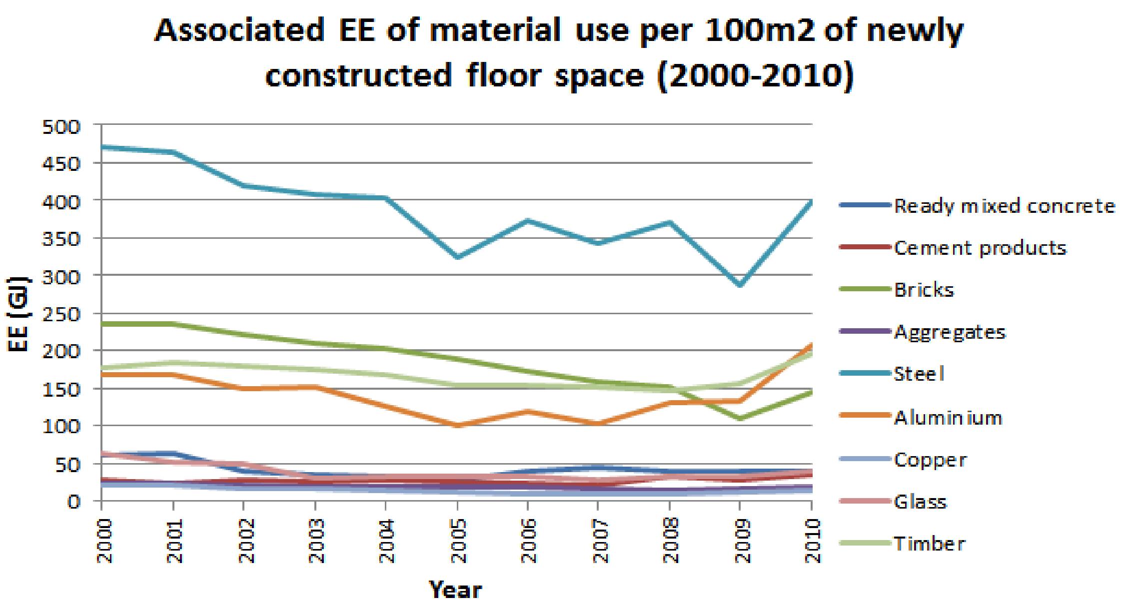


Figure 7F: *The Embodied Energy of individual materials used for construction of 100m^2 floor space per annum.*

As seen in figure 7F the dominating contributor to embodied energy per 100m^2 of new building is Steel with Aluminium becoming more important towards the end of the decade due to a steep increased use. The total embodied energy generally decreases over the period in line with the resource efficiency increase this can be seen in Figure 7G below which displays a close trend between material consumption and embodied energy due to little variation in the material mixture used to produce the average 100m^2.

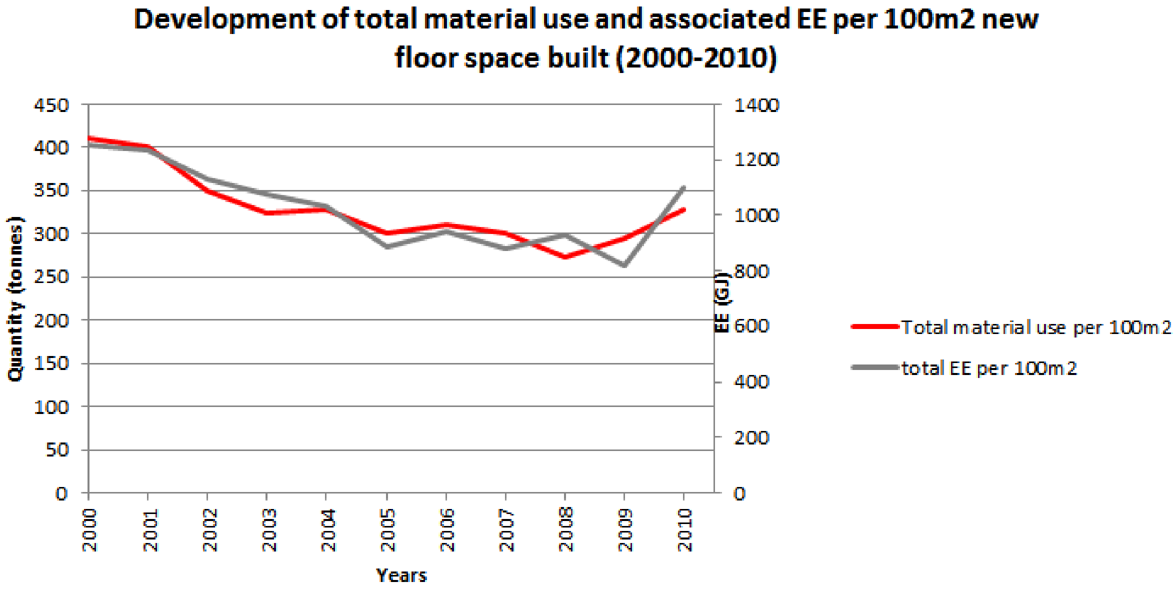


Figure 7G: *The comparison of Quantity of material use and Embodied energy use in 100m^2 over the period 2000-2010*

A key observation from figure 7G is that low amount of substitution between materials occur with a very similar proportional mixture of materials used. However, it is interesting that in 2009 the year shortly after the economic crisis hit hardest, embodied energy rose due solely to an increase in steel and aluminium use over this period displaying a delay effect. This is in fact an interesting finding that may be explained in terms of housing type. Under harsher economic circumstances multi-storey housing options such as high-rise flats provide a cheaper alternative to conventional houses especially in dense urban areas. These structures typically use less material in quantity per 100m^2, largely saving on the use of one large foundation instead of multiple areas and a lower exterior wall area per 100m^2 of useful floor space. However, these structures similar to large commercial buildings require a higher proportion of steel and aluminium frame.

When assessing what reduction targets can be achieved from the downstream demolition/ reclamation phase it is vital to establish the amount of material that can be recovered and to a lesser extent its associated embodied energy. As seen in figure 7G above resource use and embodied energy decrease per 100m^2 over the decade. Since the buildings demolished during this time and in the future will generally be from >50 years ago the material content in unknown. For this reason the composition of a 100m^2 built area for the year 2000 is adopted assuming it will be the closest match available from the results produced during the analysis of 2000-2010.

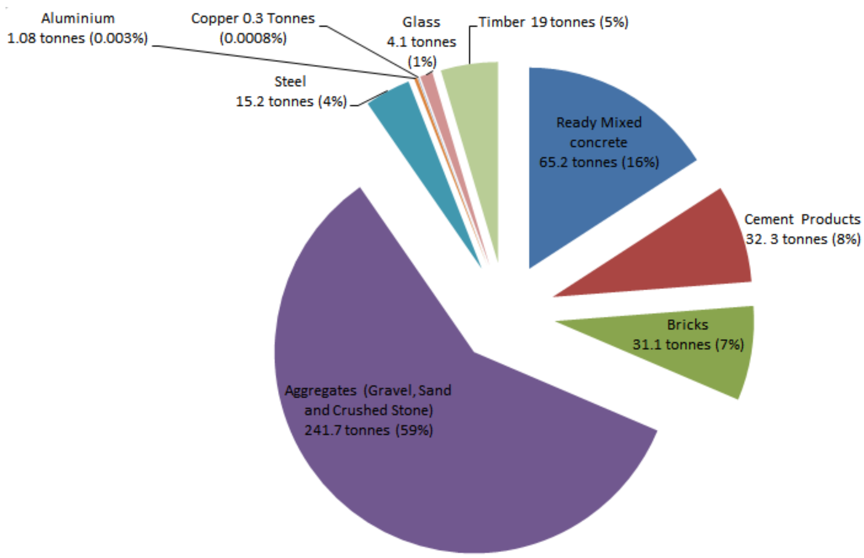


Figure 7H: *Quantities of material in 100m² of demolished building (based on 2000 construction)*

The vast majority of the materials available from demolition are products that need to be completely broken down and remanufactured for reuse or cannot be used again within the building sector. Smaller quantities of material that vastly improve the embodied energy of recycled products such as the metals are important here and can be 100% recycled. The value of recycling these materials is evident when looking at figure 7I, which identifies a 660GJ of embodied energy attributed to metals alone. This would be much lower if recycled metal is used therefore recapture of these high energy intense materials is vital when aiming to reduce the sectors overall demands.

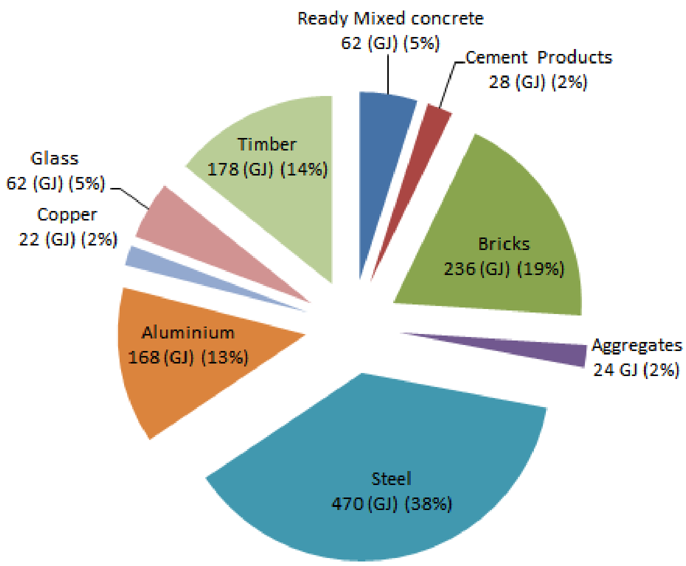


Figure 7I: *Embodied Energy of material in 100m² of demolished building (based on 2000 construction)*

8. Scenario Construction

8.1 Historical scenario (2000-2010)

The recorded consumption data for the period 2000-2010 identified in chapter 6 essentially forms a separate scenario termed "historical data". It shall be used to illustrate the hypothetical savings that could have been achieved over this period where resource consumption and embodied energy use for the sector are known. The overall building activity during this period is displayed in figure 5C, replicated below for ease of comparison.

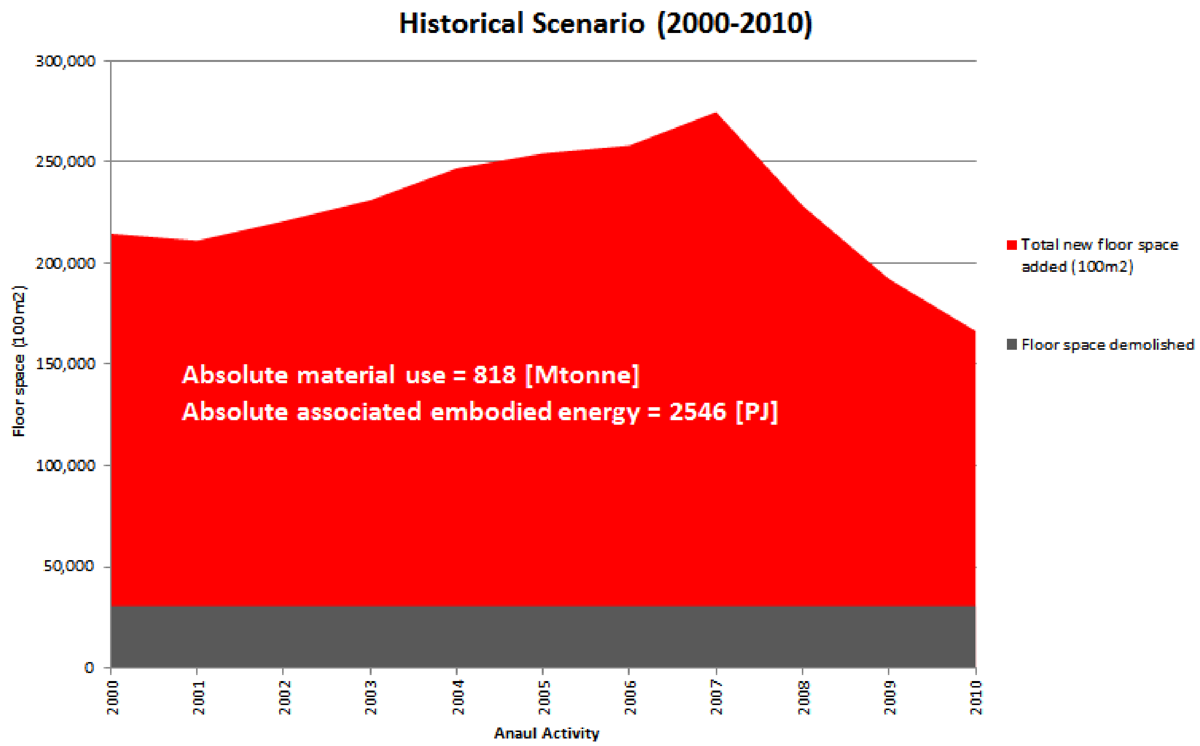


Figure 8A: *Total building and demolition activity under the historical scenario for the UK 2000-2010, with the total material use and associated embodied energy*

total Construction during the period = 2,499,629 (100m^2)

total demolition during the period = 338,414 (100m^2)

total addition to the building stock = 2,161,215 (100m^2)

As seen above in fig 8A the absolute material/energy use needed for building production is displayed. This is the level present for the bau (no implementation) development for each scenario whereby no reduction measures are implemented. Therefore, this represents the total target that reduction measures may impact and has been carried out in an identical fashion for each of the 3 future projections.

Furthermore, as with the future projections this scenario shall also be explored using 2 different deployment rates which determine the take up of the reduction measures and thus savings potential. This is discussed in more detail in the section below which describes the variable that will be explored.

8.2 Introducing the future scenarios (2011–2030)

8.2.1 Introducing the variables explored

The following section aims to create a series of possible future scenarios for the time period 2011-2030 that continue on from the observed history 2000-2010. The percentage contribution of each material for a 100m^2 building over the period 2000-2010 is plotted as a trend and extrapolated to project the proportion present in future years.

These scenarios provide a range of circumstances in which identified savings potentials may be deployed and subjected too, enabling a degree of sensitivity analysis to be performed. Due to consequential LCA methods used to identify reduction measures it is relevant to model a range of future systems in which reductions may be assessed.

Two major types of scenarios are developed. A predictive scenario aiming to assess the most likely future course based on historical data gathered over the last decade and current circumstances (scenario A) and two explorative scenarios, to assess what may happen if different actions are implemented that influence total building production (Scenario B & C). Within the construction of these future scenarios there exist two controlling sets of variables which dictate the size of target and thus total savings that can be achieved through implementation of the reduction measures. These are seen as;

1. **The Building /Demolition rate**
   - **Scenario (A) – identical building activity to previous decade (Extrapolation of historical data to create fixed rate building activity)**
   - **Scenario (B) - Medium increase in activity modelled to expected population growth**
   - **Scenario (C) High increase in activity (Primes 2009 projection of % annual building stock increase and increase in demolition (demolition needed to reach 40% house target)**
2. **The Deployment rate of the measures**
   - **BAU Base line (0% uptake)**
   - **Medium uptake (% dependent on specific measure)**
   - **High uptake (% dependent on specific measure)**

Each of the two major variables has an additional scale of severity namely no difference from any measures or expected build rate and a medium and high scale of implementation.

8.2.2 Background factors determining the projecting of future build rates (2011-2030)

Population change is a key determinant when projecting future building demand. Overall domestic population growth is measured by natural change in the form (Births-deaths) along with net migration. Births in the UK increased over the period 2000-2010 and a net immigration of 44,000 persons per annum, however fertility remained below the replacement level. This has amounted to an average increase of 338,000 persons to the total UK population per annum during this period (OFNS, 2011) whilst as observed in figure 5B, the amount of new buildings completed per annum has fell largely due to economic circumstances. One truism essential too all projections of future building rates is that more people equal more buildings especially considering the fairly static capita per household levels observed in the UK over the last decade (OFNS, 2011).

Due to this observed increase in population trend it is likely that building construction will at least in the residential sector need to increase from that observed in 2000-2010. This conclusion is reiterated in previous studies such as (Pretty and Heckett, 2009) that identified a serious shortfall in housing was emerging by the end on the 2000-2010 period. Furthermore, investigations by (RIBA, 2007) instigated a need for a national building rate of 250,000 residential properties added to the building stock per annum by 2016 to meet the demand caused by population rise. Table 8A below provides a quantitative insight into this development of shortage in residential properties and shows that there is a strong decline in properties constructed compared to the increase in the UK population.

Table 8A: *Comparison of the UK's population increase and completed residential properties at 5 year intervals*. *Source* – (OFNS, 2013)

Period	Population increase	Completed residential properties	Properties added per 1000 additional persons
1990-1994	684,000	764,820	1118
19995-1999	850,000	739,390	870
2000-2004	1,233,000	699,520	567
2005-2009	1,768,000	757,610	429

There are numerous variable factors that are able to alter the severity of interdependence between population increase and building production including aspects such as availability of mortgages, the age of a population may create need for different household sizes, national economic growth and related individual income, demand for 2nd homes etc. However, it is certain to say that the direction of both population growth and building stock is jointly upwards for the immediate future. This increase in required building stock to match the demand stimulated by population increase has also been modelled in scenarios such as Primes 2009 which is a series of reference scenarios for projected from 2009 including the expected changes in housing.

8.2.3 Constant assumptions used for future projections (2011 – 2030)

Common assumptions shared between the scenarios include

- A lack of information available to suggest that the percentage of new floor space created attributed to commercial/residential properties is likely to diverge over the time period. Therefore identical proportions are expected as seen in figure 5A. (residential [74.67%] commercial [25.33%])
- The average floor space per house also remains constant (91.6m^2) over the projections due to the UK currently having amongst the smallest average residencies in the EU. With England and Wales lacking minimum space standards, with serious opposition from the public and local planning authorities it is likely to be constant over the period (Vaughan, 2013).
- The capita per household in all scenarios does not change over the period investigated staying static at (2.4 persons per household) meaning in the exploratory scenarios house demand is assumed to be met solely by new construction.
- The energy efficiency of the production of all building materials is kept static to those values used for 2000-2010 identified in (ICE, 2008) with only reduction measures causing variance, thus the

concept of frozen technology is imposed onto this study. However it must be emphasised at this point to avoid confusion that only embodied energy is subjected to this "freeze" and resource consumption in future scenario is extrapolated from the trends per [100m^2] observed over the period 2000-2010.

- Quantity of individual materials in relative amounts (per 100m^2) are forecasted from the recorded 2000-2010 period using a linear trend which allows trends in material substitution to be continued and targets for reduction measures of total material quantity and embodied energy for each of the scenarios to be identified. Additional specific development of individual material use may need to be elaborated on later to identify to development of deployment potentials for reduction measures that concentrate on reduction into one specific material, these are provided within the subsequent sections where needed.

8.2.4 Assessing the future absolute resource and energy use (2011 – 2030)

As described in section 8.2.2 actual future building rates are largely affected by population and other less predictable tends typically unforeseeable due to unknown future governmental interaction i.e. changes to immigration laws. As such projections into the building rates formed in the subsequent sections covering the period 2011-2030 are not strictly forecasts but should be considered rather as indications of possible future developments given specified assumptions.

As a hypothetical savings potential is being explored for the period 2000-2010 it is appropriate to include practical savings potentials. For this reason two time periods shall be investigated that allow for the identification of savings that can be realised through implementation starting in the current year 2013. These periods are then

- **2013 – 2020 (8 years)** **- 2013 – 2030 (18 years)**

These periods have been selected due to the common incorporation of end of decade potentials translated to policy makers and will provide the targets latter developed in this report due to a current inadequacy of targets at an EU level to track progression in the reduction areas explored in this research.

Thus effectively the savings potential in years 2011 & 2012 are not assessed during this research but activity in these years has been reported due to the need to accurately model the building activity trends. However, consumption in these years is then not included within the absolute values for resource/energy displayed for scenarios A-C below and a dashed line is used to illustrate this cut off point.

8.3 Future scenario construction

The varying assumptions for building activity over the projected future period are discussed with justification for their inclusion into the research. For each scenario the absolute use of resources by total weight and the associated embodied energy are displayed within the visual representation for each scenario (white text) which is in essence the available target to impact for the reduction measures that will be explored.

8.3.1 Scenario A (Low building/demolition activity)

Scenario A represents the most likely path of immediate future building activity based on recent trends and economic circumstances that are likely to hamper the growth of the UK building stock. It is constructed from the extrapolation of observations for the period 2000-2010. The scenario assumes that over the period 2011-2030 an average of 187,243 residential buildings are constructed per annum thus 227,239 (100m^2) of residential and commercial building floor space will be constructed each year, which is identical to that seen in the period 2000-2010. This is on the basis of large uncertainties in the sector including demand for buildings.

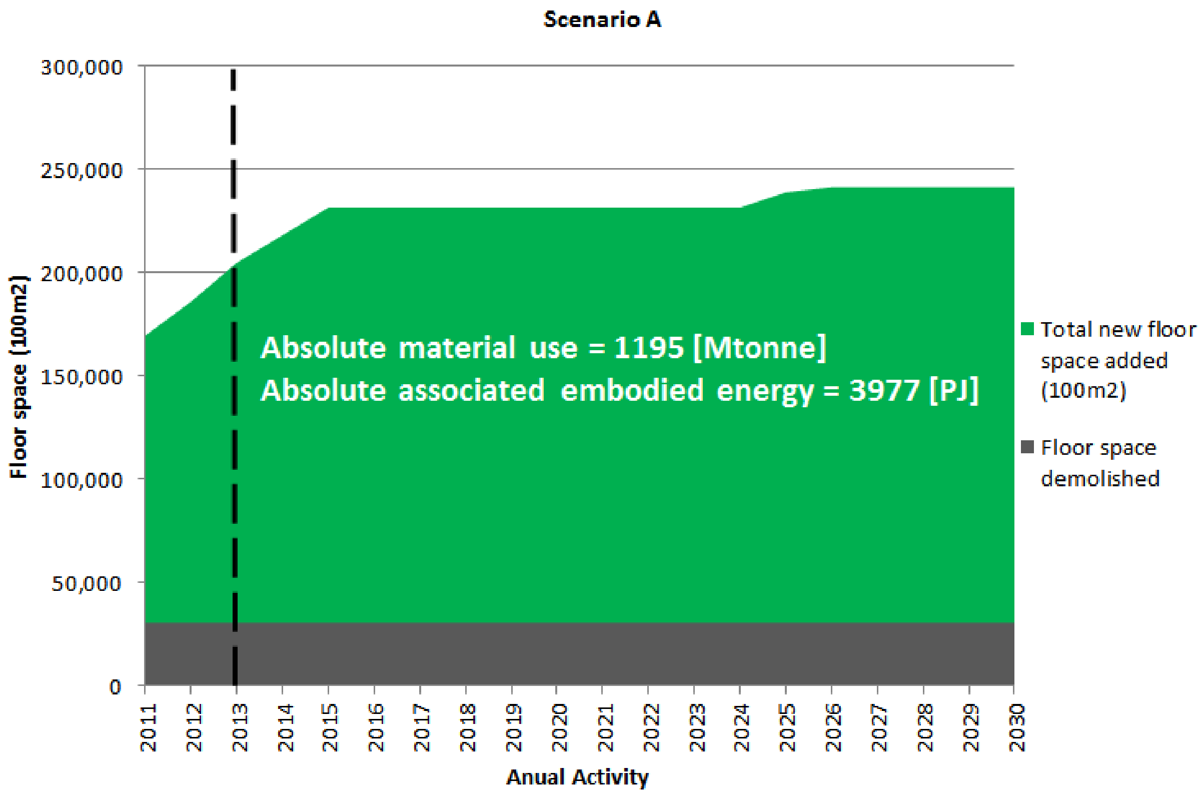


Figure 8B: Scenario A: *annual construction and demolition activity in for the UK building sector 2011 -2030 using average construction trends identified during 2000-2010.*

As seen in Figure 8B**,** the building production for the period 2011-2015 climbs back to levels recorded before recession in the period pre 2010, increasing due to population increase and a higher demand for buildings. This is then hypothetically stabilised with average annual activity identical to the 2000-2010 period. It is necessary to include such a possible development, as the strength of the recession is clearly visible on the building sector in the depression seen during 2007-2010 in figure 5B. This scenario assumes a modest growth rate of building production returning back to previous levels around the year 2015. However, in the long term after 2020 if this trend continued there would be a serious issue with housing availability in the UK. For this reason population projections are factored into the two alternative scenarios discussed next. It can be seen that this scenario provides the least impact for reduction measure.

8.3.2 Scenario B (Medium building/demolition Activity)

The UK office for national statistics released a series of projections in 2010 for population growth and building increase up to 2033 (OFNS, 2010). Within the OFNS baseline scenario, no radical change in population dynamics from the current trend is observed with an average 232,000 residential properties built per annum projected over the period 2011-2020 and a static level of demolition. To clarify this information considering the importance of population increase onto housing demand further calculations were performed below:

UK population 2010 = 62.3M (OFNS, 2011a)
UK population 2020 = 67.2 M (OFNS, 2011a)
UK population 2030 = 71.4 M (OFNS, 2011a)
change in population 2010-2020 = 9.1 M
Capita per household (static) = 2.4
Static demolition rate = 25, 350 residential properties

(4.9M / 2.4) = 2,041,667 residential properties needed to meet demand
(2,041,667 /10years) = 204,167 houses per annum added to building stock
Therefore (204,167 + 25350) = 229,517 houses needed to be built per annum to meet demand for 2020

Identical calculation show from 2020-3030 = 200,350 houses need to be constructed per annum

When compared to the earlier projections from (OFNS, 2010) these results are strikingly close and provides a firm basis in which to project likely activity stimulated by population increase. Projection for this scenario is then based on the average annual construction needed to meet demand per annum calculated above. An average 229,517 houses built per annum translating to 278,543 (100m^2) of residential and commercial building floor space each year during 2010-2020. As population growth slows during 2020-2030 this translates to 243,143 (100m^2) per annum during the second decade. Additionally this scenario adopts that there is no indication that demolition rates within the UK will increase over this period, remaining constant.

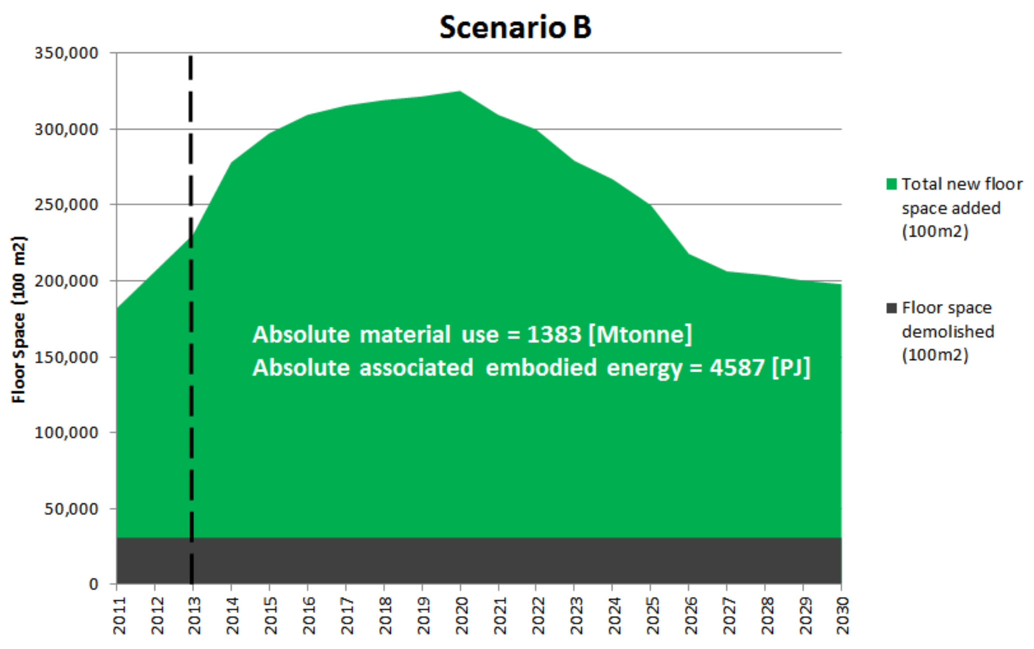


Figure 8C: Scenario B: *annual construction and demolition activity in for the UK building sector 2011 -2030 adhering to calculations to determine building demand by national projected population projections*

Seen in figure 8C, scenario B presents a far greater impact area for reduction measures than scenario A. The building activity increases rapidly to comply with the expected shortage in housing and then gradually declines to match the slower level of population growth projected for the latter decade.

8.3.3 Scenario C (High building/demolition activity)

For scenario C the UK building stock shall use projections generated in PRIMES 2009, which provides the most recent set of data at the time of writing this report. It reflects on circumstances brought about through recent economic downturn and more up to date migration assumptions used within the general equilibrium model GEM-E3 to develop build rate projections of 1% of the total building stock added per annum between 2010-2020 and 0.8 % between 2020-2030 (Capros et al, 2010).

Although on average over the period 2000-2010 this annual increase to building stock was only observed at 0.75%, this increased production fits well with the observed shortage in housing caused by the fall in production in relation to population increase observed over the past decade seen in Table 8A**.** With no observed increase in capita per household observed at a level to satisfy this demand. Furthermore, the ~1% annual increase is a common factor of developed countries and provides an insight into what can be expected within other EU Member states (Vaughan, 2013). At this level an average of (274,500 houses are constructed per annum 2011-2020) and (241, 519 for 2021 - 2030) which is fairly consistent to the estimates of 250,000 in 2016 needed to meet demand in (RIBA, 2007) estimates. This translates to on average over the period 2011-2030, (313,120 [100m^2] of residential and commercial building floor space will be constructed each year.

This is expected to be too high for the projected demand over this period. However, with the UK government targeting a reduction of 60% CO_2 emissions from the building sector by 2050 also known as the 40% house strategy a reduction of old inefficient houses within the existing building stock in needed. The present rate of demolition in the UK is seen as static within scenarios A & B at 0.1%, however this UK target requires this to ~x4 to an annual demolition rate of 80,000 houses (Boardman, 2005). This increase in demolition has been incorporated into this high activity scenario and provides lower figures of addition to the building stock calculated to meet demand in scenario B with an additional average of 178,000 houses per annum whereby 214,934 is required to completely satisfy new population. Thus whilst this scenario provides activity hence reduction opportunity the building stock in scenario B has the greatest total increase over the period 2011-2030.

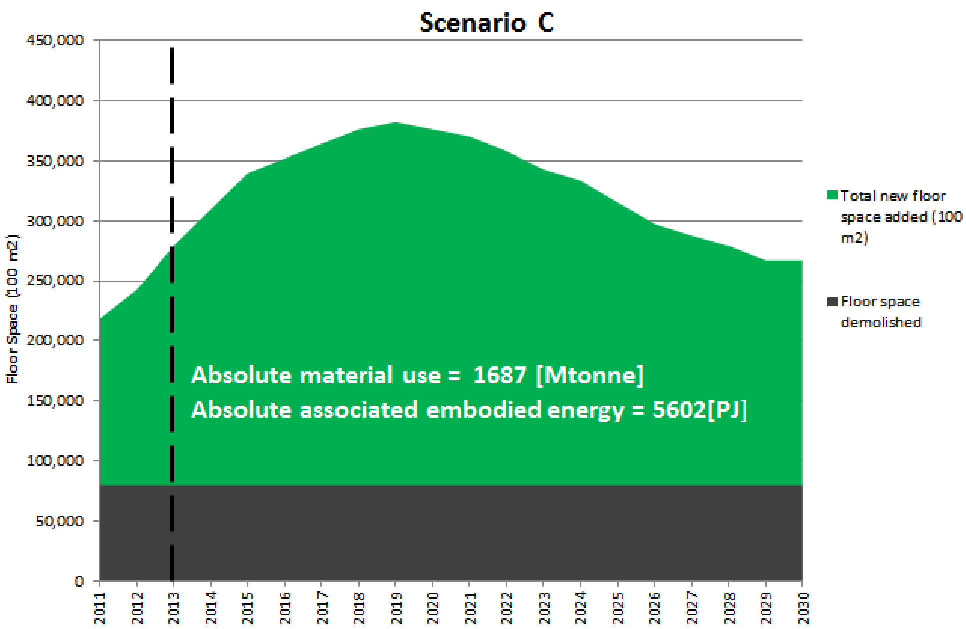


Figure 8D: Scenario C: *annual construction and demolition activity in for the UK building sector 2011-2030 with future projections adhering to the PRIMES 2009 (%) annual building stock growth for the UK and an average demolition rate in accordance to the UK 40% house target*

Whilst PRIMES 2009 gives a good indication of future construction activity and is perhaps the most well founded model available at the time of writing this report, the recovery rate from the recession was vastly over exaggerated. Therefore, the increase in building production rates have been introduced as more gradual incline over the period 2011-2013 (~250,000 [$100m^2$] per annum) at the same time the average amounts are equal to the models used, the only alteration being speed of impact onto the UK building stock. When compared to scenario B it is possible to predict that reduction measures will have the greatest impact when subjected to this projection due to a larger available consumption in both resources and energy. Also most notably, identified downstream measures will hold far more potential in accordance to the demolition rate increasing. A comparison of this demolition activity is provided below in table 8B.

Table 8B: *The total resource and embodied energy consumption present in demolition*

Total resource and associated embodied energy from demolished buildings				
		Projections 2013-2020		
	Historical (2000-2010)	**A**	**B**	**C**
Total Material in demolished buildings [Mtonne]	139	227	227	591
Total Associated Embodied energy of demolished materials [PJ]	423	692	692	1800

As seen in table 8B the ratios between resource and energy are identical for all scenarios due to the fixed embodied energy content (frozen technology) concept deployed. The quantities in Scenario A & B are identical as they run over the same time duration with identical static demolition rate. Scenario C holds the most potential for impacts from downstream reduction measures.

9. The reduction measures

9.1 identified areas of concern for reduction measures to tackle

- The **key points** (areas of concern) have been identified from quantitative comparison of each materials contribution to absolute resource and energy consumption in the sector. (Performed in chapter 7)
- The **opportunities** (specific areas to tackle) for each material have been identified through a qualitative (sometimes including additional quantitative assessment) review of the processes where reduction potential is present throughout the life cycle stages assessed in this research. (Performed in chapter 6)

Below in table 9A these "hotspots" have been outlined

Table 9A: *Summary of identified areas to tackle resource consumption and embodied energy content with greatest potential. Key: (***Issues Tackled by the proposed reduction measures in this research (section 9.2)** ***(Opportunity for further research to identify additional savings potentials)***

Material	Key points	Opportunity's/ specific areas to tackle
Aluminium	• Abundant material so likely to continue being used • Very high embodied energy • Quantities used are already very low	• **Reduce energy used in the manufacturing process especially electrolysis step.** • ***Increase recycling (small potential)*** • ***Substitute for less energy intense material***
Copper	• Abundant material so likely to continue being used • Very high embodied energy • Quantities used are already very low	• ***Reduce energy used in the manufacturing process at any stage as all relatively high, however small amounts used*** • ***Increase recycling (small potential, as it is already very high)*** • ***Substitute for less energy intense material***
Steel	• Abundant material so likely to continue being used • High embodied energy • Quantities used are relatively high	• **Reduce energy used in the manufacturing process especially BOF method and converting iron ore to pig iron** • ***Increase recycling (small potential remaining however large quantities used so could be significant)*** • ***Substitute for less energy intense material***
Aggregates	• Abundant material so likely to continue being used • Cheap to produce and extremely low embodied energy	• **Vast potential for recycling back into building production** • ***However higher embodied energy currently needed but this is negligible***
Bricks	• Negligible amounts of waste during upstream phases • Brick use appears to be declining over the period	• ***The firing and kiln phases of manufacture are the most energy intense and efforts to reduce this are key*** • **Can be substituted by timber** • ***Techniques to lower quantity of clay needed or embodied energy in brick composition (e.g. soil brick)*** • **Scope for reuse of bricks and increased recycled content**
Ready mixed concrete	• Large Quantities used with no suitable replacement • Low embodied energy	• **Amount used should be reduced** • **Embodied energy of the cement contained within the concrete is the only area of significance to tackle for EE** • **Recycled material potential is large but can only be used as aggregates**
Articles of Concrete	• Substantial quantities used and appears to be increasing • Low embodied energy	• **Embodied energy of the cement contained within the concrete is an area of significance to tackle for EE** • ***Pre-cast articles save energy in the construction phase*** • ***Also uses mechanical drying which is energy intense and this should be reduced*** • ***Can potential replace a % of bricks to reduce overall quantity and EE*** • **Replaced partly with timber**
Timber	• Used in moderate quantities • Low-medium embodied energy • Negligible amounts of waste in upstream phases	• **Largest potential is to be used as a substitute for more energy intensive** • **Potential to improve recycling and reuse in downstream stages**
Glass	• Used in moderate quantities with no suitable replacement meaning continued use at a consistent rate is likely	• ***In the manufacturing phase, production of sodium carbonate. The furnace and tin bath are all energy intense steps*** • ***Potential to increase recycling and pass on energy saving too the upstream phases***

From close inspection of table 9A it is observed that the vast majority of areas to tackle fall within the manufacturing process (phase 2) where the highest energy inputs are typically observed. This finding agrees with a study performed by (Crowther, 1999). There are some opportunities for reduction measures in the downstream phase but typically found no significant level of absolute resource reduction to be achieved in the extraction or demolition phases with the currently available techniques. Additionally the substitution of materials for alternative sources with lower embodied energy content and typically lower resource consumption will be explored

9.2 Criteria and justification for the selection of proposed reduction measures

The rating of savings potential available of the key areas identified in table 9A are largely based on the percentage shares of contribution to total resource consumption and embodied energy seen in figures 7A and 7D. The selection then follows the principle that by tackling the largest issues will harvest the largest savings, with cross cutting measures introduced where possible. These issues are displayed below in table 9B with the corresponding measures impacting them that are proposed in the next sections 9.3-9.7.

Table 9B: *The ranked contribution of resource/energy consumption by material and the corresponding measures proposed*

Largest contribution	Material	Targeted by (Measure)
Total embodied energy content		
1	Steel	2
2	Aluminium	2
3	Bricks	1
4	Timber	1 increases use
5	Cementious Materials	1 & 3
Total resource Consumption		
1	All Resources	4
2	Aggregates	*no method for total reduction identified
3	Cementious Materials	1
4	Bricks	1

Measure 1 – Timber frame and clad walls (as a substitute for conventional masonry)

Measure 2 – Best available technology to lower the embodied energy of metal

Measure 3 – Best available technology and fly ash replacement for cement production

Measure 4 – Waste management at the construction phase

9.3 Introduction of the proposed reduction measures

The building sector provides vast potential to reduce the resource consumption and energy needs of the UK. There exists a range of technologies and alternative solutions to achieve this that are currently not being implemented at a sufficient level. Below are a range of identified reduction measures that specifically target some of the key issues aforementioned in table 9A. Each provides information into the area it aims to create reduction in and a brief description of the measure with the identified potential it holds in terms of resource/embodied energy savings at a scaled down level. The high and medium deployment potential for each measure are developed in accordance to a qualitative review of the industry involved and calculated for a 20 year period. Only 20 years are needed to be projected due to the longest time span explored (2013-2030) being <20 years. In section 10 the potential of these measures will be explored when applied at national scale throughout the UK, additionally the feasibility of each option is assessed.

9.4 Measure 1: Timber framed and clad walls (as a substitute for conventional masonry construction)

9.4.1 Background and description of the measure (1)

The conventionally built UK building consist of walls constructed using an inner skin of concrete blocks (articles of cement) and an outer exposed skin made of brick work with insulation in between seen in figure 9A.

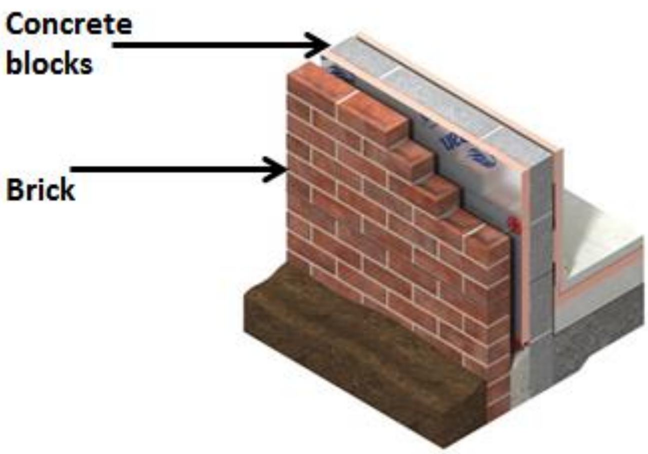


Figure 9A: *Conventionally constructed building envelope wall*

This use for bricks and concrete blocks accounts for the vast majority of the applications of these two materials within the built environment. Therefore, a suitable alternative wall structure could tackle issues regarding both of these materials at once. As seen in figure 7A bricks and article of concrete represent a significant proportion of the total quantity of material used in 100m^2 average building production. Contributing an average of 17% over the period 2003-2010. Furthermore, in terms of embodied energy per 100m^2 these two materials almost exclusively used for wall production account for on average 21% of the embodied energy content in 100m^2 newly constructed floor space.

Timber frame constructions provide a lighter weight alternative to the traditional concrete block inner skin and act as a load bearing structure, which can match the original tensile strength meaning that it is suitable under UK building regulations. This timber frame also brings about savings in the embodied energy content of a building. Timber cladding similarly provides an alternative solution to the external brick skin found in a conventional building, once again providing overall saving in quantities of materials used and embodied energy. These timber frame and clad sections can be seen below in figure 9B, they are often pre-fabricated module components built offsite in manufacturing plant and delivered ready to install. This approach provides an array of additional benefits such as reduction in waste during the construction phase which is typically ~13% of the quantity used for the buildings construction (Treloar et al, 2003). There are also significant reductions in the construction time and cost and most importantly for this research the energy required (Aye et al, 2012).

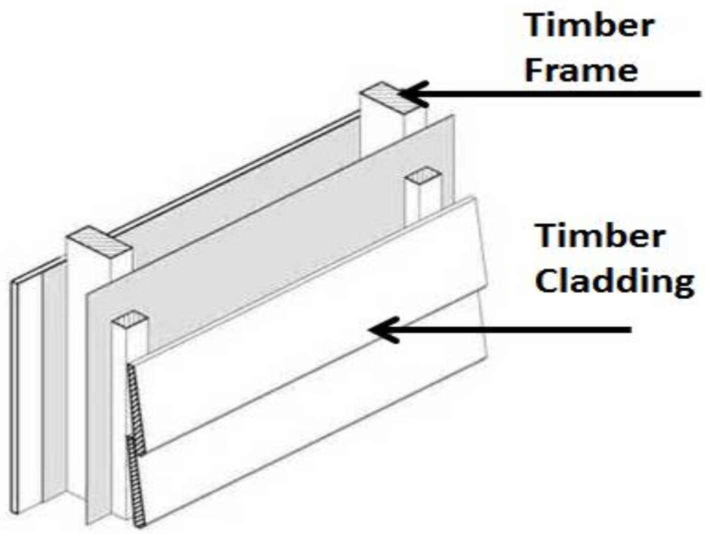


Figure 9B: *Timber frame and clad building envelope wall*

A study performed by (Monahan and Powell, 2010) analysed the savings of embodied energy and carbon that can be brought about by substitutions of the conventional wall to a timber one. The results show that the insulation properties of both walls were exactly the same (0.18Wm^{2}k) meaning that energy use during the use phase of a buildings lifecycle for heating is not affected. The case study looked at a UK house of 91.6m^2 floor area and performed LCA studies of all material input and waste during construction, with other components such as the roof and floor remaining identical. The embodied energy for each material is calculated in the exact same way as this study by multiplying the quantity in weight by the fixed embodied energy value referenced from the (ICE, 2008) used for this report. Saving in embodied energy includes efficiency gains in the prefabrication method and other elements such as less foundation support needed for the lighter frame. However, quantitative savings by weight for these additional benefits are not fully described so will be calculated for the direct substitution in walls alone. The savings that can be realised by implementation of this measure are discussed below. This measure targets savings in both embodied energy and resource consumption.

9.4.2 Identifying the resource savings at building level [100m^2]

Self-calculations are needed to identify the correct resource savings potential. The amount of resources saved are calculated for a theoretical 100m^2 floor area building using referenced amounts typically found in a conventional wall per m^2 surface area and the same for a timber wall, both provided in (Bertec, 2011). Hence the wall surface area of a 100m^2 building must first be calculated.

It is assumed that this 100m^2 floor area is split over two floors of 50m^2. This leaves a common shaped house (rectangle/ square) with a lineal perimeter of 30m exterior wall length. The average UK house height is 5m^2 (EHS, 2010). Thus a 150m^2 exterior wall surface area is the average needed for a 100m^2 of newly constructed floor space.

Calculating the quantity of resource used in a conventional wall

- The concrete block inner skin uses 90kg/m^2 of wall area built (Bertec, 2011).
- The Brick outer skin at 2.7kg per brick and 60 bricks per m^2 (Bertec, 2011) uses 162kg/m^2 of wall area built
  - The total resource consumption for a conventional wall of 100m^2 floor space = 37.8 tonnes

(90kg * 150m^2) = 13.5 tonnes of concrete blocks

(162kg * 150m^2) = 24.3 tonnes of bricks

Calculating the quantity of resource used timber frame and timber clad wall

- The timber frame work uses 70kg/m^2 of wall surface area (Bertec, 2011)
- Timber cladding with heaviest used wood type uses 5kg/m^2 of wall surface area (Bertec, 2011)
- The total for external walls constructed for 100m^2 floor space from timber (75kg * 150 m^2) = 11.25 tonnes.

This represents a total resource saving of 26.55 tonnes per 100m^2 of newly constructed floor space that is brought about by a substitution of 13.5 tonnes of concrete blocks and 24.3 tonnes of bricks, with 11.25 tonnes of timber.

*Note these calculations neglect the extra material needed for the ends of the house between the 5m height and the apex of the roof but it is presumed that the window and door spaces not factored in account for this.

9.4.3 Identifying the embodied energy savings at building level [100m^2]

In the study performed by (Monahan and Powell, 2010) the amount of embodied energy for construction of a building has been reported in [GJ/m^2] of total floor space constructed for each of types of building construction.

- Embodied energy per m^2 in the convention masonry building was recorded at [8.2 GJ/m^2] of newly constructed floor space by (Monahan and Powell, 2010).
- In this study energy per m^2 in the convention masonry building was recorded at [8.17 GJ/m^2] which is almost identical and indicates correlation between the two bodies of research, thus promoting the incorporation of Monahan and Powell's case study into this research.
- (Monahan and Powell, 2010) recorded embodied energy for the exact same building structure using the alternative timber walls recorded an embodied energy content of [5.7GJ/m^2] of constructed floor space

Thus replacement per m^2 ***= (8.17 – 5.7) = [2.47 GJ/m^2] savings per m^2***

(2.47 *100) = [247 GJ] savings in embodied energy for a 100m^2 building

In terms of the 100m^2 theoretical building used throughout this research, this results in a saving of 247GJ/100m^2 an equivalent of ~30%.

9.4.4Projecting the possible deployment rate over a 20 year time span for measure 1

Clearly the reduction potential of this measure on an individual project is very significant and provides real promise in terms of both resource and energy savings. On a national scale when considering the UK ambitions for carbon zero homes in 2016 (UK government announcement, 2012) based on full lifecycle energy use**.** In terms of embodied energy, timber is the only mainstream building material that makes sense, actually storing carbon during its production thus contributing positively. Durability is not an issue with timber buildings lasting well beyond the life span of an average building and widely accepted as the most sustainable material in both residential and commercial construction.

Timber frame alone without the cladding is the fastest increasing material used in UK buildings with a recent survey performed by the UK timber frame association conducted with leading UK contractors, developers and architects highlighting 74% would specify more timber in future projects (UKTFA, 2013). Currently the UK's timber frame sector is made up of several hundreds of small and large companies putting the nation in an ideal situation for rapid implementation of the measure and currently 25% of all houses constructed in 2012 were timber frame, however, brick is still the dominant cladding. And it is assumed 2% of houses are constructed in the base year (2013 for future projections)

Due to this recent increasing trend in timber use and recent regulations and targets surrounding energy and particularly carbon in buildings the deployment over 20 years will be explored under the premise that fairly high levels of implementation can occur over the period in both residential and commercial buildings. (Wilcox, 2013) projects that green building material consumption will double by year 2020 meaning 50% of houses would be timber framed by year 7. However, as timber clad is not a fraction as popular the high deployment assumes that by the year 20 50% of buildings are subject to both timber wall and clad.

A lower target of 30% of new construction in year 20 is explored whereby tougher issues facing the supply side of the market for timber are imposed and the willingness to substitute from the conventional wall is not as prevalent.

As we rely on the same 2% in each base year 2000 and 2013 (for future projections) the deployment curve is adequate for both projections is it is assumed that the timber industry during the historical period could have grown at the required rate to meet demand which is likely considering the growth of the timber frame industry over this period. (this is the only measure which may perhaps over emphasise the savings in the historical period due to this assumption) (all other measures presume no difference in speed of industrial scale up between the two base years as they are freshly implemented)These deployment rates over a 20 year period are displayed below in figure 9C

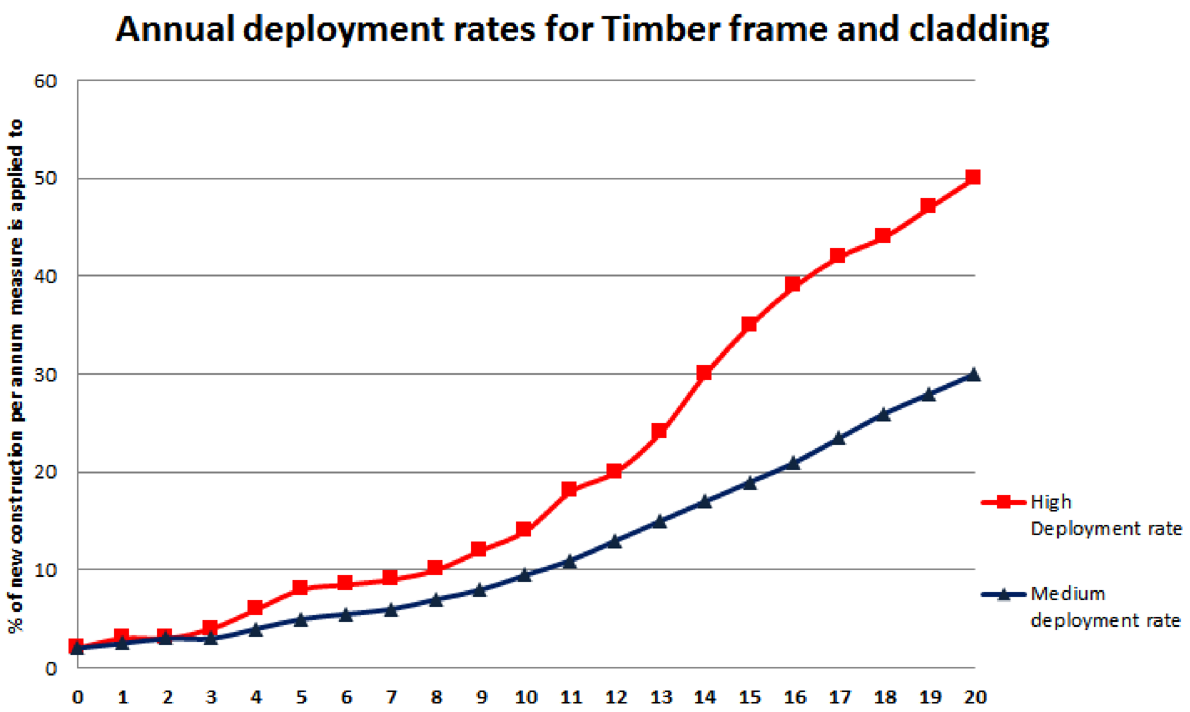


Figure 9C: *The annual deployment rates for timber frame and clad buildings.*

As seen in figure 9C both high and medium deployment rate scenarios are shown to increase more rapidly in the latter half of the 20 year period due to an assumption that earlier efforts are significantly more heavily constrained by cost and supply as seen in most technological innovations. However, the deployment rate in both scenarios continues to grow under the assumption that this measure can technically be applied to almost 100% of new buildings therefore the saturation point for this measure is not reached by the year 20. Under these restrictions during the time span investigated the supply side markets annual production never exceeds 60% from the previous year.

9.5 Measure 2: Best available technology to lower metal Embodied Energy

9.5.1 Background and description of measure (2)

As seen in figures 7D and 7F, where compared to other key materials. The embodied energy attributed to the common metals used in building construction is a crucial area to focus on when striving to bring about overall reductions, due to their large contribution. Whilst each of the three metals investigated holds unique manufacturing processes a range of best available technologies are present within each industrial sector that are able to reduce the energy required within the manufacturing, phase 2 of a buildings lifecycle. For 2 of the 3 metals (Aluminium and Steel) these current best practices are explored to identify the reductions that can be brought about through their implementation, so that combined savings can be found. As recycling of these metals is extremely high >96%, further reductions brought about by increasing this are unrealistic and provide little long term scope. Therefore, as discussed in section 6.1, technical progression to reduce the required energy intensity of the manufacturing process provides the primary route to achieve reductions.

9.5.2 Identifying the energy savings for the measure on Aluminium production at micro level [MJ/Kg]

Fixed embodied energy content for calculations to identify total energy used over the period had a constant value of 155 [MJ/Kg] as discussed in section 6. This is taken as a general amount from the Inventory of Carbon and Energy (ICE, 2008) and is based on the UK aluminium mixture, thus assumed to be the most appropriate source for representation. At this level of 155 [MJ/Kg] it is assumed in (ICE, 2008)

26.6% is extruded
55.7% is Rolled
18.7 % is cast
With a recycled content of 33% Whereby general primary aluminium is [218MJ/Kg] and secondary is [28.8MJ/kg]

Thus, ***(0.67* 218) + (0.33* 28.8) = 155 [MJ/Kg]***

Whilst this figure is representative of the embodied energy content of aluminium arising from average worldwide production over the period, there exist plants that deploy best available technologies to significantly reduce the energy intensity at the important manufacturing steps discussed in section 6.1

Many of the currently used technologies and practices during the manufacturing process are mature and wide spread throughout global production sites which is important considering ~50% of aluminium used in the EU is imported (EEA, 2012). However, there exists a range of best available technologies available to significantly reduce energy requirements. As this report aims to identify what potential is available to achieve for future reductions, current world wide best available technology is assessed. For this reason, a recent study carried by (Worrell et al, 2008) investigating the energy requirements of best available technology operationally active in at least one commercial site has been heavily used for the assessment of reduction potential relating to this measure over a 20 year period.

(Worrell et al, 2008) identified the lowest energy requirements needed for the four major manufacturing processes discussed in section 6.1.1. Additionally secondary aluminium production was also investigated with savings realised from the average intensity used in previous calculations apparent. The energy requirements from the application of the best available technology in 2008 are displayed in table 9C below

Table 9C: *World's best practice energy intensity values for Aluminium Production*. Source (Worrell et al, 2008)

		Primary Aluminium		Secondary Aluminium	
		kgce/t	GJ/t	kgce/t	GJ/t
Alumina Production (Bayer)	Digesting (fuel)	414	12.1		
	Calcining Kiln (fuel)	223	6.5		
	Electricity	145	4.3		
Anode Manufacture (Carbon)	Fuel	35	1.0		
	Electricity	22	0.64		
Aluminium Smelting (Electrolysis)	Electricity	5064	148.4		
Ingot Casting	Electricity	36	1.06		
Total		**5940**	**174.0**	**259**	**7.6**

As seen in table 9C under application of the best available technology significant savings are apparent for both primary and secondary aluminium production when compared to the referenced average values in (ICE, 2008) which are considered frozen for the non-implementation trends explored later in chapters 11 and 12.

If the recycled content of Aluminium used in the UK is assumed to remain static over the period, which is likely considering the high recycling rates.

Then, *(174 * 0.67) + (7.6 * 0.33) = 119 [MJ/Kg]*

This means a [36MJ/ Kg] saving (23%) can be achieved from the average embodied energy content [155MJ/kg].

9.5.3 Identifying the energy savings for the measure on Steel production

Average Steel production embodied energy using the recorded figures from (ICE, 2008) was 30.91 [MJ/Kg] of which 75% is from primary production and 25% from secondary sources (WSA, 2008). If it is assumed that all primary production can be met by using the Basic Oxygen furnace method currently reported at 66% of the total so a further 9% is needed to achieve 75% of total which is expected considering the other production routes such as open hearth are regarded obsolete and will be phased out in the next decade (carbon Trust, 2011). Then simple calculations may be applied to determine savings achieved from adoption of the best available technology reported in (Worrell et al, 2008). Table 9D below identifies the lowest energy requirements commercially used for each of the process steps discussed in section 6.1.3 in the year 2008.

Table 9D: World's best practice energy intensity values for Steel Production. Source (Worrell et al, 2008)

		Blast Furnace – Basic Oxygen Furnace		Smelt Reduction-Basic Oxygen Furnace		Direct Reduced Iron – Electric Arc Furnace		Scrap - Electric Arc Furnace	
		GJ/t	kgce/t	GJ/t	kgce/t	GJ/t	kgce/t	GJ/t	kgce/t
Material Preparation	Sintering	2.2	74.3			2.2	74.3		
	Pelletizing			0.8	25.7	0.8	25.7		
	Coking	1.1	36.3						
Ironmaking	Blast Furnace	12.4	423.7						
	Smelt Reduction			17.9	610.2				
	Direct Reduced Iron					9.2	315.6		
Steelmaking	Basic Oxygen Furnace	-0.3	-9.5	-0.3	-9.5				
	Electric Arc Furnace					5.9	202.9	5.5	187.7
	Refining	0.4	13.0	0.4	13.0				
Casting and Rolling	Continuous Casting	0.1	3.9	0.1	3.9	0.1	3.9	0.1	3.9
	Hot Rolling	2.4	80.4	2.4	80.4	2.4	80.4	2.4	80.4
Sub-Total		**18.2**	**622.0**	**21.2**	**723.7**	**20.6**	**702.7**	**8.0**	**272.0**
Cold Rolling and Finishing	Cold Rolling	0.9	32.1	0.9	32.1				
	Finishing	1.4	48.4	1.4	48.4				
Total		**20.6**	**702.5**	**23.6**	**804.2**	**20.6**	**702.7**	**8.0**	**272.0**

As seen in Table 9D, if the best available technology is applied to the production process a primary embodied energy content of 20.6 [MJ/Kg] is achievable for a cold rolled steel product typical of that used in the construction sector. Furthermore, using the scrap electric arc furnace production route, secondary production from recycled sources can achieve 8 [MJ/Kg], 50% needed for primary production.

Then, *(20.6 * 0.75) + (8*0.25) = 17.45[MJ/Kg]*

This represents a 13.45[MJ/Kg] reduction (43%) from the average intensity (30.91 [MJ/Kg]) reported in (ICE, 2008) and used for the frozen efficiency (no implementation trend)

9.5.4 Omission of Copper from the reduction measure

Whilst a range of different production technologies are available to the copper industry further exploration of the energy savings that can be realised have not been included in this report for 2 major reasons.

1. The energy required for the production, especially the concentrating phase is largely dependent on the quality of ore mined. This has dramatically decreased over recent decades with an ore concentration of 7-10% being mined in the UK in the 1970s which is now compared to a global average of just 1% (Farrell, 2001). Furthermore this is reflected heavily in Chile where 40% of all copper mining takes place and uncertainty about future copper ore grade leaves speculation surrounding future reductions in the production chain widely open to variation (Superneau, 2012). This may result in energy efficiencies dropping even if best available technology is implemented.
2. The use of copper in buildings was identified in chapter 7 as only a small representative of overall Embodied energy as seen in figure 7D representing on average 1% of the total annual embodied energy over the period 2000-2010 compared to steel (38%) and aluminium (14%). Furthermore, copper consumption over the period observes a steady decline seen in figure 6H indicating the savings potential further decreases up to the period 2030 as future consumption trends are based on extrapolations.

9.5.5 Projecting the possible deployment rates over a 20 year time span for measure 2

To achieve the potential savings for each of the metals would require plant all over the world to be retrofitted or replaced to the level of best available technology. The occurrence of this upgrade depends on economic viability and policy within the area the plant is located. Willingness of companies to undertake the required investment depends heavily on the payback period that the share of saved energy is of the total new production cost. With the cost of energy being considerably high in relation to the metals production, especially in the smelting / furnace stages the take up rate of the measure is assumed to be significant in both industrialised and developing countries. The short term potential for each of the industries has been estimated by the IEA and is provided in Table 9E below.

Table 9E – *The savings potential and share of production cost attributed to energy for key sectors.* Source – (IEA, 2009)

Sector	Improvement potential		Share of cost attributed to energy use
	Industrialised	Developing	
Alumina Production	35%	50%	30%
Aluminium Smelting	5-10%	5%	35-50%
Iron & Steel	10%	30%	10-30%
Copper	45-50%		?

These estimates vary, however it is seen that significant improvements can be achieved when considering the economic and political barriers. However, in some instances physical incompatibilities are observed, such as in aluminium refining in China. The bauxite deposits have a high silica content meaning only 14% are available to be used in the Bayer process and thus are not subject to best available technology whereby China represents 33% of aluminium manufacture (IEA, 2009b). Although this is only one step in the process and subsequently a minority of the material is not subject to it, issues like this prevent 100% of plants reaching the efficiencies recorded for best practice. Furthermore, to provide insight into the standard retrofitting time spans it is recorded for the copper industry that most copper plants have replaced their furnace within the last 10-15 years (Pitt and Wadsworth, 2000). As furnace replacement is a major retrofitting procedure and at the upper end of the expense scale, this indicates over a 20 year period it could be possible to reach full saturation of the technology.

Thus a high deployment scenario in which 85% of all manufactured metal is under best available technology measures implemented by the year 20 has been developed. This presumes a 15% contingency that BAT's are not able to address. A further medium deployment scenario has also been developed alongside this whereby 50% of all manufacture operates under BAT's. This potential is governed by the time constraints involved to gain market share of production due to economic and policy struggles. It is assumed under the medium deployment rate that the full saturation has not been reached by the 20th year of implementation and therefore the savings potential has not peaked by the end of this time span. These deployment scenarios are visually represented below in figure 9D.

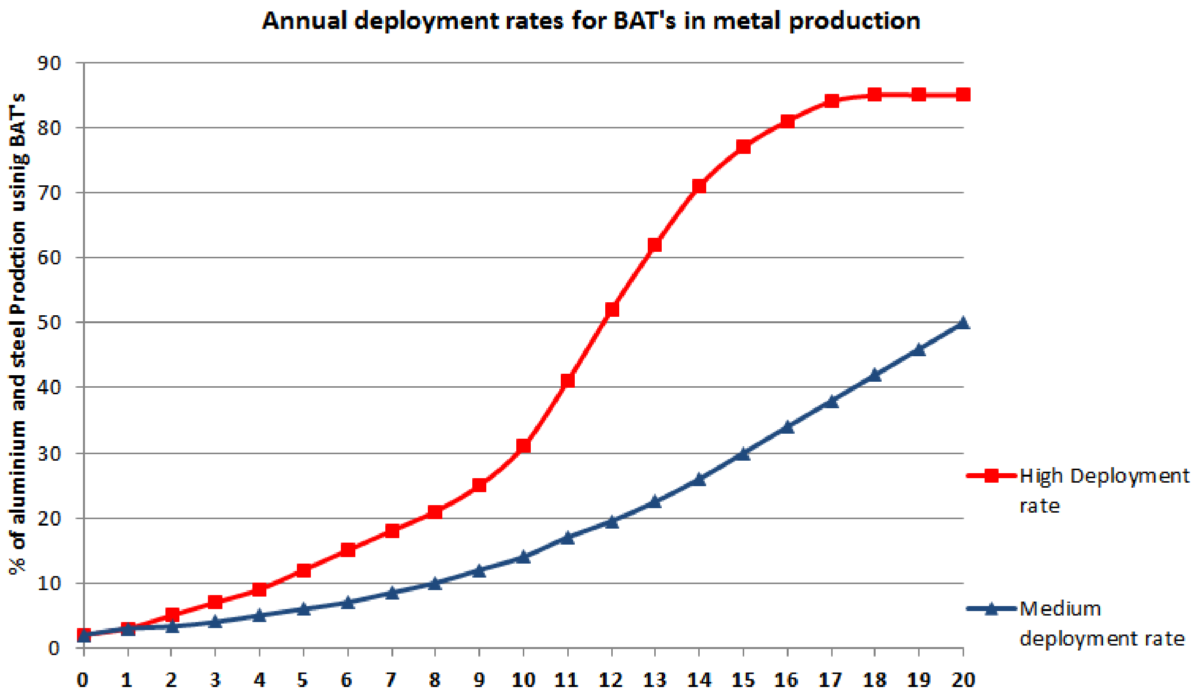


Figure 9D: *The annual deployment rates for measure 2 expressed as a percentage of annual steel and aluminium production using BAT's*

The High deployment scenario is seen to saturate the market by year 18 with the maximum amount of BAT's introduced to the operating aluminium plant. This may either be brought about by the construction of new plants during a 20 year period or retrofitting of existing plants. Under the medium deployment scenario a steady growth trajectory is observed assuming limiting factors such as economic pressures are more limiting. Both deployment rates observe an increase in uptake rate during the latter half of the time span as it is assumed some installation costs are reduced and the benefits become more apparent, which is typical for technological transitions.

Due to the assumption that both base years (2000) and (2013) have the same initial production share affected by the measure the deployment rate is identical for both. Of course the historical period will only witness the first 10 years of this implementation.

9.6 Measure 3: Reducing the embodied energy of cement through best available technology and fly ash replacement

9.6.1 Background and description of the measure (3)

Measures 1 & 2 target the largest contributors to the embodied energy measure 1 reducing that contributed by concrete block and mainly brick. Measure 2 focusing solely onto the energy intensive metal industries. From figure 7D the next largest contributor besides timber, which is classed as a renewable resource and carbon sequestration to a large extent balances out energy requirements, is the contribution from ready mixed concrete.

As discussed in section 6.4.3 cement as a component of concrete is largely responsible for the embodied energy, even though by weight it represents only a small fraction of the material. Cement is also used for concrete block production, thus when introducing a reduction measure onto the cement industry, concrete blocks will be affected. The most common cement type used in the UK is Portland cement with an embodied energy content reported in the (ICE, 2008) at 5.02 [MJ/kg].

Through the implementation of best available technologies onto the cement production chain discussed in section 6.4.3, the reduction in energy needed to produce Portland cement is lowered to ~[3.35 MJ/Kg] (Worrell et al, 2008). With most of this reduction coming from technologies implemented into the clinker making process, which is responsible for ~90% of the energy required (Worrell et al, 2008). This is equivalent to a saving of 1.67 [MJ/Kg] (33%) from the 5.02 [MJ/Kg] reported in (ICE, 2008).

Further savings can be realised with the addition of fly ash into the Portland cement, which can account for up to 35% of the mixture. The inclusion of this fly ash reduces the ratio of clinker needed, thus reducing the overall energy intensity of the product. (Worrell et al, 2008) reports the energy needed for production at 2.44[MJ/Kg] indicating a saving of 2.58[MJ/Kg] or (51.4%) from the average intensity of UK production reported in (ICE, 2008) when using both best available technologies and fly ash replacement of 35%

9.6.2 Identifying the energy savings for the measure on ready mixed concrete and concrete article production at micro level [MJ/Kg]

The proposed measure incorporates both the best available technologies and fly ash replacement for cement used in the ready mixed concrete and concrete block production .To calculate the energy savings per tonne of building material consumed it is necessary to find the contribution of embodied energy of both products that is attributed to cement production alone. In the boxes below self-calculations are presented to identify this target with accompanying reported figures.

Targeting cement contribution of embodied energy in building materials

Ready mixed Concrete

-The most common cement type used in the UK is Portland cement with an embodied energy content reported in the (ICE, 2008) at 5.02 [MJ/kg].

-The embodied energy of ready mixed concrete is 0.95[MJ/Kg] (ICE, 2008)

-At a mixture of 1:2:4 (cement: sand: aggregate) cement contributes 14.3% of ready mixed concrete by weight [0.143Kg]

Therefore, (5.02 * 0.143) = **[0.72 MJ/Kg] or 75%** of the concrete embodied energy content is due to the 143g of cement

This result perfectly matches with the (SCF, 2012) reported cement contribution of 75% of specific energy consumption for ready mixed concrete reported by (SCF, 2012).

The remaining [0.23 MJ/Kg] is mainly accounted by the further mixing and processes in the concrete plant discussed in section 6.8, with only a very small part due to aggregate and sand.

Articles of cement, typically in the form of concrete blocks contain smaller amounts of cement and have additional energy requirements such as the curing phase needed to harden pre cast articles.

Therefore the amount of total embodied energy in a concrete block attributed to cement is not the same as that of ready mixed concrete. Thus this must be calculated separately.

Articles of Cement (concrete blocks)

- 10 Mpa is the general strength used within the UK building sector and the strength assumed in previous calculation for annual consumptions.

-The energy required for production of 1m^3 concrete block including the curing process is 1.69[GJ/M^3] (Nisbet et al, 2002).

-Of which 1.18[GJ/M^3] (70%) is accounted for by the production of cement used within the mixture. (Nisbet et al, 2002).

As this is recorded per m^3, conversion and identification of this energy into metric weight is required for further calculations

-Energy required to produce 1kg of 10 Mpa concrete block = 0.67 [MJ/Kg] (ICE, 2008)

-Therefore, 70% of this embodied Energy is attributed to cement production = 0.7 * 0.67 [MJ/Kg] = **0.47 [MJ/kg]**

Direct savings due to cement production using the best available technologies and fly ash replacement of 35% (identified at 51%) can now be calculated for 1Kg of concrete and 1Kgof concrete block.

Ready mixed concrete

Energy required to produce 1kg of ready mixed concrete = 0.95 MJ/Kg
Energy attributed to cement production = 75% or 0.72 [MJ/kg]
Amount saved by implementation of BAT's and fly ash replacement = 51%
(0.72 [MJ/Kg] * 0.51) = **0.37 [MJ/Kg]**
Thus, Total embodied energy of 1kg of ready mixed concrete using measure = (0.95 – 0.37) = 0.58 [MJ/Kg]

Concrete Block

Energy required to produce 1kg of 10 Mpa concrete block = 0.67 [MJ/Kg]
Energy attributed to cement production = 70% or 0.47 [MJ/kg]
Amount saved by implementation of BAT's and fly ash replacement = 51%
(0.47 [MJ/kg] * 0.51) = **0.24 [MJ/Kg]**
Total embodied energy of 1Kg of concrete block using measure = (0.67 – 0.24) = 0.43 [MJ/Kg]

Note: the total volumes for cement articles reported earlier in the report also include prefabricated concrete articles contributing to 21% of the total. These are not subjected to the measure as the cement concentration is variable and unknown also heating and additional techniques represent a larger share of their embodied energy content.

Furthermore, to avoid double counting the remaining amount of concrete bricks left after implementation of measure 1 is adopted.

9.6.3 Projecting the possible deployment rates over a 20 year time span for measure 3

The best available technologies explored to bring about these reductions are already commercially operating. Fly ash is a by-product of coal combustion with estimates that in 2008 67 million tonnes of fly ash were produced in the EU-27, of which 32% was used directly in cement (Bech and Feuerborn, 2011). For fly ash to be used within cementious products it needs to meet the requirements of European standard EN197-12/2 for cement and further EN 450 – 1/3 for its incorporation into structural concrete (Bech and Feuerborn, 2011). It is however viable to accept that the supply of fly ash is adequate to fully fore fill the demand created by inclusion of this into all cement production especially considering the possibility of import from heavy coal consuming countries such as China. As this measure then has no supply restraints and is assumed to be applicable to all cement manufacture a high deployment rate has been formed which projects the full implementation of this measure onto all cement producing activities during a 20 year period. A medium deployment scenario has been constructed which considers the difficulties in technological take up of the best available techniques used in the clinker making and other processes, which may be due to economic constraint and concern over reliability stretching for a longer time span. The medium deployment scenario follows the same path as that for measure 2 as it is presumed similar constraints apply to both industries resulting in a 50% take up by the year 2020.

It is of crucial importance to remember that reduced resource consumption in the form of construction materials used in the built environment and embodied energy are closely tied together because of the energy requirements during manufacturing and processing. This is demonstrated through the implementation of measures 1-3, which take priority into reducing the embodied energy content of buildings by tackling the key area identified. Measures 4 aims specifically to reduce the overall quantity of resource use which actually brings about further parallel energy savings. Furthermore, it is acknowledged that under the analysis of these reduction measures a domestic material consumption approach is deployed meaning only savings of resources at the final product stage are identified where in fact a larger amount would be avoided due to the raw material inputs, however data requirements for a full savings potential inclusive of these raw materials are inadequate and indeed missing in many instances.

9.7 Measure 4: Decreasing waste production at the construction phase

9.7.1 Background and description of the measure (4)

As previously discussed the building sector is a large contributor to UK waste production. A significant proportion of this contributing waste arises at the constructional phase (Phase 4) of a buildings lifecycle, where variations in onsite activities dictate the amount of waste occurring. The efficiency in waste minimisation from site to site can vary dramatically dependant on the procedures that have been put in place and willingness of the project leaders to reduce waste streams. This waste is often in the form of unused materials, damaged materials and inefficient building techniques. For example, industry measures have recorded that ~13% of waste produced on site is new, unused material simply from over ordering (BRE, 2008). This could be avoided by identifying suppliers who accept returns.

As this report focuses on potential savings the current production of onsite waste is needed. The largest and most recent data set available for the average waste produced during the construction phase is provided by the Building Resource establishment's SMARTwaste programme which has created a benchmark for waste production at a relative 100m^2 for all building types acknowledged by this report. This study by BRE incorporates cases from 17 of the UK's 20 leading building contractor services. This data refers to new build construction only and is presented as an average for each major building type below in Table 9F.

Table 9F: *The average waste production deriving from Construction Phase only for each major building type. Data gathered over a 12 month period May 2011- May 2012*. Source (BRE, 2012)

Project Type	Number of projects data relates to	Average Tonnes/100m^2
Residential	256	16.8
Public Buildings	23	22.4
Leisure	21	21.6
Industrial Buildings	23	12.6
Healthcare	22	12.0
Education	60	23.3
Commercial Other	4	7.0
Commercial Offices	14	23.8
Commercial Retail	48	27.5

9.7.2 Identifying the resource savings at local level [100m^2] from implementation of measure 4

In table 9F it is possible to distinguish between the volumes of waste being produced between residential buildings opposed to commercial. When calculating the savings potential at a national scale it is appropriate to develop an average of these two for the theoretical 100m^2 building used in previous assessment of the consumption levels. To achieve this, the assumptions prescribed in figure 5A and used for the building production in each scenario are developed whereby

Residential buildings = 74.67% of the UK floor space

Commercial buildings = 25.33% of the UK floor space (BPIE, 2013)

Then the average waste production for the $100m^2$ theoretical building (combination of residential and commercial) is 18.8 tonnes. This calculation is provided in the box below.

The Average waste production for residential buildings = 16.8 [tonnes/$100m^2$] as seen in table 13 for (74.67% of new floor space)

As commercial building property mostly consists of Offices, Retail and Public buildings an average of these three waste production seen in table 11 is calculated
((27.5 + 23.8 + 22.4) / 3) = 24.6 [tonnes/100m²] for (25.33% of new floor space)

Thus, (16.8 * 0.7467) + (24.6 * 0.2533) = 18.8 tonnes / Theoretical $100m^2$

This average waste production at construction phase can be significantly reduced via using an adequate waste management system on site. Such management systems follow the principles of the waste hierarchy with the first task being to reduce the quantity of waste generated on site. Best practice measures under such systems involve going beyond the current baseline performance seen in table 9F which largely focuses on meeting legal obligations (BRE, 2009b). Implementation of effective waste management site plans include, efficient design, improvement in material logistics, use of offsite construction and decreasing/ eliminating the over ordering of materials (BRE, 2009b). The preparation of a robust site management plan is essential for efficient and sustainable waste minimisation, such plans require monitoring and recording of all waste streams onsite. There is a range of such systems which have been applied to all building types in the UK with notable savings that can be achieved. For the use of this report the reputable BRE's Smart waste system has been used and the results in reduction achieved for the effective implementation against the average waste production are displayed below in table 9G

Table 9G: *Comparison of the Good / Best practice waste production onsite using effective waste management systems to the average production in the UK building sector*. Source (BRE, 2012 and CRWP, 2008)

	Reported in [Tonnes/$100m^2$]		
Project Type	**Standard (Average)**	**Good**	**Best**
Residential	16.8	4.3 - 6.8	< 4.3
Commercial	24.6	4.8 - 7.3	< 4.8
All projects (both)	18.8	4.7 - 7.3	< 4.7

As seen in table 9G under best practice operating conditions using an appropriate waste management system ~ 4.7 [tonnes/$100m^2$] can be achieved for a theoretical $100m^2$ building. This represents significant opportunity for reductions in waste production of (18.8 – 4.7) = 14.1 [tonnes/$100m^2$] from the average waste produced.

9.7.3 Projecting deployment rates over a 20 year time span for measure 4

Construction clients, developers, policy makers and planning authorities across the UK are increasingly asking designers and contractors to implement good practice techniques to minimise waste streams. This is largely due to a better understanding of the environmental and economic benefit such waste management systems can provide and a range of free online templates and tools available for developing site waste management plans are available in the UK. These savings are applicable to all buildings focused on in this report and apart from initial investment this improved management provides savings for invested parties.

Under the conditions that a benchmarking system already exists and a range of tools and management companies are available to aid with deployment it is assumed by the end of a 20 year period all new construction will be carried out under best practice conditions under both medium and high deployment projections explored.

However, given the fact that it is likely there will be a sliding scale as to how well the reductions are performed (i.e. not achieving best practice but reductions are noticeable (perhaps “good” indicated in table 14) the medium deployment potential will aim to simulate this and difficulties in diffusing this measure into the sector by assuming 100% of buildings implement the measure by year 20. The high deployment potential assumes due to clear benefits all production will incorporate the measure by year 10 with rapid deployment as seen below in figure 9E.

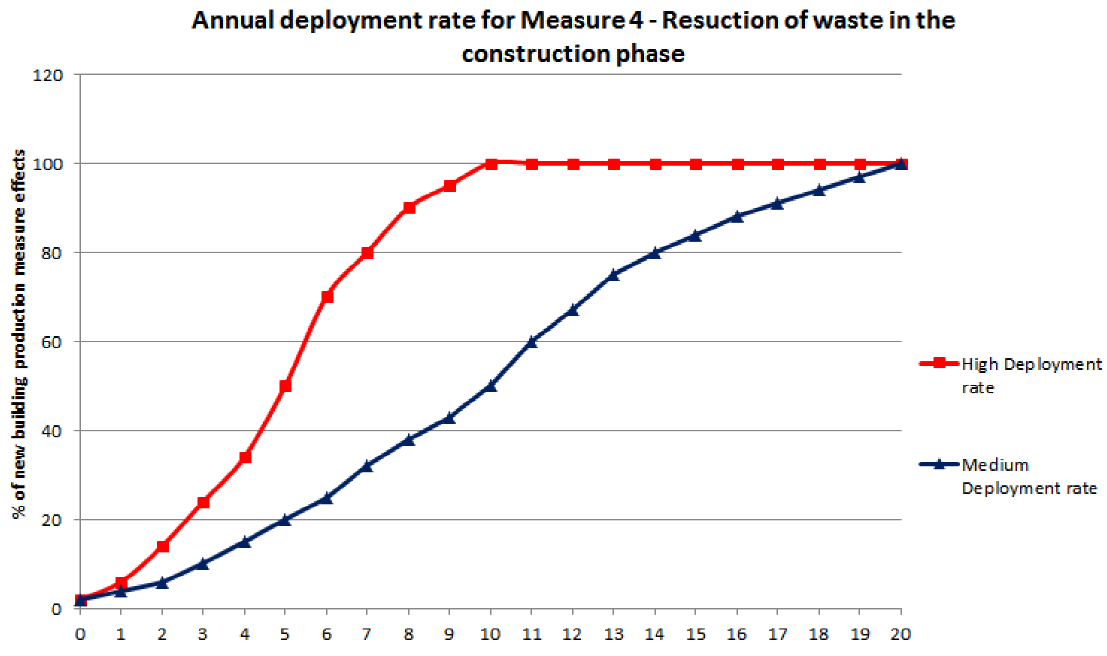


Figure 9E: *The annual deployment rates for measure 4 expressed as a percentage of annual building production performing to best practice waste management in the construction phase.*

As seen in figure 9E with no large investment costs needed and a platform and benchmarks already in place to implement the measure and track progress both deployment rate experience a relative rapid growth compared to previous measures explored which makes it perhaps more suitable when striving for short term targets.

10. Development of suitable quantitative reduction indicators

10.1 Review of the existing targets

As identified in the problem definition there are no suitable quantitative targets for resource and embodied energy savings brought about through the implementation of reduction measures in the lifecycle stages of building production outside of the operational phase.

This is due to an inherent lack of any resource efficiency targets within the EU and energy reduction targets simply specifying a reduction in absolute national-wide energy use from a given base year.

As part of the Euro 2020 strategy the European council endorsed the energy efficiency directive and in doing so set technically binding targets for energy efficiency improvements across all major energy consuming sectors including the building sector. This required reduction is set a 20% of the absolute primary energy consumption by the year 2020 compared to BAU projections of absolute primary energy consumption from a 2005 base year. This is seen in figure 10A below

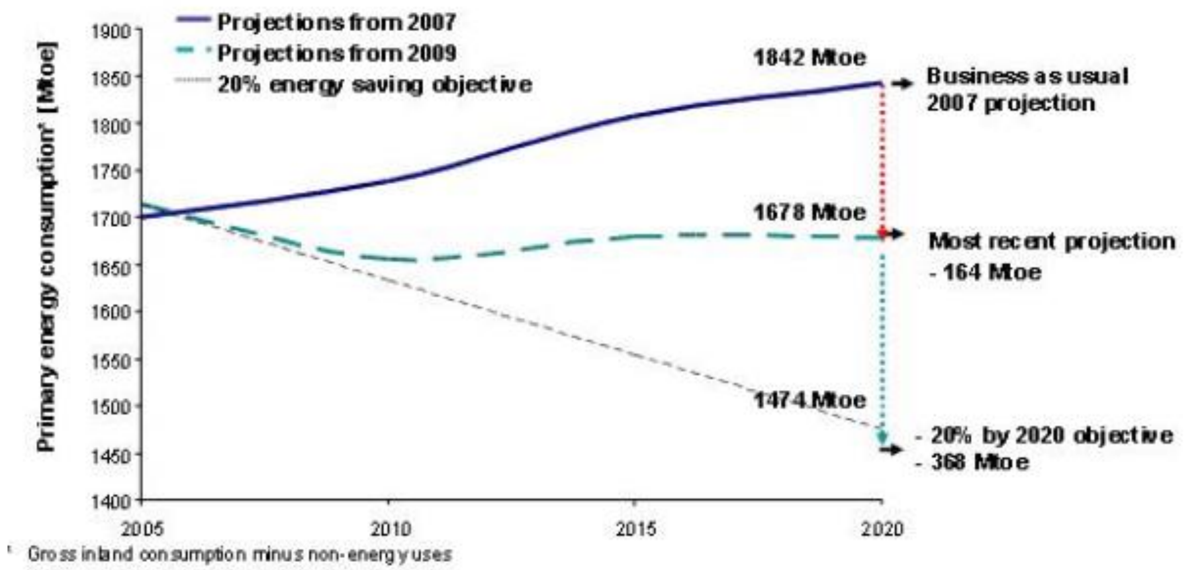


Figure 10A: *The setup of the Euro 2020 energy efficiency target. Source- (European commission website)*

Many efforts to meet this binding target are occurring in the building sector such as efficient lighting and heating. Although as seen above the more recent projections still indicate this target is now going to be met. Thus incorporating savings that can be achieved during the lifecycle stages outside of the operational phase provides additional support.

This target whilst suitable for reductions in the operational phase is however unsuitable for reductions brought about by tackling embodied energy. This is because the target uses absolute energy consumption per annum as its indicator. Whilst reduction measures in the operational phase can achieve savings from the BAU in every year up to the target year and for the whole existing building stock. Savings in embodied energy can only be realised in new building production within the target year (2020) and savings will be vastly overshadowed. Thus, a target for new building production is needed.

The energy performance of buildings directive 20002/91/EC aiming to enhance the energy performance of buildings and new construction requires the issue of energy performance certificates. However, there is no binding quantitative targets for this desired efficiency gain. This is an issue considering the European commission ambitious targets for "nearly carbon zero buildings" in the near future.

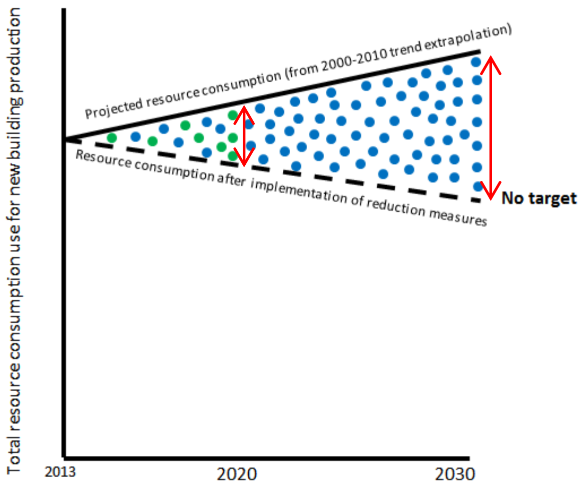
In conclusion to this review it is considered necessary to create a range of indicators suitable for assessing the reductions possible through reduction measures aiming at the resource and energy use in a buildings lifecycle outside of the operational phase

10.2 Proposed indicators

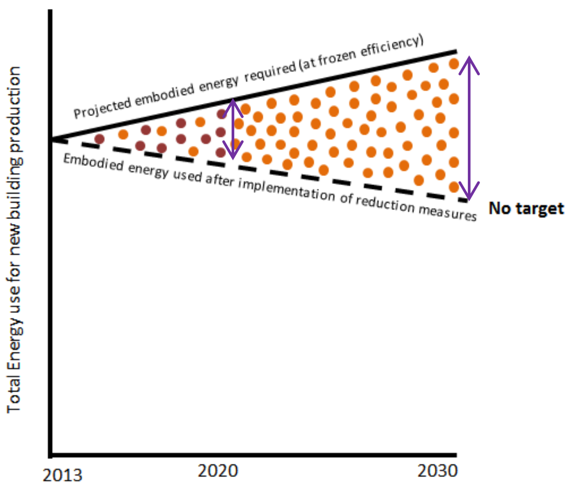
In order to accurately assess the reduction potential of the identified reduction measures in the following chapters, on an individual basis for national scale application (chapter 11) and as a collective (chapter 12). First a range of suitable indicators must be developed, as the contribution of the identified measures to existing targets is deemed inappropriate. These indicators should be formulated so that only energy and resource requirements for new building production is measured against.

The following quantitative indicators have been produced in line with a qualitative assessment of the European commission's 2020 ambitions. These developed indicators aim to allow for a fair reflection on what can be achieved in resource and embodied energy savings for new building production only. Below is a visual representation of the developed indicators.

Figure 10B: *Visual representation of the developed indicators to assess savings potentials in resource and energy efficiency in new building production.*



1. The cumulative amount of Resource consumption saved over the period (2013-2020) & (2013-2030) [Ktonne]
2. % of total resource used for new building production that is saved by the reduction measure (sector wide resource use) over the period (2013-2020) & (2013-2030)
3. % of total resources used for new building production in the target year (2020 and 2030) that is saved by the measure.



1. The cumulative amount of Embodied energy avoided over the period (2013-2020) & (2013-2030) [PJ]
2. % of total embodied energy used for new building production that is saved by the reduction measure (sector wide resource use) over the period (2013-2020) & (2013-2030)
3. % of total embodied energy used for new building production in the target year (2020 and 2030) that is saved by the measure.

As seen in figure 10B. The reductions are measured against the consumption in resources and energy that would have occurred in new building production had there been no implementation of the measures. The building production during 2000-2010 does not need a projection of expected energy and resource use because the true physical amounts have been identified in chapter 7 and thus the actual consumption trends will serve as the BAU (no implementation) scenario. For future projections the BAU is developed with the following as discussed in section 8.2.3

- The levels of materials used per 100m^2 are projected forward from the analysis of the 2000-2010 period performed in chapter 7.
- No autonomous development in energy efficiency occurs with embodied energy static at levels reported in 2008 (ICE, 2008) used throughout this research.
*This is explored for varying levels of building activity seen as scenarios A-C
- The period up to 2030 shall be assessed under the pretence that further increase in resource and embodied energy efficiency in new building production can be achieved over a longer time span.

At this point it would be easy enough to place a 20% reduction targets alongside the indicators. However, as this is the first time such an assessment has been carried out, the research refrains from throwing a number into the air (20%) and hoping it can be achieved. Electing rather to first develop a range of quantitative indicators and reflect what suitable time bound targets can be set in the discussion chapter.

11. Analysis of reduction potential at national scale for individual measures

This section takes the small scale savings for each reduction measure identified in chapter 9 and assess the cumulative savings potential at a national level for the UK if these measures were ramped up to sector wide level. This is performed for 3 distinctive periods

- **The historical period (2000 -2010)** Based on known building activity and consumption trends
- **Short term future projections (2013-2020)**
- **Longer term future projection (2013-2030)**

As the future projections both start implementation in the same base year (2013) they can be plotted together

Each measure is investigated using the previously described scenarios (chapter 8) and the deployment rates announced in (chapter 9). Results for the indicators developed in the previous chapter will be displayed throughout.

The structure of this section follows the layout below for all measures contributing to absolute savings (1-4).

- First, the historical period is explored. As discussed earlier this back casting technique which is hypothetically changing the results in terms of resource and energy use over the historical period is performed so that the highest degree of certainty in the building activity is known and effects on the savings potential brought about by changes in volume can be identified with higher confidence.
- Second, Reduction potentials for each individual measure are mapped for both future projections. As the future projections both assume implementation in the same base year (2013) they can be plotted together. A table at the end of this subsection provides total savings ranges for each of the periods (2013-2020) & (2013-2030).
- Third, to provide insight into the likelihood of occurrence, the feasibility of achieving the identified savings potentials at national scale is assessed from a qualitative perspective where appropriate identifying recent industrial developments, drivers and issues which where applicable include possible policy option to support implementation.

11.1 Interpreting the results

A reiteration of the concepts and methods deployed, specific to the analysis preformed in this section is provided below

The savings potentials for all periods investigated are presented in the following graphs as cumulative savings. These cumulative savings are the savings realised from what would have been consumed if no implementation occurred.

In this sense each scenario shown in chapter 8 acts as the BAU development (note this is different between scenarios in absolute amounts due to varying constructional activity). Thus, this consumption trend for each scenario will be referred to as (no implementation) to avoid confusion. Note for figures produced in this section (11) the horizontal axis serves as this no implementation trend line. For figures relating to combined savings in (section 12) this will be displayed as a black line.

This no implementation trend assumes no autonomous development occurs in future projections for the embodied energy required to build a $100m^2$ building (all materials investigated require the same energy input over this period). Thus, a frozen technology concept is deployed for embodied energy. This was chosen to remain frozen, as future developments in energy efficiency for the key material productions are not available.

However, Resource consumption per $100m^2$ building is not frozen as analysis of the consumption trend during the 2000-2010 period allows this to be extrapolated for future projection.

11.2 Measure 1: Timber Frame and cladding (national scale savings)

11.2.1 Savings potential for measure 1 (historical period 2000-2010)

The hypothetical savings for resource consumption over the period 2000-2010 brought about by implementation of replacing convention walls with timber frame and cladding are displayed below in figure 11A

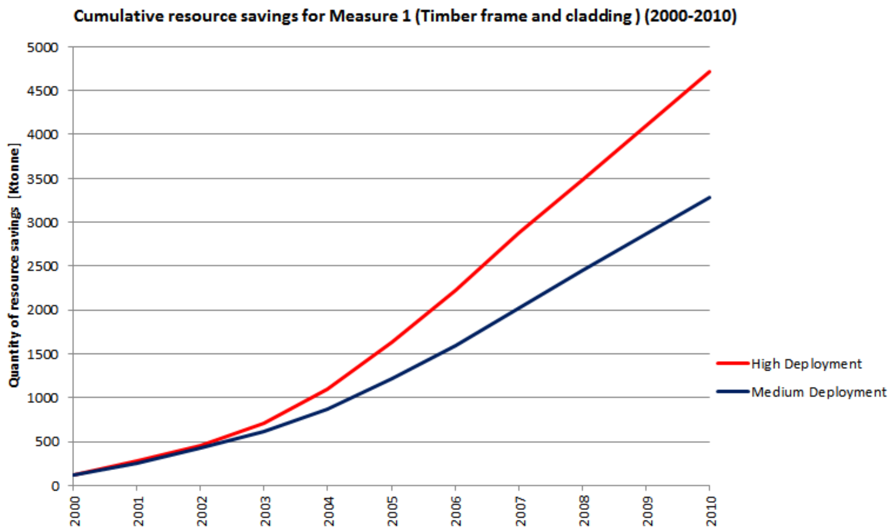


Figure 11A: *The Cumulative resource savings that may have been realised over the period 2000-2010 brought about solely from implementation of measure 1 at national scale*

Figure 11A identifies that from implementation of measure 1 alone an absolute savings range of 3283 – 4715 [Ktonnes] could have been achieved for the period 2000-2010 if implementation of the measure was started in the base year 2000. Furthermore, this result highlights the importance of supporting a more rapid take up rate which realised a 44% increase in absolute savings compared to the more modest medium deployment rate.

The embodied energy avoided by implementation of the measure is seen below in figure **11B**.

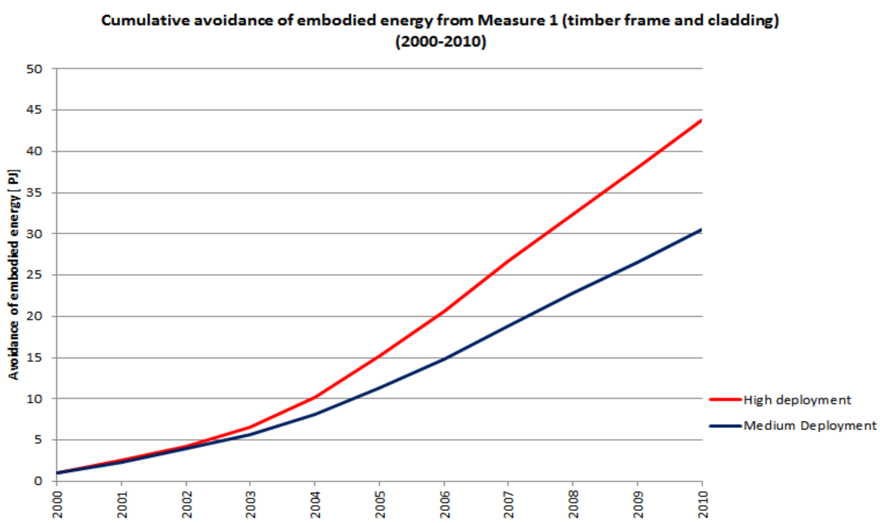


Figure 11B: *The cumulative embodied energy that may have been avoided over the period 2000-2010 from implementation of measure 1 at national scale for the UK*

Figure 11B shows that measure1 when implemented over the period 2000-2010 at national scale in the UK could have brought about avoidance of embodied energy ranging from 31 – 44 [PJ]. To put these results into context table 11A below provides key statistics at reductions arising from a sector wide perspective.

Table 11A: *Sector wide savings statistics for measure 1 (2000-2010)*

Historical (2000-2010)		
	High	Med
% of new construction measure was applied to	7.10%	4.90%
% of Total sector wide resources used, saved by measure	0.60%	0.40%
% of Sector wide total embodied energy used, saved by measure	1.70%	1.20%

As seen in table 11A only a limited amount of the total building production over this period was constructed using this measure <7.2% in the highest deployment rate. This resulted in limited savings over the period for resources and energy savings in terms of sector wide consumption. It is observed that this measure whilst tackling issues of both resource and energy efficiency is more effective at reducing the sectors energy use displaying higher savings proportions of the total at 1.7 -1.2% compared to that for resources at 0.6-0.4%.

10.2.2 Savings potential for measure 1 future projections (2013-2020/2030)

The practical application of projecting the savings potential for implementation of measure 1 over the period 2013-2020 and 2013-2030 provides insight for policy makers, providing informed options available. In figure 11C below the cumulative savings for the period 2013-2030 has been mapped for each of the 3 building/demolition activity scenarios developed in chapter 8 and each is explored under a high and medium deployment rate.

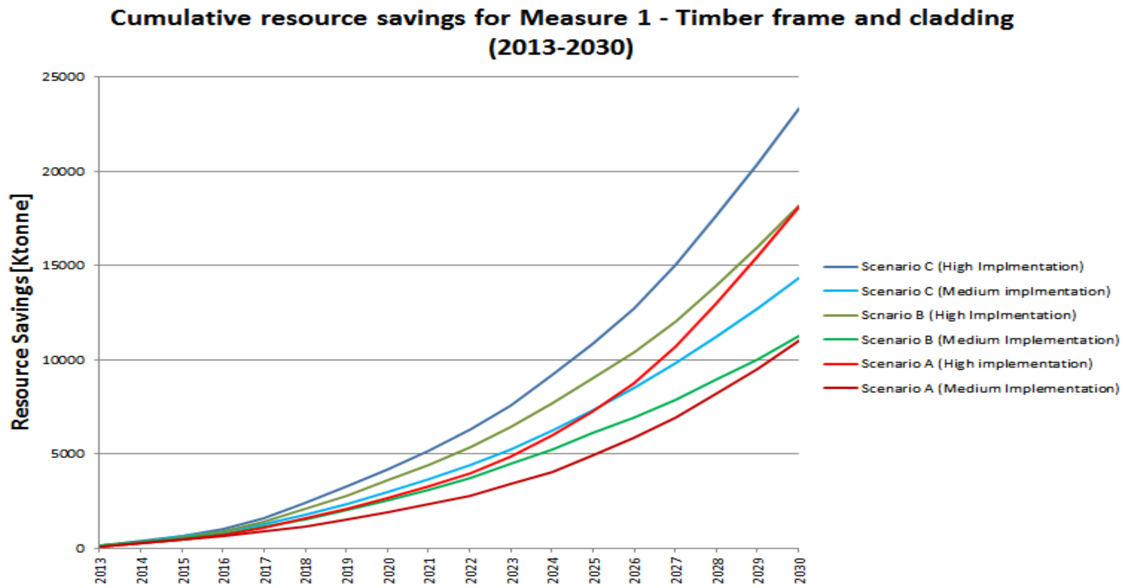


Figure 11C: *Projections of the cumulative resource savings potential brought about from implementation of measure 1 alone in the base year 2013 up to 2030 for the UK building sector. Explored under Scenarios A-C*

As expected the savings potential is greatest when construction activity is higher as it is assumed that the supply side for all measures responds directly to meet demand caused by building production.

It is interesting to see that the cumulative savings observed for measure A catch up to scenario B by 2030. The total absolute resource use over this period is greater for scenario B however much of the construction occurs within the first 8 years to 2020 as seen in figure 8C. The construction activity in scenario A is slightly greater over the last 5 years when the measure is at a higher implementation rate and thus A catches B up exactly by 2030.

It is observed that significant differences of the total savings can be realised between the high and medium deployment potentials explored in 2020, which further diverge up to 2030 identifying the importance of strong implementation. Furthermore, when assessing the potentials over the whole period it is concluded that there is an observed acceleration after 2020 for all scenarios highlighting the importance that even though smaller savings are achieved by the 2020 target year these measures hold a greater relative value for future reduction due to the need for a longer transitional period. This is highlighted by the percentage of total resource use reductions in the sector being >2x the amount over the period up to 2030 displayed in table 11B below along with other key statistics.

The total cumulative savings relating to embodied energy, also targeted by this measure (the only measure explored that tackles both) are displayed below in figure 11D

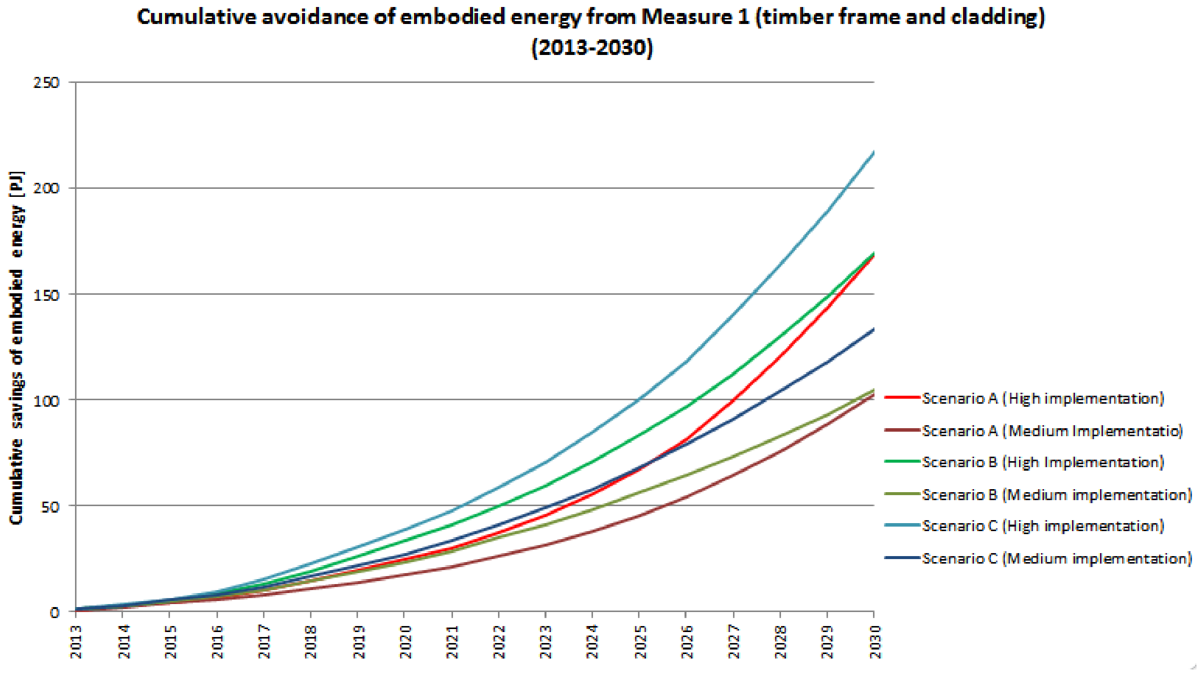


Figure 11D: *Projections of the cumulative embodied energy avoidance potential brought about from implementation of measure 1 alone in the base year 2013 up to 2030 for the UK building sector. Explored under Scenarios A-C*

Figure 11D displays similar trends to that for resource consumption as the energy avoidance is directly tied to the resource savings thus an identical trend is observed. What is important to note is that this measure contributes greater to the total sector energy use of the periods investigated than it does for the resources use. This is highlighted in the Key statistics table 11B below which show which shows a greater proportion of the embodied energy is saved and produces larger variance for 2030 than 2020

Indicating the effect of this measure on embodied energy over a longer term period is the most significant finding for reduction efforts.

Table 11B – *The key statistics for resource and energy savings brought about by implementation of measure1 in 2013. Displayed as ranges between med-high deployment for 2020 and 2030.*

	Scenario A		Scenario B		Scenario C	
	2020	2030	2020	2030	2020	2030
Total resource savings [Mtonnes]	1.9 - 2.7	11 - 18	2.5 – 3.6	11.3 – 18.2	2.9 – 4.1	14.4 – 23.4
% of sector wide Resource use saved	0.35 – 0.5%	0.9 – 1.5%	0.4 – 0.5%	0.8 – 1.3%	0.4 – 0.5%	0.9 – 1.4%
Total Embodied energy avoided [PJ]	18 - 25	103 - 169	23 - 33	104 - 169	27 – 39	133 - 217
% of sector wide energy use avoided	1 – 1.4%	2.5 – 4.2%	1 – 1.5%	2.3 – 3.7 %	1 - 1.5%	2.4 – 3.9%

11.2.3 Feasibility of the implementation of Measure 1 at national scale

The supply side is required to increase at 19% [1]per annum from the base year. It is widely accepted this growth rate is obtainable for a subsector rendering the projected savings achievable from a supply side perspective. It is apparent that in the UK timber frame houses with a cladding of bricks are becoming increasingly popular with a reported 25% of houses constructed in the year 2012 using this technique. Timber cladding is however less popular with no significant representation at national level although the pre modular frame and cladding combined unit can easily be produced using similar manufacturing processes and materials (Asher, 2011). Therefore, the production capacity is already in existence in the base year 2013 as only 2% of new building production effected by this measure. The same 2% is used in both base years because although production capacity is higher in 2013 no increase in wooden houses is observed between the two and it is other factors that predict this production such as the clear unwillingness to apply the measure in the UK.

This trend of increasing timber built houses is far from uncommon and although the UK building stock consists of <2% other EU countries such as Norway and Sweden have achieved >90% of the total building stock (BRE, 2000).

Timber buildings meet or exceed all of the required building standards set in the UK for structural strength, thermal insulation, safety etc and is thus not a barrier for this technology. However as seen in the historical analysis of the period 2000-2010 the building sector defaults to use conventional methods for building with barely any substitution occurring between key materials. Furthermore, a combination of adverse public information regarding safety and durability (no proven false) and a slowing down of building production due to economic recession has led to a dramatically dampened market share. The UK is now recovering from these effects with timber being the fastest increasing

[1] The capacity of UK timber frame producers in the base year 2000 is reported at 40000 houses typically 91m^2. If this is approximated to 100m^2 and we consider the proportion of construction during the period 2000-10 that incorporated this measure (7.1% of new building production) or 174, 974 (100m^2) of floor space. The following equation can be used to deduce the annual growth rate needed for the supply side to meet the deployment projected.

EXP. Log ((174,000/40,000)/10)) = 19 % annual increase in production required material used within the sector. The UK is 20% self-sufficient for timber used in construction with the vast majority being imported (BRE, 2000). From a sustainable perspective short-term policy is needed to ensure the imported supply chains are sourced from sustainable producers which could incorporate a compliance measure that they are FSA approved. Long-term policy should set sight on increase domestic forestry.

Further promoting the use of timber is the rapid increase of need for affordable housing at surging levels to meet the population growth. Timber provides a cheaper alternative and can reduce build times by ~80% (Bergstrom and Stehn, 2005) perfectly reflecting the current requirements. It appears then that the UK is on track to increase this technology to projected levels however, the cladding requires heavier promotion. This may be influenced by the higher weighing of credits assigned for incorporation of the material when assessed using environmental assessment schemes such as BREEAM which are voluntary based or mandatory schemes such as Code for sustainable homes requiring assessment of all buildings funded by the Housing and communities' agency, which represents a significant proportion of the affordable homes production. Additionally with a target of carbon zero homes by 2016 an ambition of the UK government further initiatives are likely to be put in place (Osmani and O'Reilly, 2009). These may include subsidies for the cladding and wide scale demonstration projects with a technical knowledge platform created sector wide.

However, the most important factor deciding the future of this measure is the willingness to go outside of the conventional techniques and as discussed above there are incentives to do this. The technical possibility is there as shown for other countries but the UK building sector has to make a strong decision.

11.3 Measure 2 Best available technology for energy reductions in Aluminium and Steel manufacture (National scale Savings)

11.3.1 Savings potential for measure 2 (historical period 2000-2010)

The savings potential presented in fig 11E represents the cumulative avoidance of embodied energy at national scale for the UK if measure 2 was hypothetically implemented over the period starting in the base year 2000.

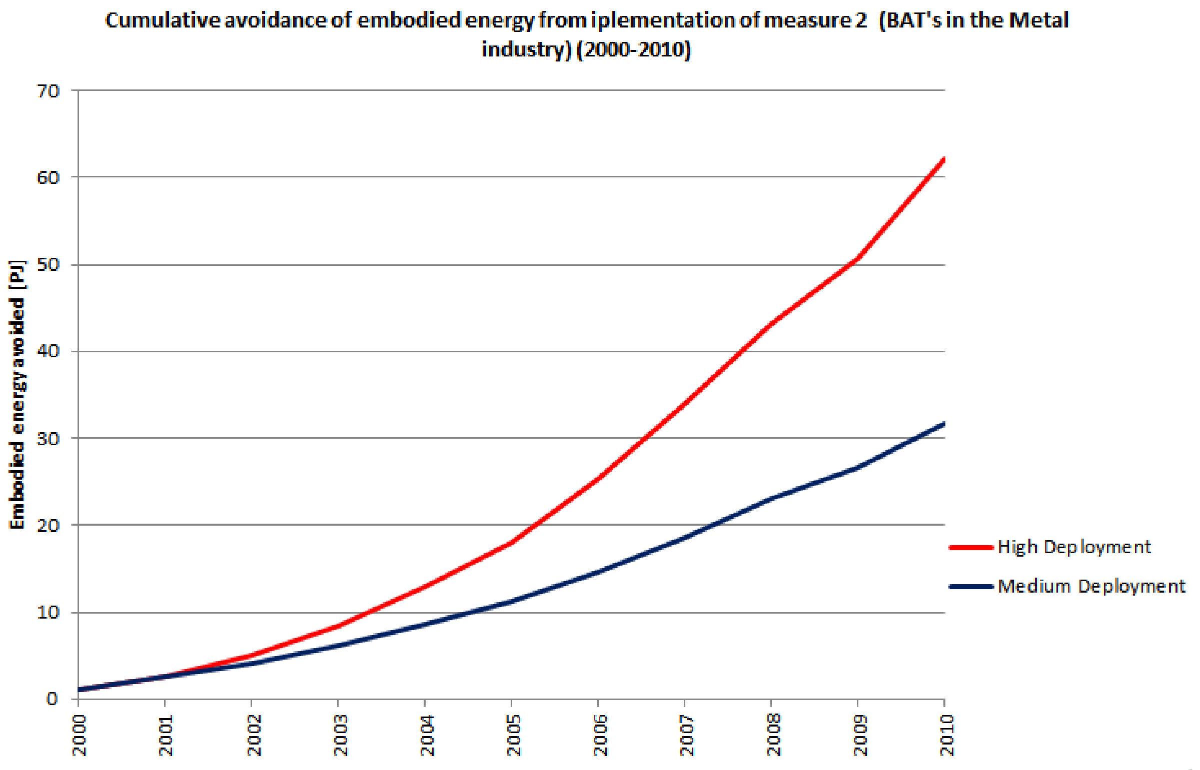


Figure 11E: *The cumulative embodied energy that may have been avoided over the period 2000-2010 from implementation of measure 2 at national scale for the UK*

The analysis shows that over the period 2000-2010 substantial savings can be made ranging from 32 [PJ] under medium deployment and 62 [PJ], almost double the savings under the high deployment scenario highlighted in table 11C below showing other key observations. During this period if the high implementation would have been adopted 2.4% of the total embodied energy used by the building sector could have been avoided which is substantial considering changes are brought about through the reduction in the metal industry alone and highlights the reason for selecting this measure.

Table 11C: Key *Sector wide savings statistics for measure 2 (2000-2010)*

Historical (2000-2010)		
	High	Med
% of Total aluminium and steel production affected	12.30%	6.30%
% of Total sector wide embodied energy avoided	2.40%	1.20%
Total savings [PJ]	62	32

11.3.2 Savings potential for measure 2 future projections (2013-2020/2030)

Future saving projections for measure two have been mapped out in an identical manner to measure one in the previous section. These are displayed below in figure 11F with additional key statistics made available in table 11D for detailed analysis.

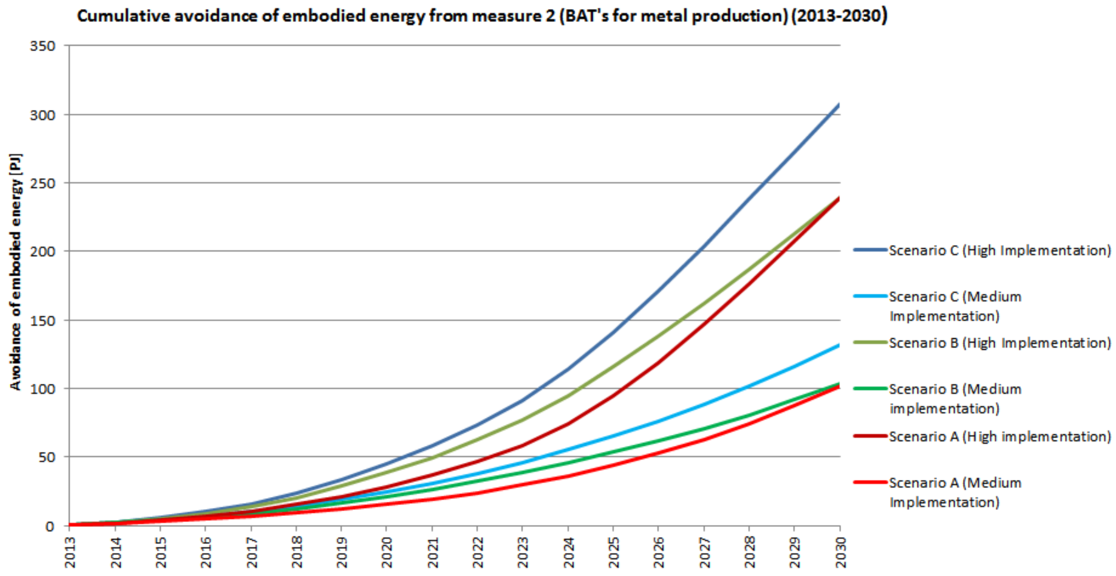


Figure 11F: *Projections of the cumulative embodied energy avoidance potential brought about from implementation of measure 2 alone in the base year 2013 up to 2030 for the UK building sector. Explored under Scenarios A-C*

As seen in figure 11F the vast majority of savings under all measures are realised after the 2020 target year due to the assumed acceleration of the deployment rate as the technology becomes more proven and accessible. It is identified again as seen for measure 1 that the cumulative saving for scenario A rapidly accelerate in the final years, 2025> due to a higher level of building activity over this period compared to scenario B which assumes building demand to ease. This results in scenario A achieving a larger reduction in the absolute energy use by the year 2030 as seen in table 11D below (Scenario A 6%[high]) & (Scenario B 5.2% [High]). By the year 2020 0.9 – 1.7% of the total embodied energy used in the sector could be avoided and further projection indicate by 2030 2.3-6% could be avoided highlighting the importance of the need for long term thinking within the sector with up to 14% of sector wide energy use avoided in the year 2030.

Table 11D: *The key statistics for energy savings brought about by implementation of measure 2 over future projections (2013-2020) & (2013-2030)*

	A				B				C			
	2013-2020		2013-2030		2013-2020		2013-2030		2013-2020		2013-2030	
	Med	High	Med	High	Med	High	Med	High	Med	High	Med	High
Total % of aluminium and steel production affected	4.8%	8.8%	14%	32.7%	4.9%	9.1%	12.2%	28.1%	5.0%	9.2%	12.8%	29.8%
Cumulative avoidance of embodied energy [PJ]	16	28	102	240	21	39	103	239	24	45	132	308
% of cumulative sector wide embodied energy avoided	0.9%	1.6%	2.6%	6.0%	0.9%	1.7%	2.3%	5.2%	0.9%	1.7%	2.4%	5.5%
% of sector wide embodied energy avoided in final year	1.5%	3.2%	6.3%	14.0%	1.5%	3.2%	6.3%	14.%	1.5%	3.2%	6.3%	14%

11.3.3 Feasibility of the implementation of Measure 2 at national scale

The technological changes required to achieve this measure are already operating and thus commercially viable. The reconstruction of these measures into additional plant is then at least from a technical perspective achievable.

On a global basis steel and aluminium account for ~10 of carbon emissions and the industries are renowned for investing heavily into energy efficiency (IEA, 2012). This is no surprise given the likely increase in pressures from the ETS sector and that a large proportion of production costs are attributed to the fuel consumption including conversion into electricity. Furthermore, the steel and aluminium industries have an obligation to stakeholders to grow, so their response to stricter legislation on CO_2 emissions and thus energy consumption must be rigorous if total production is to increase. With a major driver of reductions in energy use being in the form on CO_2 emission targets, it is likely that the future development of CCS to meet required reductions will indirectly affect efforts for energy efficiency within these industries and to a lesser extent the production of renewable electricity.

Whilst a major step change is needed to bring about the best available technologies to existing plant, these changes will become more viable with increase in the price of fossil fuels and/or carbon tax per tonne, which would essentially further decrease the pay back periods of initial investment.

Rapid technological deployment is needed to meet the savings potential realised under the higher deployment scenario over a 20 year period. The plants operating at the improved efficiency due to BAT's implementation should act as a benchmark for other manufacture plant. Industry wide policy would then need to determine a target year in which all plant must be operating at this level. A sufficient road map or framework would need to be created and communicated throughout the industries plotting the best economical course of action.

The aluminium and steel industries have shown significant increase in energy efficiency over the past 20 years, deeming the projected implementation of 85% achievable if aggressive pursuit of these innovations is carried out. However, these industries often operate a bottom line principle whereby the reduction measures effect on the production cost is ultimately the determining factor. Therefore, the interaction of the new BAT's and production costs must be further analysed to project forecasts on the industrial behaviour with confidence and weighed against the production benefits (EC, 2003).

Legislation should be considered to ensure uptake of the measure aiming to decouple increased production volume with energy requirements. Further options include the mandatory ascription of EPD's for all steel and aluminium products, placing an emphasis on customers to prefer a product with lower embodied energy, thus increasing the market share from manufacturers using the measure. Innovations such as this measure firmly rooted in the supply chain of the building sector are seen as a key driver for the production of carbon zero buildings (Osmaini and O'Reilly, 2009).

11.4 Measure 3: Best available technology and fly ash replacement for cement production (National scale Savings)

As with measure 2 the introduction of best available technology and fly ash replacement in the cement industry focuses solely on embodied energy savings. As concrete blocks are also tackled within measure 1, only concrete blocks remaining after the application of measure 1 are subjected to reductions brought about by measure 3. This follows the principle that a greater level of reductions are available through measure 1, thus it is given preference.

11.4.1 Savings potential for measure 3 (historical period 2000-2010)

The hypothetical savings that could have been brought about in the UK during the period 2000-2010 are displayed in fig 11G below with accompanying statistics presented alongside in table 11E.

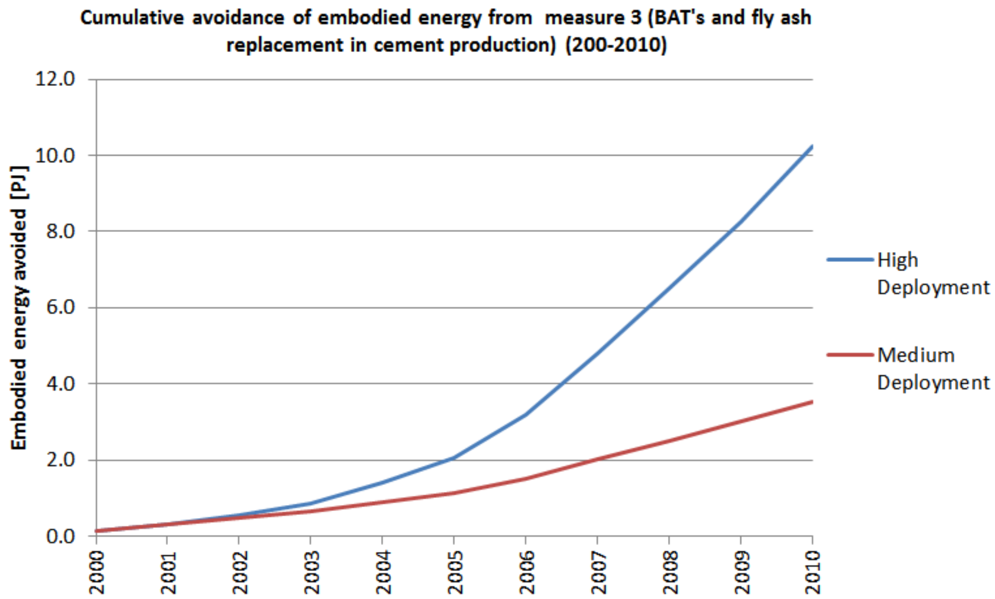


Fig 11G: *The cumulative embodied energy that may have been avoided over the period 2000-2010 from implementation of measure 3 at national scale for the UK*

Measure 3 does not appear to hold as large of a potential over the 2000-2010 period when compared to measures 1& 2. However as the concrete industry is here to stay considering there is no commercially viable option for its replacement, any reduction in this material provides long-term savings. If policy construct surrounding the measure was aggressive over this time period, represented by the high deployment curve ~2.5x as much energy could have been avoided compared to a more relaxed approach. The acceleration in the cumulative savings observed after the year 2005 is due the deployment rate assumptions that the technology required will observe a more rapid uptake during after this period thus amount of cement produced using this measure per annum increases at a greater rate.

Table 11E: Key *Sector wide savings statistics for measure 3 (2000-2010)*

Historical Period (2000-2010)		
	High	Med
Total Cumulative savings (PJ)	10	4
% of total sector side Embodied energy avoided	0.40%	0.14%
Saving in final year	1.10%	0.30%

11.4.2 Savings potential for measure 3 future projections (2013-2020/2030)

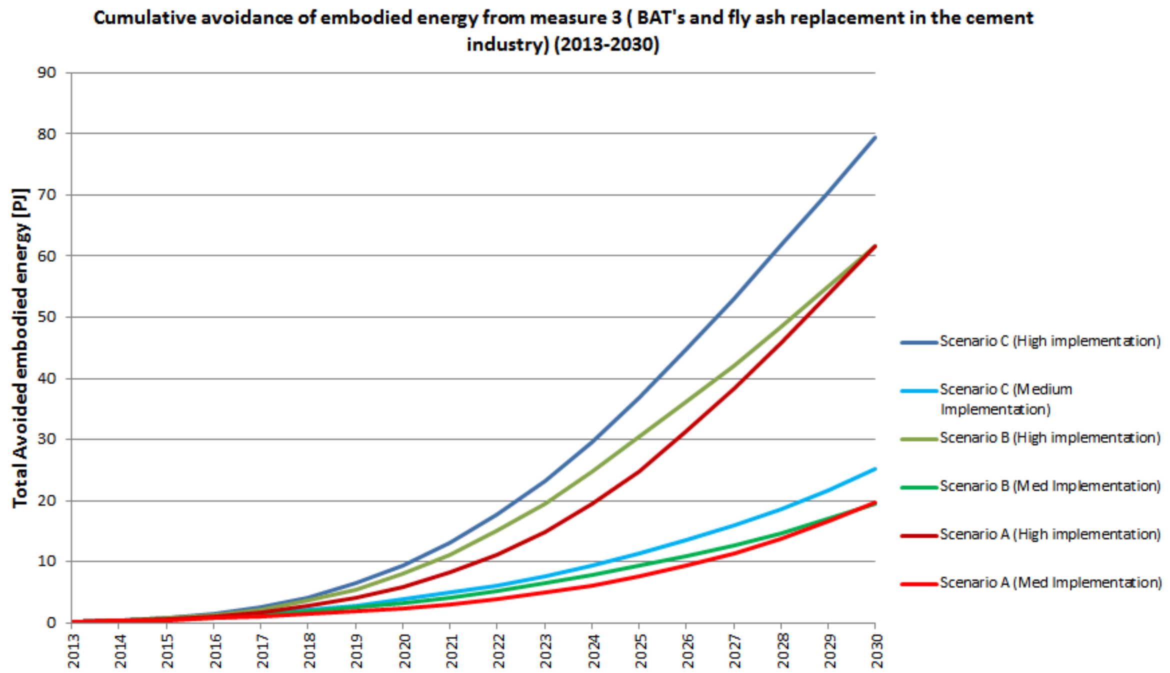


Figure 11H: *Projections of the cumulative embodied energy avoidance potential brought about from implementation of measure 3 alone in the base year 2013 up to 2030 for the UK building sector. Explored under Scenarios A-C*

The same trend observed for measure 1 and 2 whereby scenario A catches the cumulative avoidance observed for B by the year 2030 is applicable to this measure also for identical reasons. To the period up to 2017 there appears little difference between the amounts of saving between the scenarios due to the technology deployment rate needing time to scale up. After this point the constructional activity is assumed to partly govern the amount of savings per annum and rapid acceleration is observed after the 2020 target year up to the longer-term target of 2030.

It appears that the structural affect caused by the deployment rate is greater than the volume effect due to projected building activity onto the savings potential. This is highlighted in there being a larger range of savings between high and medium deployment under the same scenario than there is between high deployment between the scenarios.

When compared to measure 1 & 2 we observe a smaller potential to avoid energy as for these the lowest range of saving (med A) is greater than the largest saving of 79.4 [PJ] in scenario C under high implementation as displayed in table 11F below alongside other key statistics. Also there is a small limited potential for savings to increase post this projection as the savings in the final year show up to 3.5% of the sector wide annual embodied energy is avoided in the year 2030 when the measure is assumed to of reached its maximum deployment. However, the 3.5% is still a significant overall saving for the incorporation of one measure alone, the issue is that there is an apparent long time span required to achieve this highlighted by the respective 0.8% value for the 2020 target year.

Table 11F: *The key statistics for energy savings brought about by implementation of measure 3 over future projections (2013-2020) & (2013-2030)*

	A				B				C			
	2013-2020		2013-2030		2013-2020		2013-2030		2013-2020		2013-2030	
	Med	High	Med	High	Med	High	Med	High	Med	High	Med	High
Cumulative avoidance of embodied energy [PJ]	2.4	5.8	19.7	61.7	3.3	8	19.6	61.6	3.8	9.3	25.2	79.4
% of cumulative sector wide embodied energy use avoided	0.1%	0.3%	0.5%	1.6%	0.1%	0.4%	0.4%	1.3%	0.1%	0.4%	0.4%	1.4%
% of sector wide embodied energy use avoided in the final year	0.3%	0.8%	1.4%	3.5%	0.3%	0.8%	1.4%	3.5%	0.3%	0.8%	1.4%	3.5%

11.4.3 Feasibility of the implementation of Measure 3 at national scale

The introduction of best available technologies and the replacement of 35% by fly ash provides the cement industry with economic and ecological advantageous use of resources, which are then passed on to the concrete and articles of concrete manufacturers. The increase of competitive pressures, rising prices for both raw materials and energy coupled with stricter environmental regulation mainly surrounding CO_2 emissions are causing energy efficiency gains to be a top priority for the cement industry (Siemens, 2009). There is a huge scope for the global cement industry as a whole which annually consumes ~300 TWh thus savings of ~20% which is less than the reductions ascribed in this report (~51%) would provide enough energy to supply a major city such as London (Siemens, 2009).

The average intensity of cement manufacture is largely attributed to the clinker production stage which on average within the EU operates at under 35% thermal efficiency but can be improved using better energy management, equipment upgrades etc. With most of the reduction available coming from this stage alone it is assumed that technological knowledge will spread through the industry at a faster rate than a range of measures over the entire chain would. Furthermore, Japan with its modern production facilities has already got an average intensity close to the reported world's best practice at national level (IPCC, 2006) indicating that scale up of the implementation of this measure is viable. That fact that these BAT's have been tested and demonstrated at a commercial level provides a solid platform for rapid take up from a technical perspective.

Similar to the metal industry the energy required for production accounts for ~40% of the production costs which has stimulated a decrease of ~30% of the energy required since 1970s in the EU cement sector (IPCC, 2006). The payback period of the measure will ultimately be the dominating factor in take up rate, however this information is not readily available but assumed to be fairly diminutive considering the large saving represented.

The energy reductions also directly contribute to CO_2 reduction, especially when coupled with fly ash replacement, which can significantly reduce emissions with the (IEA, 2008) estimating a global savings potential of 300-450Mtonnes by the year 2050 lending further incentive for implementation. The recently established cement sustainability institute working under the World business council for sustainable development have produced a series of industry wide technological roadmaps aiming to scale up existing technology with policy options to support this including subsidies for developing countries and firmer emissions regulations (WBCSD, 2009).

The inclusion of fly ash as a component to produce a blended cement mix whilst offering a significant opportunity for savings would require in many instances across Europe the revision to the construction standards. However, this is seen as a small issue due to the properties in terms of structural strength not weaken but rather drying times are prolonged.

In review with the presence of an industry body promoting technological improvement and clear economic and environmental benefits the measure has every chance of becoming reality if supportive policy is designed in a way to maximise the necessary scaling up.

11.5 Measure 4: reducing waste production in the construction phase (National scale Savings)

11.5.1 Savings potential for measure 4 (historical period 2000-2010)

The resource savings potential for implementation of effective waste reduction systems during the construction phase of building production at national scale has been mapped for the UK for the period 2000-2010 in figure 11I below. Corresponding key statistics are also available in table 11G. These savings are hypothetical for what could have been achieved if implementation was introduced in the base year 2000.

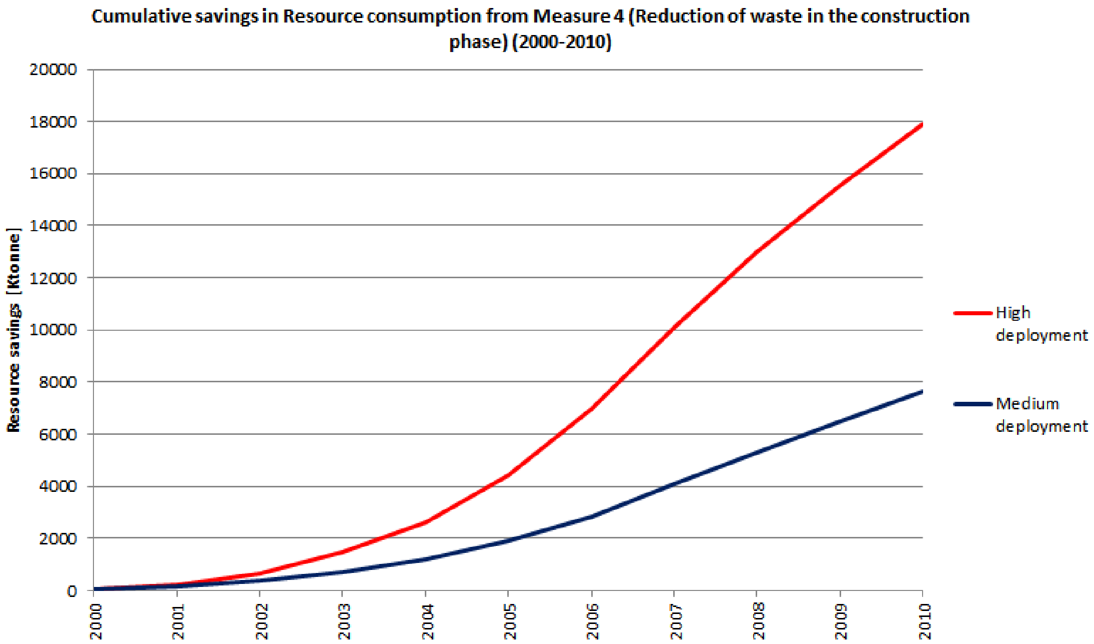


Figure 11I: *The cumulative resource savings that may have been avoided over the period 2000-2010 from implementation of measure 4 at national scale for the UK*

As with the previous measures (1-3) investigate substantial differences in the savings potential over the period 2000-2010 are observed between the medium and high deployment rates, once again identifying the potential gain of more rigorous efforts. This measure holds significant savings potentials over the period with up to 17 Mtonnes of resources avoided within the UK building sector. Creating sector wide reductions over the period of 2.1% and it is evident a longer time period would invoke further savings due to 4.3% of the sector wide resource use in the final year (2010) being avoided under high deployment.

Table 11G: Key *Sector wide savings statistics for measure 4 (2000-2010)*

Historical (2000-2010)		
	High	Med
% of new construction measure was applied to	51%	22%
Cumulative resource use saved [Ktonne]	17907	7647
% of Total sector wide resource use saved	2.1%	0.9%
% of sector wide resource use saved in final year	4.3%	2.1%

11.5.2 Savings potential for measure 4 future projections (2013-2020/2030)

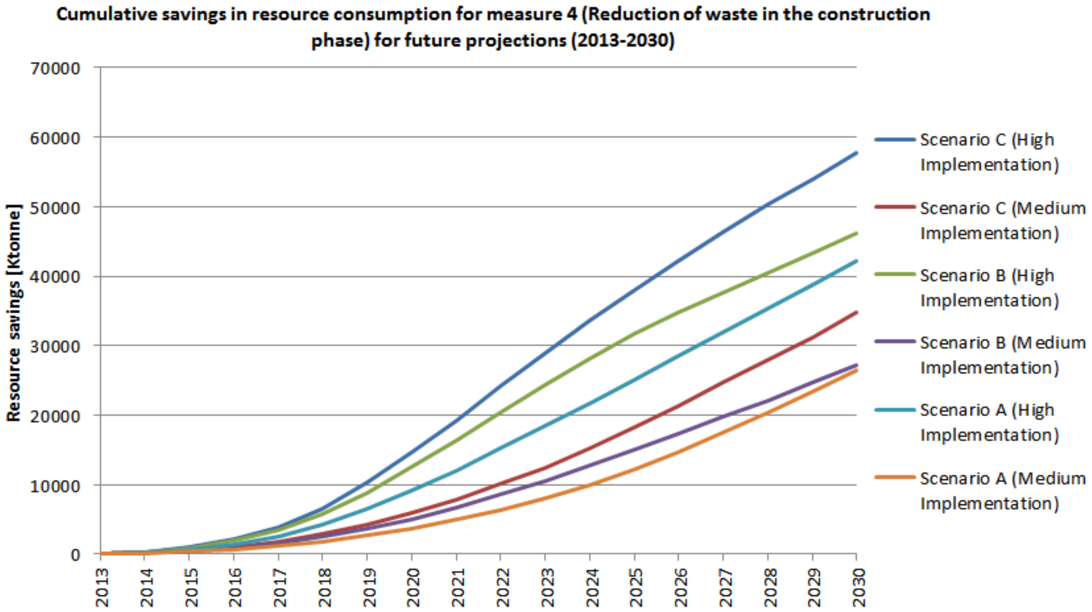


Figure 11J: *Projections of the cumulative resource savings brought about from implementation of measure 3 alone in the base year 2013 up to 2030 for the UK building sector. Explored under Scenarios A-C*

Figure **11J** identifies large savings can be achieved by the year 2020 with a clear separation of the potential between scenarios in this year due to the rapid uptake prescribed in the deployment rates. In year 2020 this ranges between 3.7 – 34 [7 Mtonnes]. This potential is carried forward so that in the year 2030 up to a maximum of 57.8 [Mtonnes] could be saved through implementation of this measure alone. Furthermore, the assumed rapid uptake of this measure provides far greater savings than measure 1(the only other measure providing resource savings). In the year 2020 the level of implementation explored allows for 1.6 – 3.9 % of the total sector wide energy use for the annum to be avoided, in 2030 this is recorded at 4.7-5.2 %, a much narrower range due to the medium deployment almost at 100% of building production in this year. Additional specific statistics are provided in table 11H.

Table 11H: *The key statistics for resource savings of measure 3 over future projections (2013-2020) & (2013-2030)*

	A				B				C			
	2013-2020		2013-2030		2013-2020		2013-2030		2013-2020		2013-2030	
	Med	High	Med	High	Med	High	Med	High	Med	High	Med	High
% of new construction measure was applied to	15%	36%	45%	71%	15%	37%	40%	68%	15%	37%	42%	70%
Cumulative resource use saved [Mtonne]	3.7	9.1	26.1	42.4	5	12.5	27.2	46.2	5.9	14.6	34.7	57.8
% of Total sector wide resource use saved	0.7%	1.7%	2.2%	3.5%	0.7%	1.8%	2%	3.3%	0.7%	1.8%	2%	3.4%
% of sector wide resource use saved in the final year	1.6%	3.9%	4.7%	5.2%	1.6%	3.9%	4.7%	5.2%	1.6%	3.9%	4.7%	5.2%

11.5.3 Feasibility of the implementation of Measure 4 at national scale

A proven ability to dramatically reduce waste production in the constructional phase of a buildings lifecycle has been demonstrated in the UK through the recorded waste production from completed projects using waste management systems. This includes best practice observations achieving [4.7 tonnes/100m^2] used in this report from the incorporation of BRE's Smartwaste site waste management plan. With a series of benchmarks already made public and regularly updated by the BRE and a developed methodology/performance indicators, coupled with the availability of free resource platforms for aid in development and use of site waste management plans. The UK is in a position to rapidly increase the implementation of this measure onto new building construction.

Policy is already in place to act as a driving force including the Waste Strategy 2007 stating obligations to reduce waste sent to landfill at a national level and supportive fiscal measures including the land fill tax and aggregate levy, which impose financial incentives to reduce waste (Parsons Brinckerhoff, 2012). Additional recent UK policy has enforced the requirement of a site waste management plan to any project >£300,000, furthermore, other environmental assessment schemes such as Code for sustainable homes and BREEAM also require these plans (BRE, 2012). However, no specific reductions are obliged from the standard waste amounts observed in the benchmarks. To achieve waste minimisation at the scale reported in the previous sub section requires more stringent policy at least in the infant years, which would likely entail the mandatory monitoring of all onsite waste production. These policy measures all create a greater accountability on the waste producers.

Whilst relevant training of staff and firm policy are needed there also exists a range of benefits that aid the measures diffusion into the market. A spread of knowledge to influence current habits by identifying monetary savings occurring directly from resource savings are realised with (BRE, 2008) estimating saving of 2% of the total construction cost when a "good" practice of waste reduction in the construction phase is carried out. This limiting of waste production also helps to secure the supply of building materials to the sector and increase companies' environmental performance and corporate reputation.

The implementation of this measure at national scale to 100% of new building production appears viable and provides a solid route for the European Commission's concerns on resource consumption to be addressed. However, it is likely that the reductions will occur gradually over the future period as best practice levels are more difficult to attain and in some instances carry a negative associated economic cost. Thus a level of good practice operating within economic constraints and achievable quick wins seems a more likely future for an interim target.

12. Identifying the total combined savings potential of the reduction measures

The purpose of this chapter is to identify the total savings potential for the proposed reduction measures at sector level when performed simultaneously as part of a package. The layout shadows a similar fashion to that of the previous chapter and is constructed as follows:

First, Resource consumption after implementation of the reduction measures will be identified for the historical period 2000-2010.Its incorporation is to provide an accurate account of what savings may have been achieved in the UK when resource use data is known and not projected, and perhaps holds a more accurate reflection due to the average energy intensities for each material being taken from within this period from the inventory of carbon and energy 2008. Whereas for future projections they are frozen and possible hide some savings due to autonomous development, thus emphasising the savings potential obtained to an unknown degree.

Secondly, the savings potential for the future periods (2013-2020) and (2013-2030) will be identified for resource savings. These savings potentials brought about by the reduction measures are then assessed to what contribution they hold towards total resource and energy use for new building production over the periods

Third, a comparison of the contribution of each of the measure towards the total savings potential will be performed to provide insight into where priority should be placed.

The steps are then repeated for embodied energy.

Note at the end each section a table is provided giving all key results to the indicators developed in section 10.

12.1 Combined resource consumption savings potential

The measures that reduce resource consumption include

- **Measure 1** (Timber frame and clad walls for replacement of conventional masonry)
- **Measure 4** (Reduction of waste in the construction Phase)

A combined package including all the cumulative savings achieved from implementation of both measures represent the total savings that can be realised from the production of this research. These are further explored to describe the potential in total savings and efficiency savings under a series of varying deployment rates and construction activity represented by the scenarios described in section 8

12.1.2 Combined resource consumption savings 2000-2010

The total cumulative resource consumption savings that could have hypothetically been saved for the UK building sector if implementation of measures 1& 4 commenced in the base year 2000 are displayed below in figure 12A. A range of 10.9 -22.6 Mtonnes could have been saved over this period, which represents up to a maximum of 2.8% of the total material required for new building production throughout the decade. After the year 2007 the rate of savings appears to decelerate in line with the material used for buildings over this period as the economic recession hits and production decreases. This is due to the assumption that savings are directly linked with the building activity in this research.

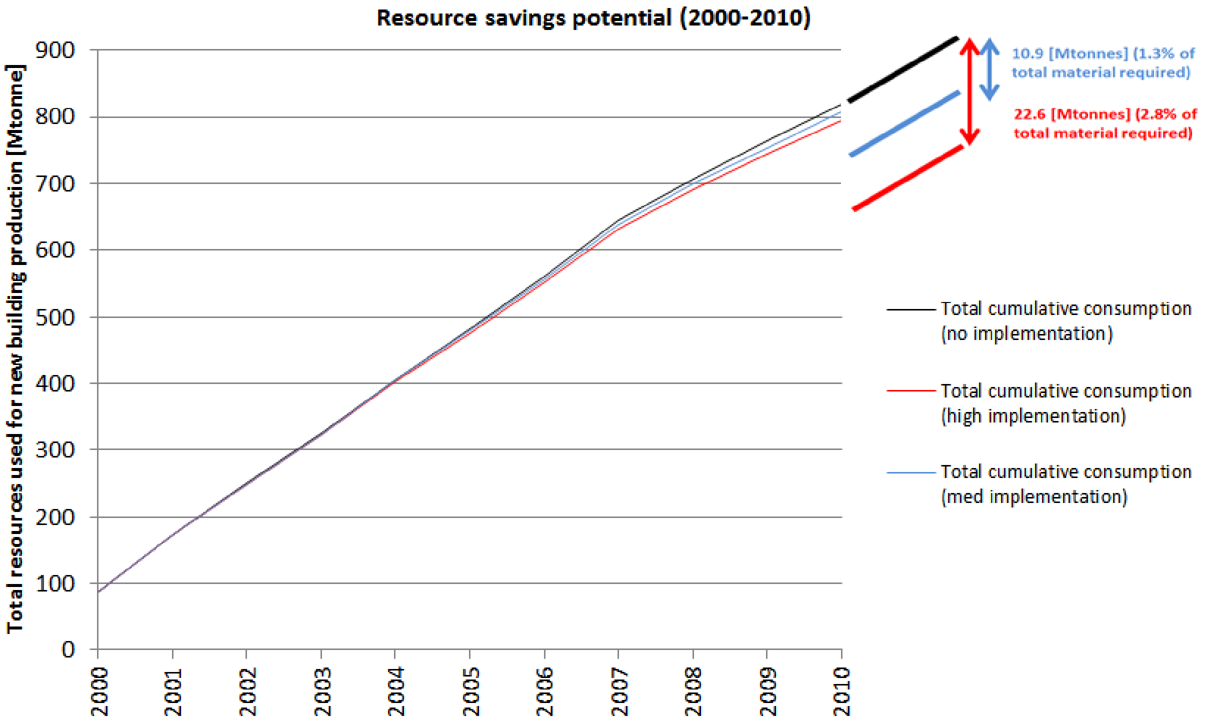


Figure 12A: *The combined cumulative resource savings for (2000-2010) in the UK*

Whilst (2.8%) is not an eye catching figure, for the application of just two reduction measures alone the savings are respectable especially when considering that 2.8% of the whole material requirement is a lot. To put this into perspective figure 12B below translates these savings into the amount of houses that could be built as a direct result of these savings.

The amount of material need to build a 100m^2 building (average of residential and commercial) in the year 2010 with no implementation = 329 tonnes

Therefore, the average 91m^2 house sized building the material requirement would be ~(329 * 0.9) = 299 tonnes

Figure 12B: *The amount of resources saved over the period (2000-2010) translated into material needed for house production*

Furthermore, as identified in Table 12A below there is a far larger potential for these reduction measures when considering that up to 5.4% of the material needed for new building production in the year 2010 was saved under high deployment. This saving is substantial and reduces the resources need for a 100m^2 building production by 18 tonnes. Then any building produced after this year would have seen a reduction of at least 18 tonnes under a high level of implementation.

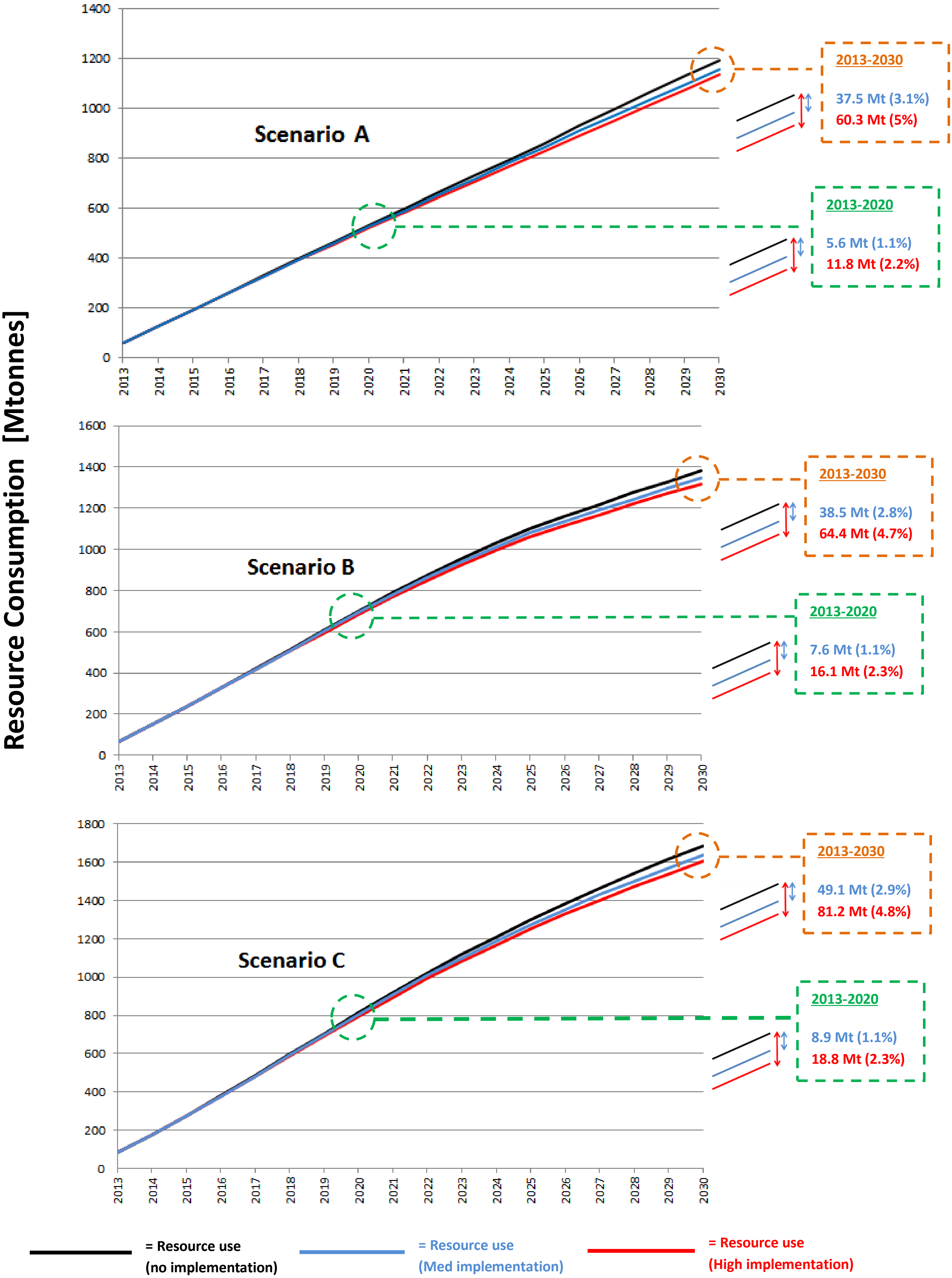
Table 12A: *Key statistics for the combined resource savings (2000-2010)*

Combined Resource savings (2000-2010)		
	Med	**High**
Total cumulative Savings [Mtonnes]	10.9	22.6
% of Total Resources used for new building production saved	1.3%	2.8%
% of resources used for new building production saved in year 2010	2.9%	5.4%
In the final year tonnes saved per 100m^2	10	18

12.1.3 Combined resource consumption savings for the periods (2013-2020) & (2013-2030)

The total cumulative resource savings that could be achieved in the UK building sector at national level if implementation of measures 1 & 4 were carried out are displayed below in figure 12C. The savings for the period (2013-2020) and longer-term potentials from (2013-2030) are identified. These potentials have been explored for both high and medium deployment and varying levels of building activity carried out under scenarios (A-C).

Figure 12C: *The combined resource savings potential (2013-2020) & (2013-2030) for scenarios A-C*



As seen in figure 12C, the rate of savings and expected resource use decelerates for scenarios B & C around the year 2024. This is due to the building production decreasing over the latter half of the time period in scenario B due to housing shortage demand in the UK largely being met by this point and Scenario C the decrease in building rate projected by Primes 2009.

For the period 2013-2020 a range of 5.6 – 8.9Mtonnes of resources can be saved under medium implementation of measures 1 & 4. This is ~ doubled under the high implementation, with a saving range of 11.8 – 18.8 Mtonnes. This difference highlights the importance of pursuing an aggressive approach supported by firm policy. Over this period then up to 2.3% of the total resources needed for building production in the UK can be saved.

When the reduction measures are allowed a longer time frame to establish themselves within the sector, a large increase in this savings potential is observed. This is seen for the period 2013-2030 achieving a savings potential of up to 3.1% of the total resource use under medium implementation and a significant increase up to 4.8% [81.2Mtonnes] under high deployment. This result emphasises the need to allow the measures an appropriate transitional period in which they are supported to allow for a greater savings potential. To provide context into these absolute savings that could be realised over the periods investigated they have been translated into amount of houses that could be built using the same method as for the 2000-2010 period and displayed below in figure 12D

Figure 12D: *The amount of resources saved over the periods (2013-2020) & (2013-2030) translated into material needed for house production*

As seen in figure 12C, the constructional activity taking place over an identical period of time dramatically affects the amount of absolute savings potential that can be realised. This is clearly visible for the period (2013-2030) where under high implementation a range of 37.5 – 49.1 Mtonnes are projected.

This is a direct effect of the built in assumption that an increase in building activity will bring about a higher absolute implementation of reduction measures. This assumption is true for measure 4 (reduction of waste produced on the construction site), which depends on the building activity (volume) for absolute savings. However, for measure 1 this may not be the case as production of

Timber walls may not be able to rise quickly enough to meet demand caused by higher building production. However, it is assumed in this research that it can and its incorporation instead governed by a percentage of new buildings in which developers chose to use timber walls. This assumption affects the results as if the supply side for measure 1 was capped then the percentage of cumulative resource saved would become lower for scenario C, as a higher proportion of the buildings being produced in this scenario would not be able to implement measure 1.

2013 is the base year used for the future projections. With the trend in level of resources used per $100m^2$ building production over the period 2000-2010 extrapolated and multiplied by the level of building activity projected for each of the scenarios. If 2020 and 2030 are considered as years to set potential reduction targets from this projected consumption then the savings in those years compared to the (no implementation) projections provide guidance for what can be achieved. The results for these 2 years are displayed below in figure 12E.

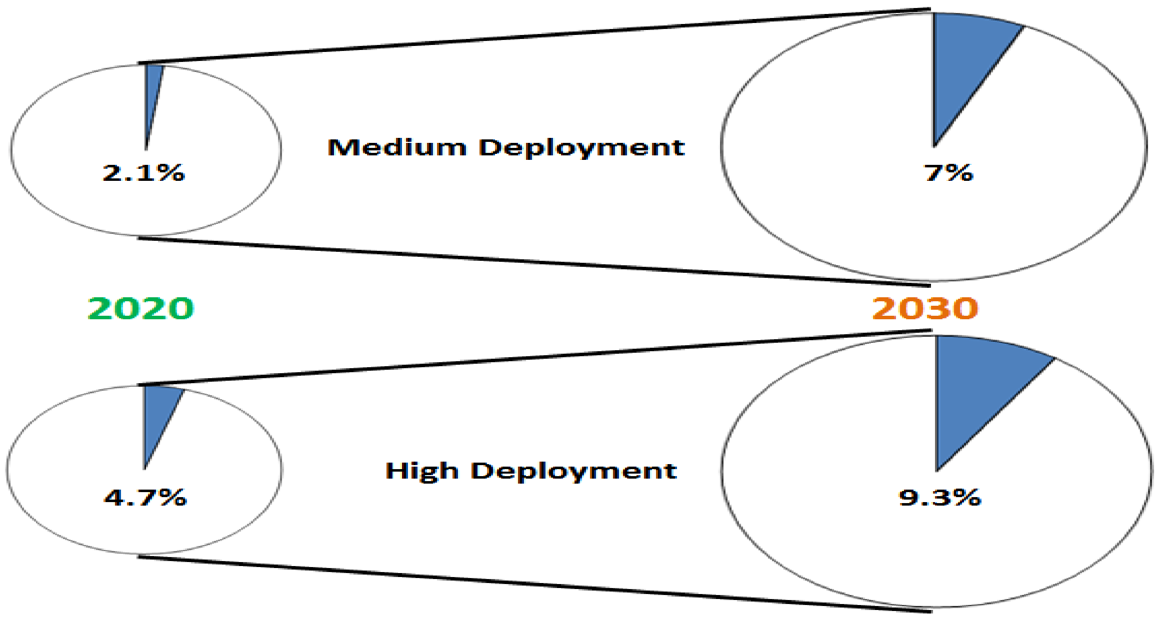


Figure 12E: *The % of resource reduction in the target years (2020) & (2030) compared to no implementation projections.*

Figure 12E once again identifies the benefits of allowing a longer time period for measures to fore fill their maximum potential. These results are invaluable for policy makes wishing to set a future quantitative target for resource efficiency improvements in the sector. They indicate that by the year 2020 if implementation were to start in 2013 ~2.1-4.7 % of the resources need for building production in 2020 could be saved and longer standing targets in the year 2030 would realistically aim ~7-9.3% if only these two reduction measures were to be followed through.

To provide an idea of where priorities should be placed if a less than full implementation of these measures were to be carried out. Figure 12F below indicates that the vast amount of the savings potential is attributable to measure 4 especially under the high implementation strategy.

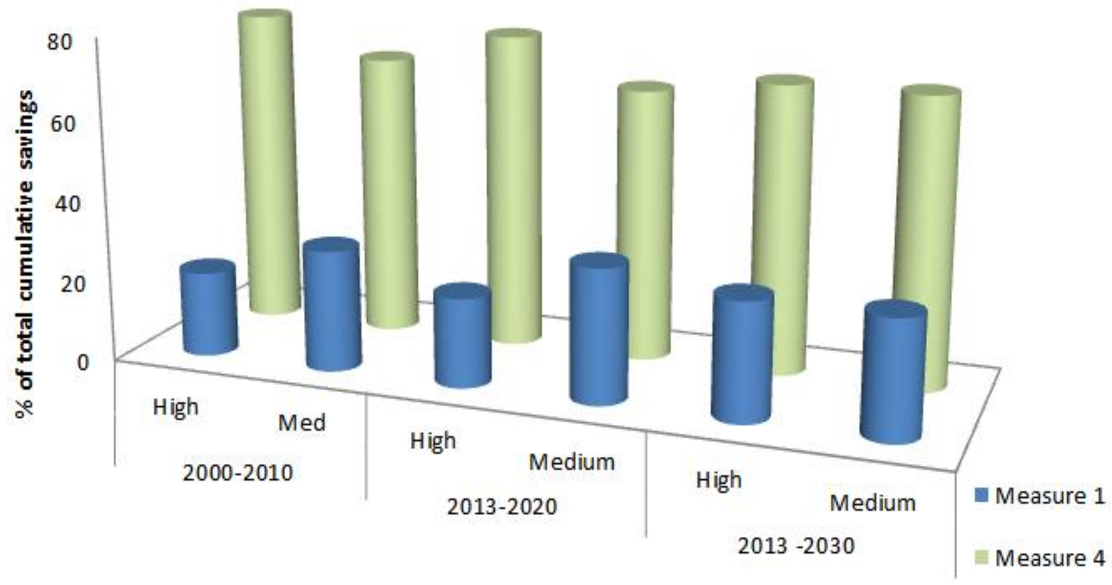


Figure12F: *The contribution of individual measures to the total combined resource savings potential*

All results for the indicators assessed are displayed for convenience of reference in table 12B below with additional projections of how these savings translate to tonnes per 100m^2

Table 12B: *The key statistics for the combined resource savings potential projections for periods (2013-2030) & (2013-2030) under scenarios (A-C)*

	A				B				C			
	2013-2020		2013-2030		2013-2020		2013-2030		2013-2020		2013-2030	
	Med	High	Med	High	Med	High	Med	High	Med	High	Med	High
Total cumulative Savings [Mtonnes]	5.6	11.8	37.5	60.3	7.6	16.1	38.5	64.4	8.9	18.8	49.1	81.2
% of Total Resources used for new building production saved	1.1%	2.2%	3.1%	5.0%	1.1%	2.3%	2.8%	4.7%	1.1%	2.3%	2.9%	4.8%
% of resources used for new building production saved in target year (2020) & (2030)	2.1%	4.7%	7.0%	9.3%	2.1%	4.7%	7.0%	9.3%	2.1%	4.7%	7.0%	9.3%
Tonnes saved per 100m^2 in Target year (2020) & (2030)	6.1	13.7	19.1	25.3	6.1	13.7	19.1	25.3	6.1	13.7	19.1	25.3

12.2 Combined Embodied Energy savings Potential

The combined savings potential for embodied energy in the building sector will be explored in a similar fashion as above for resource savings. The measures explored to reduce the embodied energy within the building sector include

- **Measure 1** (Timber frame and clad walls for replacement of conventional masonry)
- **Measure 2** (Best available technologies for energy reductions in Aluminium & Steel manufacture)
- **Measure 3** (Best available technologies and fly ash replacement for cement production)

A combined package of these 3 measures is explored to identify the total cumulative and annual savings that can be realised under implementation at varying deployments rates and constructional activity using the indicators developed in chapter 10.

12.2.1 Combined embodied energy savings (avoidance) 2000-2010

The total combined savings potential for reduction of embodied energy over the historical period 2000-2010 where building activity is known is displayed below in figure 12G. These hypothetical savings are displayed for both a high and medium rate of implementation.

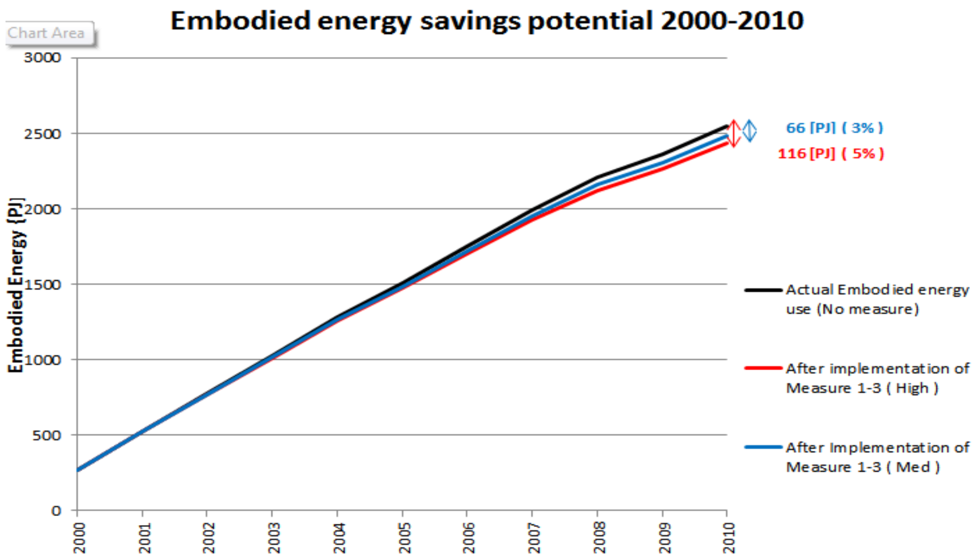


Figure 12G: *The total Embodied energy savings for a 10 year period (2000-2010) in the UK building sector*

As seen above when compared to the savings in resource consumption observed in figure 12A for the same time period comparatively higher savings are realised for embodied energy than resource consumption with 3-5% of projected embodied energy consumption over the period being avoided. This result suggests that it is respectively easier to achieve higher efficiency in the energy needed for new building production than it is for resource use. Up to 5% of the total embodied energy provides opportunity for a substantial saving considering only 3 reduction measures are explored. Under the high implementation of these measures 116 [PJ] could have been avoided.

As the purpose of this research is to highlight the quantitative energy savings that can be realised through tackling embodied energy in the lifecycle stages not currently targeted a comparison of what efforts are needed to meet this in the operational phase are drawn below in figure 12H to provide context to the contribution to energy saving at national level (all sectors).

Assumptions:

The replacement of light bulb to more efficient ones is a common measure used to reduce energy consumption in EU member states.

If a 40w light bulb was replace by a 10w CFL then = 30w saving per annum
Assuming the average house has 20 light bulbs each turned on for an average 3hrs a day
Then (20*30) = 60hrs a day (60 hrs * 30w) = house uses 1.8KWh for lighting each day
(1.8KWh * 365 days) = 657 KWh per annum

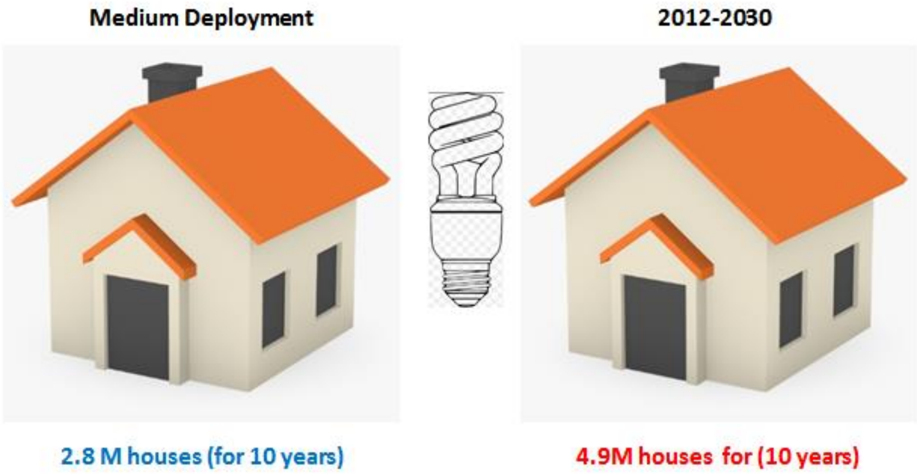


Figure 12H: Amount of houses required to change all bulbs from 40W to 10w CFL to bring about identical energy savings as those for measures 1-3 (2000-2010)

As seen in figure 12H the amount of absolute reduction that could have been realised in the period 2000-2010 are equal to 2.8 – 4.9 million houses changing from 40w to 10w bulbs for 10 years

Up to 10.5% of the energy saved for building production in the year 2010 could have been avoided, which indicates, larger cumulative savings are to be expected if the implementation period extended into future years. All key results for the period are displayed below in table 12C

Table 12C: *Key statistics for the hypothetical combined embodied energy savings over the period 2000-2010*

Historical 2000-2010		
	Med	**High**
Total cumulative energy avoided [PJ]	66	116
% of total cumulative energy used for new building production avoided	2.6%	4.6%
% of energy used for building production avoided in the final year	5.2%	10.5%
Energy avoided [GJ] per 100m^2 of new building production in the final year	58	116

12.2.2 Combined embodied energy consumption savings for the periods (2013-2020) & (2013-2030)

The combined cumulative embodied energy savings potential for the periods (2013-2020) & (2013-2030) are displayed below in figure 12I and are representative of the reduction from projections under no implementation.

Figure 12I: *The combined embodied energy savings potential (2013-2020) & (2013-2030) for scenarios A-C*

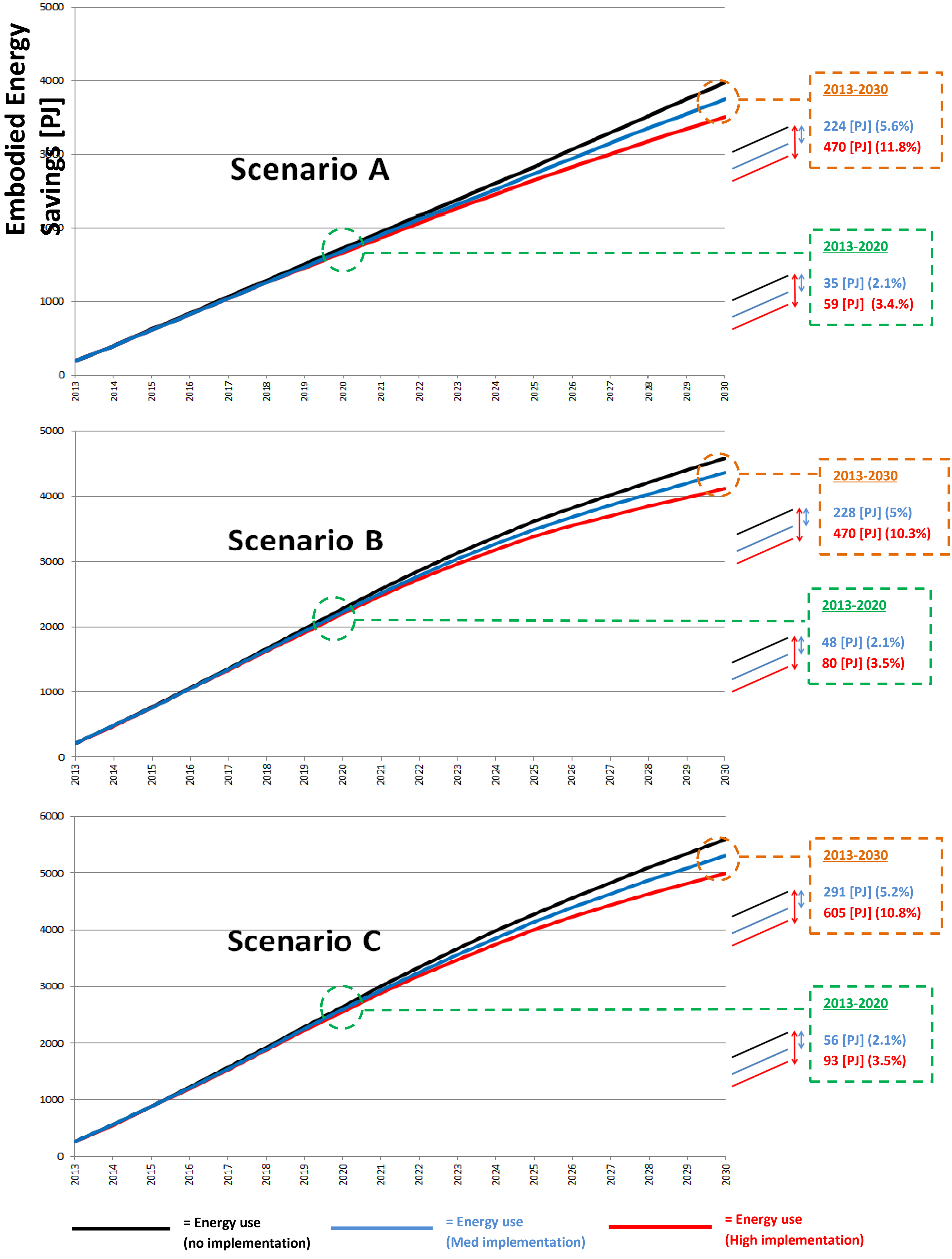


Figure 12I identifies that larger efficiency gains could be realised for the embodied energy consumption in new building production when compared to resource use. Over the period (2013-2020) this is equivalent to 2.1-3.5% of the total, and longer-term implementation (2013-2030) could bring about cumulative reductions of 10.3-11.8%. Considering all paths of building activity explored this translates to absolute savings of 35-93 [PJ] by 2020 and 224-605 [PJ] by 2030.

The percentage of cumulative energy use saved (2013-2030) is actually higher for the scenario with the lowest building activity (scenario A). This is due to a higher proportion of the total construction in this period being performed in the latter years of the period when the reduction measures are applied to a larger percentage of the new construction per annum. This highlights how the volume effect total savings when deployed over a period of time when construction levels are unknown. This is once again an outcome caused by the assumed linking of absolute reductions bought about by the measure and building activity. This assumption for measures 2 & 3 is due to the measures being applied at global scale and the UK receiving its fair share of higher efficient products, assuming overall the sectors demand drives the take up rate of measures throughout the global industries.

The reductions reported are however likely exaggerated to a degree as a frozen efficiency of the embodied energy needed to create all key materials is deployed. This method was adopted due to a lack of projections into the likely decrease in energy intensity required in the manufacturing process for the future periods.

To put the recorded savings into perspective for the reductions required during the operational phase. The amount of houses needed to change 40w light bulbs to 10w CFLs to bring about identical savings are displayed below in figure 12J

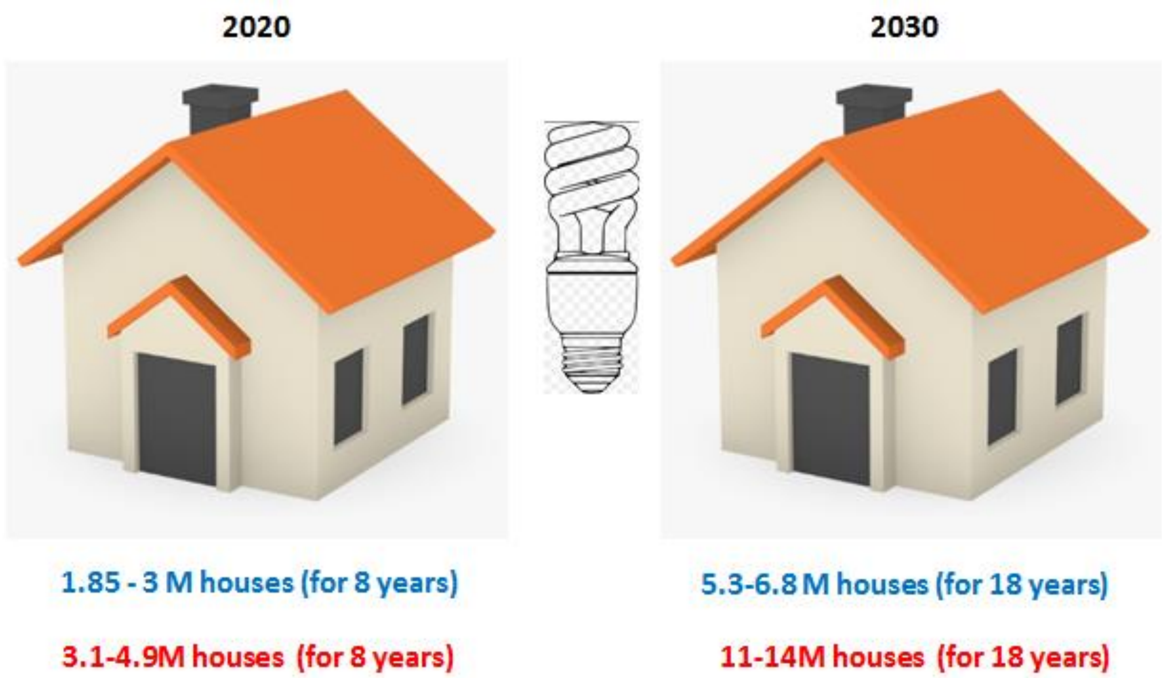


Figure 12J Amount of houses required to change all bulbs from 40W to 10w CFL to bring about identical energy savings as those for measures 1-3 (2013-2020) & (2013-2030)

When compared to the projected embodied energy required for new building production under no implementation. If the years 2020 and 2030 are considered future target years for desired energy efficiency gains for new building production. Assessing the savings achieved in these years compared to the projected use in the annum from the 2013 base year, will provide guidance for what can be realistically achieved considering the measures explored tackled the largest problems. These efficiency improvements are displayed in figure 12K below.

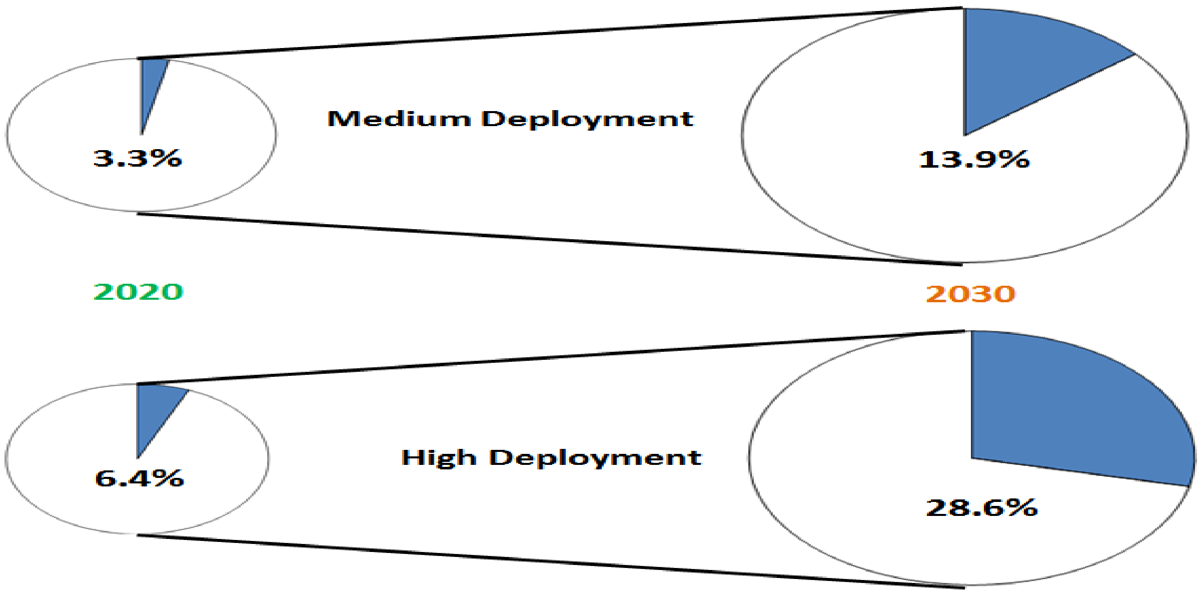


Figure 12K: *The % of embodied energy avoided in the target years (2020) & (2030) compared to no implementation projections.*

As seen in figure 12K there are significant efficiency gains that could be realised for embodied energy consumption. With improvements of 3.3 – 6.4% for new buildings possible by the year 2020 and building production in 2030 requiring 13.9-28.6 less energy input. This provides a real opportunity and promise for future contributions to total UK energy consumption reductions.

To provide insight into where policy makers should place priority should all measures not be implemented, figure 12L below shows that measures 1&2 provide roughly equal contribution to the reduction with measure 3 contributing on average <10%.

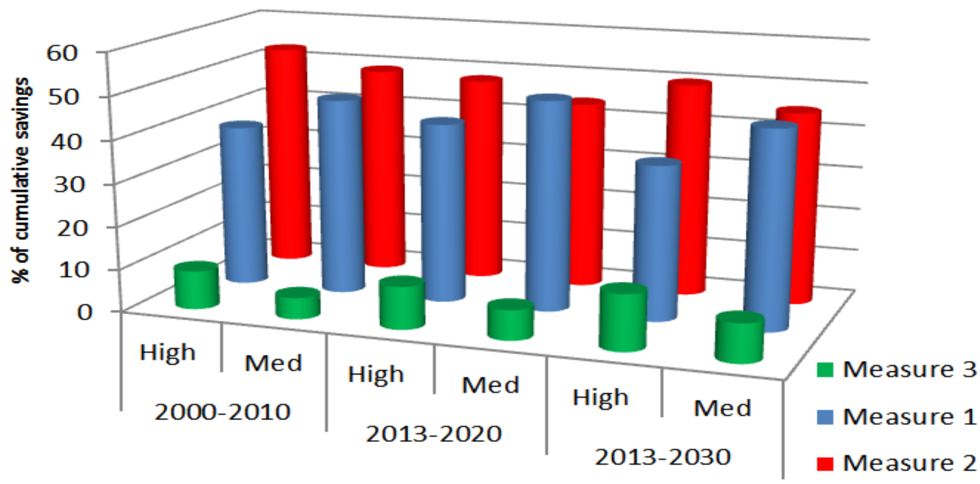


Figure 12L: *The contribution of individual measures to the total combined embodied energy savings potential*

Table 12D below provides the results for all of the indicators used to assess embodied energy reductions with additional projections of how these translate into savings per 100m^2 building.

Table 12D: *The key statistics for the combined embodied energy savings potential projections for periods (2013-2030) & (2013-2030) under scenarios (A-C)*

	A				B				C			
	2013-2020		2013-2030		2013-2020		2013-2030		2013-2020		2013-2030	
	Med	High	Med	High	Med	High	Med	High	Med	High	Med	High
Total cumulative energy avoided [PJ]	35	59	224	470	48	80	228	470	56	93	291	605
% of total cumulative energy used for new building production avoided	2.1	3.4	5.6	11.8	2.1	3.5	5.0	10.3	2.1	3.5	5.2	10.8
% of energy used for building production avoided in the target year (2020) (2030)	3.3	6.4	13.9	28.6	3.3	6.4	13.9	28.6	3.3	6.4	13.9	28.6
Energy avoided [GJ] per 100m^2 of new building production in the target year (2020) (2030)	32	61	131	269	32	61	131	269	32	61	131	269

13. Discussion

The findings of this research allows for the quantitative savings potential for resource use and energy within the building sector in lifecycles outside of the operational phase currently underexplored to be identified. The implications of these savings are discussed below.

Resource savings

Key findings

For the reduction measures explored significant cumulative savings were attained for the resource use over the periods investigated. The research identified potential cumulative savings of up to 2.3% of the projected use by 2020 and 4.8% by 2030 for the building sector, which is acknowledged as one of the three key sectors to tackle in the European Commission's Flagship Initiative for a Resource Efficient Europe.

What targets can be set

The developed indicators allowed for saving potential brought about by the implementation of the reductions measures to be identified for the proposed target years 2020 & 2030. As no time bound quantitative targets are currently in place for the resource use in the EU, the results from this research allow for provisional targets to be set for this sector whereby a current lack of quantitative understanding in the existing body of literature prevented this. The results show that up to 4.7% of the resource used per annum for new buildings can be saved 2020 and 9.3% in the year 2030.

From these findings provisional targets can be set at

- 5% resource efficiency gains by 2020
- 10% resource efficiency gains by 2030

These targets incorporate an ambitious strategy whereby the high deployment rate identified in this research is adopted and additional measures (which table 9A, presents a selection of) are also implemented to a degree. It is theorised that the provision of achievable time bound quantitative targets will increase the UK's chances of realising possible reductions and aid in the formulation of detailed strategies to support the ambitions of the European Commission.

What this means for the total UK resource use

As no resource targets are in place, for insight into what the reduction potential means at a national scale the research elects to compare the annual potential savings to the annual Domestic material consumption for the UK.

The domestic material consumption data for the UK is not projected for future years but data was available for the year 2010. This was reported by the office for national statistic as 566Mtonnes (including fossil fuels).

From performing analysis of the historical period the results from the research identified that a maximum of

- 3Mtonnes of resources
- 19.2 PJ of embodied energy or 0.65 Mtonnes of Coal equivalent

could have been avoided in the year 2010 if implementation of the measures were introduced in 2000. Thus

(Total savings$_{2010}$ [3 + 0.6]) / (Domestic Material Consumption$_{2010}$[566]) * 100 = 0.65%

It is highly likely that the European Commission's ambitions to increase resource efficiency although not presently quantitatively stated will be significantly larger than 0.65%. This means that whilst significant resource savings are available within this sector, at a national scale the majority of savings will need to come from other sectors. This will probably greatly rely on improving the fuel efficiency of fuel heavy industries.

What it means for the sector

In the Roadmap for a Resource Efficient Europe (EC, 2011b) the following milestone is identified

*"**Milestone:** By 2020 the renovation and construction of buildings and infrastructure will be made to high resource efficiency levels. The Life-cycle approach will be widely applied; all new buildings will be nearly zero-energy and highly material efficient. "*

It is difficult to interpret what is considered "high resource efficient levels" when no quantitative indication is made within these ambitions and the forthcoming communication on sustainable buildings (2013) is not likely to expand on this. This research shows that if a 5% increase in resource efficiency from the levels projected from the period 2000-2010 is classed as "high resource efficient levels" then this milestone for the building sector is possible if supported by policy to the level required to attain the high deployment scenario used in this report. Anything above 5% would need a radical change to the way current buildings are designed and is an extremely unlikely event considering the consistency in the material quantities displayed over the past decade.

It is important that the European Commission also looks at the longer term savings achievable using the measures in this research alone where higher targets can be achieved and accept that a longer term attitude should be taken considering the transitional period required to realise the maximum potential of the reduction measures. Furthermore, at this level of 5% resource efficiency gains, whilst perhaps not at first strikingly impressive it is important to remember that this sector is of huge volume across the EU and in the UK represents reductions of >13.7 tonnes for every 100m^2 floor space created.

Energy Savings

Key findings

The energy savings potential brought about by the identified reduction measures, when compared to the projections under no implementation provided larger efficiency gains, thus overall comparative reductions than for the resource use. The identified cumulative savings potential by the year 2020 was recorded at up to 3.5% [93PJ] and for 2030 up to 11.8% [605PJ]. This vast difference between the time periods was due to the reduction measures explored requiring a longer time span to penetrate the supply chain market.

What targets can be set

Targets aiming for energy efficiency improvements in the EU such as the 20% target from the 2005 base year by the year 2020 set in the EURO 2020 targets are not suitable to assess the efficiency gains brought about for embodied energy. This is because the absolute savings per annum achieved for embodied energy in the sector are dictated by the level of new building activity in the target year thus the research elected to assess the efficiency gains against embodied energy levels projected for new buildings under no implementation.

The results showed that a maximum of 6.4% could be achieved by 2020 and 28.6% by 2030 if implementation started in 2013. This allows for quantitative provisional targets to be proposed of

- 7% embodied energy efficiency gains by 2020
- 30% embodied energy efficiency gains by 2030

These proposed targets require the high implementation of the identified reduction measures to be carried out and additional savings of <1% by 2020 and <2% by 2030 to be acquired through additional reduction measures which are known to exist (displayed in table 9A) and are assumed to be able to meet this extra potential.

It is interesting to note that when aiming to open this area of energy savings up for reductions that can contribute to the national energy targets. A long-term strategy is essential as the reductions in 2030 vastly overshadow those that can be realised in the short term

What this means for the total UK energy use

To provide insight into how the observed future savings potentials could contribute to the national energy savings, projections of the Gross Inland Energy Consumption for the UK have been taken from the PRIMES 2009 scenario (Capros et al, 2010) and are almost identical to that of the DECC's 2012 primary energy consumption projections (DECC, 2012).

Table 13A: *The contribution to total UK energy efficiency gains brought about through the reduction of embodied energy in new building production in the target years 2020 and 2030*

	Gross inland Energy consumption (PRIMES 2009)		Saved in target year	
	Reported in [Ktoe]	Converted to [PJ]	[PJ]	% of total energy consumption projected
2020	208829	8743	23	0.26%
2030	204549	8564	72	0.85%

*The savings displayed in table 13A are for those brought about under maximum deployment in scenario C where the largest absolute savings are observed.

As seen in table 13A the percentage of the total national energy consumption avoided from the Primes 2009 projections are not at first glance impressive being <1% in both target years. From a national perspective then it is clear that the energy savings potential available from opening up the building sector to reduction measures at lifecycle stages outside of the operational phase is not realistically going to have a large effect on energy savings at a national level. Especially not in the short term contributing a maximum efficiency improvement of 0.26% to the Euro 2020 target.

However, it must be remembered that the reduction measure put forward by this research are only affecting newly built construction in the target year which is less then 1% of the entire building stock and this is impressive considering the whole sector only account for 40% of total national energy use.

What it means for the sector

The EC Energy Efficiency Action Plan (EC, 2011d) acknowledges the building sector has the largest savings potential available for energy reductions. However, efforts currently focussing on the operational phase alone are currently unable to meet the 20% reductions needed. Whilst not fully bridging the additional savings required by 2020 the reductions identified in this report do contribute to the gap that needs to be breached if targets are to be realised.

The savings identified become increasingly important when considering the (EIO, 2011) estimates the ratio of a buildings total life energy use has moved from 80:20 to 60:40 (operational: embodied) due mainly to reduction measures in the operational phase.

So if by 2020 20% of the building operational energy is to be reduced this equates to (60 * 0.2) 12% of its total life cycle energy. And this is currently not on target even though reduction measures have been implemented for some years now.

If the ratio 60:40 is assumed to stand until 2030 what the results from this research indicate is that in the year 2030 up to 30% of a building embodied energy can be reduced from the measures identified in this report. This equates to (40 *0.3) 12% total lifecycle energy use of a new building avoided. This is the exact same amount, which is unable to be reached by operational phase reduction measures at present by the year 2020 for the existing building stock. Hence if given the same respect reduction of embodied energy in buildings can achieve the targeted reduction but it will now take until 2030 because measures were not deployed earlier, which is only fair considering the attention in the previous year to reduction measures in the operational phase.

It is the intention of this report that this be seen as a Eureka moment within this research and perhaps the most valuable result for future strategies. A famous idiom springs to mind “don’t put all your eggs in one basket”. This is likely to become increasingly important for new buildings with a very energy efficient “nearly zero energy” operational phase, which the UK plans to adopt by 2021 at the latest. This would involve the incorporation of renewable energy and would mean the 60:40 split would become far less for the operational phase and embodied energy would be the dominant factor.

Lessons for Europe

There is a wide and varied resource use and performance level throughout regions in the EU with average resource intensity per m^2 floor space observing drastic differences. Thus by identifying the resource savings that can be achieved for the UK serves only as a proxy for the levels that may be achieved across the EU with nations likely excelling or underperforming for individual measures. Additionally, it is extremely complex to determine what contribution the identified measures play into total resource savings for the EU as they only address 1 (perhaps 2 including industrial) sector, thus at a EU wide or even national level this will ultimately depend on the makeup of the economy.

With longer-term targets in mind the World business council for sustainable development predicts a need to reduced resource consumption levels to just 10-25% of current levels by 2050. Under the reduction measures explored in this research, savings potentials in the building sector are unlikely to meet this reduction. However, during this research it was identified that there is significant scope for the rest of Europe to improve the use of primary resources in the building sector. This was identified by the reductions of primary aggregate use (the largest material by quantity) for the building sector being much higher for the EU average than for the UK. With the percentage of aggregates used deriving from recycled source being 23% for the UK compared to a EU average of 5% (BAA, 2005).

For energy savings the measures explored provide real opportunity for the EU building sector as a whole and it is predicted similar levels of efficiency gains can be achieved for new building production in most member states due to the choice of materials investigated as they are consistently used in buildings throughout the EU. The replacement of conventional walls by timber structures would have a significant effect for many member states however would be more limited in counties such as Norway and Sweden which already have >90% of the total building stock constructed this way (BRE, 2000). Measure 2 and to an extent measure 3 are more international measures which means there implementation would by default affect the whole of the EU.

The results obtained from this research then serve to act as an example of what may be achieved for the EU building sector as a whole if these measures where to be adopted as harmonised EU standards. However, to calculate the accurate savings potential would likely require that the resource consumption for each nations building sector be identified and projected forward as done within this report.

Issues Encountered (limitations of the Research)

Over the course of the research a number of practical difficulties in particular surrounding the analysis of the savings potentials were encountered. Choices that were made to overcome these issues have been explained and justified. However, the accuracy of the produced results are affected to an unknown extent as an outcome. This may lead to the over exaggeration or underreporting of the savings potential explored, but most likely the former. These issues are discussed below.

The selection of reduction measures investigated are aimed at tackling areas of resource and embodied energy consumption deemed most important from a quantitative analysis of the sectors absolute consumption over the period 2000-2010. However, other reduction measures that are reported at small scale projects and some of which listed in table 9A may hold a greater absolute potential even if they do not aim to tackle the major areas of concern. This is doubtful but it is important to acknowledge this may be the case. Further investigation into a broader range of reduction measures would enable the research to answer this.

The development of the deployment potentials explored during the research was largely based on the assessment of similar technological or behavioural transitions performed in various sectors. However, for these deployment potentials to be more accurately predicted and thus the timescale in which savings can be brought about better understood, the research would benefit from a deep cost benefit analysis of each proposed measure. This is under the premise that stakeholders within the sector will predominantly base their decision on whether to implement the measures on whether they are economically viable.

The incorporation of a frozen technology baseline for the embodied energy requirements needed for the production of buildings (for each material) was adopted throughout. This technique means that autonomous improvements in the energy efficiency of material production are not factored into the results produced. Ultimately this means that the (no implementation) projections for future periods may over report the energy demand of new building production, thus the savings potential for energy are likely to be slightly lower than projected by this research. One way to avoid this would be to incorporate the projected energy requirements for building product production up to the furthest data point 2030. However, due to the fact that manufacturers often display varying energy requirements for the same product and there being no readily available projection of these expected efficiency gains this was not possible during the analysis at present.

Within the framework of this project, one could expect that building materials production (especially of metals) technologies are becoming less energy intensive in general through increased efficiency. However, the efficiency increase, although quantitatively unknown, is expected not to influence the prioritization of measures selected, as the changes are not large enough to cover the differences among the materials.

The absolute reductions brought about by the implementation of the identified measures in this research is calculated from the deployment potential for each measure being linked with building activity in a way that presumes the more building production the more absolute savings. If this deployment potential were to be delinked from the building production then absolute amounts of savings per time step (annum) would stay static over the scenarios meaning that a higher percentage of the total sector wide resource and energy use would be saved in scenarios with lower building production for measure 1-3 as the deployment over an 18 year period (the maximum length assessed 2013-2030) does not reach 100%. The results for measure 4 where deployment reaches 100% means higher absolute savings would be brought about in the higher building production scenarios.

Whilst for measure 4 this technique holds true as the more building production occurring the more waste can be saved during the construction phase. For measures 1-3 this assumes that more effort is placed on implementing the measures due to the economic profits of the related industries from more sales to the sector. This may not accurately model the supply sides capability, as growth may not develop in line with building activity.

Further Research & Recommendations

Analysis of further reduction measures

As suggested for the 2020 and 2030 targets there is a prospect to increase the saving potential available for both resource and energy consumption. A range of additional options are listed in table 9A and further research into the potentials they hold would only serve to increase the contribution of savings to national consumption projections. The methodology deployed within this study allows for the scope of this research to be expanded to incorporate a broader array of reduction measures with no alterations needed. This may be built into an updatable database with little additional work needed allowing multiple researchers to add to the overall savings and with a deep cost benefit analysis would enable a marginal abatement cost curve to be developed for savings available in the building sector from a whole lifecycle perspective as is currently available for the operational phase.

Construction of a database that records resource consumption

For an accurate assessment of the quantity of the main resources used for new building construction in the UK the period 2000-2010 was explored, as data was available. However, this data is not readily available and certainly not easily accessible. A series of national consumption indicators mainly provided in Eurostat's Prodcom database and various industry databases had to be rigorously analysed and cross-checked where possible. Even after this step these quantities were only true for total consumption at national scale or for the UK construction sector as a whole, which includes infrastructure such as roads. Thus, further investigation in industry wide sales and market share breakdowns had to be located and analysed to find the percentage (quantity) of which was attributed to the building sector. This was no easy task and required a large proportion of the time spent during this research. For the UK this research then provides a method for tracking this consumption for the time being. However, if market shares of materials for the built environment should change these would have to be factored in. For this reason it is essential that an annually updated database is created for resource consumption in new building production. This would ideally be carried out by the building companies themselves and record all projects material input into an electronic online database which should be designed so that it automatically compiles the data inputs from all building companies. This is especially important for assessment at EU level, as it is not known if these material consumptions can currently be tracked for other member states that may have even greater information deficiencies.

Policy analysis and Impact Assessment

The results produced from this research provide invaluable information for EU policy makers with regards to directing the strategies of building design, construction and manufacturing processes throughout the supply chain of the UK building sector, and furthermore that of the EU. The provision of these savings projections provide further aid in future tasks surrounding the monitoring and review of performance of implemented measures compared to the maximum savings potential and defined targets.

However, the direct route to the implementation of these reduction measures will require additional policy support and regulation of the current process involved in building production and building product manufacture throughout the supply chain. This may also require additional policy action to promote the adoption of green building techniques. Further research into what this entails and the best route at national and EU level is needed. It is likely that the on-going project performed in part by the internship company Triple E entitled "Sustainable Building" for the European Commission's DG Environment will aid in this task. The sustainable building project focuses on the policy objectives defined by the EC to improve the take up rate of sustainable buildings that primarily focus on decreasing resource use. The study also aims to provide an ex ante impact assessment on how the introduction of such policy would affect the sector and its stakeholders as well as the wider society and environment, which includes the economic pressures that may appear as a result. This study is expected to be completed by late 2013.

Addressing resource use in other sectors

As discussed under the heading "What this means for the total UK resource use" above, the reductions applicable in the building sector for total UK resource use per annum only achieved 0.65% if hypothetically implemented in the 10th year of implementation from the 2000 base year. Whilst this figure is subject to increase given a longer period of time it is not going to produce a large resource efficiency increase. Therefore, research into the resource savings in other sectors especially those which are fuel intensive is needed to bring about more significant improvement. It is highly likely that the role of renewable energy will dramatically affect any ambitions to decrease absolute resource use when fuel is considered. Any larger savings in resource use in the built environment would require technological improvements currently not available or the willingness to completely change the notion of what materials a building is constructed from.

14. Conclusion

The research questions proposed by this study were answered upon completion and are concluded as follows

Recap of Research questions:

Main Question

What are the quantitative potential savings in resource use and associated embodied energy available in new building construction that can be brought about through the implementation of currently available reduction measures at sector wide scale for the UK?

Sub questions

What are the main resources used within the UK building sector?

What is the average intensity of use for each of these materials between 2000-2010 in UK building production in terms of Kg/m^2 and the associated embodied energy KJ/m^2?

What are the largest contributors to resource and energy consumption during building production?

What are the reduction measures available to tackle the areas of concern in excess consumption and what potential do they hold at local level (tonnes/100m^2) [MJ/100m^2]?

What are the hypothetical savings at National level in terms of resource use and embodied energy for each of the identified reduction measures for the period 2000-2010?

What is the potential for these identified savings if translated into actual future savings that can be realised at national level over the periods 2013-2020 and 2013-2030?

Are these identified reduction measures feasible at national scale?

Can Resource and embodied energy efficiency improvements for new building production be tracked? If so 1) what levels of improvement can be projected up to 2020 & 2030, 2) Can suitable quantitative time bound targets be created?

Identifying the potential resource and energy savings for new construction in the UK building sector that may be brought about by the implementation of reduction measures was the intention of this research. The results obtained indicate significant resource savings can be achieved over the short to mid term future and that an even greater proportion of the embodied energy used for new building production can be reduced within the time periods investigated. In the wider context of national consumption the savings identified per annum appeared insignificant for both resource and energy use representing saving of <1% of the projected national consumption. However, it must be acknowledged that savings identified are only achievable in new building production of which represents <1% of the existing building stock (which accounts for ~40% of national energy use).

A deep analysis of the UK's building sector over the period 2000-2010 allowed for the major materials used within the construction of new buildings to be identified along with the absolute consumption trends and intensity of use for new construction. This was achieved through rigorous data collection and analysis of Eurostat and industry databases and market share reports to isolate the quantities used within the building sector.

Once identified each key materials quantity was multiplied against a fixed embodied energy figure reported in (ICE, 2008) which allowed for the total energy requirements to be identified. Further identification of the levels of building activity recorded per annum in the UK allowed for the intensity of resource and energy use per 100m^2 of floor space produced to be identified.

The analysis of the historical period allowed for insight into what the largest contributors to overall energy and resource consumption were in the sector identified as:

- Resources: Aggregates, Cementious material, Bricks
- Embodied Energy: Steel, Aluminium, Bricks, Cementious material

The reduction measures proposed to tackle these areas were identified as

- **Measure 1** – Timber frame and clad walls (as a substitute for conventional masonry)
- **Measure 2** – Best available technology to lower the embodied energy of metal
- **Measure 3** – Best available technology and fly ash replacement for cement production
- **Measure 4** – Waste management at the construction phase

The absolute savings potentials were identified for each time period investigated for these measures at local level, national scale and when combined as a package. These results are displayed below in table 13A

Table 13A: *The savings potential held by each measure at local and sector wide scale, also presented combined savings for implementation as a package for the time periods investigated.*

Measure	Local level		National level					
			2000-2010		2013-2020		2013-2030	
	Resource	EE	Resource [Mt]	EE [PJ}	Resource [Mt]	EE [PJ}	Resource [Mt]	EE [PJ}
1	26.55 [tonne/100m2]	247 [GJ/100m2]	3.3-4.7	31-44	1.9-4.1Mtonne	18-39	11-23.4 Mtonne	103-217
2		36 [GJ/tonne of Aluminium] 13.45 [GJ/tonne of Steel]		32-62		16-45		102-308
3		0.37 [GJ/tonne of ready mixed concrete] 0.24 [GJ/tonne of concrete block]		4-10		2.4-9.3		19.7-79.4
4	14.1 [tonne/100m2]		7.6-17.9		3.7-14.6		26.1-57.8	
		Combined savings	10.9-22.6	66-116	5.6-18.8	35-93	37.5-81.2	224-605

The measures are considered to be technically feasible at the scale required to bring about the identified savings owing largely to the fact that they are already commercially viable at project level or in at least in one production plant for measures that require reductions in the manufacturing stage.

From the development of a new indicator set it was possible to track how these absolute quantitative savings could improve the levels of efficiency observed for projections under no implementation table 13B below identifies these improvements.

Table 13B: The efficiency gains brought about by implementation of the reduction measures for new building production

Efficiency improvement possible through measures		
	Target year 2020	**Target year 2030**
Resource Efficiency improvements	4.70%	9.30%
Energy Efficiency improvements	6.40%	28.60%

The tracking of these improvements allowed for provisional time bound quantitative targets to be set that include the incorporation of other reduction measures identified but not explored in this report. These are

- 5% resource efficiency gains by 2020
- 10% resource efficiency gains by 2030
- 7% embodied energy efficiency gains by 2020
- 30% embodied energy efficiency gains by 2030

Whilst the importance of these savings for a new buildings construction are subject to change considering efforts in the operational phase are likely to increase, especially considering the role of renewable energy such as PV panels and wind turbines for individual buildings. The fact remains no house will be "nearly energy zero" when a whole life cycle perspective is taken and that the reductions identified in this report offer further absolute savings then tackling the operational phase alone. These savings should not be over looked no matter how energy efficient the use phase becomes.

"Facts are stubborn things, but statistics are more pliable" **Mark Twain**

"Some people see the glass half full. Others see it half empty.
I see a glass that's twice as big as it needs to be" **George Carlin**

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16.Annex

Within this section of the Report the data sheets have been compiled with references attached for ease of use for the reader and future research purposes.

Aluminium 2000-2010 (Data Sheet)

Table: *Aluminium consumption and associated embodied energy*

UK Aluminium Consumption (2000-2010)											
	2000	**2001**	**2002**	**2003**	**2004**	**2005**	**2006**	**2007**	**2008**	**2009**	**2010**
Quantity (Ktonne)											
Production	738.7	690.9	607.4	560.5	564	518.1	622.1	551.8	499.8	355.62	380.8
Imports	406	404.8	437.6	520.5	422.1	424.3	491.5	528.5	556.4	488	658.9
Exports	248.4	218.9	224.1	208.1	208	301.3	354.3	376.2	315	206.3	178.1
Total Consumption	896.3	876.8	820.9	872.9	778.1	641.1	759.3	704.1	741.2	637.32	861.6
Used in building Sector	233.0	228.0	213.4	227.0	202.3	166.7	197.4	183.1	192.7	165.7	224.0
Embodied Energy (TJ)	36120.9	35335.0	33082.3	35177.9	31357.4	25836.3	30599.8	28375.2	29870.4	25684.0	34722.5

Table: *Aluminium consumption UK (raw data)*

Wrought & Cast Despatches	**2000**	**2001**	**2002**	**2003**	**2004**	**2005**	**2006**	**2007**	**2008**	**2009**	**2010**
Bar section and Tube (Ktonne) (excluding Forging Bar)	184.7	177.1	168.3	158.7	157	140.9	138.1	120.8	94.4	70.82	97.3
Plate, sheet, Strip & Circles (Ktonne)	419.1	384.8	312.2	274.3	267.3	274.2	325.4	291	291.9	204.8	182.3
Castings (Ktonne)	134.9	129	126.9	127.5	139.7	103	158.6	140	113.5	80	101.2
Exports	**2000**	**2001**	**2002**	**2003**	**2004**	**2005**	**2006**	**2007**	**2008**	**2009**	**2010**
Primary Ingot	347.7	203.4	214.7	244.3	305.1	364.4	309.6	250.6	230.8	214.1	335.2
Secondary Ingot	84.2	59.9	35.7	26.9	30.8	32.3	40.6	47.5	99.7	107.7	58.3
Extruded products	25.5	20.6	15.3	14.2	15.8	15.9	65.6	89.6	63.2	46.3	58.1
Rolled Products	222.9	198.3	208.8	193.9	192.2	285.4	288.7	286.6	251.8	160	120
Imports	**2000**	**2001**	**2002**	**2003**	**2004**	**2005**	**2006**	**2007**	**2008**	**2009**	**2010**
Primary Ingot	277	313.3	353.2	274.6	221.5	189.3	281.5	278.8	239.4	335.2	190
Secondary Ingot	23.5	33.6	17.9	20.2	12.7	11.5	12.7	16.5	16.1	11.7	14
Extruded Products	72	72.5	76.1	82	90.3	95.1	120.3	144.6	147.3	97.6	210
Rolled Products	334	332.3	361.5	438.5	331.8	329.2	371.2	383.9	409.1	390.4	448.9

The Raw data in the parallel table is collected from the Aluminium Federation 2011 annual Report[1] and displays the despatches of Aluminium castings, extrusions and rolled products from the UK producers and imports/exports of these components (highlighted in yellow). The delivery of aluminium products to the downstream sectors can be inferred by adding the dispatches and imports and then subtracting the exports of the three categories of aluminium products. The proportion of aluminium going into each industry sector is then estimated using a percentage split provided by Alfed(26% building sector)

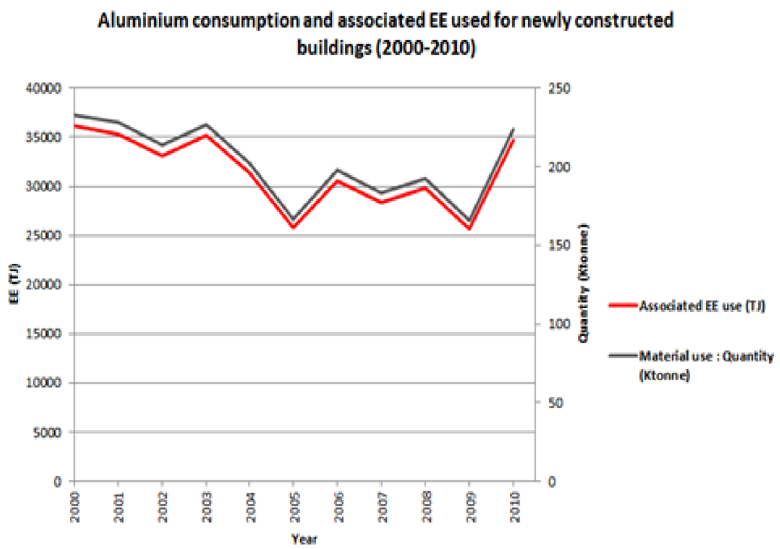


Figure A9: *The Total consumption of Aluminium by the UK building sector and associated embodied energy(2000-2010)*

Supportive information

Quantity

The Quantity of aluminium consumption has been calculated using the amount of sold aluminium in the downstream sectors which provide the building industry with the components used. This data refers to the despatches of Aluminium castings, wrought ,extrusions and rolled products from the UK producers and imports/exports of these components highlighted in table aluminium Consumption (Raw data)

Of this sold aluminium product quantity 26% is directly used in the building industry[2]

(Despatch + Imports - Exports) * 0.26 = Total aluminium used in UK buildings

Embodied Energy

Embodied energy of aluminium = 155 (MJ/Kg) (ICE, 2008)

Total aluminium used in UK buildings (Ktonnes) * 155 = Total Aluminium EE (TJ)

[2] Aluminium Federation LTD,. 2011. Annual Report 2011. AF Publication available through internal website. Last accessed on 1/5/2013 http://www.alfed.org.uk/downloads/documents/XE6KD7HOCC_alfed_annual_2011_single.pdf

Copper 2000-2010 (Data Sheet)

Table: *Copper consumption and associated embodied energy*

UK Copper Consumption (2000-2010)											
Quantity (Ktonne)	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010
Total UK consumption of Refined Copper	310.0	303.0	261.0	250.0	243.0	203.0	170.0	182.0	164.0	149.0	153.0
Copper Consumed in the Construction industry (29%)	89.9	87.9	75.7	72.5	70.5	58.9	49.3	52.8	47.6	43.2	44.4
Copper used directly for buildings (75%)	67.4	65.9	56.8	54.4	52.9	44.2	37.0	39.6	35.7	32.4	33.3
Embodied energy (TJ)	4653.7	4548.6	3918.1	3753.0	3647.9	3047.4	2552.0	2732.2	2461.9	2236.8	2296.8

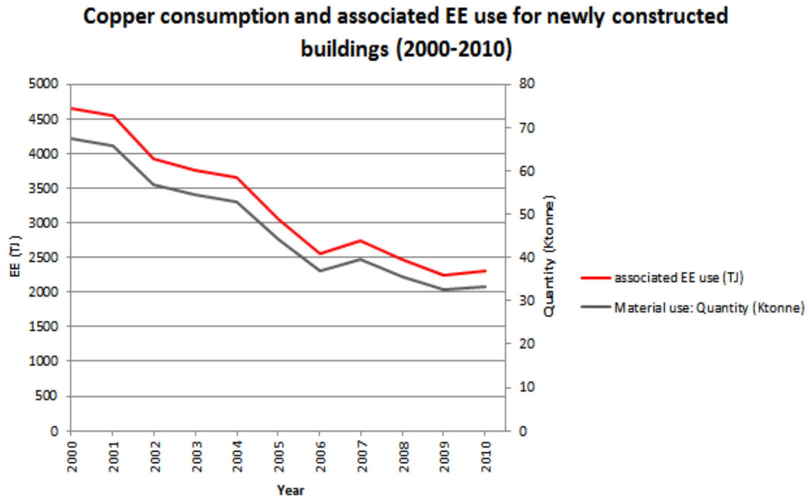


Figure A14: *The Total consumption of Copper by the UK building sector and industry associated embodied energy (2000-2010)*

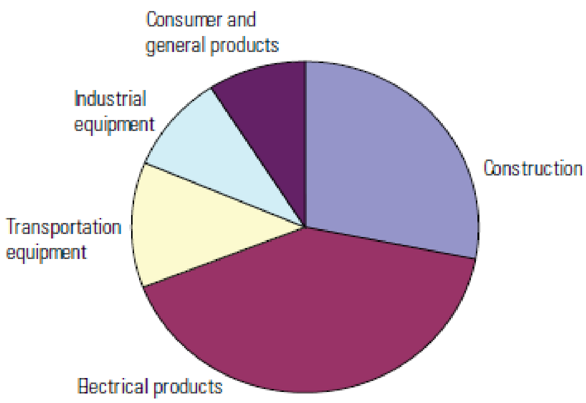


Figure A10: *Copper consumption in breakdown by absolute quantity*. **Source – (**BGS, 2007)

Supportive Information

Quantity

All copper products used within the building industry must first be refined. The Total amount of Refined copper consumption used in the UK is reported by World Beauru of Metal statistics[3] and used as the raw data for UK consumption.

Of all Refined Copper consumed in the UK 29% is used in construction seen in figure A10.

Of this 29% (75%) is used directly in buildings[4]

Embodied energy

As seen observed for Aluminium, Copper is not used within the UK building industry to the extent of other metals in terms of quantity. However, it too has a high embodied energy content

Embodied energy of Copper = 69.02 (MJ/Kg)   (ICE, 2008)

[3] World Beurau of Metal Statistics, 2011. World metal statistics 2011. Online database http://www.world-bureau.com/

[4] European Copper Institute (ECI),. 2011.The environmental profile of copper products A 'cradle-to-gate' life-cycle assessment for copper tube, sheet and wire produced in Europe. Avenue de Tervueren 168, b-10 1150 Brussels / Belgium

Steel 2000-2010 (Data Sheet)

Table: *steel consumption and associated embodied energy*

UK Steel Consumption (2000-2010)											
Quantity (Ktonne)	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010
Steel Production	15100	13400	11500	13100	13800	13200	13900	14100	13500	10100	9700
Import	7700	8100	8900	8200	8800	7800	8900	9400	8000	4400	6200
Export	7800	6900	6600	7300	7800	8700	8500	9500	8900	6300	6000
Total Consumption	15000	14600	13800	14000	14800	12300	14300	14000	12600	8200	9900
Consumed by construction sector (29%)	4350	4234	4002	4060	4292	3567	4147	4060	3654	2378	2871
Consumed by building Sector (75%)	3262.5	3175.5	3001.5	3045.0	3219.0	2675.3	3110.3	3045.0	2740.5	1783.5	2153.3
Embodied Energy (TJ)	100843.9	98154.7	92776.4	94121.0	99499.3	82692.0	96137.8	94121.0	84708.9	55128.0	66557.0

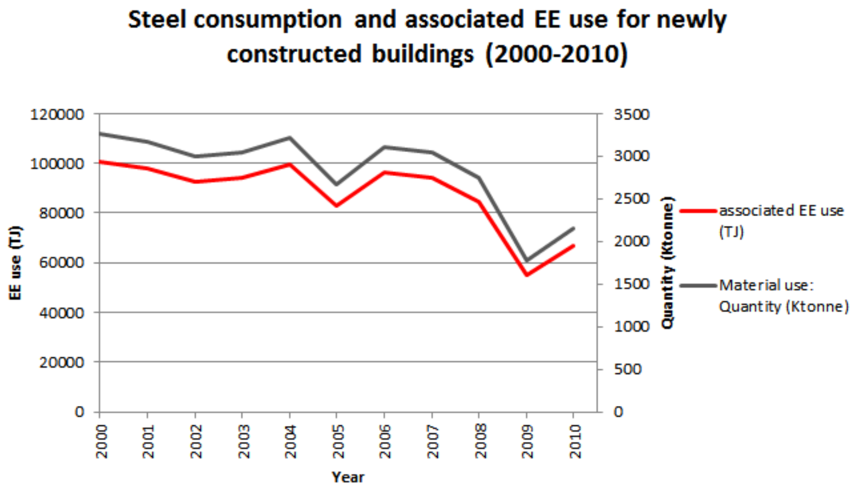


Figure A16: *The Total consumption of Steel by the UK building sector and associated embodied energy(2000-2010)*

Supportive Information

Steel is the dominant metal used within the UK construction sector[5]

Quantity

The Domestic Production of UK steel is calculated using

(Production +Imports) – Exports) = Total consumption per annum the data was collected from EEf UK steel data[6]

According to the EEF UK Steel 29% of Steel consumed in the UK is contributed to the construction sector, of this 29% (75%) is directly used in buildings[2]

Therefore, quantity used in building per annum = ***(Total national Annual consumption * 0.29) * 0.75 = Total annual Steel consumed in building sector***

Embodied Energy

The Embodied energy of structural steel = 30.91 (MJ/ Kg) (ICE, 2008)

Therefore Total embodied energy = ***(Total quantity of Steel used per annum [Ktonnes] * 30.91) = Total embodied energy of steel used [TJ]***

[5] Smith, R.A, Kersey, J.R and Griffiths, P.G ,. 2002. The Construction industry Mass balance: Resource use, wastes and emissions. Viridis Report. VR4

[6] EEF,.2010.EEF UK steel Statistic 2010. EEF publication London

Aggregates 2000-2010 (Data Sheet)

Table: *Aggregate consumption and associated embodied energy*

UK Aggregates Consumption (2000-2010)											
	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010
Quantity (Ktonne)											
Gravel and sand used in construction	89234	88210	82721	80221	86057	82392	80242	78501	27127	55709	54303
Gravel and sand used in buildings (24%)	21416	21170	19853	19253	20654	19774	19258	18840	6510	13370	13033
Crushed Stone											
Production	129122	121912	112946	108686	121435	121000	124000	131000	118000	91470	82733
Imports	203	123	189	347	420	558	340	251	236	248	255
Exports	2390	3416	3566	3136	4360	4765	5402	6026	5216	4668	4942
Total Consumption	126934	118619	109569	105897	117495	116793	118938	125225	113020	87050	78046
Used in Buildings (24%)	30464	28469	26296	25415	28199	28030	28545	30054	27125	20892	18731
Total Aggregates											
Total Gravel, Sand & Crushed stone consumption	51880	49639	46149	44668	48852	47804	47803	48894	33635	34262	31764
Embodied Energy (TJ)											
Total Embodied energy for Aggregates	5188	4964	4615	4467	4885	4780	4780	4889	3364	3426	3176

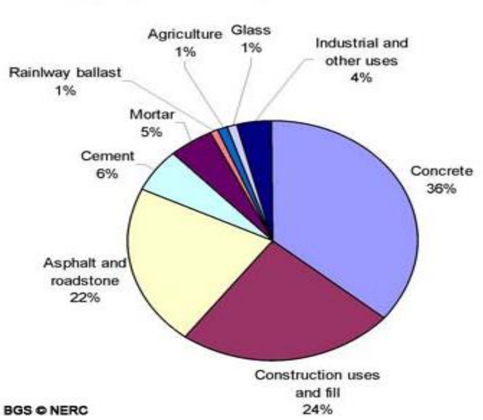


Fig Ag 1. *Breakdown of aggregates end use*

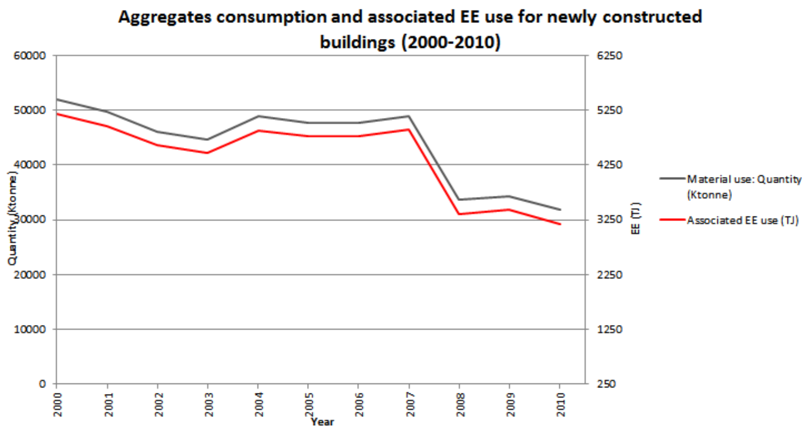


Figure A18: *Consumption of Aggregates by the UK building sector and associated embodied energy*

Supportive Information

Gravel & sand and crushed stone are the most heavily used aggregates in the building sector. These two materials are investigated to identify annual consumption and associated embodied energy

Quantity

Sand and Gravel

The table above shows the total amount of Sang and gravel used in the UK per annum reported in the Annual Raised Mineral Enquiry[7]. Of this total 24% is attributed directly to the building sector excluding concreting seen in fig Ag 1[8] this percentage is also reported by (Smith, Kersey and Grifiths, 2002).

Crushed stone

Crushed Stone quantity is total use in the UK for construction calculated using the (Production + Imports – Exports) method, with data taken from the Eurostat prodcom database [9]24% of crushed stone is attributed to building industry according to the European Aggregates Association 2012 Report[10]

Embodied Energy

General aggregates such as sand crushed stone and gravel have an average embodied energy = 0.1 (MJ/Kg) (ICE,2008)

7 Office for National Statistics,. 2012. Annual Raised Mineral Inquiry.

8 Natural Environment Research Council,. 2011. Consumption end market for Aggregates. British geological Survey Commissioned report

9 Eurostat,. 2013. Prodcom Database . Accessed through http://epp.eurostat.ec.europa.eu/portal/page/portal/prodcom/data/database

10 EEA,. 2012. A Sustainable Industry for a Sustainable Europe: Annual Report 2011-2012. EEA Publication

Brick 2000-2010 (Data Sheet)

Table: *Brick consumption and associated embodied energy*

UK Brick Consumption (2000-2010)											
Quantity (Ktonne)	**2000**	**2001**	**2002**	**2003**	**2004**	**2005**	**2006**	**2007**	**2008**	**2009**	**2010**
Total Brick Consumption for buildings	6684	6540	6456	6445	6653	6358	5878	5789	4576	2820	3197
of which classed as Facing bricks (88%)	5882	5755	5682	5672	5854	5595	5172	5094	4027	2482	2813
of which classed as engineering bricks (12%)	802	785	775	773	798	763	705	695	549	338	384
Embodied Energy (TJ)											
Facing bricks	48231	47190	46588	46507	48005	45877	42414	41773	33019	20352	23067
Engineering bricks	2406	2354	2324	2320	2395	2289	2116	2084	1647	1015	1151
Total Embodied Energy	50637	49545	48913	48827	50400	48166	44530	43857	34666	21367	24218

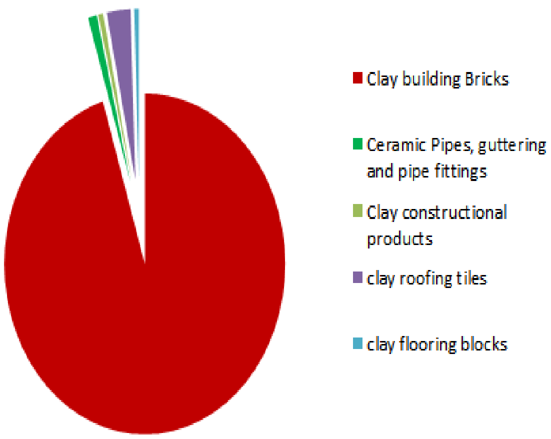


Fig BR: *% of clay building products*

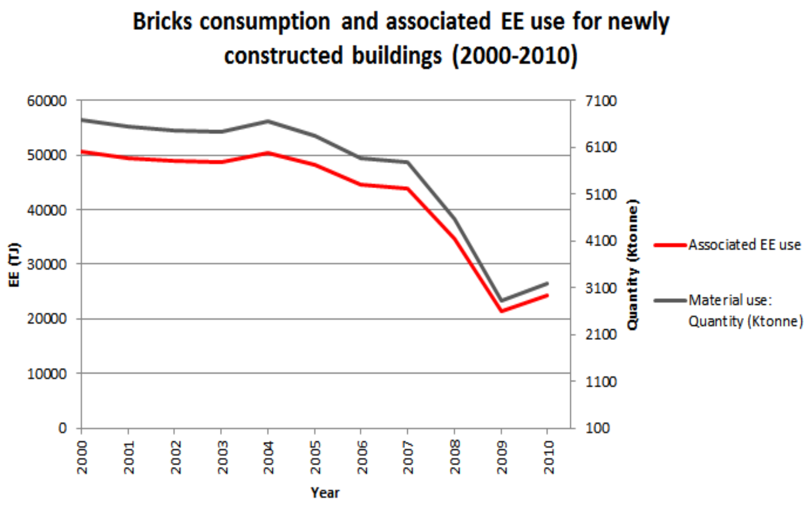


Figure A20: *The Total consumption of Bricks by the UK building sector and associated embodied energy(2000-2010)*

Supportive Information

As displayed in figure BR clay Bricks account for >95% of all clay products used within the UK building sector by weight[11]. Therefore the product most representative of clay consumption for the industry

Quantity

Brick consumption is reported in the Table above and Identifies all bricks sold for direct use in the UK building industry over the decade, consulting two verified sources The Brick Development Association Database[12] and the UK annual Raised mineral inquiry 2011[13]. Furthermore, brick sales are reported in the form of two generic types; Facing bricks which contribute 88% of all bricks used in buildings while 12% are classed as common engineering bricks[14]. The UK is essentially self-sufficient in brick production with imports and exports being negligible[15] therefore exports and imports are negligible

Embodied Energy

Embodied Energy for Facing Bricks = 8.2 (MJ/Kg) (ICE, 2008)
Embodied Energy for Engineering Bricks = 3 (MJ/KG) (ICE, 2008)

[11] Smith, R.A, Kersey, J.R and Griffiths, P.G ,. 2002. The Construction industry Mass balance: Resource use, wastes and emissions. Viridis Report. VR4

[12] The Brick Development Association Database (BDA, Database) accessed through http://www.brick.org.uk/ Membership required (1 day access provided through direct contact)

[13] Office for National Statistics,. 2011. Annual Raised mineral inquiry 2011. Report undertaken by OFNS, OFNS publication

[14] Office for National Statistics,. 2013. Monthly statistics of Building Materials and Components : March 2013. Department for Business innovation and Skill Publication

[15] Natural Environment Research Council,. 2001. Brick Clay - Issues for Planning. British Geological Survey Commissioned Report CR/01/117N

Ready Mixed Concrete 2000-2010 (Data Sheet)

Table: *Ready mixed concrete consumption and associated embodied energy*

UK consumption of Ready Mixed Concrete											
Quantity (Ktonne)	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010
Production	58611	58215	39531	36397	36890	31382	46815	54637	40533	34026	30065
Import	0	0	1	0	0	0	11	28	31	30	33
Export	262	211	259	291	302	538	442	577	684	253	137
Total consumption	58350	58004	39273	36106	36588	30844	46384	54088	39880	33803	29961
used in Buildings (24%)	14004	13921	9426	8665	8781	7403	11132	12981	9571	8113	7191
Embodied Energy (TJ)											
Total embodied energy	13304	13225	8954	8232	8342	7032	10575	12332	9093	7707	6831

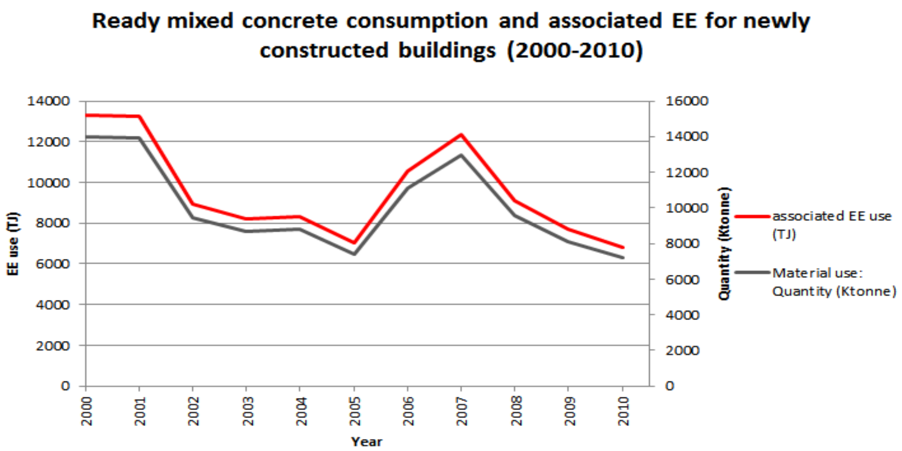


Figure **A26:** *The Total consumption of Ready mixed concrete by the UK building sector and associated embodied energy(2000-2010)*

Supportive Information

The largest use of concrete in the UK building sector is Ready mixed Concrete followed by articled made from cement and concrete used direct in buildings[16]

Quantity

The quantity of ready mixed concrete sold in the UK was obtained through the Eurostat Prodcom Database[17] Domestic Consumption per annum calculated by *(Production + Imports) - exports*

The Quantity of Concrete domestically consumed used for buildings is 24% according to The European Cement Association's 2011 activity Report[18]

Therefore (total quantity domestically consumed * 0.24) = quantity used for buildings

Embodied Energy

The Average Ready mixed concrete used in the UK is a consistency of ratio 1:2:4 (cement, sand aggregate respectively)[2]at this mixture: the Embodied Energy for Ready mixed concrete = (0.95 MJ/Kg) (ICE, 2008)

[16] Smith, R.A, Kersey, J.R and Griffiths, P.G ,. 2002. The Construction industry Mass balance: Resource use, wastes and emissions. Viridis Report. VR4

[17] Eurostat Prodcom Databse accessed through http://epp.eurostat.ec.europa.eu/portal/page/portal/prodcom/data/database

[18] CEMBUREAU,. 2011. Activity Report 2011. Published by CEMBUREAU The European Cement Association, Brussels

Cement Articles 2000-2010 (Data Sheet)

Table: *Cement consumption and associated embodied energy*

UK Consumption of Cement Product (2000-2010)												
Quantity (Ktonne)		2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010
Cement & concrete Building Blocks	Production	14436	11804	15512	15612	16453	13325	14288	14998	17757	14354	15486
	Import	9	31	36	23	26	37	22	21	59	27	23
	Export	360	365	388	416	526	482	475	501	385	202	149
	Total consumption in buildings (24%)	3380	2753	3638	3653	3829	3091	3320	3484	4183	3403	3686
Tiles Flagstones and similar Articles of Cement	Production	10956	10644	9719	9057	13626	11806	10866	7131	7034	5271	5392
	Import	30	35	29	38	29	36	53	47	54	38	33
	Export	233	235	262	301	340	340	398	438	411	200	138
	Total consumption in buildings (24%)	2581	2507	2277	2111	3195	2760	2525	1617	1602	1226	1269
Prefabricated Cement components for buildings	Production	4277	3578	4645	4820	5203	5882	5280	5556	7327	4541	5481
	Import	12	11	16	30	37	36	51	91	108	72	82
	Export	201	130	130	134	15	243	225	199	164	70	64
	Total consumption in buildings (24%)	981	830	1087	1132	1254	1362	1225	1308	1745	1090	1320
Total Annual Consumption		6942	6089	7002	6895	8278	7214	7071	6409	7531	5720	6275
Embodied energy (TJ)												
Total Embodied energy for standard cement blocks		3994	3524	3963	3861	4706	3921	3916	3418	3876	3102	3320
Total Embodied energy for prefabricated cement blocks		1962	1660	2175	2264	2508	2724	2451	2615	3490	2180	2640
Total embodied Energy for cement Products		5956	5184	6138	6125	7214	6645	6367	6033	7366	5282	5960

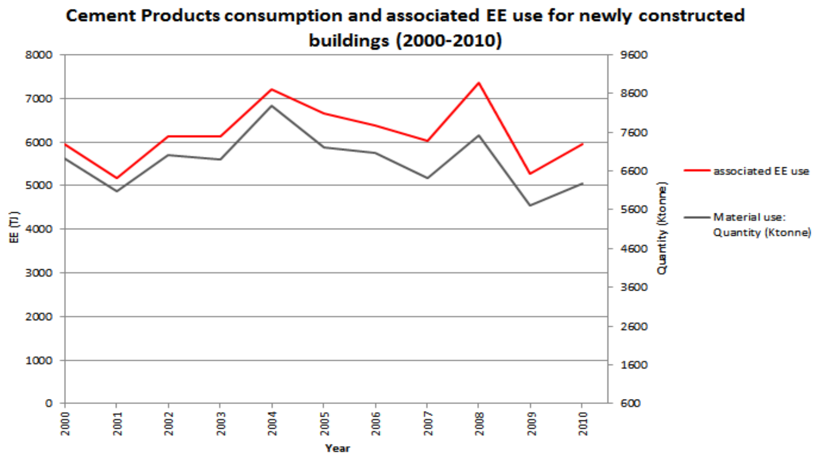


Figure **A27:** *The Total consumption of Concrete articles by the UK building sector and associated embodied energy(2000-2010)*

Supportive Information

Quantity

These vast majority of cement articles used in buildings are classes as 3 catergories of products

1) Cement & concrete Building Blocks used for buildings. 2) Tiles Flagstones and similar Articles of Cement

3) Prefabricated Cement components for buildings

The data for these product types has been collected using the Eurostat Prodcom Database[19] with the (Production + Import) – Export method used, the data is displayed in the table above. 24% of these articles are used directly in new construction[20]

Embodied Energy

the average normalised strength of a concrete block used in UK construction is 10Mpa[21]

The Average embodied energy for standard building use concrete blocks (at 10 Mpa compressive strength) = 0.67 [MJ/Kg] (ICE, 2008)

The Average embodied energy for a prefabricated concrete block = 2 [MJ/Kg]

Therefore :

(Quantity of common blocks used in buildings[Ktonne] * 0.67) + Quantity of prefabricates blocks used in buildings [Ktonne]* 2 = Total Associated Embodied Energy for all articles of Cement

[19] Eurostat Prodcom Databse accessed through http://epp.eurostat.ec.europa.eu/portal/page/portal/prodcom/data/database

[20] CEMBUREAU,. 2011. Activity Report 2011. Published by CEMBUREAU The European Cement Association, Brussels

[21] Concrete Block Association,. 2011. Aggregate Concrete Blocks Normalised strength of aggregate concrete blocks. Data Sheet, CBA publication, Leicester, UK

Timber 2000-2010 (Data Sheet)

Table: *Timber consumption and associated embodied energy*

UK Timber Consumption (2000-2010)											
Quantity (M³)	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010
Production (m³)	5897382	5965853	5922370	6103219	6304742	6179000	6403000	6694000	5955255	5886458	6470646
Import (m³)	11159800	11399370	11980975	12205546	12465550	11774223	11647355	12316063	9275005	7739525	8400065
Export (m³)	540800	572652	717103	886375	889709	878060	925148	944731	742013	653851	704047
Total consumed (m3)	16516382	16792571	17186242	17422390	17880583	17075163	17125207	18065332	14488247	12972132	14166664
Quantity (Ktonne)											
Total consumed Ktonne	7845	7976	8163	8276	8493	8111	8134	8581	6882	6162	6729
Used in buildings (52%)	4080	4148	4245	4303	4417	4218	4230	4462	3579	3204	3499
Embodied Energy (TJ)	38185	38823	39733	40279	41338	39476	39592	41766	33496	29991	32752

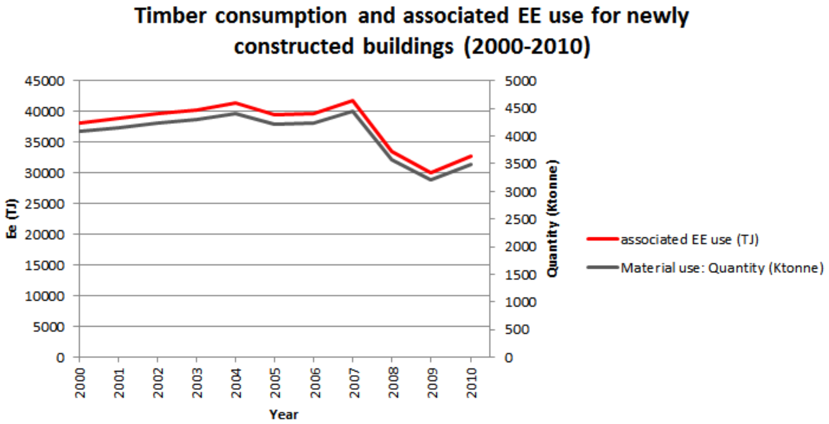


Figure A29: *The Total consumption of Timber by the UK building sector and associated embodied energy (2000-2010)*

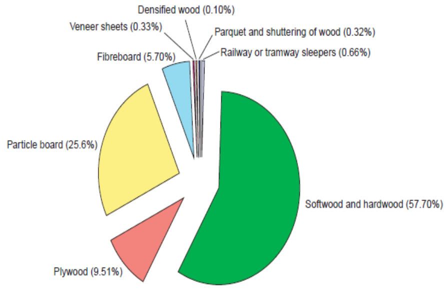


Figure A28: *Timber products used in the UK construction sector in 1998*[22]

Supportive Information

As seen in figure A28 Sawn wood and wood based panels are the two major timber products used within the UK construction sector[1]

Quantity

The annual consumption data is displayed in the table above in m^3 obtained from the Food & Agricultures Organisation of United Nations Forestat Database[23]

To convert m3 wood consumption into Ktonnes the density of the most common types of wood used in the UK in the form of sawn wood and wood based panels were averaged to form an average density applied to the total quantity[24]

Pine wood density = 0.5 tonne / m^3 and **Spruce wood** density = 0.45 tonne / m^3 = **Average density** = 0.475 tonne / m3

52% of all sawn wood and wood based panel consumption in the UK is directly consumed by the building industry[25]

Embodied Energy

The Embodied energy for general timber representing an average of all products investigated -=9.36 (MJ/Kg) (ICE, 2008) this includes all of the products investigated in this analysis and is required as some wood based panels pass through a mechanical heating phase to set glue quick and dry the wood. This adds to energy requirements.

(Total Timber consumed by the building sector [Ktonne] * 9.36) = Total Embodied energy [TJ]

[22] Smith, R.A, Kersey, J.R and Griffiths, P.G ,. 2002. The Construction industry Mass balance: Resource use, wastes and emissions. Viridis Report. VR4

[23] Food & Agricultures Organisation of United Nations Forestat Database(FAO Database) Accessed through http://faostat.fao.org/site/626/default.aspx#ancor

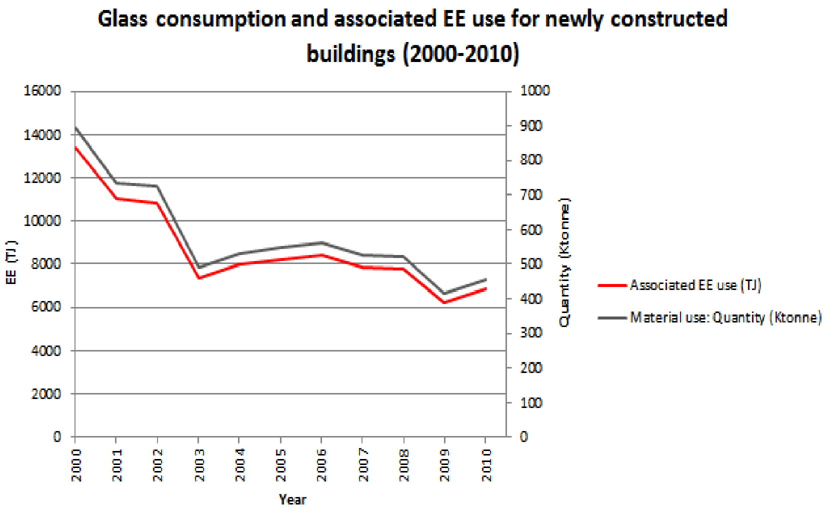
[24] The Engineering toolbox: online wood density index. Accessed through http://www.engineeringtoolbox.com/wood-density-d_40.html

[25] Food & Agricultures Organisation of United Nations,. 2009. State of the World's Forests: Global demand for wood Products. FAO Publication

Glass 2000-2010 (Data Sheet)

Table: *Glass consumption and associated embodied energy*

UK Glass Consumption (2000-2010)											
Quantity m²	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010
Production	67050173	63873128	63555224	62100008	62913432	64920859	71936737	60741532	61273071	44668630	51331335
import	25728620	15478105	19470303	1288772	7061944	6369852	7695242	8894302	5496875	3707904	4836091
Export	8611872	10179507	14884290	16996663	19942292	19768715	26908617	20210810	17750988	9198597	13164053
Total Consumption of Flat glass in the UK	84166921	69171726	68141237	46392117	50033084	51521996	52723362	49425024	49018958	39177937	43003373
Quantity (Ktonne)											
Total Consumption of Flat glass in the UK	1052	865	852	580	625	644	659	618	613	490	538
Total UK flat glass consumption in buildings (85%)	894	735	724	493	532	547	560	525	521	416	457
Embodied Energy (TJ)	13414	11024	10860	7394	7974	8211	8403	7877	7812	6244	6854



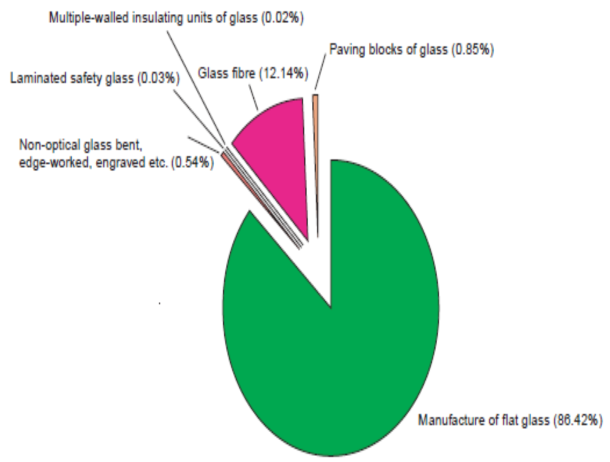


Figure A31: *The Total consumption of Glass by the UK building sector and associated embodied energy (2000-2010)*

Figure A30: *Breakdown of Glass products used in the UK construction sector*[26]

Supportive information

Quantity

As Seen in Figure **A30** 86% of Glass used in the UK construction sector is flat Glass . Of the Glass used in the UK construction sector Glass for Europe state 80-85% of this flat glass is used in the building sector (email contact with glass for Europe employee)

The Raw data in the table above is reported in m² of glass using the ((Production + Imports) – Exports) method from the Eurostat Prodcom database[27].

To convert this into Ktonnes the weight of glass = 2.5kg per m² for 1mm thick, the average thickness of the uk window = 5mm[28]

Therefore (quantity in m² * 5 * 2.5 = kg /10⁶) = quantity of glass consumed in Ktonnes

Embodied Energy

The Average Embodied energy of UK glass = 15 (MJ/Kg) (ICE, 2008)

Quantity of glass used in UK building sector [Ktonne] * 15 = Total embodied energy [TJ]

26 Smith, R.A, Kersey, J.R and Griffiths, P.G ,. 2002. The Construction industry Mass balance: Resource use, wastes and emissions. Viridis Report. VR4

27 Eurostat,. 2013. Prodcom Database . Accessed through http://epp.eurostat.ec.europa.eu/portal/page/portal/prodcom/data/database

28 Trident Glass manufacturer conversion Method. Available online. Accessed through http://www.tridenthardware.com.au/FAQs/Whatistheweightofglass.aspx

New Building Construction per annum (Data Sheet)

Building Data Table: *Raw data and results from applying calculations for new building construction (2000-2010)*

New construction per annum in the UK (Residential and Commercial) (2000-2010)											
	2000	**2001**	**2002**	**2003**	**2004**	**2005**	**2006**	**2007**	**2008**	**2009**	**2010**
Residential											
Number of New buildings (N)	176,850	174,080	181,960	190,490	203,490	209,580	212,820	226,420	188,290	158,410	137,280
Floor space added (m2)	16,026,147	15,775,130	16,489,215	17,262,204	18,440,264	18,992,140	19,285,748	20,518,180	17,062,840	14,355,114	12,440,314
Commercial											
Floor space added (m2)	5,436,485	5,351,333	5,593,569	5,855,787	6,255,416	6,442,626	6,542,226	6,960,299	5,788,158	4,869,627	4,220,077
Total											
Total new floor space (m2)	21,462,632	21,126,463	22,082,785	23,117,991	24,695,679	25,434,766	25,827,974	27,478,479	22,850,997	19,224,741	16,660,391
Total new floor space (100 m2)	**214,626**	**211,265**	**220,828**	**231,180**	**246,957**	**254,348**	**258,280**	**274,785**	**228,510**	**192,247**	**166,604**

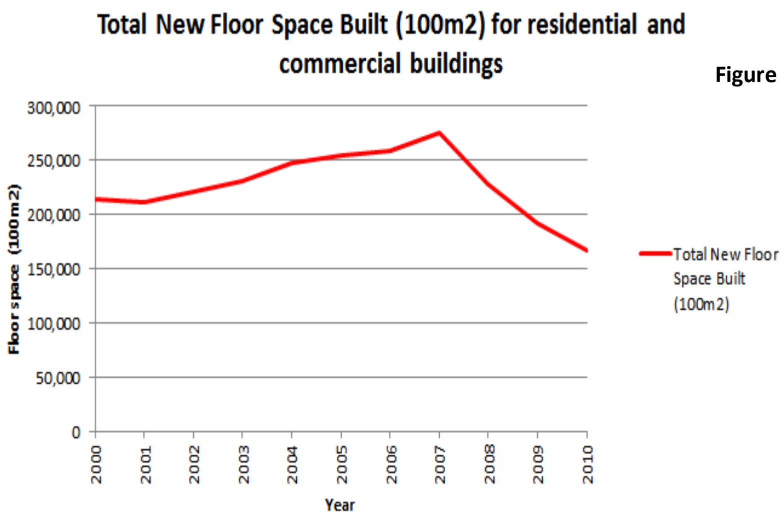


Figure /

Figure A4: *Annual new floor space built for both residential and commercial buildings in the UK (2000-2010)*

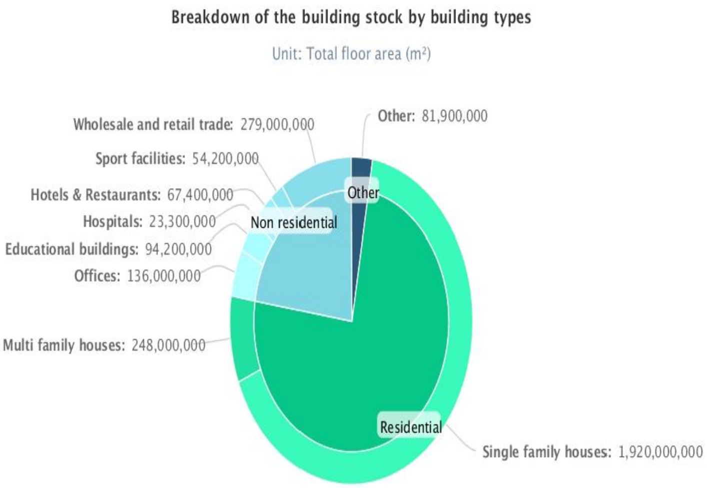


Figure A3: *Breakdown of the UK building sector into general classifications in 2012*[29]

Supportive information

The number of new residential buildings is provided by UK national Statistic[2]

The Average size of a residential property in the UK 2008 was 90.62m[2 3]. It is assumed that this average floor area remained constant over the period of investigation

The residential floor space built per annum can then be calculated using

(Total residential properties per annum x Average floor space)

As no available information was located on the amount of commercial floor space added per annum the % share of floor space for building seen in figure A3 for 2012 is used and assumed to be a static split throughout the time period investigated[1].

Residential buildings = 74.67% of the UK floor space
Commercial buildings = 25.33% of the UK floor space

Therefore to find total new added floor space

(Floor space for residential property added pa/ 0.7467 = total new floor space pa)

(Total new floor space pa - Floor space for residential property added pa)= Commercial floor space added pa

[29] BPIE,. 2013. The Data hub for the Energy Performance of Buildings – UK fact sheet. BPIE publication

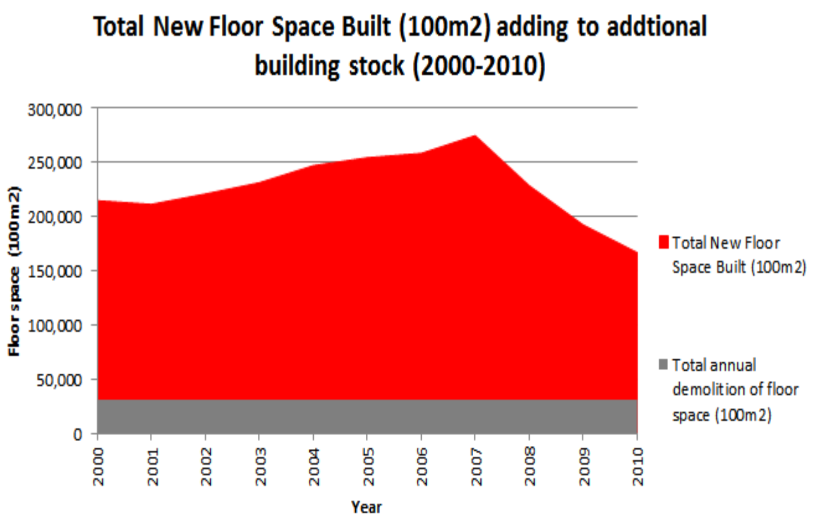
[2] UK national statistics,. 2013. Department for communities and local government. House building statistics series. Table 241 accessed through https://www.gov.uk/government/statistical-data-sets/live-tables-on-house-building

[3] Enerdata,. 2013. The Odyssee Database on energy efficiency indicators. Trail edition with access to 2008 data only. Accessed through http://odyssee.enerdata.net/nrd_web/site/

Building Demolition (2000-2010) (Data Sheet)

Demolition data Table: *Raw data and results from applying calculations for annual building demolition (2000-2010)*

UK demolition (2000-2010)											
	2000	**2001**	**2002**	**2003**	**2004**	**2005**	**2006**	**2007**	**2008**	**2009**	**2010**
Houses demolished (N)	25350	25350	25350	25350	25350	25350	25350	25350	25350	25350	25350
Residential floor space demolished (m^2)	2297217	2297217	2297217	2297217	2297217	2297217	2297217	2297217	2297217	2297217	2297217
Commercial floor space demolished (m^2)	779276	779276	779276	779276	779276	779276	779276	779276	779276	779276	779276
Total Floor space demolished (m^2)	**3076493**	**3076493**	**3076493**	**3076493**	**3076493**	**3076493**	**3076493**	**3076493**	**3076493**	**3076493**	**3076493**



Supportive information

The demolition rate in the UK 1996-2004 was 0.1% (around 20000 houses per annum)[30]
This rate is still consistent in the estimates of the English housing survey in 2010[31]

In 2010 the total UK housing stock = 26.1 M showing an increase of 6.1% from 2000. Therefore 26.1/ 106.1 = 24.6M houses in 2000 [32]

0.1% of 24. 6 M = 24600 for the year 2000
0.1 % of 26.1 M = 26100 for the year 2010 ((24600 + 26100) / 2) = an average of 25350

The average of 25350 houses per year will be demolished over the time period investigated. This constant demolition rate is suitable considering the UK's slow housing stock growth and the historically stable demolition rate.

This means that 25350 x 90.62m^2 = 2297217m^2 of residential floor space floor space is demolished per annum

Assuming that the residential / commercial floor space split is static throughout the time period
(74.67% residential) (25.33% Commercial)

Total floor space and commercial floor space demolished is calculated by

(Residential floor space demolished (m^2) / 0.7467 = Total floor space demolished (m^2))

(Total floor space demolished (m^2) - Residential floor space demolished (m^2) = commercial floor space demolished (m^2))

[30] Boardman, B. Darby, S. Killip, G. Hinnells M. Christian, N. Palmer J and Sinden G,. 2005. 40% House. Chapter 5 Building fabric and Housing Stock. Environmental Change institute, Oxford University

[31] English Housing Survey,. 2010. Housing Stock Report 2010.Department for communities and local government. Office for National statistics publication.

[32] Halifax,. 2010. The UK Housing Market over the past 50 years. Lloyds bank press release. Online Press release accessed through http://www.lloydsbankinggroup.com/media/pdfs/research/2010/50_Years_of_Housing_UK.pdf