European Commission

JRC SCIENCE AND POLICY REPORTS

Identifying macro-objectives for the resource efficiency of EU buildings

(Draft) Working Paper

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May 2015

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1. Introduction

The European Commission's 2014 Communication on Resource Efficiency Opportunities in the Building Sector identified the need for a common EU approach to the assessment of the environmental performance of buildings. A study to develop this approach is now being taken forward by DG ENV and DG GROW, with the technical support of DG JRC-IPTS.

The first stage in this study is the identification of 'macro-objectives' for the environmental performance of buildings. This working paper is intended to inform this exercise. It provides an analysis of:

- EU and Member State policies and initiatives on resource efficiency,
- Evidence for the most significant environmental impacts along the life cycle of buildings, and;
- The priorities of existing schemes and tools that are used in the EU property market.

It is intended that the evidence brought together in this working paper, together with the input of stakeholders, will help to identify macro-objectives. These in turn will set the scope for possible environmental indicators, although not all areas covered by the macro-objectives may be addressed.

1.1 Background and objectives of the study

In July 2014, as the result of an initiative lead jointly by DG ENV and DG GROWTH, the European Commission adopted the Communication on Resource Efficiency Opportunities in the Building Sector - COM(2014)445 [1]. This Communication identified the need for a common European approach to assess the environmental performance of buildings throughout their lifecycle, taking into account the use of resources such as energy, materials and water.

In response to the need identified in the aforementioned Communication, a study to identify an EU common framework of indicators to assess the environmental performance of buildings will be carried out by the JRC, during 2015-2017. DG ENV and DG GROW will lead development of the framework with the technical support of the Joint Research Centre, its in-house science service, and in close co-operation with relevant stakeholders.

The overall aim of the study is to develop a common framework of indicators that is flexible so that it can be integrated in existing and new assessment schemes, or be used on its own, although the intention is not to create a new standalone building certification scheme. The framework should be rigorous enough to drive improvement in performance and allow for comparison between buildings. Moreover, there should be a clear link between the indicators and a set of overarching macro-objectives, thereby ensuring that there is a clear and measurable contribution to strategic policy objectives. The potential benefits of such a framework, as set out in the 2014 Communication are summarised in Box 1.

Box 1. The anticipated benefits of a EU core framework of indicators

- Allow easier communication of information to professional and non-experts;
- Provide reliable and comparable data to be used in decision-making covering the entire life-cycle of buildings;
- Enable the setting of clear objectives and targets, including system boundaries, for building performance, complementing already existing European legislation on buildings;
- Increase awareness of the benefits of sustainable buildings among actors engaged in providing buildings, as well as private and public clients, including users of buildings;
- Facilitate the effective transfer of good practices from one country to another;
- Reduce the cost to assess effectively and communicate the environmental performance of buildings;
- Provide public authorities with access to core indicators and to a critical mass of relevant data on which to base their policy initiatives, including Green Public Procurement;

[1] COM(2014)445 Communication from the Commission to the Council, the European Parliament, the European Economic and Social Committee and the Committee of the Regions on resource efficient opportunities in the building sector

- Widen the market for sustainable buildings to more countries than current trends indicate and to other buildings sectors such as non-residential buildings and eventually, to the residential market.

In addition to the sectoral benefits summarised in Box 1, the 2014 Communication also highlights the following potential advantages for building sector professionals (including SMEs).

- Architects, designers, manufacturers of construction products, builders, developers and investors, will be able to benefit from competitive advantages based on environmental performance;
- Manufacturers of construction products will only have to provide product information needed for building assessment in one way, resulting in cost savings;
- Architects and builders will be supported via greater information on both product and building level, with reduced costs when incorporating sustainability aspects;
- Developers will more easily be able to compare performance of projects;
- Investors, property owners and insurers will be able to improve the allocation of capital and to integrate environmental risk into their decisions.

Considering the wide range of buildings in the EU, as well as differences in constructing new buildings or renovating existing ones, the Communication considers that the framework will not cover all aspects of environmental performance, but comprise a set of core indicators, focusing on the most essential aspects, which will be identified together with stakeholders. This will allow comparability and provide consumers and policy makers with easier access to reliable and consistent information.

The Communication goes on to exemplify areas for further investigation in the framework development, based on the results on an initial consultation with stakeholders in 2013.

- Total energy use, including operational energy,
- The embodied energy of products and construction processes,
- Material use and the embodied environmental impacts,
- The durability of construction products,
- Design for deconstruction,
- Management of construction as well as demolition waste (CDW),
- Recycled content in construction materials,
- Recyclability and reusability of construction materials and products,
- Water used by buildings,
- The use intensity of (mostly public) buildings (e.g. flexible functionality for different users during different times of the day),
- Indoor comfort.

These broad areas of focus therefore provide a starting point for the scope of the study which, based on evidence gathered and the input of stakeholders during the current process, could be adjusted. Moreover, it is open for discussion whether the indicators could be introduced in phases or tiers, with the most critical environmental impacts addressed by a first set of indicators, which could then be followed up by further sets.

Importantly, this process will closely follow the development of a European Voluntary Scheme for non-residential buildings, targeting energy efficiency, led by the European Commission, DG ENER, and will ensure compatibility between the two products.

1.2 Identifying and defining 'macro-objectives'

The aim of this working paper is to inform the identification of the most relevant macro-objectives for a building's life cycle resource efficiency. These macro-objectives will in turn inform and set the scope for the common framework of indicators.

This paper will be presented as the basis for discussion at the first stakeholder working group meeting on the 16th June 2015. At that meeting the proposed boundaries, scope and coverage of the macro-objectives will be

discussed. Feedback from those discussions, together with follow-up written feedback, will be used to prepare a final set of macro-objectives that will be used to set the scope for the framework of indicators.

For the purpose of this exercise, macro objectives are understood as encompassing not only resource efficiency considerations as such, but also any significant environmental effects or functional performance aspect associated with the lifecycle of buildings which should be addressed at EU level. An initial definition of 'macro-objectives' is proposed as follows:

> *An environmental effect, resource use or functional performance aspect of significance to the lifecycle environmental performance of buildings at EU level.*

Moreover, it is also important to establish from the outset of the study the principle that buildings shall provide comfortable, healthy and productive spaces for people to live and work in, now and into the future. The objective of achieving resource efficient buildings should, wherever possible, re-inforce and not contradict, the fundamental human, cultural and economic requirements of building owners and occupiers. Conversely, this social and economic capital should not be achieved at the expense of natural capital.

In order to develop initial proposals for discussion, this paper reviews existing legislation, scientific evidence, building schemes, collaborative research projects and other relevant literature. A high level scoping of environmental and resource efficiency 'hot spots' along the life cycle of buildings has been carried out. Potential linkages and trade-offs between resource use, impacts along the life cycle and functional performance, with a specific focus on health and wellbeing aspects, have also been identified.

1.3 The structure of this working paper

This paper sets out to answer a number of key questions in relation to the identification of relevant macro-objectives for buildings. These questions are presented in Box 2 and it is anticipated that these, together with further questions that arise from each chapter of the report, will be investigated further with the input of stakeholders.

Box 2. Key questions in relation to macro-objectives

- To what extent are macro-objectives for buildings already defined by EU policy frameworks?
- Which significant environmental and resource efficiency 'hot spots' for buildings should be addressed by the macro-objectives?
- Which environmental and resource efficiency macro-objectives are currently used by building assessment and reporting tools in the EU market?
- How do these compare and contrast with those in EU policies and identified as 'hot spots' from technical evidence?
- Are there are any contradictions between different macro-objectives from the point of view of resource efficiency and/or other functional aspects such as comfort, health and productivity?
- Based on the evidence reviewed, what should be the scope and boundary for defining the macro-objectives?
- To what extent should health, wellbeing, productivity and functional performance aspects be addressed as macro-objectives?

This paper has been structured in order to review three main areas of evidence considered of importance to the identification of macro-objectives:

1. The existing EU policy framework for resource efficiency buildings: The focus of EU policies for improving the environmental performance of buildings, as well the broader policy framework and evidence base for making progress towards a more resource efficient economy, have been reviewed. Member State policies in these two areas have also been briefly reviewed, including selected examples of leading resource efficiency policies and initiatives.

2. Evidence for macro-scale environmental 'hot spots' along the life cycle of buildings: Top down LCA studies of the buildings and construction sector, bottom up LCA studies for commercial and residential building typologies, and technical research into material resource efficiency have been

reviewed. The relevance of wider 'induced' environmental effects that may occur beyond the boundary of a single building or urban development – such as commuter journeys or new infrastructure to serve buildings - together with other factors that may influence the performance and life span of a building are also briefly reviewed.

3. Priorities, scope and boundaries of existing assessment and reporting tools: A selection of the leading building environmental assessment schemes and investor reporting tools used in the EU have been analysed in order to understand the basis on which they prioritise resource efficiency hot spots within their criteria, as well as to compare and contrast their scope and boundaries.

The insight and conclusions that can be drawn from these three sections is then summarised and used to formulate initial proposals for macro-objectives, as well as to identify open issues for wider discussion with project stakeholders.

1.4 The scope of buildings typologies to be addressed

There were estimated in 2013 to be 233 million residential and commercial buildings in the EU [2]. Residential buildings account for the majority of the EU's total building stock, accounting for approximately 75% of the total floor area (m^2) [3]. This is followed by retail (7%), offices (6%), education (4%), hotels and restaurants (3%) and healthcare (2%). Other uses such as industrial and sports facilities account for approximately 4% of the total floor area.

Residential buildings appear to be the most important in terms of the proportion of the EU building stock they account for, but in general they tend to have longer life and slower replacement rate, so it will be important to compare and contrast this with other building uses. The distinct variations in usage patterns, form and construction techniques between the other predominant other uses suggest that buildings designed for high intensity, day to day occupation by people – namely offices, education facilities and hotels – could be a further focus of attention. Retail, industrial and sports facilities tend to consist of large volume spaces with a very different construction form and servicing needs. It might therefore be more complex to address these uses within the same scope.

The age of the buildings to be addressed is also a major consideration. Figure 1.1 illustrates the age of the residential building stock, with the majority of the stock being pre-1990, in general predating more stringent building standards to regulate energy use. With an estimated annual replacement rate 1-2% and a renovation rate of between 0.5% and 1.2% for the EU building stock, the performance of the existing buildings is therefore significantly more important within the short to medium term than new buildings.

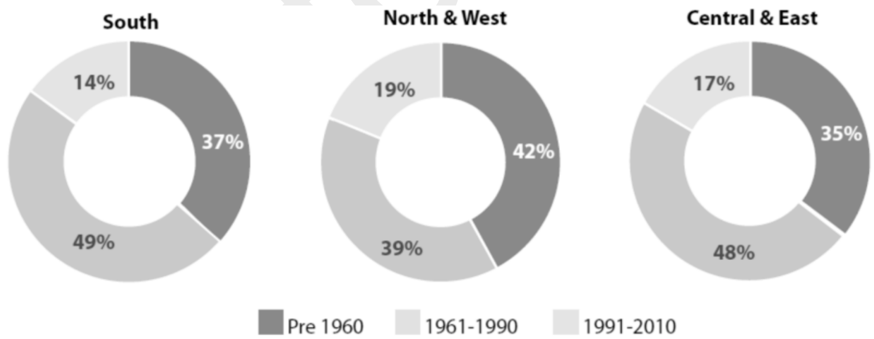

Figure 1.1 The age of the housing stock in three broad areas of the EU (2010)

Source: BPIE (2011)

As can be seen in Figure 1.2, Europe's office building stock is also dated. For example, in Germany, 59% of the stock dates from between 1950 and 1990 and, in the UK, 22% dates from before 1960. The average rate of replacement of offices across Europe is cited as being between 1% and 2%, but can be closer to 3% in major

[2] Ecorys and the Copenhagen Resource Institute, *Resource efficiency in the building sector*, Final report to DG Environment, 23rd May 2014.

[3] Building Performance Institute Europe, *Europe's buildings under the microscope*, October 2011

centres such as London [4]. The market has seen an increased focus on better use of existing building assets, reflected in a wider trend in EU office markets – both public and private - for major renovations instead of new-build projects.

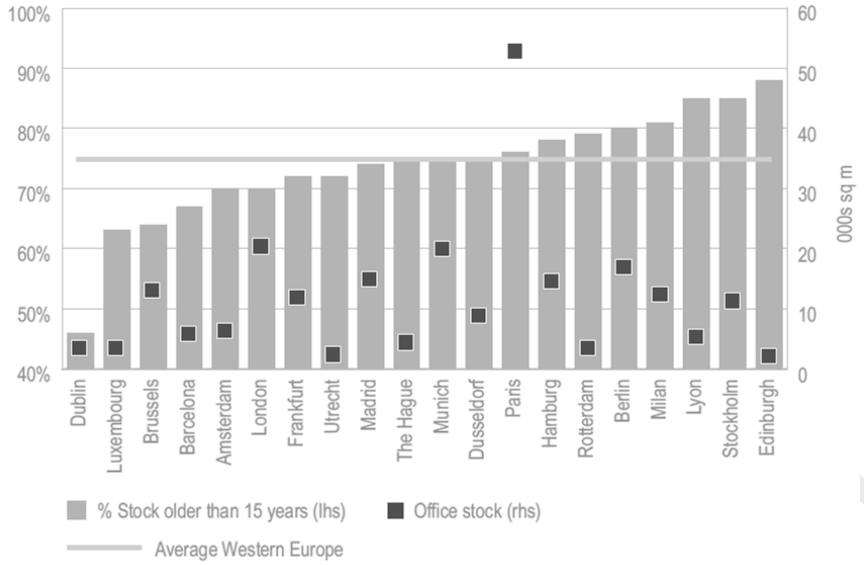

Figure 1.2 The proportion of office building stock older than 15 years in Western European cities

Source: Jones Lang La Salle (2013) lhs=left axis rhs=right axis

Inclusion of existing buildings within the scope is also important because of the stock of materials and structures contained within those buildings. Estimates from Germany, for example, suggest that the country's built environment forms a repository of approximately 50 billion tonnes [5].

Questions to stakeholders on the scope of buildings to be addressed

1.1 Should the focus be on residential and office buildings, or should other buildings intended for high intensity, day to day occupation be included? e,g, schools, hotels

1.2 Should large volume retail, industrial and storage buildings be kept within the scope given that they have very different construction and servicing needs?

1.3 In addition to new buildings, should the scope encompass all existing buildings or only the potential for performance improvement at the point of renovation?

[4] Jones Lang La Salle (2013) *From obsolescence to resilience*, 'Advance' white paper

[5] Federal Ministry for the Environment, Nature Conservation and Nuclear Safety (2012) *German Resource Efficiency Programme, (ProgRess)*

2. Review of the existing EU policy framework for resource efficient buildings

In this section, the existing EU policy framework has been reviewed in order to identify environmental and resource efficiency policies that are of significance to the built environment and the construction sector. Member State policies on resource efficiency have also been briefly reviewed, together with selected examples of leading initiatives.

2.1 Current EU policies and their macro-objectives

The EU has developed a series of policy frameworks that establish relevant macro-objectives for the economy as a whole, cities and urban areas, individual building performance, construction products and specific industrial activities in the supply chain. These take a number of different forms:

- Broad frameworks for action: These include the 7th Environment Action Programme, the Climate and Energy Package, the Thematic Strategy for the Urban Environment, the Roadmap to a Resource Efficiency Europe and the Blueprint to Safeguard's Europe's Water Resources;
- Directives and Regulations requiring action: These include the Energy Performance of Buildings Directive, the Waste Framework Directive, the Industrial Emissions Directive and the Construction Products Regulation;
- Initiatives targeting and monitoring specific aspects of resource efficiency: These include the scoreboard of Resource Efficiency indicators, Material Flow Accounting and the Raw Materials Initiative.

The policy frameworks identified, the form they take and their macro-objectives are briefly reviewed for their relevance in the following sections.

2.1.1 Broad frameworks for action

2.1.1.1 The 7th Environment Action Programme

The 7th Environment Action Programme of the European Union (EAP) [6] re-enforces the 2020 objective of creating a 'low carbon and resource-efficient economy'. Moreover, the EAP sets out objectives to reduce the overall impact of resource use, including the prevention and reduction of adverse impacts relating to a range of different resources and ecosystem services, as well as enhancing the sustainability of cities. Adverse impacts on the climate, forests, air quality, waste and land degradation are addressed.

Priority Objective 2 of the EAP places a specific focus on resource efficiency, in which the importance of reducing greenhouse gas emissions, improved industrial resource efficiency, improvements in the environmental performance of goods along their whole life cycle, and the need to move to a life cycle driven 'circular' economy are specifically highlighted. The EAP highlights the role of the Commission's Roadmap to a Resource Efficient Europe ('the Roadmap') as a framework for future action.

Priority Objective 8 of the EAP is of relevance to buildings because it seeks to 'enhance the sustainability of the Union's cities' and to place environmental sustainability at the core of urban development strategies. It states that, by 2020, the programme should ensure that the majority of the Union's cities '*are implementing policies for sustainable urban planning and design, including innovative approaches for urban public transport and mobility, sustainable buildings, energy efficiency and urban biodiversity conservation*.' Moreover, it states that there should be a focus on

'the integration of urban planning with objectives related to resource efficiency, an innovative safe and sustainable low-carbon economy, sustainable urban land-use, sustainable urban mobility, urban biodiversity management and conservation, ecosystem resilience [and] water management….'

2.1.1.2 EU climate change strategy

[6] Decision No 1386/2013/EU of the European Parliament and of the Council of 20 November 2013 on a General Union Environment Action Programme to 2020 '*Living well, within the limits of our planet'*

The EU is committed under the UN Framework Convention on Climate Change to reduce its greenhouse gas emissions. The climate and energy package is a set of binding legislation which aims to ensure that the European Union meets its ambitious climate and energy targets for 2020 [7]. These targets, known as the '20-20-20' targets, set three key objectives for 2020:

- A 20% reduction in EU greenhouse gas emissions from 1990 levels;
- Raising the share of EU energy consumption produced from renewable resources to 20%;
- A 20% improvement in the EU's energy efficiency upon 1990 levels.

The targets were set by EU leaders in March 2007, when they committed Europe to become a highly energy-efficient, low carbon economy, and were enacted through the climate and energy package in 2009. A further set of targets for 40% reductions below 1990 levels have been proposed by the EU for 2030, together with the long-term objective to reduce greenhouse gas emissions by 80-95% below 1990 levels by 2050.

Obligations relating to the built environment were laid down in the Renewable Energy Directive 2009/28/EC, the recast Energy Performance of Buildings Directive 2010/31/EU and the Energy Efficiency Directive 2012/27/EU, which are described further in Section 2.1.2. Obligations relating to major producers of construction materials, such as cement and steel, were laid down in reforms of the EU Emissions Trading Scheme (EU ETS).

A related aspect of climate change that is now also being addressed is climate change adaptation to ensure resilience in the face of predicted adverse effects of future climate change. An EU strategy on adaptation to climate change was published in 2013 [8]. The strategy highlights the need for the 'climate proofing' of cities as well as physical infrastructure and assets. Major threats to buildings and constructions are identified as [9]:

1. Extreme precipitation;
2. Extreme summer heat events;
3. Exposure to heavy snow fall;
4. Rising sea levels increasing the risk of flooding.

The overheating of the built environment is also highlighted, with implications not just for building materials but also for the comfort and wellbeing of occupiers.

The Commission anticipates that the need for adaptation strategies are needed at local, regional, national and EU level. Due to the varying severity and nature of climate impacts between regions in Europe, most adaptation initiatives are envisaged as being taken at the regional or local levels. The ability to cope and adapt will also differ across populations, economic sectors and regions within Europe.

2.1.1.3 Thematic Strategy for the Urban Environment

Although it dates from 2006, Communication COM/2005/0718 on a Thematic strategy for the urban environment is still of relevance to this study because buildings cannot be seen in isolation from their urban context [10]. It is also notable for highlighting the multiple resource efficiency benefits of compact urban development forms.

The Communication highlights the importance of urban areas in delivering the objectives of the EU Sustainable Development Strategy and of taking an integrated approach to the environmental challenges facing cities. It identified a common set of complex and inter-related environmental problems facing cities and, in line with the preceding 6th Environment Action Programme suggested actions under four main priority themes – urban management, sustainable transport, construction and urban design. Measures suggested included:

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[7] European Commission, *The 2020 climate and energy package*, http://ec.europa.eu/clima/policies/package/index_en.htm

[8] COM(2013)216, Communication from the Commission to the Council, the European Parliament, the European Economic and Social Committee and the Committee of the Regions, *An EU Strategy on Adaptation to Climate Change*

[9] Commission Staff Working Document, *Adapting infrastructure to climate change*, SWD(2013) 137, Brussels, 16.4.2013

[10] COM(2004)60 Communication from the Commission to the Council, the European Parliament, the European Economic and Social Committee and the Committee of the Regions, *Towards a thematic strategy on the urban environment*

- Better urban planning to support EU legislation, including the co-ordination of land use planning with sustainable urban transport;
- A priority focus on transport and buildings, including setting and enforcing standards on sustainable construction and supporting the retrofitting of existing buildings;
- Planning to avoid urban sprawl through high density and mixed use development patterns, with environmental advantages relating to land use, transport and heating which will contribute to less resource use per capita

2.1.1.4 The Roadmap to a Resource Efficient Europe

The Roadmap to a Resource-Efficient Europe COM(2011) 571 highlights the significant impact of construction on natural resources [11]. The Roadmap outlines how Europe's economy can be transformed into a sustainable one by 2050. It proposes ways to increase resource productivity and decouple economic growth from resource use and its environmental impact. Buildings are identified as a specific sector responsible for some of the most significant environmental impacts.

The Roadmap highlights how more efficient construction and use of buildings in the EU would influence approximately 42% of final energy consumption, 35% of greenhouse gas emissions, more than 50% of all extracted materials and up to 30% of water. It proposes that existing policies for promoting energy efficiency and renewable energy use in buildings should be complemented with policies for wider resource efficiency. Such policies would address a range of environmental impacts along the life-cycle of buildings.

The Roadmap suggests the use of the ratio of Gross Domestic Product (GDP) to Domestic Material Consumption (DMC) as a provisional indicator of resource efficiency at EU level. The need was identified to complement this with a 'dashboard' of indicators to measure environmental impacts on natural capital or ecosystems, as well as thematic sector indicators such as for buildings. The initial set of indicators, and the evidence supporting their selection, are analysed further in section 2.1.3.1.

2.1.1.5 The Blueprint to Safeguard Europe's Water Resources

The Blueprint Communication COM (2012)673 [12] aims to achieve better implementation of current water legislation (including the Water Framework Directive), the integration of water policy objectives into other policies, and to address gaps in policy on water quantity and efficiency. It's overall objective is to ensure that *'a sufficient quantity of good quality water is available for people's needs, the economy and the environment throughout the EU'*.

The Blueprint recognises the influence of industry and urban development on water resources, with the pressures from pollutant emissions and over-use (water stress) being of particular relevance. Water is clearly identified as a resource that should be addressed by resource efficiency policies. The scope to improve water efficiency of industry and buildings is emphasised as being important in order to counter trends towards greater water scarcity and stress. Water efficiency targets are proposed to be established at river basin level, taking into account levels of water stress. Special objectives identified include increased metering take-up, efficiency in buildings and maximisation of water re-use.

2.1.2 Directives and Regulations requiring actions

2.1.2.1 Energy Performance of Buildings Directive (EPBD)

The construction and refurbishment of buildings in order to reduce energy use and CO_2 emissions is a central environmental policy objective for Europe. The recast *Energy Performance of Buildings Directive 2010/31/EU*

[11] COM (2011) 571 Communication from the Commission to the Council, the European Parliament, the European Economic and Social Committee and the Committee of the Regions, *Roadmap to a Resource Efficient Europe*

[12] COM(2012)673 Communication from the Commission to the Council, the European Parliament, the European Economic and Social Committee and the Committee of the Regions, *A Blueprint to Safeguard Europe's Water Resources*

(EPBD) [13] sets out requirements for buildings that contribute towards ambitious EU targets for energy efficiency by 2020. It requires Member States to transpose the following into national legislation:

- Minimum, cost optimal energy performance requirements for new buildings, for major renovation of buildings and for the replacement or retrofit of building elements (e.g. heating and cooling systems, roofs, walls)
- The inclusion of energy performance certificates in all advertisements for the sale or rental of buildings
- All new buildings must be 'nearly zero energy' by 31 December 2020 and all public buildings by 31 December 2018

Linked to this, Member States are additionally required to prepare national plans to ensure that all new buildings are 'nearly zero energy' by 2020. This is defined in Article 2(2) of the EPBD as:

> *'…a building that has a very high energy performance, as determined in accordance with Annex I. The nearly zero or very low amount of energy required should be covered to a very significant extent by energy from renewable sources,'*

National plans should set requirements for primary energy use expressed in kWh/m^2 per annum. Intermediate requirements shall be set for 2015. It is understood that fifteen Member States have already set intermediate targets.

Notably the Directive broadens the focus from renewable energy generation to the integration of *low or zero carbon energy generation systems* into new building designs. In Article 6 it refers to 'high efficiency' systems that use the electricity from the grid more efficiently to provide heating or cooling (e.g. heat pumps) or which use fuels more efficiently to generate electricity, heating and cooling (e.g. Combined Heat and Power supplying district heating and cooling). It states that for new buildings:

> *'…the technical, environmental and economic feasibility of high-efficiency alternative systems such as those listed below, if available, is considered and taken into account:*
>
> *(a) decentralised energy supply systems based on energy from renewable sources;*
>
> *(b) cogeneration;*
>
> *(c) district or block heating or cooling, particularly where it is based entirely or partially on energy from renewable sources;*
>
> *(d) heat pumps.'*

The new Communication on the Energy Union [14] highlights the efficiency gains from district heating and cooling, noting that it will be addressed by a future Commission Strategy.

2.1.2.2 The Energy Efficiency Directive

The Energy Efficiency Directive 2012/27/EU [15] establishes a binding package of energy efficiency measures that Member States must implement in order to meet the EU's 2020 target for energy efficiency. A key focus of the Directive is the raising of the energy efficiency of new and existing buildings. A central requirement is that EU countries must establish national plans for renovating their existing building stock which currently accounts for approximately 38% of the EU's CO_2 emissions. These plans shall include the *'identification of cost-effective approaches to renovations relevant to the building type and climatic zone'* and '*policies and measures to stimulate cost-effective deep renovations of buildings, including staged deep renovations'*. A specific

[13] Directive 2010/31/EC of the European Parliament and of the Council of 19 May 2010 on the energy performance of buildings (recast)

[14] COM (2015)80 Communication from the Commission to the Council, the European Parliament, the European Economic and Social Committee and the Committee of the Regions, *The Energy Union* package*: A Framework Strategy for a Resilient Energy Union with a Forward-Looking Climate Change Policy*

[15] Directive 2012/27/EU of the European Parliament and of the Council of 25 October 2012 on energy efficiency

renovation rate of 3% of the total floor area of central government buildings to the minimum EPBD levels is set as a target.

2.1.2.3 The Renewable Energy Directive

The Renewable Energy Directive 2009/28/EC states that *'Member States shall introduce in their building regulations and codes appropriate measures in order to increase the share of all kinds of energy from renewable sources in the building sector'*. Moreover, Member States shall also ensure that new public buildings and existing buildings subject to major renovation 'fulfill an exemplary role'.

Whilst the definition of near zero energy buildings laid down in the recast EPBD highlights that remaining energy requirements should be '*covered to a very significant extent by energy from renewable sources, including energy from renewable sources produced on-site or nearby'* there is no consistent reference point in EU legislation for the minimum proportion of renewable energy that should be supplied, or the level of CO_2 emissions reduction to be achieved, by different forms of energy generation supplying buildings.

2.1.2.4 The Waste Framework Directive

Construction and demolition waste (CDW) accounts for between 25% and 30% of the waste generated in the EU [16]. CDW has been identified as a priority waste stream by the European Union because there is a high potential for recycling and re-use of this waste type, based on the potential value and the use of well developed technologies and strategies. The importance of CDW management is reflected in the Waste Framework Directive [17] which requires that:

> *'Member States shall take the necessary measures designed to achieve that by 2020 a minimum of 70% (by weight) of non-hazardous construction and demolition waste excluding naturally occurring material defined in category 17 05 04 in the List of Wastes shall be prepared for re-use, recycled or undergo other material recovery" (including backfilling operations using waste to substitute other materials).'*

The Waste Framework Directive has the high level aim of moving towards a *'European recycling society with a high level of resource efficiency*'. Based on a recent assessment of CDW, the potential for increasing the level of recycling and re-use is significant, with performance at Member State level varying between under 10% and over 90% [18]. The average recycling rate was calculated as part of the same assessment to be 46% across the EU.

2.1.2.5 The Construction Products Regulation

The aim of the Construction Products Regulation [19] is to provide reliable information on the performance of construction products. This is to be achieved by providing a 'common technical language' based on uniform assessment methods of the performance of construction products. This is to be implemented by:

- Manufacturers when declaring the performance of their products,
- The authorities of Member States when specifying requirements for them.
- Users (architects, engineers, constructors etc..) when choosing the products most suitable for their intended use in construction works.

Annex 1 of the Regulation lays down 'basic requirements for construction works' which include specific reference to emissions to the environment (requirement 3) and the sustainable use of natural resources (requirement 7). Basic requirement 7 states that:

[16] European Commission, *Construction and Demolition Waste*, tttp://ec.europa.eu/environment/waste/construction_demolition.htm

[17] Directive 2008/98/EC of the European Parliament and of the Council of 19 November 2008 on waste

[18] BIO Intelligence Service, *Management of construction and demolition waste*, Final report for DG Environment (task 2), February 2011

[19] Regulation (EU) No 305/2011 of the European Parliament and of the Council of 9 March 2011 laying down harmonised conditions for the marketing of construction products

'the construction works must be designed, built and demolished in such a way that the use of natural resources is sustainable and in particular ensure the following:

(a) reuse or recyclability of the construction works, their materials and parts after demolition;

(b) durability of the construction works;

(c) use of environmentally compatible raw and secondary materials in the construction works.'

2.1.2.6 The Industrial Emissions Directive

The Industrial Emissions Directive (IED) [20] is the successor of the Integrated Pollution Prevention and Control (IPPC) Directive. It's aim is to minimise pollution from various industrial sources throughout the European Union and to ensure the prudent management of natural resources. Operators of industrial installations carrying out activities covered by Annex I of the IED are required to obtain an integrated permit from the authorities in the relevant EU countries.

The IED is relevant to this study because it applies to a range of production processes for materials and products that form a significant component of EU building material flows. Examples include cement works, the processing of metals, the manufacturing of glass, ceramics and polymers. Permitting shall take into account integrated performance standards, emissions limit values and Best Available Techniques (BAT) for the type of activity carried out.

2.1.2.7 The Legal sourcing of timber

The Timber Regulation (EC) 995/2010 [21] introduced new requirements for the sourcing of timber products from 2013. It prohibits illegally harvested timber from being placed on the EU market and introduces requirements for 'due diligence', which it defines as comprising:

(a) measures and procedures providing access to the [origin of] the operator's supply of timber or timber products placed on the market;

(b) risk assessment procedures enabling the operator to analyse and evaluate the risk of illegally harvested timber or timber products derived from such timber being placed on the market.

(c) except where the risk identified in course of the risk assessment procedures referred to in point (b) is negligible, risk mitigation procedures which consist of a set of measures and procedures that are adequate and proportionate to minimise effectively that risk and which may include requiring additional information or documents and/or requiring third party verification.

The Regulation defines legally harvested as wood and wood-based materials (excluding packaging and recycled wood) that has been '*harvested in accordance with the applicable legislation in the country of harvest'*. EU FLEGT and UN CITES licenses are deemed to provide assurance of legality. Europe is in the process of introducing the FLEGT (Forest Law Enforcement Governance and Trade) licensing scheme. FLEGT is based on bilateral agreements between the EU and timber producing countries. Third party forest and forest products certification systems that meet the due diligence criteria set out in Article 6 of the Regulation can also be used.

2.1.3 Initiatives targeting specific aspects of Resource Efficiency

2.1.3.1 Development of EU Resource Efficiency indicators

As proposed in the Roadmap to a Resource Efficient Europe, a process was initiated to develop a 'dashboard' of resource efficiency indicators in order to guide action and progress at EU level. The provisional indicators as reported in the first 'resource efficiency scoreboard' provide a high level view of where attention on resource efficiency should be focussed at EU level [22]. They are structured in the following way, with only those indicators of relevance to the built environment highlighted for discussion in this paper:

[20] Directive 2010/75/EU of the European Parliament and of the Council of 24 November 2010 on industrial emissions (integrated pollution prevention and control)

[21] Regulation (EU) No 995/2010 of the European Parliament and of the Council of 20 October 2010 laying down the obligations of operators who place timber and timber products on the market

[22] European Commission (2014) *Resource Efficiency Scoreboard 2014 Highlights*, Directorate-General for Environment

- A lead indicator of resource productivity, linking Domestic Material Consumption (DMC) with Gross Domestic Product (GDP);
- 'Dashboard' indicators of environmental pressures, with greenhouse gas emissions, urban land use and water use;
- Thematic indicators relating to transformation of the economy (including 'turning waste into a resource' but excluding major mineral wastes) and natural capital (including 'safeguarding clean air' with a focus on urban PM_{10} exposure).

A thematic indicator for 'improving buildings' was also proposed, with an initial focus on energy consumption for space heating.

The value of these indicators in defining and measuring progress was reviewed by experts from the European Resource Efficiency Platform (EREP) [23]. Three examples taken from the scoreboard of indicators – DMC, urban land use and PM_{10} emissions - are briefly discussed below, both in terms of their potential relevance as macro-objectives for buildings and also to illustrate the challenges in using them to measure the resource efficiency of the built environment.

Material consumption could be particularly relevant to the large flows of materials associated with the construction sector. However, the difficulty was highlighted of simply focussing on (refined) material flows. This is because materials have a wide range of different upstream and potentially extra-EU impacts. These will be distinct to each type of material and could include environmental pollution, ecosystem damage and resource scarcity. The need to capture 'hidden' flows or 'Raw Material Equivalents' such as mine tailings and processing waste has also been highlighted in other research projects [24]. The potential scale and significance of these flows is illustrated at a Member State level in Figure 2.1. The nature of EU-wide construction resource flows is examined further in Section 2.1.3.2.

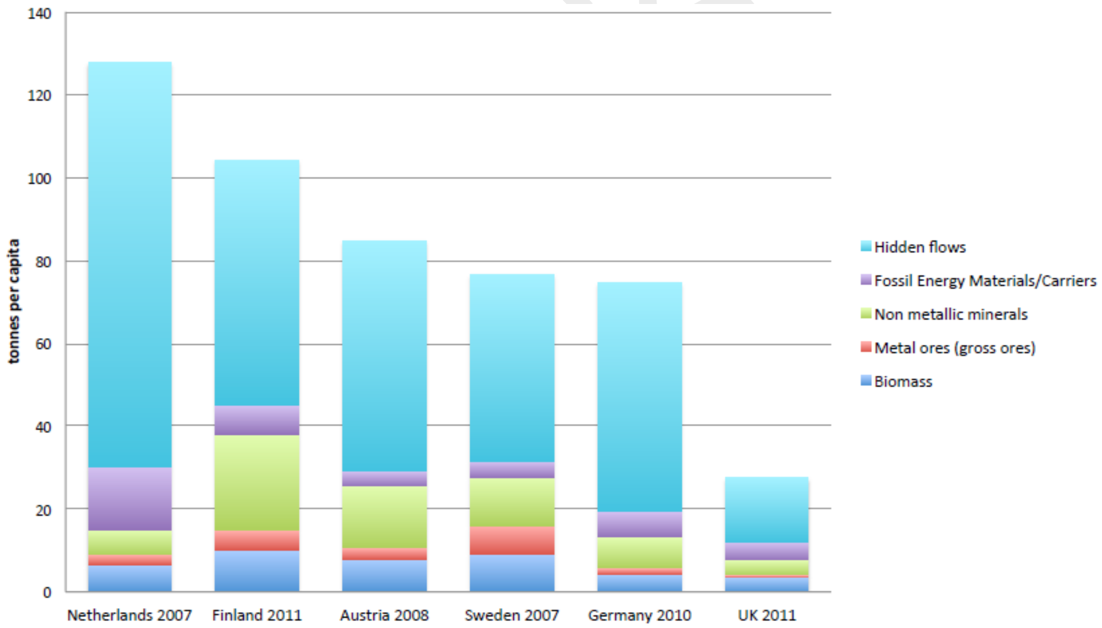

Figure 2.1. Domestic material consumption inclusive of 'hidden' flows for selected MS at points in time

Source: POLFREE (2014)

Urban land use at the expense of agricultural land could be relevant as a measure of how efficient urban develop is. The importance of reducing soil degradation and urban soil sealing is highlighted in the

[23] European Commission, *European Resource Efficiency Platform (EREP)*, http://ec.europa.eu/environment/resource_efficiency/re_platform/index_en.htm

[24] POLFREE, *Comparing trends and policies of key countries*, Deliverable D1.3, Prepared by Wuppertal Institute, 31st May 2014

Commission's 2006 Thematic strategy for soil protection [25]. Figure 2.2 illustrates how construction has exhibited pressures on land use in different Member States during the period 1990-2006. Spain, for example, saw an unprecedented period of urban expansion, which included a move to lower density residential and commercial development. The UK, in contrast, whilst also experiencing a property boom sought to reduce 'greenfield' development whilst increasing urban densities and in-fill. The potential relevance of urban density and form is examined further in Section 3.1.3.

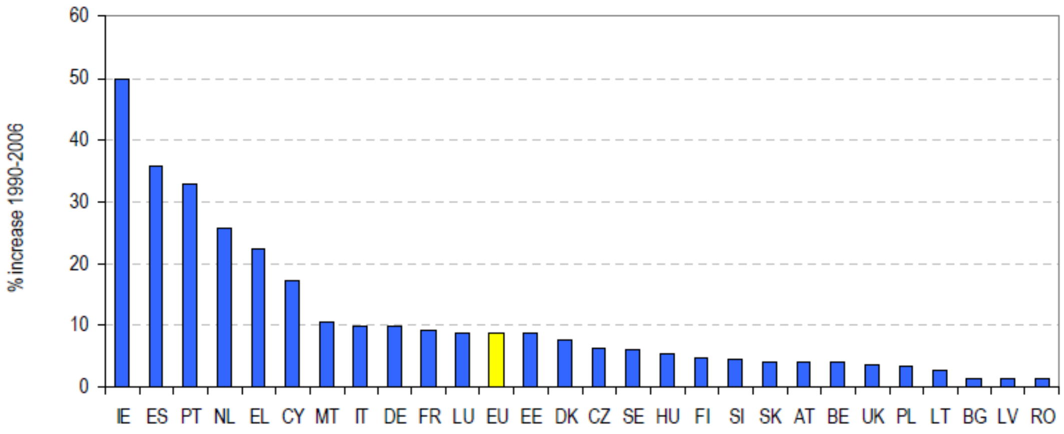

Figure 2.2. Percentage increase in built up areas by member state, 1990-2006

Source: Eurostat (2006), CORINE (1990)

Urban exposure to air pollution, including PM_{10} emissions, is relevant in terms of construction sites, the physical proximity of a building to pollution sources (e.g. adjacent to major arterial roads) and also so-called 'induced' environmental impacts that may be generated as a result of the form and location of building (e.g. lower density residential areas, car based commuting to or from a location). The potential significance of 'induced' impacts is examined further in Section 3.1.3.

2.1.3.2 Material Flow Accounting (MFA)

In support of EU policies on resource efficiency, Eurostat compiles sectoral data for the European economy. According to an assessment of EU sectoral resource use based on Multi Regional Input Output (MRIO) modelling, the construction sector uses the largest amount of materials in the EU economy (5.4 billion tonnes in 2007). This is mainly accounted for by non-metallic minerals, sand and gravel, as illustrated in figure 2.3.

[25] COM (2006)231 Communication from the Commission to the Council, the European Parliament, the European Economic and Social Committee and the Committee of the Regions, *Thematic Strategy for Soil Protection*

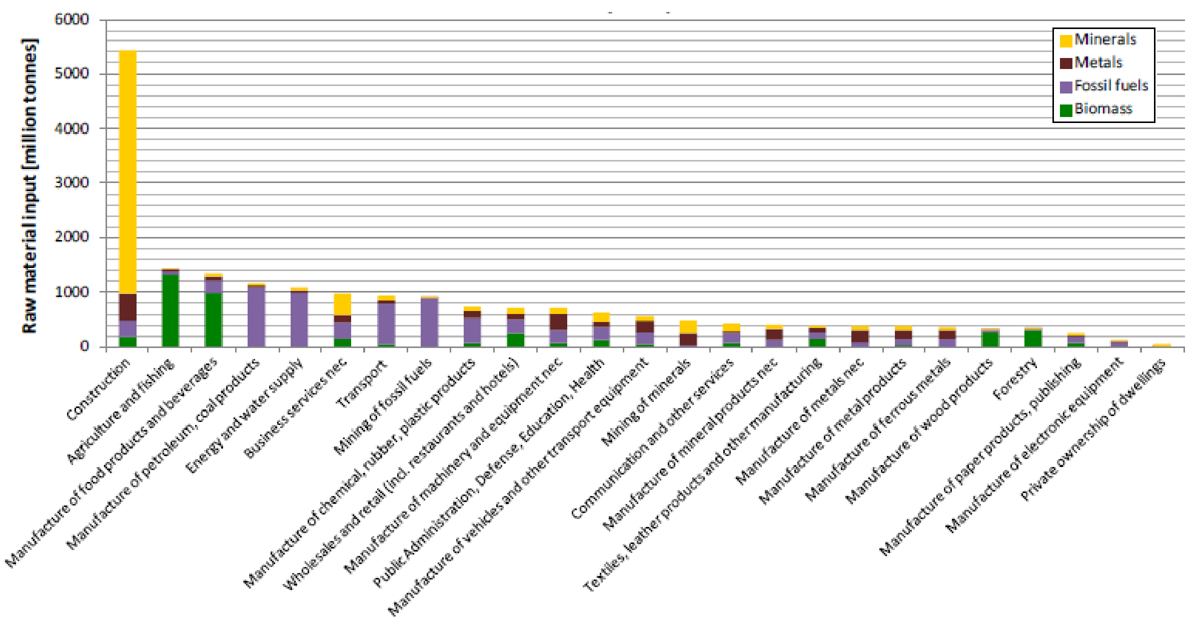

Figure 2.3. The annual Raw Material Input of economic sectors in the EU-27 in 2007

Source: European Commission (2013)

As already highlighted in Section 2.1.3.1, a high level resource efficiency objective for the EU is an improvement in resource productivity i.e. how much economic value is created for each kg of flow. The construction sector is resource intensive, which means that it generates relatively low economic value considering its resource use, compared with many other sectors of the EU economy. Recent analysis for the European Commission [26] showed that the sector has, however, shown a trend towards a 'decoupling' of economic growth from resource use, as illustrated in figure 2.4. It is important to note though that gross resource use increased over this period, so the increase in resource productivity could mask an overall increase in the sector's environmental impacts.

The most resource intensive Member States are illustrated in figure 2.5, which highlights how some smaller Member States such as Portugal, Ireland and Finland use large amounts of materials in proportion to their population. It also indicates the potential for variation in the split between mineral, metal, fossil fuel and biomass use, which may reflect different construction practices and material choices.

[26] European Commission, *Sectoral resource maps: information hub*, Report prepared by BIO Intelligence Service and SERI for DG Environment, March 2013

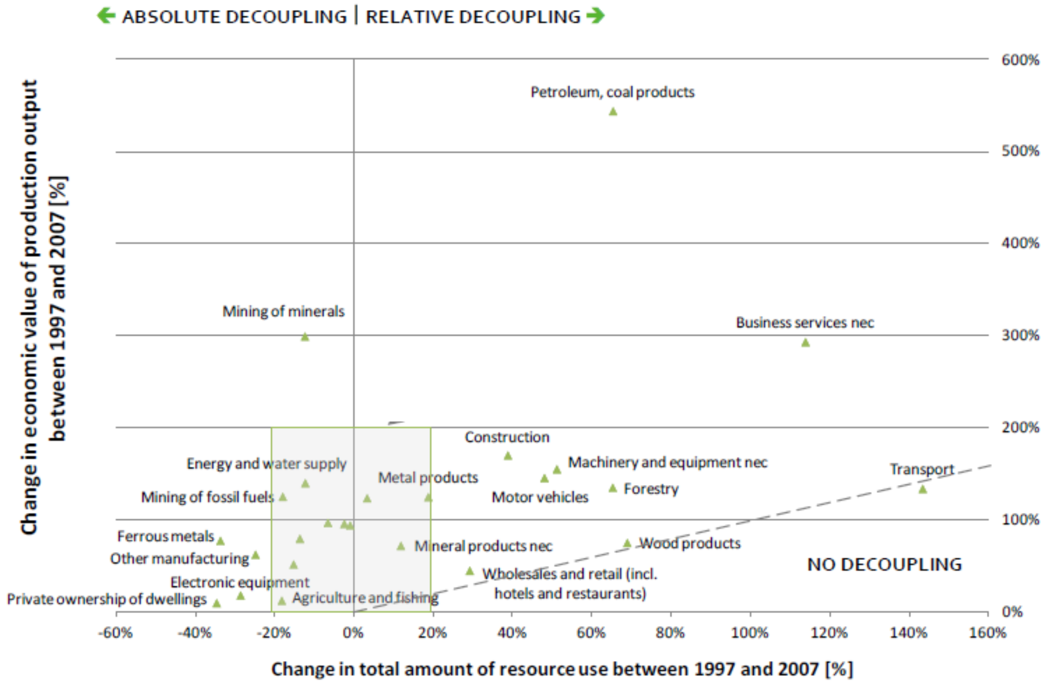

Figure 2.4. The change in material resource use compared with the change in economic value generated over the same time period. *Source: European Commission (2013)*

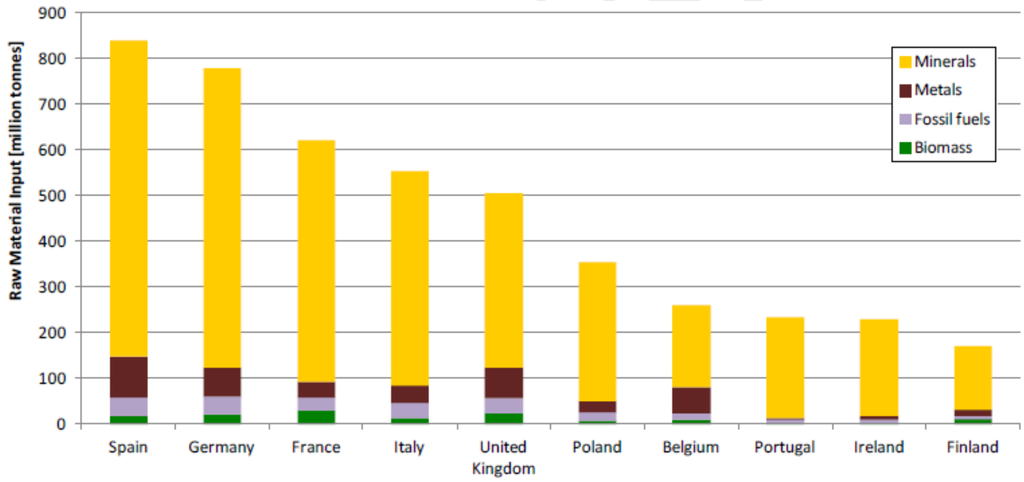

Figure 2.5. Member States with the most material intensive construction sectors (2007)

Source: European Commission (2013)

2.1.3.3 The Raw Materials Initiative

In 2008, the Commission adopted the Raw Materials Initiative [27], which set out a strategy for tackling the issue of access to raw materials in the EU. This strategy has three pillars which aim to ensure:

1. Fair and sustainable supply of raw materials from global markets: The EU has committed to pursue a Raw Materials Diplomacy reaching out to third countries through strategic partnerships and policy dialogues.

[27] COM(2011)25 Communication from the Commission to the Council, the European Parliament, the European Economic and Social Committee and the Committee of the Regions, *Tackling the challenges in commodity markets and on raw materials*

2. Sustainable supply of raw materials within the EU: The EU is dependent on the imports of many raw materials. Even though the potential for mining and quarrying in Europe is strong, the land area available for extraction is constantly decreasing. To facilitate the sustainable supply of raw materials from European deposits, the European Commission aims to secure the right legal and regulatory conditions.
3. Resource efficiency and supply of 'secondary raw materials' through recycling: Production using recycled materials is often much less energy intensive than manufacturing goods from virgin materials. Recycling can thus reduce production costs and GHG emissions and has a great potential to improve Europe's resource efficiency.

The European Innovation Partnership (EIP) on Raw Materials is the major EU initiative implementing the Raw Materials Initiative stakeholder platform. The main objective of the Partnership is to help raise industry's contribution to the EU's GDP to around 20% by 2020 by securing its access to raw materials. It will also play an important role in meeting the objectives of the Roadmap to a Resource Efficient Europe. It will do this by ensuring the sustainable supply of raw materials to the European economy whilst also increasing benefits for society as a whole.

2.2 Member State policies and objectives for resource efficiency

2.2.1 Review of Member State policies and objectives

The European Environment Agency has reviewed the policies and approaches to resource efficiency of the EU28 [28]. The results of the survey which informed their 2011 report suggest that there is a lack of a clear definition and common understanding of the term resource efficiency, with other terms such as decoupling, sustainable use of resources or minimising use of natural resources used interchangeably. A new catalogue of policies is currently being finalised for publication during 2015 and may provide further insight into the evolution of these policies and objectives, as well as their impact.

With the exception of Austria, Cyprus, Hungry, Poland and Spain, which focus on raw material use, the term has been applied to a broad range of resources and natural capital. In 2011, only Austria, Germany and Belgium (Flanders) were highlighted as having a dedicated strategic policy with high level objectives, although sectoral policies applying to energy, waste and specifically building and construction were identified in some cases.

Resources that are prioritised are, in descending order of importance, energy, waste, minerals and raw materials, water, followed by forests and timber, biodiversity, biomass and renewable energy. Where priority resources are categorised, raw materials were identified as a specific category bringing together minerals, construction materials and metals.

In terms of objectives and targets for resource efficiency, the majority tended to be in areas where EU directives mandate action. An overview of the most common targets is provided in table 2.1. These include general targets for the economy as a whole and some that are specific to buildings or construction. Notably only six countries reported targets for material efficiency – Germany, Romania, Austria, Estonia, Italy and Sweden. Examples of selected specific targets are grouped below under common headings:

Greenhouse gas emissions

- *General target adopted across the EU*: Reduce greenhouse gas emissions associated with buildings, industrial sectors, infrastructure and transport

Energy use

- *General targets adopted across the EU*: Increase the overall energy efficiency of buildings, increase the share of renewable energy in total energy use
- Double energy productivity by 2020 compared to 1990 (Germany)

[28] European Environment Agency, *Resource efficiency in Europe: Policies and approaches in 31 EEA member and co-operating countries*, EEA Report No 5/2011

- Reduction in energy intensity of at least 20% by 2020 (Austria)
- By 2020, new buildings shall use 75% less energy than in 2009 (Denmark)
- Reduce energy consumption of existing buildings by at least 38% by 2020 (France)
- Reduce district heating and fuel input by 30% in existing housing in comparison to 2004 (Lithuania)
- Achieve 'thermal rehabilitation' of all buildings built in the period 1950-1980 by 2020 (Austria)

Material use and efficiency

- Resource productivity should increase by a factor of four (Austria)
- Double abiotic material productivity by 2020 compared to 1994 (Germany)
- Reduce the consumption of fossil fuels by 20% by 2020 (Switzerland)
- Reduce Total Material Requirement (TMR) 75% by 2030 and 90% by 2050 (Italy)
- Reduce annual extraction of natural gravel to not more than 12 million tonnes by 2010 (Sweden)
- Increase per capita consumption of wood from sustainable forestry from 1.1m^3 to 1.3m^3 (Germany)

Waste

- *General targets adopted across the EU*: Reduce the amount of waste disposed of, increase the amount of waste separated, increase recycling rates
- Recycling at least 60-75% of construction-demolition waste by 2020 (Czech Republic, Estonia, Hungary, Latvia, Slovenia)

Water

- Achieve 80% efficiency of water consumption within ten years (Portugal)
- Increase the use of rain water in order to preserve water resources (Belgium)

Land use

- Growth in land use for housing, transport and soil sealing should be reduced to 30 hectare/day by 2020 (Germany)
- Use spatial planning to contribute to reducing energy consumption (Denmark)

A targeted review of national resource strategies by the UK's Department for the Environment, Food and Rural Affairs (DEFRA) highlighted the lead taken by Germany, France, Finland and the Netherlands in the area of raw material supplies [29]. The main focus of these strategies tend, however, to be on materials with a level of criticality i.e. their natural reserves are under physical, political or economic pressure.

A summary overview of the German ProgRess programme, which is recognised as a leading example of policy in this area, is provided in Section 2.2.3, including specific areas of focus in the building and construction sector.

2.2.2 Reviews of the progress and impact of EU and MS policy frameworks

A number of recent studies have highlighted slow progress in the implementation of requirements laid down in the recast Energy Performance of Buildings Directive and the Energy Efficiency Directive. These include a focus on how to address the lack of progress towards targets and standards on 'nearly zero energy buildings' [30] and renovation strategies for existing public and private buildings [31].

[29] DEFRA, *A review of national resource strategies and research*, UK, March 2012

[30] Report from the Commission to European Parliament and the Council, *Progress by Member States towards Nearly Zero-Energy Buildings*, COM(2013)483, Brussels, 7.10.2013

[31] Buildings Performance Institute Europe (2014) *Renovation strategies of selected EU countries: A status report on compliance with Article 4 of the Energy Efficiency Directive* and The Coalition for Energy Savings, *Implementing the EU Energy Efficiency Directive: Analysis of Member State's plans to implement Article 5*, May 2015

The FP7 project POLFREE, led by University College London, has analysed EU policy experiences in support of the aim of a resource-efficient economy [32]. The project highlights the need to consider the 'geological and economic framework conditions' for each MS – i.e. endowment with raw materials and raw material dependence - as these may shape resource efficiency plans and programmes [33]. Specific plans and programmes highlighted for analysis include those of Austria (the REAP plan), Germany (the ProgRess programme) and Italy (sustainability strategy 2002).

The project's work package on the role of national policies highlights the current lack of strong and coherent overall strategies, but points to the success of individual instruments targeting specific areas of resource use. Examples cited include the German building modernisation programme's impact on energy efficient renovations and the UK aggregates levy's impact on domestic material flow. In this respect the work of the European Environment Agency in bringing together MS policies is suggested as a helpful way of disseminate good practice.

[32] POLFREE, *Policy options for a resource efficient economy*, FP7 collaborative project, Accessed April 2015, http://www.ucl.ac.uk/polfree

[33] POLFREE, *Comparing trends and policies of key countries*, Deliverable D1.3, Prepared by Wuppertal Institute, 31st May 2014

Table 2.1. Resource efficiency target areas and indicators most commonly reported by EEA countries

Categories	Materials					Energy					Water			Land			Waste		Others		
Indicators	Components of DMC/DMI	Total Material Requirement (TMR)	Domestic Material Consumption (DMC)/GDP/DMC/DMC/capita	Direct Material Input (DMI)/ DMI/GDP or GDP/DMI	Domestic extraction (DE)	Energy efficiency of buildings	Biofuels share in transport	Share of renewable energy	Energy consumption	Energy efficiency	Exploitation index of renewable water resources	Water quality	Water use (total or by sector)	Forest area	Share of agricultural area under organic/agro-environmental farming	Land use/conversion of land/soil	Amount of waste recycled and/or the amount of waste deposited	Waste generation (total or per waste stream or sector)	Fisheries	Eco-efficiency of different sectors	Transport and infrastructure
Austria			•	•	•													•			
Belgium (FL)			•	•		•		•	•	•			•				•	•		•	•
Belgium (WA)		•								•	•		•							•	
Bulgaria	•		•														•	•	•		
Croatia			•				•	•	•		•		•	•	•	•	•	•	•		
Cyprus								•	•			•		•	•						
Czech Republic			•					•	•	•	•	•		•	•	•	•	•			•
Denmark				•		•		•	•				•				•	•		•	
Estonia					•			•				•		•		•	•		•		
Finland	•	•	•	•	•		•	•	•	•	•		•	•	•	•	•	•		•	
Former Yugoslav Republic of Macedonia								•	•	•					•	•		•		•	•
France			•					•	•	•		•			•		•	•			
Germany				•		•		•		•						•					•
Greece																					
Hungary										•			•		•	•	•	•			
Ireland			•						•				•					•			
Italy		•	•	•	•						•		•				•	•			
Latvia						•								•							•
Liechtenstein																	•	•			
Lithuania																					
Netherlands																					
Norway								•		•											
Poland			•		•		•	•	•	•	•		•	•		•	•	•	•		
Portugal			•					•	•	•							•	•			
Romania	•		•				•	•	•		•	•	•	•	•	•	•	•	•		
Slovakia			•	•	•			•	•	•		•	•	•	•	•	•	•		•	
Slovenia	•		•	•			•	•	•	•				•		•	•	•			•
Spain																					
Sweden			•	•	•			•	•					•	•	•	•	•	•		•
Switzerland			•			•		•	•	•		•	•	•	•	•	•	•			•
Turkey																					•
United Kingdom			•		•				•	•			•							•	
Total	**4**	**3**	**17**	**9**	**8**	**5**	**5**	**18**	**17**	**15**	**7**	**7**	**13**	**12**	**11**	**13**	**18**	**20**	**6**	**7**	**9**

Source: European Environment Agency (2011)

2.2.3 Case studies of Member State plans and programmes

2.2.3.1 The 'ProgRess' resource efficiency programme, Germany

The goal of Germany's RE programme is to make '*the extraction of and use of natural raw materials more sustainable and to reduce associated environmental pollution as far as possible'* [34]. The main focus is on raw materials, including abiotic and biotic non-energetic resources, with associated links to the use of natural resources such as water, air, land, soil, biodiversity and ecosystems, although these are addressed by other policies and programmes. The following strategic approaches are considered:

- Securing a sustainable raw material supply;
- Raising resource efficiency in production;
- Steering consumption towards resource efficiency;
- Enhancing resource efficient, closed cycle management;

The construction sector is identified as one of the country's most resource intensive, with environmental pressures identified in relation to:

- Raw materials extraction (e.g. gravel, sand and quarry stone);
- Processed raw material use (e.g. cement, metals and two thirds of national sawn timber production);
- Land take and high specific traffic density due to lower density urban fringe development;
- Use phase energy consumption.

Also highlighted in relation to these objectives and targets is that existing structures represent a 50 billion tonne repository of mineral resources (estimate from 2000). Box 2 summarises the strategic objectives and targets relating to the construction sector.

Box 2. Construction sector objectives and targets identified by the 'ProgRess' programme, Germany

Energy use

- Improved building energy efficiency

Material use

- Improve the resource efficiency of material use e.g lightweight timber use
- Concrete aggregate substitution and alternative materials and processes for cement production
- The greater use of 're-growable' raw materials e.g. timber

Waste reduction

- Avoid waste and close material cycles e.g. re-use or recycling of demolition materials
- Step up the cascade use of materials i.e. avoiding 'down cycling'

Urban sustainability

- Reduce land take to 30 hectares/day by 2020
- Making more sustainable use of existing urban land and infrastructure with a focus on compact development

Life span

- Extending the useful life of buildings, accompanied by energy efficient modernisation

Source: Federal Ministry for the Environment, Nature Conservation and Nuclear Safety (2012)

[34] Federal Ministry for the Environment, Nature Conservation and Nuclear Safety (2012) *German Resource Efficiency Programme (ProgRess): Programme for the sustainable use and conservation of natural resources*, Germany Government

2.2.3.2 'Le Plan Bâtiment Durable' (sustainable building plan), France

In 2012 a working group on 'responsible building' was launched within the frame of country's Sustainable Building Plan (Plan Bâtiment Durable). The plan has two overarching goals [35]:

- To reduce the energy consumption of existing buildings by 38% (from 250 to 150 kWh/m^2/year) by 2020, and by a further 100 kWh/m^2/year before 2050;
- To ensure that France is building '*low consumption buildings'* by 2012, and '*positive energy buildings'* by 2020.

In total, 20 working groups have been launched since the creation of Plan Bâtiment Durable, with the latest focus on the development of a voluntary label for energy and environment performance of new buildings.

The proposed new label would consider not just energy in the use phase but along the whole life cycle in order to analyse the overall performance of a building [36]. The aim is to pilot test the label in 2016-2017 with three main criteria: total energy use, total water consumption and CO_2 emissions. Criteria on waste and public transportation may also be added in order to assess overall building performance.

Seven working groups have been created in order to define this label and are currently working on the following topics:

- Life-cycle assessment
- Environmental performance display
- Environmental data
- Economic stakes
- Users
- BEPOS (positive-energy building) and urban integration
- Quality of use

The focus of the label reflects a shift in French building energy efficiency policy to overall performance (energy, environment, cost) and from the building scale to the district scale, with the need to take district energy into consideration.

[35] World Green Building Council, *Collaborative policy making case study:Le Plan Bâtiment Durable, France*

[36] Background to the case study kindly provided by the World Green Building Council's European Regional Network

Summary of findings on EU and MS policies

- Existing EU frameworks, regulation and initiatives, as well as leading plans and programmes established by Member States, establish clear high level objectives which can form a starting point for this work to identify macro-objectives;
- Existing EU legislation has created clear regulatory framework for action to reduce building-related energy use and CO_2 emissions. This includes a near zero energy objective for new buildings and the progressive renovation of the existing building stock. Climate change adaptation is a related area of activity that is of particular relevance to existing buildings;
- A set of resource efficiency indicators has been developed at EU level. Whilst these are not specifically targeted at the building sector, they could provide a useful initial reference point. The indicators includes measures of resource use, pressures on environmental capital and thematic indicators. Links can be made to EU strategies on raw material use, water use, forestry and air pollution;
- Waste reduction and circular material flows are specific focus for attention, including targets for the reduction of construction and demolition waste going to landfill;
- Various EU and Member State strategies highlight the need to interrelate urban planning, infrastructure, and building form and location. The multiple resource efficiency benefits of compact, land efficient and public transport connected buildings are highlighted and cited as an objective.

3. Evidence for macro-environmental ‘hot spots’ along the life cycle of buildings

In this section, the results of technical studies that have analysed buildings and major construction materials from both a 'top down' sectoral and 'bottom up' building typology perspective are reviewed. From these results, environmental and resource efficiency ‘hot spots’ for the improved performance of residential and commercial buildings are then identified.

The boundary and scope for addressing environmental and resource efficiency ‘hot spots’ relating to buildings is also explored. This includes a focus on ‘induced’ effects – those that relate to wider urban infrastructure - as well as in-direct or consequential factors to take into account. The latter include the potential of comfort and health & wellbeing factors to influence the performance, lifespan and value of buildings.

The need has been highlighted for further work to identify suitable indicators of resource efficiency for the construction sector [37]. The Commission's work on indicators, together with issues highlighted in literature, therefore also inform the analysis in this section, with a focus on the following areas:

- Abiotic and biotic materials flows , as well as stocks and recycling loops;
- The relationship between material input and the functional unit of service;
- The design and service life of buildings, both as a whole and also with a focus on structures;

The results of the analysis from this section will then be compared and contrasted with those from the review of EU policy (Section 2) and existing assessment and reporting tools (Section 4).

3.1 Top down analysis of building stock LCA impacts

3.1.1 Construction sector life cycle impacts

3.1.1.1 EREP EU construction resource efficiency scenarios

The most significant top down study of construction environmental impacts was carried out in support of the work of the European Resource Efficiency Platform (EREP). The study assessed ‘scenarios and options towards a resource efficient Europe’ in support of the EU Roadmap to a Resource Efficient Europe [38]. The study drew upon three analyses: economy-wide Material Flow Accounting (MFA) and environmentally extended input-output analysis (EI-IO) of the residential construction sector [39] and an LCA case study of the UK construction sector [40].

The MFA and EI-IO analysis showed that 50% of bulk materials such as sand, gravel, clay and stone are used by the sector and between 10-20% of wood and bulk metals, with iron and copper being the most significant. The bulk materials are predominantly sourced from within each Member State, whereas metals are generally imported. Cradle to grave emissions for the sector are in line with the overall GDP contribution, at between 7-15%, although this rises to 35% when use phase energy is included. The main contributors to life cycle environmental impacts, excluding the use phase, are energy related emissions for cement, clay and metal production, as well as construction itself on site.

[37] Heite. M, *Material consumption in the construction sector: resource efficiency from an interorganisational perspective*, Center for Environmental Systems Research (CESR), University of Kassel, p-366 from papers submitted to the First International Conference on Resource Efficiency in Inter-organisational Networks, 13th – 14th November, 2013,

[38] European Commission, *Assessment of scenarios and options towards a resource efficient Europe – An analysis for the European built environment*, final report, March 2014

[39] European Commission, *Topical papers 1: Resource efficiency in the built environment – a broad brushed, top-down assessment of priorities*, Authored by CML and AAU-SEC, February 2013 *and* European Commission, *Topical papers 9: Indicators for resource efficiency – potential ways of representing results*, Authored by TNO, February 2014

[40] European Commission, *Topical papers 2: Strategies for decoupling – options to consider in the field of buildings and infrastructure*, Authored by PE International, February 2014

This part of the study highlighted the importance of addressing the 'stocks-in-use', 'waste generation' and 'recycling rates'. This is because of the large flows and relatively long lifespans of buildings. Due to the specifics of each resource, it is suggested to address stocks individually or for each broad type of material, with use normalised according to a unit of consumption [41].

A case study LCA analysis was carried out for the UK construction sector, combining data for the building and road construction sectors. The results indicate that abiotic resource depletion is dominated by the production stage of materials, whilst the use stage of buildings dominates emission related indicators. In the production phase, significant environmental impacts are related to non-metallic minerals, with cement production and materials made from fossil fuels specifically highlighted, as illustrated by Figure 3.1. Metals such as copper are also very significant contributors to the sectors environmental impact. Impacts relating to the use of wood were not fully captured because of methodological problems with LCA land use indicators. It is important to note that the construction of road infrastructure has an influence on the results, as can be seen from the significant contribution of bituminous materials to the majority of the impact categories.

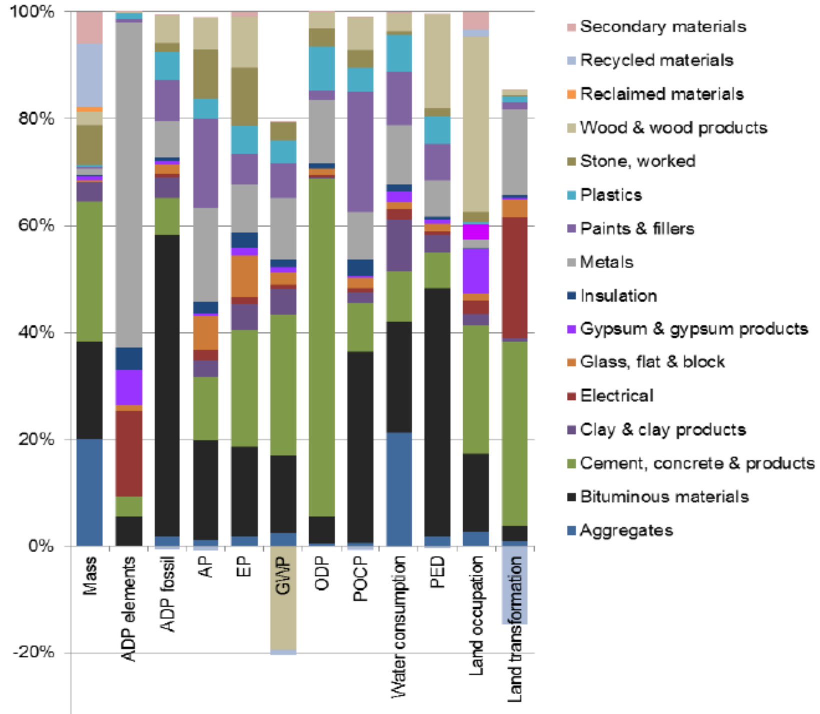

Figure 3.1. LCA results for the UK construction sector

Source: European Commission (2014)

The study concluded that policy measures with a focus on large flows of materials will have the greatest impact. The areas of attention with the greatest potential to reduce environmental impacts were as follows:

- The production of products that are more resource efficient, based on evidence from EPDs for their embodied energy, abiotic resource depletion and water use. Examples cited include a shift from concrete/masonry to timber materials, hollow pre-cast concrete, concrete formwork with void formers and hollow blockwork;
- A reduction in the size of new housing and offices (i.e. a more efficient use of space per occupant). This is linked to an increased density of the built environment;
- A reduction in the amount of waste from construction, including upstream waste arising from extraction and processing;

[41] Ekins,P and J.H.Spangenberg, *Resource efficiency indicators and targets in relation to the resource efficiency roadmap*, EREP working paper – Expert group of economists on resource efficiency, January 2013

- The recycling of large flows of construction and demolition waste, with a focus on closed loop recycling instead of down cycling from the building to the road construction sector;

In addition, further scenarios for long-term improvements in resource efficiency were modelled, with the following identified as priorities:

- Design for repair, disassembly and recycling (deconstruction). This is described as design to re-use modules or whole elements of constructions;
- Ensuring a high adaptability, flexibility and functionality of design in order to extend the service life of buildings.

Despite evidence for the significant potential reductions in use phase energy demand, renovation did not appear in the final list of significant measures. This is because the scenario modelled resulted in increased abiotic resource depletion and high upfront capital costs. However, the potential saving in new construction and optimised energy savings from economies of scale achieved by large renovation programmes of the kind implement in Germany were not modelled.

3.1.1.2 Environmentally extended input-output analysis for Ireland

An environmentally extended input-output analysis was carried out on the contribution of the Irish construction sector to the countries greenhouse gas (GHG) emissions [42]. The analysis was based on data for 2005 for those activities classified as NACE 'civil and structural construction works'. The results showed that the sectors domestic emissions contributed towards 8.26% of national emissions, excluding use phase emissions from the energy use of buildings. Of this contribution the emissions were split between 17% direct on site emissions from construction works, 41% from upstream indirect domestic emissions and 42% from upstream indirect emissions outside of Ireland (i.e. emissions associated with imports).

The relative contribution of emissions from different construction activities, both with and without imported emissions, is illustrated by Figure 3.2 which separates out groundworks, structural works, services, fit-out/finishing and plant/operations. Indirect emissions associated with the supply chain were estimated to have made the most significant contribution. The study highlights that only the cement industry is regulated under the EU Emissions Trading Scheme (ETS). It concludes that the provision of product specific information about the embodied greenhouse gas emissions of construction materials would enable choices to be made to reduce the indirect greenhouse gas emissions intensity.

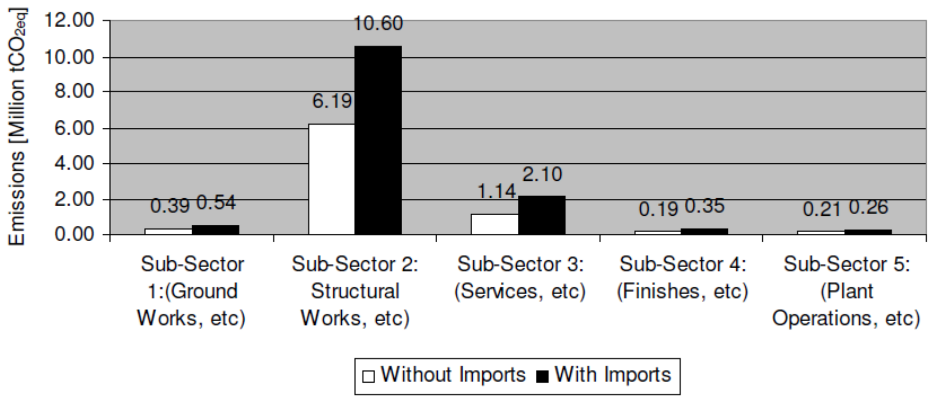

Figure 3.2. Total emissions of the Irish construction sector (2005)

Source: Acquaye and Duffy (2010)

[42] Acquaye, A and A.Duffy, A (2010) *Input-output analysis of Irish construction sector greenhouse gas emissions*, Building and Environment, Volume 45, Issue 3, Pages 784-791

3.1.1.3 Environmentally extended input-output analysis for Sweden

An environmentally extended input-output analysis was carried out on the environmental impacts of the Swedish buildings and related construction and property management activities [43]. The analysis was based on data from 2005. The resource use and environmental effects analysed were broader than the Irish IO study referred to in 3.1.1.2, with energy use and CO_2 emissions supplemented by other Green House Gases and emissions to air (CH_4, NO_X, SO_2, CO, NMVOC), emissions to water (COD, BOD, nutrients and metals), solid waste and hazardous waste.

The results showed that the building construction and propery management are responsible for between 10% and 40% of the overall normalised environmental impacts of the Swedish economy, depending on the midpoint. The proportional contributions (excluding use phase heating) to waste (27-40%), CO_2 equivalents (16%) and the use of hazardous chemical products (16%) were the most significant. The latter is mainly attributed to the production of non-metallic mineral products. The most important upstream processes contributing to Green House Gas emissions related to the production of non-metallic mineral products, such as bricks and cement, followed by the production of metals, and construction and supply chain related transport.

It is important to note that Sweden has a high proportion of renewable electricity and heat generation. This mean that domestic emissions relating to energy generation reported in the study will be lower than for comparable building sectors in many other Member States.

3.1.2 The importance of the functional unit in capturing the intensity of resource use

The proposed thematic focus of EU resource efficiency indicators on 'improving buildings' has highlighted the importance of considering the functional unit of resource use. Expert commentary submitted to the EREP emphasised the need to ensure that progress is related to how the resource is consumed, so as to ensure that meaningful comparisons can be made. This commentary is summarised in Box 3. The intensity of use of a building resource may be temporal (e.g. proportion of time the space is used during the day or week) or spatial (e.g. per household, person or workstation). The choice of functional units is also highlighted in relation to building structures, with design and engineering parameters cited as being as significant in determining overall resource efficiency per unit of load capacity per unit dimension [44].

Whilst the functional unit is particularly relevant to the development of indicators, it is nevertheless also important when considering macro-objectives e.g. a simple comparison of building efficiency by floor area may mask significant variations in performance relating to density, form and space utilisation. To take an example cited during the development of EU Green Public Procurement criteria for office buildings, a refurbishment project was able to achieve a 70% increase in occupancy, together with an associated reduction in CO_2 emissions per desk space, whilst increasing satisfaction in the working conditions [45].

Box 3. Choice of functional unit when measuring the resource efficiency of buildings

DG Environment's expert group of economists on resource efficiency made specific comments on the Commission's proposals for 'improved buildings' sectoral resource efficiency indicators. Ekins and Spangenberg in their January 2013 paper [46] highlight that, taking the example of residential heating energy, resource use should be normalised per person, household and residential unit – i.e. floor space per person and household unit. This would ensure that the resource use is understood in terms of economics and social trends. If heating energy, or indeed material use, were to be measured solely in terms of usage per m^2 this would mask socio-economic trends relating to demand for the resource.

Source: Ekins and Spangenberg (2013)

[43] Toller.S, Wadeskog.A, Finnveden.G, Malmqvist.T and A.Carlsson, *Energy use and the environmental impacts of the Swedish building and real estate management sector*, Journal of Industrial Ecology, p.394-404 Vol.15 No.3 2011

[44] Purnell, T, *Material nature versus structural nurture: the embodied carbon of fundamental structural elements*, Environmental Science & Technology, 2012 Mar 20;46(6):3599

[45] WRAP (2012) *Refurbishment Resource Efficiency Case Study: Elizabeth II Court*, Winchester

[46] Ekins,P and J.H.Spangenberg, *Resource efficiency indicators and targets in relation to the resource efficiency roadmap*, January 2013

3.1.3 'Induced' life cycle impacts of building spatial form and location

A recurring theme in urban planning literature is the relationship between urban density, building form and transport energy use. Steemers (2003) outlines the potential to optimise the energy efficiency of the built form by increasing residential densities up to 200 dwellings per hectare (0.01 km^2) whilst minimising building plan depths [47]. For office buildings the layout and form is considered more important than density, with narrow plan depths to maximise daylighting and facilitate natural ventilation identified as being fundamental. Floor to ceiling heights are also cited as a factor influencing passive thermal control [48].

Schiller (2007) [49] further highlights the relationship between material consumption and building density, extending the analysis to identify the material flows associated with urban infrastructure required to service buildings, including roads and utilities. This aspect can be linked to the promotion of heating and cooling networks in the recast Energy Performance of Buildings Directive (see Section 2.1.2), with both new and existing buildings having the potential to benefit from existing high efficiency and low carbon energy infrastructure.

Anderson et al (2015) describe additional energy use associated with transport as an 'induced' effect of buildings, arguing for the environmental impacts resulting from the interaction between individual buildings and their urban context to be captured [50]. The methodology proposed to capture these impacts is illustrated in Figure 3.3. A range of studies reviewed from the EU and US demonstrate a strong correlation between location and accessibility, with reduced car use where buildings are well connected in relation to extensive, multi-node public transport networks.

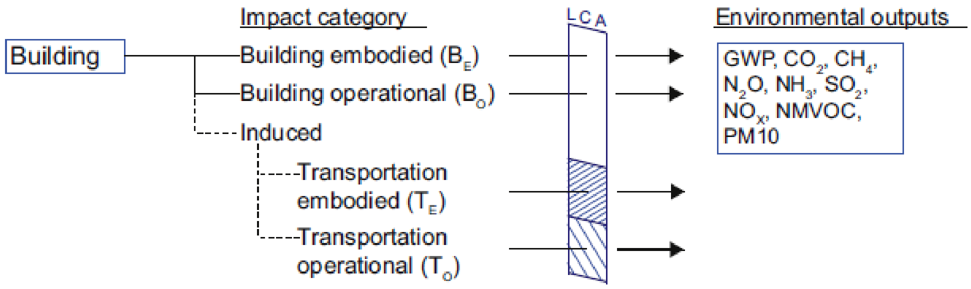

Figure 3.3. Proposed methodology to capture 'induced' built environment impacts

Source: Anderson et al (2015)

Steemers (2008) estimates there to be a ratio between building energy use the use phase and urban transport energy use of 2:1, citing estimates from London (UK) as well as international comparisons for major cities. A strong relationship between population and employment density of urban areas and variations in transport energy use is identified in literature. For example, North American studies suggest that transport energy use can vary by 17-19% between high and low density locations, depending on location and public transport accessibility. This finding is supported by carbon footprint analyses for office buildings in the UK [51]. However, analysis in the US and Canada suggests that transport related energy use has the potential, for some modern low energy buildings, to be greater than building energy consumption in the use phase [52].

[47] Steemers.K, *Energy and the city, density, buildings and transport*, Energy and Buildings 35 (2003) 3–14

[48] Kimpian,J and S,Watts. *A blueprint for the future office*, Council on Tall Buildings and Urban Habitat (CTBUH) Conference, 2012

[49] Schiller,G (2007) *Urban infrastructure: challenges for resource efficiency of in the building stock*, Building Research & Information, 35(4), p.399-411

[50] Anderson.J.E, Wulfhorst.G and W.Lang, *Energy analysis of the built environment — A review and outlook*, Renewable and Sustainable Energy Reviews, 44(2015)149–158

[51] British Council for Offices, *Whole life carbon footprint measurement and offices*, March 2012, UK

[52] Victoria Transport Institute, *Recommendations for improving LEED transportation and parking credits*, January 2015, http://www.vtpi.org/leed_rec.pdf *and* Wilson.A and R.Navaro, *Driving to Green Buildings: The Transportation Energy Intensity of Buildings*, Building Green, September 2007, https://www2.buildinggreen.com/article/driving-green-buildings-transportation-energy-intensity-buildings

3.2 Bottom up LCA analysis of selected building typologies

3.2.1 Residential building typologies

Residential buildings are the most significant building typology in terms of resource use across the EU. A number of LCA studies have therefore been reviewed in order to identify macro-scale environmental impacts. Studies have primarily been selected that take a sectoral perspective, modelling and comparing the performance of common residential building forms. With over 40% of the residential building stock pre-dating 1960 and a replacement rate of 1-2%, the role of renovation was also considered important to analyse.

3.2.1.1 EU wide potential for environmental improvement

The Environmental Improvement Potentials of Residential Buildings (IMPRO Buildings) was carried out by JRC-IPTS [53]. A life cycle assessment was carried out encompassing 72 residential building typologies, 53 of which were existing stock and 19 new construction forms. The building form and typologies were selected and described in order to be representative of the forms of housing that typify the EU stock (single family houses, multi family houses, high rise apartments) and the variations in climate conditions (split into three zones – north, middle and south). The boundary and life cycle stages modelled reflected those described in EN 15978. A functional unit of 1m^2 of living space was defined. The key findings of the study were as follows:

- The use phase of buildings is the most important because of primary energy use for, in particular, space heating, hot water and lighting;
- For new buildings the construction phase becomes proportionally more important, with exterior walls, basements and floors/ceilings the most significant modelled impacts.
- The effect of building form and geometry is reflected in a general trend for higher energy demand for larger, single family houses;

The most significant options for improvement identified were further design improvements to reduce the energy use of new buildings, the substitution of concrete and bricks by wood in new construction, and renovation measures to improve roofs, façades and air tightness. Moreover, the resource efficiency potential of more compact dwelling forms was also highlighted. The improvement potential of the option of selecting wood should be caveated based the discussion in Section 3.3.3, as the environmental effects associated with forestry are not yet well addressed by LCA methods.

3.2.1.2 Supporting literature addressing residential building typologies.

Similar to the IMPRO study described above, Cuéllar-Franca and Azapagic (2012) analysed common residential building forms [54]. The study focussed on detached, semi-detached and terraced house forms in the UK, cross-checking the results with house forms in Spain. The results mirror those of IMPRO (2008), as well as Asdruballi et al (2013) [55], Khasreen et al (2009) [56] and Ortiz et al (2008) [57], with the use phase being of greatest importance followed by the production phase, which is modelled to account for 9-15% of embodied environmental impacts.

[53] Nemry et al (2008) *Environmental improvement potentials of residential buildings (IMPRO-Buildings)*, Joint Research Centre IPTS, European Commission.

[54] Cuéllar-Franca.R.M and A.Azapagic, *Environmental impacts of the UK residential sector: Life cycle assessment of houses*, Building and Environment 54 (2012) p.86-99

[55] Asdrubali.F, Baldassarri.C and V.Fthenakis, *Life cycle analysis in the construction sector: guiding the optimisation of conventional Italian buildings*, Energy and Buildings, 64(2013), p.73-89

[56] Khasreen.M.M, Banfill.P.F.G and G.F.Menzies, *Life-Cycle Assessment and the Environmental Impact of Buildings: A Review*, Sustainability 2009, 1, 674-701

[57] Ortiz.O, Castells.F and G.Sonnemann, *Sustainability in the construction industry: A review of recent developments based on LCA*, Construction and building materials, 23(2009), p-28-39

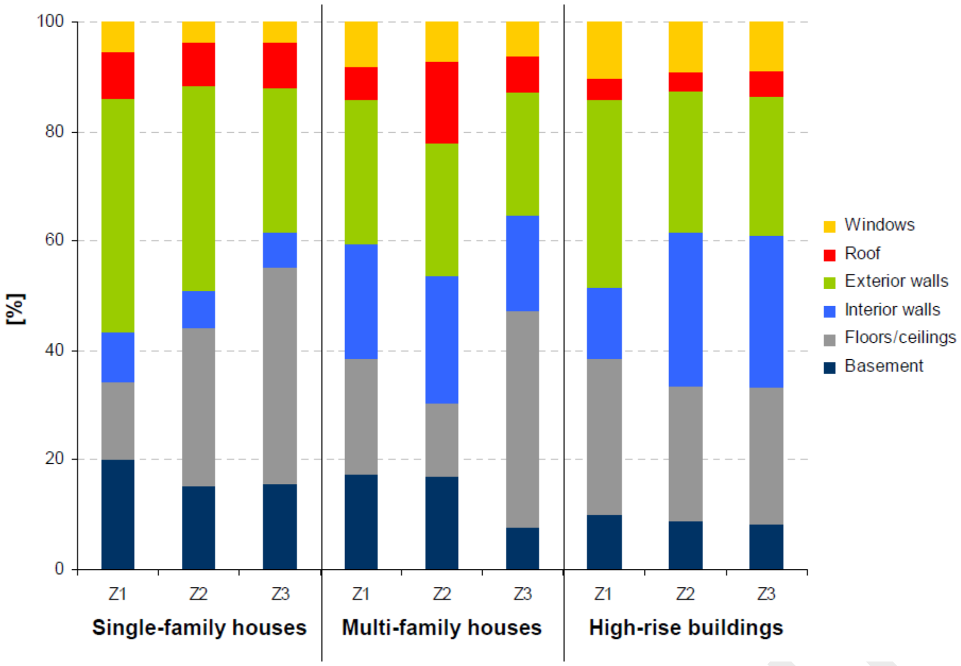

Figure 3.4 **Contribution of individual construction elements to the embodied energy of new residential properties according to climate zone and building typology**
Source: JRC-IPTS (2008)

Only for higher density and taller building forms do embodied impacts currently appear to take on a greater significance, with the life cycle significance rising to 45% (Thomark 2002). However, it is important to note that the overall balance between energy consumption in the use phase (regulated by building permits) and embodied energy in construction materials is shifting towards embodied energy. This is because modern buildings have lower primary energy demand in the use phase and may have increased embodied energy associated with, amongst other factors, improvements in the thermal efficiency of the building fabric [58].

So-called 'unregulated' electricity use associated with appliances and other plug loads within a home must be considered separately as these are difficult to estimate at the design stage. Unregulated in this context means that it is not regulated as part of building permitting. The growth in household appliance and electrical equipment ownership across the EU has led to an increase in this portion of use phase energy use. EU product policies such as Ecodesign address this electricity use, but home builders and landlord can also play a role in specifying or offering low energy appliances and fittings.

In addition to further reductions in CO_2 emissions and therefore global warming potential (GWP), the importance of building smaller or more compact dwellings which share party walls was highlighted. This finding is also supported by Norman et al (2006) [59]. It is important to note that the improvement potential of the latter can only be identified if the functional unit is changed from m^2 of dwelling to the dwelling space per occupant. This point was also highlighted by Ekins and Spangenberg (2013) in Section 3.1.2.

3.2.2 Office building typologies

3.2.2.1 EU wide potential for environmental improvement

Broad evidence for the life cycle environmental impacts of office buildings across the Europe's distinctive climatic zones indicates that energy use during their occupation is responsible for the most significant impacts [60]. An LCA carried out in support of the EU Green Public Procurement (GPP) criteria for office buildings highlighted the significance of primary energy use during the occupation of a building - also referred to as the

[58] Sartori.I and A.G.Hestnes, *Energy use in the life cycle of conventional and low energy buildings: a review article*, Energy Build, 2007, 39(3), p.249-257

[59] Norman.J, MacLean.H, and C.Kennedy, *Comparing High and Low Residential Density: Life-Cycle Analysis of Energy Use and Greenhouse Gas Emissions*, Journal of Urban Planning and Development, March 2006, Vol. 132, No. 1 : pp. 10-21

[60] European Commission, *GPP Office buildings: Technical Background report*, JRC-IPTS 2011 and 2014 revisions

use phase - is associated with the most significant environmental impacts. These impacts were mainly attributed to greenhouse gas emissions from the consumption of electricity and natural gas for heating, cooling, ventilation, lighting and hot water.

The Energy Performance of Buildings Directive has led to the adoption of stricter regulations on energy use at Member State level (see Section 2.1.2). Office buildings have, as a result, become more energy efficient and the significance of space heating, particularly in northern Europe, has reduced. Space heating requirements are, however, still significant in older office buildings, which may therefore be candidates for major renovation. Intelligent lighting controls have allowed for lighting systems to become more responsive to occupancy and daylighting levels, thereby saving electricity. The thermal efficiency of the building fabric, building orientation and façade configurations, water use, together with a buildings depth and layout, all play a role in influencing heating, cooling, lighting and ventilation requirements in existing buildings [61].

Cooling-related energy use has become more significant, particularly in warmer climates, because of the increased use of computers and the installation of larger IT servers which generate waste heat. The installation of more intensive HVAC systems is a choice that allows for greater flexibility of floor layouts as well as more cost efficient use of floor plates. This may however be false economy because it does not necessarily optimise the productivity of indoor work environments, as evidenced by building performance evaluations in the UK and other Member States [62].

As office buildings have become overall more energy efficient in terms of regulated energy use, this has at the same time resulted in an increase in the importance of environmental impacts associated with their construction. The use of more energy intensive insulation materials, the beneficial use of increased thermal mass and façade systems in order to meet higher energy efficiency standards has, for example, tended to increase the overall environmental impact of the construction materials used [63]. These features cannot be seen in isolation as they have an important role to play in passive building design, as illustrated by the moderating effect of thermal mass on interior temperature during a heatwave, in Figure 3.5. The balance between production and use phase energy is explored further in the next Section 3.2.2.2.

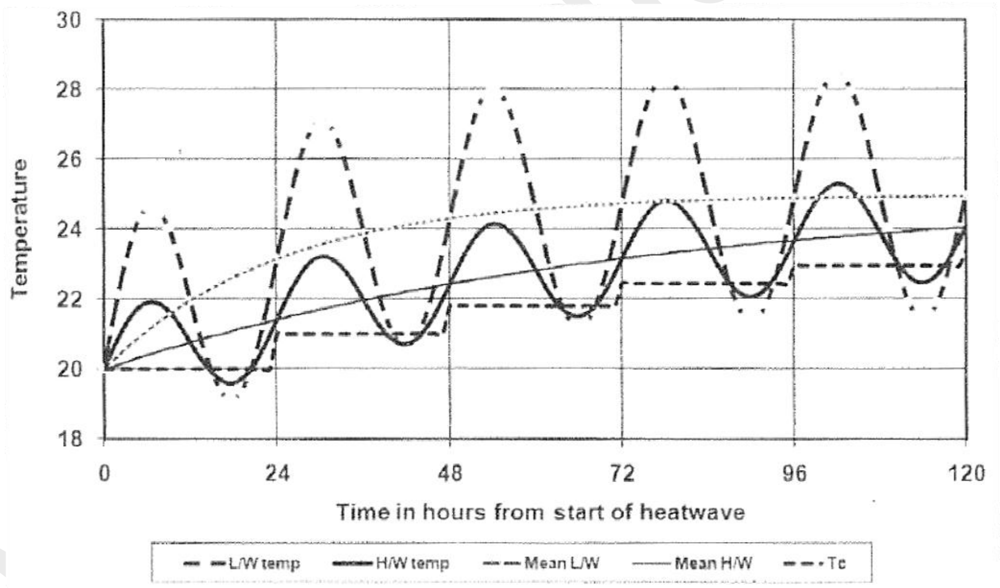

Figure 3.5 Comparison of indoor thermal variation of light weight and heavy weight buildings

Source: Nicol et al (2012)

[61] Baker,N & K,Steemers (1999) *Energy and environment in design: A technical design guide*, Taylor and Francis.

[62] Innovation UK, *Building performance evaluation*, https://connect.innovateuk.org/web/building-performance-evaluation

[63] Rawlinson, S & D,Weight, *Embodied carbon*, Building Magazine, p-88-91, 12th October 2007

3.2.2.2 Changes in the balance between production and use phase impacts

The balance between the significance of the production phase and the use phase is dynamic and has been changing as energy requirements for building permits have become stricter [64]. In support of the methodology published by RICS in the UK [65] Figure 3.7. illustrates for embodied carbon emissions the current balance for a number of different building typologies and the indicative overall change that has occurred in the UK between 2006 and as projected for 2016/19. The production phase increases marginally as more energy intensive materials are specified whilst the energy use of a building decreases to a position of net zero carbon.

It is important at this point to distinguish between 'regulated' and 'unregulated' operational energy use and CO_2 emissions. The increased energy demands of IT equipment highlighted in section 3.2.2.1 is reflected in an increase in 'non-regulated' electricity use i.e. plug loads connected to the electricity main within a building. Whilst some Member States have attempted to include estimates of this electricity use within their definitions of 'nearly zero energy' buildings, they are more difficult to estimate and control at design stage.

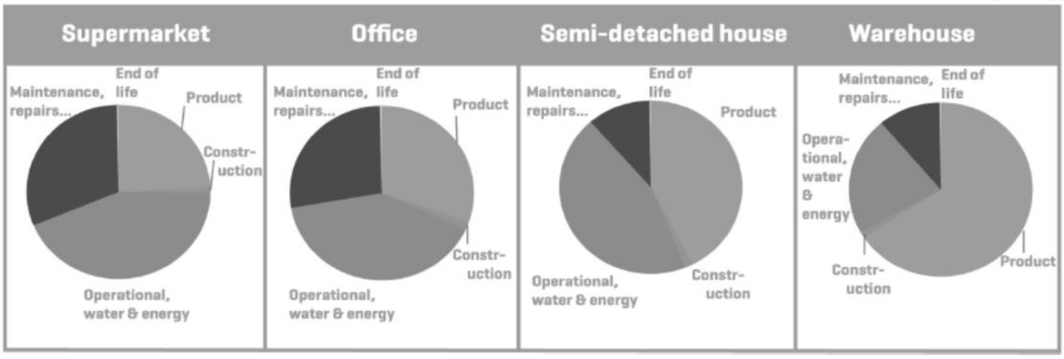

Figure 3.6. Indicative balance of embodied CO_2 by life cycle phase for four building typologies

Source: RICS (2014)

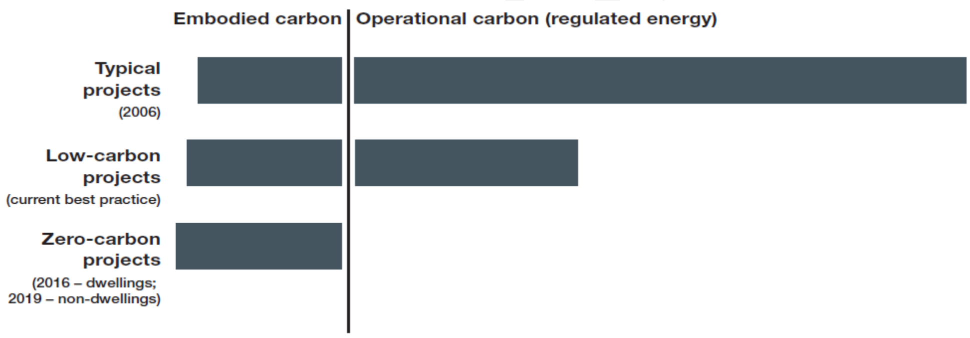

Figure 3.7. The ratio of embodied to use phase CO_2 emissions in relation to building standards **(2006-2019)**
Source: RICS (2014)

The production of construction materials and products is responsible for the next most significant environmental impacts. These relate to the resources used to manufacture products, as well as emissions arising from material extraction and energy used in their processing, generally termed embodied energy. Resource use is also related to the amount of waste generated during product manufacturing, construction on-site and demolition processes, which can make up a significant proportion of the overall material flows on a construction site. Taken together, these factors highlight the importance of designing and specifying for overall resource efficiency, with evidence from JRC-IPTS and other LCA studies [66] suggesting that the most significant building elements to address are the floors, roof, structure (including foundations) and external walls. For

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[64] Sartori.I and A.G.Hestnes. *Energy use in the life cycle of conventional and low-energy buildings:a review article*, Energy Build, 2007, 39(3):249–57.

[65] Royal Institute of Chartered Surveyors (2014) *Methodology to calculate embodied carbon*, RICS guidance note

[66] See footnote 60

example, the contributions of the different building elements to the overall normalised and weighted environmental impact of 1m^2 of office building located in London are reported in Figure 3.7.

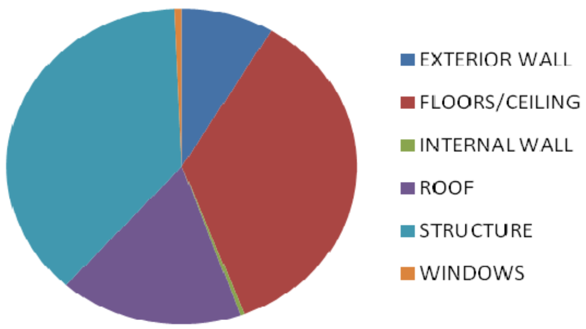

Figure 3.8. Contribution of building elements to the product stage environmental impacts of 1m^2 of a hypothetical office building located in London Source: JRC-IPTS (2011)

A further factor to consider is the lifespan of the building, which is also sometimes referred to as its service life, and related to this its functionality as a healthy working environment. The longer the lifespan of the main structural elements of the building, the lower their associated life cycle environmental impacts, assuming that the overall energy performance is also prioritised as part of the overall approach during the service life.

3.3 Bottom up LCA analysis for common building materials

In this section a brief review is made of LCA analyse for the most common building materials, namely mineral-based, metallic and wood, and with a focus on building structures. The distinct resource efficient aspects associated with each material and improvement options are identified. As was highlighted in relation to the choice of functional unit for comparing resource use, the fundamental design and engineering parameters for structures have also been shown to be a key factor in comparing the overall resource efficiency per unit of load capacity per unit dimension [67].

3.3.1 The improvement potential for non-metallic minerals

The review of LCA evidence has highlighted the significance of structural materials as the main hot spot environmental impact of residential and commercial buildings. An initial review has therefore been made of LCA and relevant scientific evidence that highlight hot spots that offer the prospect of resource efficiency improvements.

The construction materials used for buildings across the EU varies by Member State and also reflect sub-regional and regional construction traditions. This is reflected in choices of structural materials (e.g. concrete, steel, wood) as well as associated external cladding and façade materials (e.g. brick, block/render, metal, tile, wood). It is therefore considered important that, at a macro-objective level, the most common forms of raw materials are separately addressed rather than forcing comparative judgements to be made of their environmental impacts which may not reflect the sub-regionally or regionally available construction resources.

As was illustrated in Section 2.1.3.2 EU construction material flows are dominated by the use of mineral resources, including limestone, clay, gravel and sand, which are used to produce, amongst other materials, concrete, bricks and tiles. Figure 3.9 provides an overall breakdown of non-metallic mineral extraction for the EU-27 (as was). Moreover, top down LCA evidence suggests that the most significant environmental impacts are associated with the use of concrete and steel.

[67] See footnote 44

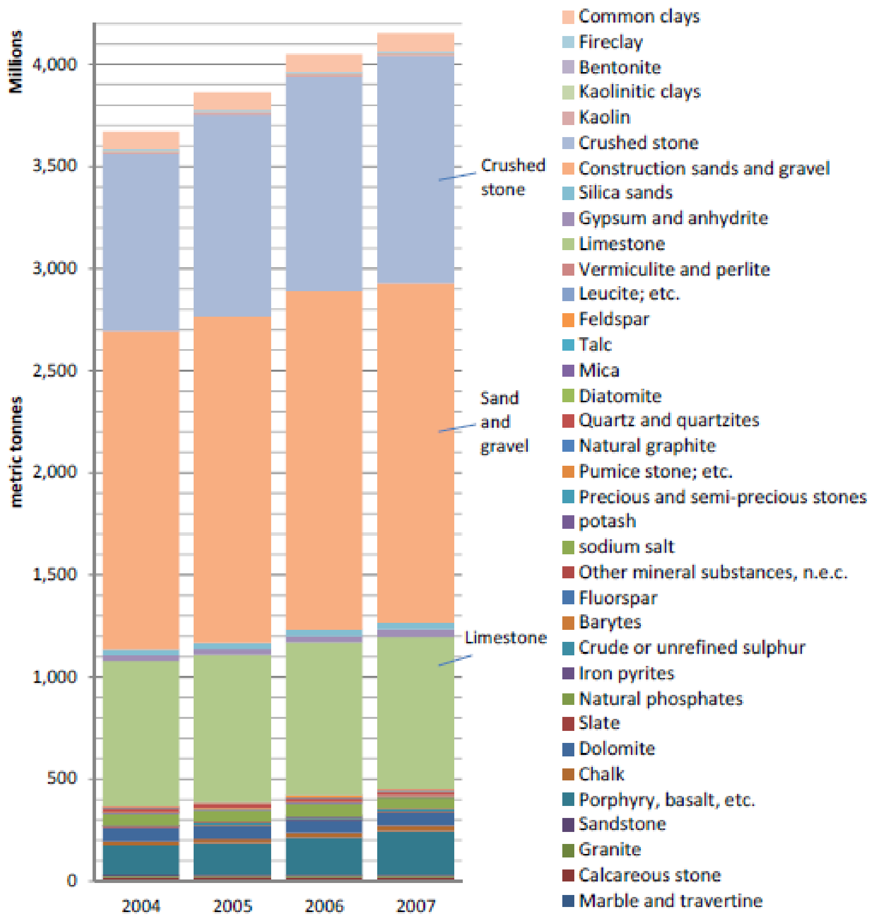

Figure 3.9. Non-metallic minerals resource extraction of the EU-27 (2004-2007)

Source: European Commission (2013)

Given the significance of concrete to the EU construction sector, relevant literature has been reviewed to identify production hot spots and key areas of focus for improvement. Marinkovic et al (2014) highlights that cement makes the largest contribution to the environmental impacts of concrete, with CO_2 emissions from the calcination of limestone and the burning of fossil fuels accounting for between 75% and 94% across all impact categories whereas aggregate production accounts for 0.8% and 5.4% across all impact categories. Transport distances are also a significant consideration for concrete, with the contribution ranging from 3% to 20% depending on the distances.

Whilst much attention has focussed on the use of recycled concrete aggregates (RCA) from construction and demolition waste, with resulting reductions in mineral extraction volumes and waste arisings, the resulting reduction in the Global Warming Potential of concrete is relatively small compared to the improvement potential associated with addressing the production of portland cement, as well as the concrete mix design and design specification of structures. It is also important to note that a reduction in large volume construction material use is not fully captured by the abiotic depletion impact category used in EN 15978, primarily because these flows are subject to local and regional constraints that are not picked up in the calculation of resource criticality.

At a fundamental level, significant reductions in the global warming potential of emissions from concrete can be achieved by the replacement of cement clinker or Portland cement. Habert (2014) summarises the state of the art in terms of addressing both the impacts of the most common form of cement used – Portland cement based on limestone – as well as substitutes for clinker and cementitious binders by industrial by-products (e.g. power station fly ash, blast furnace slag, copper slag) and alternative raw minerals (e.g. magnesium hydrates) [68].

[68] Habert.G, *Assessing the environmental impact of conventional and 'green' cement production in Eco-efficient construction and building materials* (2014) Woodhead publishing, p.199

Structures research by Arup [69] (2014) and international building performance benchmarking projects such as the Concrete Usage Index [70] (2012) have highlighted the potential to reduce CO_2 emissions by up to 50% through the optimised use of concrete. Options which have been implemented include better mix designs (e.g. the use of superplasticisers), light weighting (e.g. hollow pre-cast slabs or voids in formwork) and high strength concrete. Attention is being focussed on the improvement potential of concrete at a global level by the World Business Council on Sustainable Development's (WBCSD) Cement Sustainability Initiative and at a EU level by the Concrete Initiative.

3.3.2 The improvement potential for metals

Alongside concrete, steel is a predominant structural material and is associated with significant environmental impacts across the construction sector. Research by the University of Cambridge on resource flows associated with steel production has sought to identify both the most significant production-related environmental hot spots and macro-scale improvement opportunities [71].

Reducing demand for new materials production has been identified as the most significant improvement opportunity, with light weight design, longer life spans for structural components and more intensive use of the space created by structures emerging from analysis as the most effective options. Attention to fundamental structural design parameters has also been highlighted as being as important in minimising embodied energy [72].

The re-use of steel and aluminium was also identified as a significant potential improvement opportunity, but the environmental benefits may be reduced because the diverted waste metal would need to be replaced by more primary production [73]. The sector is 'scrap constrained' as a high proportion of recycled material is already used, meaning any reduction in supply could create demand for primary production.

3.3.3 The improvement potential for wood

Wood construction materials are renewable raw materials. As such their continued availability is dependent on the management of forests as biological systems and habitats. This factor is the subject of ongoing debate in the LCA community as the potential environmental effects of forestry are currently not well accounted for within the commonly used LCA methods and impact categories. This issue was recognised during preparation of the background study to the Commission's European Resource Efficiency Platform (EREP). Factors that are the focus for continued discussion and debate include land use, soil depletion, CO_2 sequestration, ecosystem services and ecosystem damage [74] [75].

The importance of ensuring that the wood and wood-based materials used in the construction and renovation of buildings are sourced from legal and sustainable sources is a policy objective at EU level. Moreover, there is significant experience in Member States and within the timber and construction industries in sourcing according to the sustainable forestry criteria of established private certification schemes such as the Forestry Stewardship Council (FSC) and the Programme for the Endorsement of Forest Certification (PEFC). These certification schemes are based on the UNEP and FAO principles of Sustainable Forestry Management (SFM)

[69] Arup, *Can we us structural materials more efficiently?,* http://thoughts.arup.com/post/details/359/can-we-use-structural-materials-more-efficiently

[70] Centre for Sustainable Buildings and Construction and the Building and Construction Authority (2012) *Concrete usage index*, Singapore

[71] University of Cambridge, *WellMet2050*, http://www.lcmp.eng.cam.ac.uk/wellmet2/introduction *and* Allwood.J.M (2013) *Transitions to material efficiency in the UK and steel economy*, Philosophical transactions of the Royal Society, UK

[72] See also 44

[73] Milford.R, *Re-use without melting: emissions savings from case studies*, University of Cambridge, September 2010

[74] Allacker.K, Maia de Souza.D and S,Serenella, *Land use impact assessment in the construction sector: an analysis of LCIA models and case study application*, International Journal of Life Cycle Assessment (2014) 19:1799–1809

[75] Päivinen.R, Lindner.M, Rosén.K and M.J.Lexer, *A concept for assessing sustainability impacts of forestry-wood chains*, European Journal of Forest Resources (2012), 131:7-19

established at the Rio Earth Summit in 1992 [76]. These principles, although not defined in detail in UNEP or FAO literature, provide an internationally agreed reference point.

The use of timber as a structural frame for houses is largely based on the high quality timber from forestry, although lower grade and waste material is used for Orientated Strand Board (OSB) cladding. In order to construct taller buildings and structures with wider bay widths, such for apartments, schools and offices, glued laminate, compressed fibre or hybrid wood products are required in order to achieve the necessary structural design parameters. These engineered timber products may, in some cases, be energy intensive to manufacture, although there may be savings on material use in foundations. A life cycle approach is therefore required to make performance comparisons for these type of timber products.

3.3.4 Improvement potential from material recovery and cycling

Construction waste is generated at two key points in the life cycle of buildings – during the production stage and at the end of life. Waste can also be minimised by cycling materials, either by re-use or recycling. The European Resource Efficiency Platform (EREP) top down study cited in Section 3.1 highlights the life cycle importance of:

- Recycling concrete instead of landfilling,
- The use of recycled construction and demolition waste, and
- A reduction in the amount of waste from construction.

Contractors and designers can make major improvements in materials efficiency, by minimising waste generation in construction and demolition, maximising the recycling rate, reusing materials and selecting construction products with a higher recycled content and lower embodied impacts.

According to Osmani et al (2008), on average 33 % of waste generation from a construction site is the responsibility of a failure to implement waste prevention measures during both the design and preliminary construction phases [77]. Reporting on findings from a survey of projects in the Netherlands, Bossink and Brouwers (1996) found that on average 9% by weight of purchased construction materials leaves a site as waste [78]. Significant contributors by weight included stone cladding (29%), piles (17%), concrete (13%), mortar (8%), packaging (7%) and bricks (3%). Additional causal factors highlighted included ordering errors during procurement, damage during materials handling and on-site operational practices. A review of twenty-three published studies by Mália et al (2013) concludes that concrete and brick generally accounted for approximately 70% of the overall waste volume generated.

Analysis of the environmental improvement potential associated with the selective demolition and recovery of waste construction materials has highlighted the sectoral importance of replacing virgin raw materials with recycled and/or re-used materials or building elements [79]. Current practices such as 'soft strip outs' to recover fit -out materials, together with the down cycling of high volumes of recovered aggregates, ceramics and brick into fill material and non-structural construction products (e.g. road bases), have been modelled to only deliver improvements of less than 5% across the most significant environmental impact categories.

To make significant improvements, selective deconstruction would be required, with practices used that would enable the re-use of wooden, masonry and metal building elements. The processing of crushed and graded concrete to a quality sufficient for replacement of coarse natural aggregate in structural concrete would contribute towards reducing total building material flows.

[76] Castaneda, F. *Criteria and indicators for sustainable forestry management*. UN FAO, http://www.fao.org/docrep/x8080e/x8080e06.htm#TopOfPage

[77] Osmani, M., Glass, J., Price, A.D.F., 2008. *Architects' perspectives on construction waste reduction by design*. Waste Management 28, 1147-1158

[78] Bossink,B.A.G and H.J.H.Brouwers, *Construction waste: Quantification and source evaluation*, Journal of Construction Engineering and Management, March 1996

[79] A.Coelho and J de Brito, *Influence of construction and demolition waste management on the environmental impact of buildings*, Journal of waste management, 32(2012), p.532-541,

According to the European Commission's Reference Document on Best Environmental Management Practice in the building and construction sector [80], the use of materials with high recycled content is one of the best practices with the potential for greatest influence on resource efficiency in construction. This finding is supported by extensive work with the construction sector by WRAP in the UK [81]. However, as was noted in Section 3.3.1 for bulk materials the environmental benefits of recycling can be outweighed by transport related emissions, so careful consideration is required.

3.4 Factors that may create a gap between design and actual performance

The potential for gaps to emerge between the modelled energy performance of a building and its services at design stage and its performance upon occupation has become the focus of increasing attention. This is in part due to an expectation that investment in higher performance buildings delivers the expected benefits. Two of the most common cited factors are briefly discussed in the next two sub-sections. Other potential areas of focus include Building Energy Management Systems, lighting and on-site energy generation [82].

In this section the main focus is on possible design versus actual performance variations in energy use, for which evidence already available. There appears, however, to be a gap in the evidence base for other resource efficiency aspects. A study has been commissioned by DG ENV to investigate this issue further, the findings of which will feed into this work.

3.4.1 The quality and integrity of the building fabric

In order to guarantee a high performing low energy building, it is important to ensure that the completed building fabric has a low level of air infiltration (i.e. it is air tight and does not leak air) and minimal thermal bridges where heat can be conducted through the buildings structure from outside to inside (or vice versa). This should be addressed at the design stage by careful detailing of the external fabric and at the construction stage by ensuring quality and precision on-site, as demonstrated by the Passivhaus standard developed in Germany and now promoted across the EU, which also includes post-construction testing [83].

In some Member States, such as the UK and Ireland, 'accredited details' are specified for designers and builders. These are examples of building elements and construction details that minimise thermal bridging. In general, however, limited guidance is provided across the EU [84]. In Italy there is understood to be a certification scheme for construction details. Only Denmark is understood to currently legally require thermal imaging to test construction quality [85].

The UK PROBE building post-occupancy project identified air tightness as a common problem in new-build completions [86] and it was identified by the IMPRO Buildings study as a major improvement option for renovations (see Section 3.2.1). Recognising the importance of air tightness, at least 11 Member States now require some form of testing of the integrity of the building fabric at national or regional level, with Denmark, Ireland, France and the UK setting minimum requirements in their building regulations [87]. The most common form of testing is the blower door test.

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[80] European Commission, *Reference Document on Best Environmental Management Practice in the building and construction sector* (2012): http://susproc.jrc.ec.europa.eu/activities/emas/documents/ConstructionSector.pdf

[81] WRAP (2009) *Delivering higher recycled content in construction projects*, UK

[82] JRC-IPTS, *Green Public Procurement Criteria for the design, construction and management of Office buildings*, Draft technical report, December 2014

[83] Passipedia, *Thermal bridges, Passivhaus Institut*, http://www.passipedia.org/passipedia_en/basics/building_physics_-_basics/heat_transfer/thermal_bridges#what_defines_thermal_bridge_free_design

[84] Asiepi (ASsessment and Improvement of the EPBD Impact), *An effective Handling of Thermal*

Bridges in the EPBD Context, Final Report of the IEE ASIEPI Work on Thermal Bridges, 31st March 2010

[85] Asiepi (ASsessment and Improvement of the EPBD Impact), *Analysis of Execution Quality*

Related to Thermal Bridges, 18th October 2009

[86] PROBE, *Final report 4: Strategic conclusions*, Report to DEFRA (UK Government), August 1999, http://www.usablebuildings.co.uk/Probe/ProbePDFs/SR4.pdf

87 Heike.E-K, Erhorn.H, Lahmidi.H and R,Anderson, *Airtightness requirements for high performance building*

3.4.2 Heating, Ventilation and Cooling (HVAC) systems

Evidence from the monitoring of building projects from design through to handover and operation suggests that the performance of the building services – i.e. the Heating, Ventilation and Cooling (HVAC) systems – is an important factor to control in the overall management of energy use. The increasing complexity and energy intensity of these systems means that if they are not commissioned and operated correctly, they can contribute to higher energy use.

Evidence from surveys of buildings commissioned in the US suggests based on findings from a database of 643 buildings that energy-related commissioning problems can increase energy use by approximately 15% [88]. A study of low energy buildings by the UK's Carbon Trust revealed that 40% of the building developers involved did not meet their low energy goals because of problems that could have been addressed by better commissioning. Evidence has also emerged in relation to energy saving technologies such as heat pumps, as demonstrated by the findings from monitored projects in programmes such as EnOB in Germany [89].

3.5 In-direct factors influencing the performance, service life, productivity and value of buildings

3.5.1 What are the links between health, wellbeing and building performance?

There is increasing attention being given to the importance of creating comfortable and healthly buildings for occupiers – whether they be office workers or home owners – as a means of differentiating green buildings. This is in part because, alongside the financial benefit of lower running costs, this can influence the attractiveness of 'green' buildings. It also allows a clearer link to be made between the upfront financial costs and long term benefits, with the potential for this to be reflected in the design and service life of 'green' buildings [90].

In order to illustrate the potential linkages between health and wellbeing and levels of satisfaction with buildings in the property market two indicative examples are described below, drawing upon cited evidence:

- *A healthy and attractive working environment* with good daylighting, ventilation, stable seasonal temperatures, user control and views of green/blue spaces can contribute to greater workforce satisfaction, less illness related absences and greater productivity [91]. The performance of the workforce is important because staff costs can account for up to 90% of operating costs. These factors may in turn translate into improved valuations (offset for occupiers by improved workforce productivity and lower running costs), a differentiator in the market and longer service lifespan.
- *Comfortable and healthy homes* with stable internal temperatures and humidity levels, as well as good ventilation and daylighting can contribute to less seasonal illnesses and respiratory problems (particularly in small children and the elderly), and an improved sense of wellbeing [92]. These factors may in turn translate into more attractive properties, more stable valuations over time (offset by lower occupier running costs), differentiation in the market, a reduced burden on health services, reduced public/private renovation costs and a longer service lifespan in the housing market.

The interplay between these linkages will depend on the nature of a buildings ownership and occupation. For example, a house builder will not benefit from lower running costs and more comfortable homes, but may be able to attribute greater value to them or use these factors to differentiate their product in the market. In

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Envelopes, Published by Asiepi, 2010 and ATTMA, Measuring air permeability of building envelopes, Technical standard L2, October 2010

[88] Lawrence Berkeley National Laboratory, *Building Commissioning: A Golden Opportunity for Reducing Energy Costs and Greenhouse Gas Emissions*, Report prepared for the Californian Energy Commission, USA, July 21st 2009

[89] EnOB, *Research for energy optimised building*, Germany http://www.enob.info/en/analysis/analysis/details/workplace-satisfaction-and-comfort/

[90] CIBSE Journal, *Taking the temperature – roundtable on health, wellbeing and productivity*, March 2015, UK, http://portfolio.cpl.co.uk/CIBSE/201503/roundtable/

[91] Useable Buildings Trust, *PROBE post occupancy study series*, Building Services Journal 1995-2002, http://www.usablebuildings.co.uk/

[92] Building Performance Institute Europe, *Indoor air quality, thermal comfort and daylight*, March 2015

contrast, pension funds and social landlords retain ownership of properties in the long-term. For a social landlord, lower running costs for tenants may in turn reduce rent arrears. In both cases lower life cycle costs and future resilience could reduce financing and insurance costs.

3.5.2 Evidence for the significance of health and wellbeing factors

There is increasing scientific and market evidence to support these linkages, as evidenced by the launch in the US of the Well Building Standard [93], which is the result of extensive research and consultation with medical professionals, and by a recent evidence collecting exercise by the World Green Building Council for office buildings [94]. The pre-conditions for Well Building certification that are independent of occupier choices are listed in Table 2.1. Features relating to water, nourishment and fitness have been omitted.

Table 2.1. New construction pre-conditions for Well Building standard certification

Category	Required features
Air	- Air quality standards - Ventilation effectiveness - VOC reduction - Air filtration - Microbe and mold control - Fundamental material safety - Moisture management
Light	- Visual lighting design - Circadian lighting design - Electric light glare control - Solar glare control
Comfort	- Exterior noise intrusion - Internally generated noise - Thermal comfort
Mind	- Post-occupancy surveys - Biophilia (qualitative)

Adapted from International Well Building Institute (2014)

Research across the EU has also focussed on the existing housing stock, which in certain countries, regions and climate zones of the EU is of high concern because of the issues of fuel poverty, unhealthy conditions and related health impacts [95]. This may in turn be a factor for consideration by governments, as the direct and indirect costs of addressing these problems can be high, particularly in more deprived areas.

The following sub-sections briefly summarise, with reference mainly to evidence relating to office buildings in particular, the four health and wellbeing factors most commonly cited in literature and addressed by existing reporting and assessment tools:

3.5.2.1 Thermal comfort

In low energy or passive office buildings, the control of thermal comfort and overheating is an important factor. This is because uncontrolled thermal gain from natural lighting and ventilation, as well as insufficient thermal mass within a building's structure, can lead to uncomfortable conditions that may require additional cooling energy. The recast EPD Directive 2010/31/EU specifically addresses overheating, stating that:

> *'…there should be focus on measures which avoid overheating, such as shading and sufficient thermal capacity in the building construction, and further development and application of passive cooling techniques, primarily those that improve indoor climatic conditions and the micro- climate around buildings.'*

[93] International Wellbeing Institute, *The Well Building standard*, http://www.wellcertified.com/

[94] World Green Building Council (2014) *Health, wellbeing & productivity in office – the next chapter for green buildings*.

[95] Building Performance Institute Europe, *Alleviating fuel poverty in the EU*, May 2014

Literature based on post-occupancy surveys suggests that although occupants may have a greater tolerance for hot and cold conditions in a low energy building – following the 'adaptive' approach to comfort [96] - they also place a significance on being able to control their working conditions to within self-defined parameters [97].

As was also highlighted in Section 3.1.1, adverse climate change may also lead to problems with overheating at building and urban scale. Climate change resilience may necessitate adaptations to existing buildings as well as their surroundings, for example by adding solar control features, adjusting internal layouts and increasing/adding the presence vegetation and water features. The latter as a design feature has multiple benefits because there is strong evidence that so-called 'biophilia' – the fundamental human need to be in natural spaces - increases wellbeing.

3.5.2.2 **Daylighting**

Natural light has been shown to contribute to more conducive and productive working environments and is preferred by office workers, who also tend to seek a window location. The plan depth of an office will dictate how much of the floor area can be illuminate with natural light. At a plan depth of more than 4-6 metres, a glazing ration of 30% and a ceiling height of 3 metres, natural light levels will fall below the level of 500 lux (lumens/m^2) necessary for a working environment – equivalent to a Daylighting Factor of 2%[98].

However, without careful design, natural light can make the internal environment uncomfortable and, potentially, result in more energy use than predicted. Whilst a design may achieve an ideal Daylighting Factor of 2% at a plan depth of 6 metres, this would result in unwanted glare and thermal gains near the windows. As a result, solar control strategies are required.

3.5.2.3 **Indoor Air Quality**

Indoor air quality is an important measure of the health of a building. Studies suggest that healthy indoor air quality is a factor that can improve productivity. Conversely, the problem of so-called 'sick building syndrome' can lead to reduced productivity and even lost time due to work-related illness. In an air tight modern home or office, the most significant direct emissions sources are understood to be paints and varnishes, textile furnishings, floor coverings and fit-out incorporating particle board [99]. In contrast, in older residential buildings, humidity and draughts may be more important considerations and have other implications for the health of occupants. It is important to note, however, that indirect outdoor sources such as traffic can be equally significant in urban areas.

As workers' salaries represent the majority of a business's expenditure (significantly greater than energy use), improvements in air quality can be attributed a value. Research suggests that by increasing ventilation rates from 2.5 l/s to 10 L/s per person, productivity can be increased by around 5% [100]. Related to this, productivity has been observed to increase by approximately 1% for every 10% reduction in dissatisfaction with indoor air quality.

WHO IAQ guidelines exist for the level of indoor exposure levels for a number of contaminants, including PM2.5 particulates, CO, NO_2, formaldehyde, benzene and naphthalene. Of these contaminants, DG Health & Consumers identified fine particulate matter from outdoor air pollution and indoor combustion equipment as the most significant source of indoor exposure [101]. This finding is supported by the European Collaborative Action (ECA) on 'Urban air, indoor environment and human exposure' [102], the EnVIE project [103] and EU monitoring projects such as Officair [104].

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[96] Nicol.F, Humphreys.M and S,Roaf (2012) *Adaptive thermal comfort: principles and practice*, Routledge

[97] Wagner.A et al, *Thermal comfort and workplace occupant satisfaction—Results of field studies in German low energy office buildings*, Energy and Buildings 39 (2007) 758–769

[98] Baker.N and K,Steemers (1999) *Energy and Environment in Architecture: A Technical Design Guide, Taylor & Francis and European Commission (1994) Daylighting in buildings*, THERMIE project

[99] Bluyssen et al, *European Indoor Air Quality Audit in 56 office buildings*, Indoor Air: 1996, 6(4), p-221-228

[100] Djukanovic et al, *Cost benefit analysis of improved air quality in an office building*, Proceedings: Indoor Air 2002

[101] European Commission (2011) *Promoting actions for healthy indoor air*, DG Health & Consumers

[102] JRC-IHCP, https://ec.europa.eu/jrc/en/research-topic/human-exposure

The monitoring and control of emissions from priority chemicals, including Volatile Organic Compounds (VOC's), has been the focus of action at EU level. Work is ongoing to support the CE marking of products under the Construction Products Regulation with two relevant areas of focus - the harmonisation of health-based evaluations of emissions from construction products (based on Lowest Concentration of Interest values) and the development of an emissions performance class system for reporting to consumers. A number of Member States now have legislation and associated product labelling schemes for emissions from construction products, including France, Germany and Belgium.

3.5.2.4 Acoustics and noise

The potential for acoustic disturbance from both inside and outside a building is cited as an important aspect of occupant satisfaction. The potential for disturbance depends on the nature of the buildings use, servicing and internal layout. In offices, for example, it may relate to open plan environments as well as poor acoustic separation between cellular offices or meeting rooms. Servicing such as air conditioning, as well as server rooms, can cause disturbance. In apartments and terraces, acoustic insulation of party walls and floors is particularly important to ensure privacy, in terms of both impact and airborne transmission of sound. In both cases external sources such as traffic and street activity can be sources of disturbance. In commercial buildings this can lead to decisions to seal windows and mechanically ventilate spaces.

Questions to stakeholders on health and wellbeing aspects

2.1 Does a healthier building always equate to a building with better environmental performance?

2.2 What evidence exists that the associated improvements in occupier satisfaction and productivity translate into more resource efficient buildings?

2.3 What evidence exists that health and wellbeing aspects can extend the design/service life of buildings?

[103] EnVIE, *Co-ordination Action on Indoor Air Quality and Health Effects*, FP6 project final activity report, 10th February 2009

[104] Officair project, http://www.officair-project.eu/

Summary of findings on macro-environmental 'hot spots'

- Whilst environmental impacts related to the use phase of buildings remain important, particularly for the existing building stock, the increased energy efficiency of new and renovated buildings is shifting the balance towards impacts associated with construction materials;
- Structures appear as the main hot spot for material impacts. Addressing these impacts entails a focus on the life cycle impacts of the most significant mineral and metals flows, which comprise concrete, brick, ceramic, steel and timber;
- The environmental impacts associated with each of these materials are distinct and cannot be addressed by a focus on one aspect alone, for example material flow. A composite approach is therefore needed that can address the distinct impacts associated with non-metallic mineral, metal and wood-based materials.
- The efficiency and intensity of use of structures, space and land is an important focus for improvement. For homes, more compact building forms are more land, material and energy efficient. Design for adaptability and extension of the life span of structures can reduce material impacts;
- The choice of functional unit is critical in defining how the intensity of resource use is measured at macro-objective and indicator level;.
- Externalised, 'induced' effects beyond the conventional LCA boundary of a building can be as significant as those related to buildings themselves. For example, transport related emissions influenced by the accessibility of a building to public transport networks and amenities;
- Evidence from occupant surveys show that comfort, health and wellbeing aspects such as thermal comfort, natural light, indoor air quality and acoustics are critical to performance and occupant satisfaction with buildings, which in turn can influence productivity and property values.

4. Priorities, scope and boundaries of existing assessment and reporting tools

In this section two broad types of tools currently used to assess the performance of buildings are examined in order to compare and contrast their macro-objectives. Building assessment schemes tend to be used to carry out 'asset ratings' for new building designs. Investor reporting tools tend to be used to carry out 'operational ratings' for existing buildings and renovations.

For each tool, their macro-objectives as defined by broad categories or criteria areas, e.g. materials and resources, location and transportation, have been identified. The weighting or scoring system is then examined in order to compare and contrast the relative importance assigned to each category or criteria area.

4.1 The use of assessment and reporting tools in the property market

The demand for tools to evaluate and compare the environmental performance of buildings has led to the development of a range of building assessment schemes and reporting tools. The majority of these carry out evaluations that are an '*asset rating'* i.e. an evaluation is made of the building at the design stage, which is then followed up in the construction and completion stages.

The outcome is generally in the form of an '*endorsement label'*. This indicates that a building is third party verified to comply with the schemes requirements, usually at a specific benchmark level of performance. Property investment reporting tools tend not to include this step. Instead they generally only report on an evaluation that has taken place, together with the outcome in the form of normalised data for specific categories of environmental performance.

An increasing trend can be observed in the market for the '*operational rating'* of a building i.e. an evaluation is made of the performance of the building in use. This form of rating is becoming more important with the increase in focus on building renovation to improve energy performance. A good example is the requirement for public buildings to have Display Energy Certificates (DEC) in the UK. Commissioning and post-occupancy assessment of new buildings is also on the increase as clients seek a narrowing of design and actual performance.

The outcome is generally in the form of a '*comparative label'* which indicates that a building achieves a benchmark level of performance. Energy Performance Certificates are the most common example that can be found in the EU. However, many of the existing building assessment schemes that have, up until now, been providing asset ratings are now moving to also provide endorsed (i.e. third party verified) operational ratings.

4.2 The move towards standardised frameworks for reporting

4.2.1 The harmonisation of product declarations and environmental performance assessments

The Construction Products Regulation (EU) No 305/2011 seeks to ensure that reliable information on the environmental performance of products is provided in the EU market. To this end, it seeks to harmonise Declarations of Performance for building products for which there exist EN standards. With the advent of the European single market for construction products, there was a concern that national Environmental Product Declaration (EPD) schemes and building level assessment schemes based on LCA principles would represent a barrier to trade across Europe. As a result, two standards were developed and published by CEN/TC 350:

- EN 15804 [105] (2012) This standard provides the Product Category Rules for all construction products and services, with the aim to ensure that all EPDs of construction products, construction services and construction processes are derived, verified and presented in a harmonised way.

[105] EN 15804: 2012 + A1:2013. *Sustainability of construction works - Environmental product declarations – Core rules for the product category of construction products*

- EN 15978 [106] (2011) This standard deals with aggregation of the information at the building level, among other describing the rules for applying EPD in a building assessment. The identification of boundary conditions and the setting up of scenarios are major parts of the standard.

These standards do not, as such, provide macro-objectives for the environmental performance of buildings, but they do provide a harmonised set of environmental and resource use indicators for use in the reporting of performance.

With the onset of these two standards, the major building assessment schemes are moving to harmonise their approach to environmental performance on a life cycle basis. The life cycle stages defined by EN 15804 and EN 15978 have therefore been used in Section 4.3 of this working paper to compare the scope of selected schemes – namely product, construction, use and end of life.

4.2.2 Industry-led initiatives to harmonise environmental performance indicators

One of the most important industry-led initiatives is that of the Sustainable Building Alliance (SBA) [107]. The SBA has since 2009 convened a group of representatives from the major EU building assessment schemes with the aim of working towards a harmonised framework of core indicators for the environmental performance of buildings. An initial set of indicators (the 'Common Metrics') was selected based on a combination of expert judgement and reference to aforementioned EN standards.

With the co-operation of the SB Alliance partners the common metrics identified have now been pilot tested in two phases on example buildings [108]. The common metrics pilots have focussed on four LCA-orientated indicators - non-renewable primary energy consumption, CO_2 equivalents, drinking water consumption and waste production – as well as measures of thermal comfort and indoor air quality.

The CESBA (Common European Sustainable Built Environment Assessment) movement was established in 2011 and aims to respond to the perceived confusion caused by the proliferation of building assessment schemes across the EU [109]. The movement brings together a number of other projects and platforms that have been developing assessment systems, such as ENERBuild.

The CESBA partners have developed a set of Key Performance Indicators (KPIs) that are being tested in eight Member States. They comprise primary energy use, CO_2 emissions, reused/recycled materials, water consumption and solid waste, as well as building life cycle costs, health and wellbeing factors (IAQ and thermal comfort) and monitoring/optimisation in operation. Analysis of the criteria and weightings of seven existing systems resulted in the composite weighting in table 4.1.

Table 4.1 Synthesis of the weightings of seven building assessment schemes

Criteria area	Weighting
Energy	37%
Materials	20%
Water	9%
Site	9%
Comfort	6%
Process	6%
Servicing	5%

[106] EN 15978: 2011. *Sustainability of construction works - Assessment of environmental performance of buildings - Calculation method*

[107] Sustainable Building Alliance, http://www.sballiance.org/

[108] Sustainable Building Alliance (2011) *Piloting SBA Common Metrics – Phase 1, Technical and operational feasibility of the SBA common metrics, and* Sustainable Building Alliance (2011) *Beyond research to operational application and comparability,* Phase 2 summary, August 2014

[109] Common European Sustainable Built Environment Assessment (CESBA), http://wiki.cesba.eu/wiki/Main_Page

Waste	5%
Economy	3%

Source: CESBA (2015)

4.3 Comparative framework used for comparing macro-objectives

An important part of the initial study of macro-objectives is to identify those of the most common building assessment and reporting tools available in the market. These correspond to what the FP7 Superbuildings project refers to as the *'subjects of concern'* and *'protection goals'* for each scheme or tool [110].

The most significant building assessment schemes and reporting tools were identified from literature and market research. These were split into multi-criteria schemes that are verified by accredited assessors and reporting tools used on both a verified and unverified basis by investors and building occupiers.

For each tool, the generic core criteria set used for the purpose of scheme adaption or direct implementation across the EU is identified. From this core criteria set, the scope and prioritisation of the criteria areas is then identified and sub-divided into the following three categories:

- 'Direct' impacts relating to the building life cycle stages defined by EN 15978
- Extension of the EN 15978 LCA boundary to capture 'induced' impacts
- Potential 'in-direct' influences on the performance, service life and value of a building

These categories reflect the broad areas of potential focus identified from the review of the life cycle evidence in Section 1. They also seek to capture different potential influences and perspectives on life cycle performance and the holistic design of buildings so that they can form the basis for further discussion and evidence gathering.

The weighting or scoring system used by each tool is also examined in order to compare and contrast the relative importance assigned to each category or criteria area. Here only those aspects that directly influence the environmental performance of buildings, or which were flagged up in section 3 of this paper, were checked for their contribution.

4.3.1 Multi-criteria schemes verified by accredited assessors

In this section, the five building assessment schemes with the greatest uptake in the EU market are analysed using the proposed framework for comparison of macro-objectives. The schemes analysed are as follows:

- The Code for a Sustainable Build Environment, Building Research Establishment (Origin: UK)
- Haute Qualité Environnementale (HQE), Centre Scientifique et Technique du Bâtiment (Origin: France)
- Deutsche Gesellschaft für Nachhaltiges Bauen (DGNB), German Sustainable Building Council (Origin: Germany)
- Sustainable Building (SB) Tool, International Initiative for a Sustainable Built Environment (Origin: International)
- Leadership in Energy & Environmental Design (LEED), US Green Building Council (Origin: USA)

It should be noted that SB Tool forms the basis for a number of distinct national schemes, including the Czech Republic (SBTool CZ), Portugal (SBTool PT), Italy (Protocollo ITACA) and Spain (Verde). Only the generic SB Tool is analysed in this paper.

For each scheme analysed, the generic criteria set used as the basis for international adoption, together with underlying technical evidence for the prioritisation of the criteria (where available) is analysed.

[110] VTT, *Sustainability and performance assessment and benchmarking of buildings*, Tarja Häkkinen (Ed.), Summary findings of the SuPerBuildings Project, Espoo 2012.

4.3.1.1 Code for a Sustainable Built Environment, BRE

The UK-based Building Research Establishment (BRE) has developed and operates the BREEAM sustainability assessment scheme for buildings, which was first launched in the UK in 1990. Since then the scope of BREEAM has expanded to cover a full range of domestic and non-domestic building typologies and life cycle stages. To support the use and adaptation of the BREEAM family of schemes across the EU and internationally, BRE has developed a Code for a Sustainable Built Environment (CSBE), which sets out a set of strategic principles and requirements for the assessment of the built environment. The CSBE is interpreted through core process and technical standards, which all scheme operators shall adhere to when adapting BREEAM to local conditions.

The core technical standard for buildings, which currently covers the 'new construction', 'in-use' and 'refurbishment and fit-out' life cycle stages, has been analysed and categorised in table 4.2. The BREEAM scheme weightings follow a common methodology so they can be set to suit the local context and building life cycle stage of each scheme. The category contributions of the BREEAM International New Construction 2013 scheme criteria are used in Table 4.3 to illustrate a possible weighting.

Table 4.2. BRE CSBE: life cycle boundaries, scope and prioritisation

Aspect of building	**Assessment and reporting tool scope**
Building life cycle stages (as defined by EN 15978)	
Product	○ Low environmental impact materials
Construction	○ Design, construction and commissioning management ○ Construction site emissions and impacts ○ Construction waste management and monitoring ○ Material life cycle efficiency ○ Sustainable and efficient land use
Use	○ Post-handover aftercare ○ Energy demand reduction and monitoring ○ Low and zero carbon energy generation ○ Water demand reduction and monitoring ○ Alternative water sources ○ Operational waste storage, management and monitoring ○ Minimise operational chemical pollution
End of life	○ *Not currently addressed*
Extended LCA boundary to capture 'induced' impacts	
Transport	○ Minimise transport related energy use, pollution and congestion ○ Access to public transport networks and alternative modes of transport
In-direct influences on the performance, service life and value	
Cost and value	○ Service life planning and life cycle costing
Functional quality	Visual comfort ○ Lighting controls ○ Daylighting, glare control and flicker ○ View out Indoor Air Quality ○ Ventilation ○ Building product emissions Thermal comfort ○ Thermal performance and control Acoustic comfort ○ Acoustic performance (internal and external sources)
Building configuration	○ Future functional adaptability ○ Adaptability to climate change

Adapted from BRE Global (2015)

Table 4.3. BREEAM International New Construction weightings: Contribution of each category

Category	Credits achievable	Overall weighted contribution
Management	22	12%
Health & wellbeing	10	15%
Energy	30	19%
Transport	9	8%
Water	9	6%
Materials	12	12.5%
Waste	7	7.5%
Land use & ecology	10	10%
Pollution	13	10%
Innovation	10	10%

Source: BRE Global (2014)

4.3.1.2 Buildings under construction, HQE International

HQE was launched in 2005. 'Buildings under construction' is a set of criteria designed to improve the environmental quality of residential and non-residential buildings. It lays down requirements to assess and monitor the environmental performance of buildings, as well as addressing the comfort and health of building end users. The criteria are developed and updated by the Centre Scientifique et Technique du Bâtiment (CSTB) in France. The main certification body is Certivea, which is a subsidiary of CSTB [111], although outside of France this is carried out by its subsidiary Cerway. Assessment and auditing is carried out at three stages during the progression of a construction or renovation project - programming, design and execution. The HQE Buildings under construction criteria are analysed in Tables 4.4 and 4.5.

Table 4.4. HQE Buildings under construction: life cycle boundaries, scope and prioritisation

Aspect of building	Assessment and reporting tool scope
Building life cycle stages (as defined by EN 15978)	
Product	○ Choice of construction products to limit the environmental impact of the building
Construction	○ Optimisation of site waste management
Use	○ Reduction in energy use and CO_2 emissions through design, systems, services and renewable energy generation ○ Reduction in drinking water consumption ○ Optimisation of operational waste recycling ○ Construction products, systems and processes that are easy/low impact to maintain
End of life	○ Removability/separability of construction products
Extended LCA boundary to capture 'induced' impacts	
Transport	○ Control of travel methods and encourage least polluting modes ○ Promote public transport
In-direct influences on the design, service life and value	
Cost and value	○ *Not specifically addressed*
Functional quality	Planning for sustainable development ○ Encouraging the greening of areas within the plot Quality of outdoor spaces accessible for users ○ Outdoor climatic environment Limiting health related impacts ○ Choice of construction products in order to limit health related impacts Occupier comfort ○ Hygrothermal comfort ○ Monitoring and control of comfort conditions ○ Acoustic comfort ○ Optimised natural and artificial light

[111] HQE Association, *La certification NF batiments tertiares*, http://assohqe.org/hqe/spip.php?rubrique62 *and* Certivea, 2012, http://www.certivea.fr/

	○ Effective ventilation and control of indoor air pollution
Building configuration	○ Adaptability over time based on forecast lifespan and useage

Adapted from Cerway (2014)

Table 4.5. HQE Buildings under construction weightings: Contribution of each target

Theme	Target area	Points available	Overall weighted contribution
Energy	Energy	45	25.00%
Environment	Site	91	4.17%
	Components	53	4.17%
	Work on the site	43	4.17%
	Water	40	4.17%
	Waste	14	4.17%
	Maintenance	45	4.17%
Comfort	Hygrothermal comfort	40	6.25%
	Acoustic comfort	4	6.25%
	Visual comfort	23	6.25%
	Olfactory comfort	5	6.25%
Health	Spaces quality	20	8.33%
	Air quality	32	8.33%
	Water quality	24	8.33%

Source: Cerway (2014)

4.3.1.3 Core 14 buildings, DGNB

The DGNB system was launched in 2009 and is run by the German Sustainable Building Council. The system is implemented internationally using the Core 14 catalogue criteria set. This consists of five core criteria groups, together with separate consideration of the siting of the building. Assessments are based on the whole life cycle of the building, with the environmental quality criteria including a requirement for an LCA and the economic quality criteria including a requirement for Life Cycle Costing. The DGNB Core 14 criteria are analysed in Tables 4.6 and 4.7.

The DGNB system informed the development of the German Federal Building Ministry's Assessment System for Sustainable Building (BNB) [112]. This system is used for the evaluation of offices and administrative buildings and has many similarities with the DGNB system. It is compulsory for federal buildings, so is therefore significant for public procurement.

Table 4.6. DGNB Core 14: life cycle boundaries, scope and prioritisation

Aspect of building	Assessment and reporting tool scope
Building life cycle stages (as defined by EN 15978)	
Product	○ Material production ○ Sustainable timber sourcing
Construction	○ Land use (soil sealing) ○ Building envelope quality
Use	○ Primary energy demand ○ Water demand
End of life	○ Deconstruction and disassembly
Extended LCA boundary to capture 'induced' impacts	
Transport	○ Cycling convenience ○ Public transport accessibility
In-direct influences on the design, service life and value	

[112] Federal Ministry for the Environment, the Protection of Nature, Construction and Nuclear Safety, *Assessment system for sustainable building*, http://www.nachhaltigesbauen.de/sustainable-building-english-speaking-information/assessment-system-for-sustainable-building.html

Cost and value	○ Life cycle costs ○ Value retention, suitability for third party use
Functional quality	○ Thermal comfort ○ Acoustic comfort ○ Visual comfort ○ Indoor air quality ○ Quality of outdoor spaces
Building configuration	○ Efficient use of floor area ○ Suitability for conversion

Adapted from DGNB (2015)

Table 4.7. DGNB Core 14: Contribution of selected criteria and criteria groups

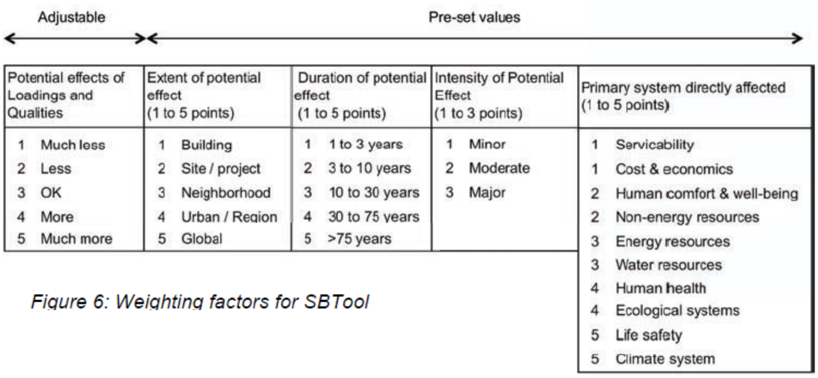
Criteria groups and selected relevant sub-criteria	% contribution achievable	Potential contribution to total score
Environmental quality - LCA - Local environmental impact - Environmentally friendly material production - Primary energy demand - Drinking water demand and wastewater volume - Land use	 7.9% 3.4% 1.1% 5.6% 2.3% 2.3%	22.6%
Economic quality - Building related lifecycle costs - Value retention, suitability for third party use	 9.6% 9.6%	22.4%
Sociocultural and functional quality - Occupier comfort - Indoor air quality - User influence on building operation - Quality of outdoor spaces - Cyclist facilities	 7.8% 2.6% 1.7% 0.9% 0.9%	22.5%
Technical quality - Building envelope quality - Sound insulation - Deconstruction and disassembly	 4.1% 4.1% 4.1%	22.5%
Process quality	-	10%
Site quality - Transport access - Access to amenities	n/a	*Considered separately*

4.3.1.4 SB Tool, iiSBE

The Sustainable Building (SB) Tool was developed by the International Initiative for a Sustainable Built Environment (iiSBE). The framework developed by iiSBE is designed to be adapted to local conditions and building types. It forms the basis for schemes in a number of EU countries, including the Czech Republic (SBTool CZ), Portugal (SBTool PT), Italy (Protocollo ITACA) and Spain (Verde).

The iiSBE framework consists of seven assessment categories. These categories address the pre-design, design, construction and operational phases of a building. Third party users of the criteria are able to choose the number of criteria and therefore the comprehensiveness of the building assessment. The design phase categories have a minimum number of criteria of 14 and a maximum of 103. The SB Tool criteria mid scope (53 criteria) are analysed in Tables 4.8 and 4.9.

The scoring used by SB Tool is notable in that it is weighted to take into account the extent, duration and intensity of environmental impacts, as illustrated in Figure 4.1.



Potential effects of Loadings and Qualities	Extent of potential effect (1 to 5 points)	Duration of potential effect (1 to 5 points)	Intensity of Potential Effect (1 to 3 points)	Primary system directly affected (1 to 5 points)
1 Much less	1 Building	1 1 to 3 years	1 Minor	1 Servicability
2 Less	2 Site / project	2 3 to 10 years	2 Moderate	1 Cost & economics
3 OK	3 Neighborhood	3 10 to 30 years	3 Major	2 Human comfort & well-being
4 More	4 Urban / Region	4 30 to 75 years		2 Non-energy resources
5 Much more	5 Global	5 >75 years		3 Energy resources
				3 Water resources
				4 Human health
				4 Ecological systems
				5 Life safety
				5 Climate system

Figure 6: Weighting factors for SBTool

Figure 4.1. Calculation of weighting factors and identification of end points for SB Tool

Source: iiSBE (2012)

Table 4.8. SB Tool: life cycle boundaries, scope and prioritisation (mid scope)

Aspect of building	**Assessment and reporting tool scope**
Building life cycle stages (as defined by EN 15978)	
Product	○ Embodied non-renewable energy in construction materials ○ Degree of re-use of suitable existing structure(s) ○ Use of virgin non-renewable materials
Construction	*Not specifically addressed*
Use	○ Extent of on-site parking facilities ○ Development density to ensure efficient land use ○ Consumption of non-renewable energy - Passive solar orientation - Orientation for passive ventilation - GHG emissions from primary energy use - Use of vegetation to provide ambient cooling ○ Contribution to heat island effect ○ Use of water by occupants ○ Optimisation/maintenance of operating performance
End of life	*Not specifically addressed*
Extended LCA boundary to capture 'induced' impacts	
Transport	○ Impact of private cars on the capacity of local roads
In-direct influences on the design, service life and value	
Cost and value	○ Operational and maintenance costs
Functional quality	○ Controllability ○ Air temperature and relative humidity ○ Indoor air quality and ventilation ○ Daylighting and illumination

Adapted from iiSBE (2014)

Table 4.9. SB Tool 2014: Contribution of categories and selected criteria (mid scope)

Category headings and selected relevant sub-criteria	**% contribution achieveable**	**Potential contribution to total score**
Site regeneration and development, urban design and infrastructure	0.8%	9.3%
- Use of vegetation to provide ambient cooling	3.0%	
- Orientation for passive solar gain and ventilation		
- Development density to ensure efficient land use	2.0% 3.0%	
- Extent of on-site parking facilities	1.6%	

Energy and resource consumption		35.4%
- Embodied non-renewable energy in construction materials	10.1%	
- Consumption of non-renewable energy	10.1%	
- Degree of re-use of suitable existing structures	3.0%	
- Use of virgin non-renewable materials	2.4%	
- Use of water	9.7%	
Environmental loadings		28.5%
- GHG emissions from primary energy use	12.6%	
- Impact of private cars on capacity of local roads	0.5%	
- Contribution to heat island effect	3.2%	
Indoor environmental quality		5.1%
- Effectiveness of natural ventilation	3.0%	
- Air temperature and relative humidity	1.2%	
- Daylighting and illumination	0.6%	
- Noise and acoustics	0.2%	
Service quality		4.9%
- Spatial efficiency	0.2%	
- Controllability	0.3%	
- Optimisation/maintenance of operating performance	1.4%	
Social, cultural and perceptual aspects	-	4.0%
Cost and economic aspects		1.5%
- Operating and maintenance cost	0.61%	

Source: iiSBE (2014)

4.3.1.5 Building design and construction, LEED

The Leadership in Energy and Environmental Design (LEED) system was developed by the US Green Building Council and launched in 2000. LEED 'Building design and construction' is targeted at new constructions and major renovations. It consists of five environmental categories and an innovation in design category [113]. The credits are weighted according to their significance using LEED's weighting methodology. The credit requirements are written for the USA context as it predominantly based on US standards developed by bodies such as ASHRAE and ASTM, however, 'Alternative Compliance Paths' are described for projects seeking to become certified outside of the USA. The LEED criteria are analysed in Tables 4.10 and 4.11.

Table 4.10. LEED Building design and construction, life cycle boundaries, scope and prioritisation

Aspect of building	**Assessment and reporting tool scope**
Building life cycle stages (as defined by EN 15978)	
Product	○ Building life cycle impact reduction
Construction	○ Construction pollution prevention ○ Construction/demolition waste management planning ○ Commissioning and verification
Use	○ Minimum or optimised energy performance ○ Building-level energy metering ○ Renewable energy production ○ Water use reduction ○ Rainwater management ○ Heat island reduction ○ Storage and collection of recyclables
End of life	○ Construction/demolition waste management planning
Extended LCA boundary to capture 'induced' impacts	
Transport	○ Surrounding density and diverse uses ○ Access to quality transit ○ Bicycle facilities ○ Reduced parking footprint

113 US Green Building Council, *LEED 2009 for new construction and major renovations*, Updated version November 2011.

In-direct influences on the design, service life and value	
Cost and value	*Not specifically addressed*
Functional quality	○ Indoor air quality performance and strategy ○ Thermal comfort ○ Interior lighting and daylight ○ Quality views ○ Acoustic performance

Adapted from US GBC (2014)

Table 4.11. LEED New Construction and Major Renovation: Contribution of categories and selected criteria

Category	**Credits achieveable**	**Credits (out of 110)**
Location and transportation		15%
- Surrounding density and diverse uses	4.6%	
- Access to quality transit	4.6%	
- Bicycle facilities	0.9%	
- Reduced parking footprint	0.9%	
Sustainable sites		9%
- Construction activity pollution prevention	*Required*	
- Rainwater management	2.8%	
- Heat island reduction	1.8%	
Water efficiency		10%
- Outdoor and indoor water use reduction	*Required*	
- Building-level water metering	*Required*	
- Further water use reduction	7.3%	
Energy and atmosphere		30%
- Commissioning and verification	*Required*	
- Minimum energy performance	*Required*	
- Building-level energy metering	*Required*	
- Enhanced commissioning	5.5%	
- Optimised energy performance	16.5%	
- Renewable energy production	2.8%	
Materials and resources		12%
- Storage and collection of recyclables	*Required*	
- Construction/demolition waste management planning	*Required*	
- Building life cycle impact reduction	4.6%	
- Environmental Product Declarations	1.8%	
- Sourcing of raw materials	1.8%	
- Material ingredients	1.8%	
Indoor environmental quality		15%
- Minimum indoor air quality performance	*Required*	
- Enhanced IAQ strategies	1.8%	
- Low-emitting materials	2.8%	
- Indoor IAQ assessment	1.8%	
- Thermal comfort	0.9%	
- Interior lighting	1.8%	
- Daylight	2.8%	
- Quality views	0.9%	
- Acoustic performance	0.9%	
Innovation in design	-	6%
Regional priority	-	4%

Source: US GBC (2014)

4.3.2 Investor and occupier reporting tools

In this section three tools that are currently used by property investors and occupiers at a EU and international level to benchmark the performance of portfolios are briefly analysed using the framework for comparison of macro-objectives. Their main focus is on the operation of commercial buildings such as offices. Their increasing use reflects a shift towards investors being more aware of the benefits and risks associated with ownership and occupancy [114].

The three tools that have been selected are:

- The Environment Code, Investment Property Databank (IPD) (Origin: UK)
- Construction and Real Estate, the Global Reporting Initiative (Origin: International)
- Global Real Estate Sustainability Benchmark (GRESB), Green Building Certification Institute (Origin: USA/Netherlands)
- Green Rating, Green Rating Alliance (Origin: European)

A feature of these tools is that they form part of wider company or fund reporting on Corporate Social Responsibility (CSR) and Socially Responsible Investment (SRI) policies. This means that their environmental criteria tend to be embedded within a broader reporting framework.

For each tool the same macro-objective framework is used as in Section 4.3.1. When analysing the contribution of categories and criteria to the total potential score on those sub-criteria of direct relevance are highlighted.

The policies and criteria of specialist portfolios such as the igloo Regeneration Fund (UK) are also of relevance to this study, but leading examples such as igloo's Footprint policy [115] are not specifically analysed in this working paper.

4.3.2.1 The Environment Code, IPD

The Investment Property Databank (IPD) Environment Code is a framework for collecting property related environmental information. It was launched in 2008. The aim of the Code is to respond to investor and occupier demands for performance data that can be linked to financial performance and the management of property portfolios. The Code is supported by Barclays and Bureau Veritas in association with the Sustainable Building (SB) Alliance. The Code focusses attention on energy use, water usage and waste production, although the supporting 'health check' also covers travel, pollution and health. The Environment Code's criteria and credits and analysed in Tables 4.12 and 4.13.

Table 4.12. IPD Environment Code, life cycle boundaries, scope and prioritisation

Aspect of building	**Assessment and reporting tool scope**
Building life cycle stages (as defined by EN 15978)	
Product	*Not specifically addressed*
Construction	*Not specifically addressed*
Use	○ Energy use (total and sub-metered) - Electricity use (renewable and non-renewable) - Fuel use (fossil and renewable) - Other energy use (communal and renewable) - CO_2 equivalent emissions ○ Water use - Sourced water - Harvested and recycled water ○ Waste - Landfilled and incinerated - Recycled and composted
End of life	*Not specifically addressed*

114 Lutzkendorf.T and D.Lorenz (2005) *Sustainable property investment: valuing sustainable buildings through property performance assessment*, Building Research & Information, 33(3), p.212-234

115 igloo Regeneration Fund, Aviva Investors, UK http://www.igloo.uk.net/

Extended LCA boundary to capture 'induced' impacts	
Transport	○ Public transport facilities ○ Cycling, alternative vehicle and car pool facilities
In-direct influences on the design, service life and value	
Cost and value	*Not specifically addressed*
Functional quality	○ Frequency of checks made on HVAC, temperature and air quality ○ % workstation access to daylight and outside view ○ Personal control over indoor climate (temperature and lighting) ○ Occupier surveys

Source: IPD Environment Code (2010)

Table 4.13. IPD Code, Environmental Health Check weighting of sections

Section	Selected credits	Total credits achievable	Weighting
Management - Energy, water and waste management plan - Health and wellbeing management plan - Travel and transport management plan	 30 10	80	16%
Energy - Type of indoor climate system - Seasonal and occupancy linked heating, cooling and lighting - Type of lighting and glazing - Type of energy used for HVAC and hot water - Proportion of non-renewable energy offset - Extent of sub-metering	 10 20 20 10 10 10	120	24%
Water - Extent of water efficient fittings	 20	45	9%
Waste - Extent of general waste separation - Extent of other wastes collected separately	 10 10	50	10%
Travel - Extent of 'green travel plan' for the building - Public transport facilities nearby - Extent of cyclist facilities - Alternative vehicle facilities - Car pooling facilities and parking	 10 10 10 10 5	55	11%
Pollution	-	50	10%
Health - Frequency of checks made on HVAC, temperature and air quality - % workstation access to daylight and outside view - Personal control over indoor climate (temperature and lighting)	 40 10 10	100	20%

Source: IPD Environment Code (2010)

4.3.2.2 Construction and Real Estate, GRI

The Global Reporting Initiative (GRI) was established in the US by CERES and UNEP. It provides organisations in a range of sectors with sustainability reporting tools. The GRI Construction and Real Estate Sector Supplement (CRESS) was launched in 2011 [116].

The CRESS is targeted at companies that invest in, develop, construct or manage buildings. It includes a specific sub-section on the Environment, addressing the themes of materials; energy; water; biodiversity; emissions, effluents and waste; and transport. No weighting or credit system is applied to each environmental reporting aspect. Each is identified as a 'core' reporting aspect. The GRI CRESS reporting aspects are analysed in Table 4.14.

Table 4.14. GRI CRESS, life cycle boundaries, scope and prioritisation

Aspect of building	Assessment and reporting tool scope
Building life cycle stages (as defined by EN 15978)	
Product	○ Materials - By weight, value of volume - Recycled and re-used input materials
Construction	*Not specifically addressed*
Use	○ GHG emissions - Total direct and indirect emissions - GHG emissions intensity of buildings - GHG emissions intensity of construction activity ○ Energy - Direct consumption by primary source - Indirect consumption by primary source - Building energy intensity - Savings due to conservation and efficiency ○ Water use - Total withdrawal by source - Water recycled and re-used - Building water intensity ○ Waste - Total weight of waste by type and disposal method
End of life	*Not specifically addressed*
Extended LCA boundary to capture 'induced' impacts	
Transport	○ Significant impacts of transporting members of the workforce
In-direct influences on the design, service life and value	
Cost and value	*Not specifically addressed*
Functional quality	*Not specifically addressed*

Source: GRI (2011)

4.3.2.3 Global Real Estate Sustainability Benchmark

GRESB is an international tool developed to support benchmarking and reporting by institutional investors. It is based around an annual survey, the results of which are presented as a 'scorecard' and in an anonymised way in order to support benchmarking comparisons [117]. The survey includes environmental, social and governance issues.

Seven sustainability aspects are addressed, including a specific scoring for 'new constructions and major renovations'. No weighting or credit system is applied to each environmental reporting aspect. GRESB is aligned with GRI CRESS and a full range of building typologies are included within the survey, including

[116] Global Reporting Initiative, *Construction and Real Estate*, https://www.globalreporting.org/reporting/sector-guidance/sector-guidance/construction-and-real-estate/Pages/default.aspx

[117] Global Real Estate Sustainability Benchmark, *GRESB participant guide 2015*, https://gresb.com/survey

residential assets, allowing for a combination of data collection on the performance of new and existing assets. The GRESS reporting aspects are analysed in Table 4.15.

Table 4.15. GRESB, life cycle boundaries, scope and prioritisation

Aspect of building	Assessment and reporting tool scope
Building life cycle stages (as defined by EN 15978)	
Production	○ Policies on construction materials - Local extraction and recovery - Rapidly renewable, low embodied carbon and recycled materials - Ease of recycling - Low emitting materials
Construction	○ Targets for waste reduction, re-use and recycling
Use phase	○ Energy consumption - Minimum energy efficiency requirements, including net-zero energy codes/standards - Generation from on-site renewable sources - Savings due to implemented measures ○ Water consumption - Minimum water efficiency requirements - Savings due to implemented measures ○ Metered and sub-metered data collection from operation - Energy, GHG emissions, water and waste
End of life	*Not specifically addressed*
Extended LCA boundary to capture 'induced' impacts	
Transport	○ Site selection for connection multi-modal transit networks ○ Location of projects within existing developed areas ○ Employee travel and transportation
In-direct influences on the design, service life and value	
Cost and value	*Not specifically addressed*
Functional quality	○ Building measures focussed on occupant wellbeing - Daylight - Natural ventilation - Occupant controls - Indoor air quality monitoring - Provision of green/social spaces ○ Data collection - Indoor environmental quality - Occupier comfort and satisfaction

Source: GRESB (2015)

4.3.2.4 Green Rating, GRA

The Green Rating Alliance was founded in 2009 by a number of major real estate investors, including AEW, AXA, Allianz and Invesco [118]. Its assessment tool was launched in 2011 and aims to assess, monitor and improve the sustainability performance of existing buildings. Their tools seek to allow for the benchmarking of all buildings, in contrast to assessment schemes which only offer a pass or fail system. The assessment system comprises two elements, with six metrics which can be applied to office, retail and logistic buildings:

1. Quantitative based on bills: Energy use, carbon dioxide emissions and water use;
2. Qualitative based on interviews and audits: Transport, waste and wellbeing.

The quantitative metrics are intended to reflect service charges and total occupancy costs, while the qualitative metrics reflect on occupier locational decisions and loyalty. The Green Rating tool is analysed in Table 4.16.

[118] Green Rating Alliance, *Green rating tool*, http://www.green-rating.com/index.php/methodology/green-rating-tool/

Performance is third party assessed and submitted on an anonymised basis so as to allow comparisons to be made across the portfolios of the members. Benchmarking is made based on the intrinsic, actual and potential performance of a building.

Table 4.16. Green Rating: life cycle boundaries, scope and prioritisation

Aspect of building	**Assessment and reporting tool scope**
Building life cycle stages (as defined by EN 15978)	
Product	*Not specifically addressed*
Construction	*Not specifically addressed*
Use	○ GHG emissions - Total direct and indirect emissions ○ Energy - Total consumption by primary source ○ Water use - Total consumption by primary source ○ Waste - Total weight of waste by type and disposal method
End of life	*Not specifically addressed*
Extended LCA boundary to capture 'induced' impacts	
Transport	○ Transport modes used by occupiers
In-direct influences on the design, service life and value	
Cost and value	*Not specifically addressed*
Functional quality	○ Aspects of wellbeing relating to the building and location

Source: Green Rating Alliance (2015)

Summary of findings on assessment and reporting tools

- The assessment tools tend to focus on the design of new-build or renovation projects, whereas the reporting tools tend to focus on existing building performance.
- The scoring or weighted contribution of criteria areas within the majority of the tools analysed is determined by panels of experts, as well as wider stakeholder consultations. Only one is directly shaped by LCA evidence.
- Primary energy use or CO_2 emissions in the use phase are weighted as the most significant in all tools followed by aggregated scores or combinations of criterion for construction material impacts;
- Water use and waste arisings (construction or use phase) are weighted less significantly in assessment tools but are commonly included in reporting tools
- Location close to public transport connections is weighted significantly in two tools, reported on in three tools and is addressed to a lesser extent in three others.
- The aggregated scores for common combinations of occupant comfort and wellbeing criteria – typically IAQ, thermal comfort, daylighting and acoustics - are weighted significantly in all assessment tools, but are only weighted significantly in one reporting tool.

5. Initial conclusions and outlook on macro-objectives

In this section the findings from each chapter of this working paper are discussed and initial conclusions drawn on how they may influence the outlook on the selection of macro-objectives for EU buildings. Initial proposals and questions relating to open issues are presented for discussion and consultation with stakeholders.

5.1 Macro-objectives identified from EU and Member State policies

From the initial review in Chapter 2 of this working paper, the EU environmental policy frameworks, requirements and initiatives that are of more direct relevance to the identification of building resource efficiency macro-objectives have been identified as follows:

- Reduction of greenhouse gas emissions: The EU climate and energy package establishes legally binding greenhouse gas reduction targets. Consumption of primary energy by buildings in the use phase accounts for a significant proportion of the EU's CO_2 emissions. Legislation has therefore been put in place which requires the implementation of minimum standards and, in the medium to long term, a 'near zero energy' requirement for new buildings and the progressive energy efficient renovation of the existing building stock. Climate change adaptation is a related area of focus for the Commission because of the cost and risks it may pose.

- Resource use and its impact on natural capital: The Roadmap to a Resource Efficient Europe was followed-up by the development of resource efficiency indicators to define, monitor and guide progress towards a low carbon and resource efficient EU. Those indicators that can be directly related to the built environment consist of:

  - Resource use: Material flow intensity related to GDP, energy productivity, share of renewable energy, water use, urban land use;
  - Environmental pressures on 'natural capital': greenhouse gas emissions, water exploitation;
  - Thematic indicators: Urban air quality (PM_{10} emissions).

  Water use is the subject of a Blueprint for action at EU level. Greater efficiency is proposed in order to reduce stress but measures are to be set at local/regional level depending on water stress. Notably, mineral waste and construction waste recycling are specifically excluded from the indicators.

- Waste reduction and circular material flows: The Waste Framework Directive establishes a 2020 target for 70% of Construction and Demolition Waste to be re-used, recycled or recovered. Given the wide variation in the current performance of Member States, ranging from 10% to 90%, this represents a significant challenge. This target is complemented by resource efficiency objectives to reduce and transform material flows, with mineral flows associated with construction accounting for approximately 40% of EU material flows and, based on evidence from Germany, very significant material stocks.

- Resource efficient urban development: A theme that recurs in the 7th EAP, the Roadmap to a Resource Efficient Europe and in leading Member State resource efficiency strategies is the need to interrelate urban planning, infrastructure, and building form and location. The multiple resource efficiency benefits of compact, land efficient and public transport connected buildings are highlighted and cited as an objective.

Together these high level objectives provide a clear starting point for identifying macro-objectives. Several of these macro-objectives are legally binding but now require a drive for implementation at building level. Others are more complex as they imply further investigation in order to relate them to buildings, or because they integrate several facets of building design and urban planning.

The high level resource efficiency objective of reducing domestic material flows requires further attention. This is because a simple focus on domestic material flow does not capture 'hidden' flows and impacts from imported materials. These may include environmental pollution from abiotic resource extraction, ecosystem damage from biotic resource extraction and relative abiotic resource scarcity.

Questions to stakeholders on EU and MS policies

3.1 Which aspects of EU frameworks, regulation and initiatives should be the priority focus to identify macro-objectives for this study?

3.2 Do the current EU resource efficiency indicators provide a useful starting point for macro-objectives?

3.3 Are evaluations of the relative success or impact of MS resource efficiency policies available?

3.4 Are there examples of MS policy frameworks and macro-objectives on resource efficiency that are linked to building performance indicators?

5.2 Macro-objectives identified from 'hot spots' for improving resource efficiency

Environmental and resource efficiency 'hot spots' for the improved performance of buildings were identified in Chapter 3 of this working paper. These are based on the findings and results of technical studies of buildings and major construction materials from both sectoral and building typology perspectives. The use of normalisation and weighting in LCA studies is the subject of controversy and most of the studies reviewed do not carry out these steps, making it more difficult to clearly prioritise hot spot environmental impacts. Nevertheless, it is possible to identify those of significance and, with reference to Chapter 2 of this paper, make the link to EU policy priorities.

Overall the use phase of buildings is the most significant in the life cycle of buildings because of the Global Warming Potential of emissions related to primary energy use. But the balance is changing as the 'regulated' energy used by buildings reduces and more energy and resource intensive construction elements may be required to achieve higher performance. Increased cooling and auxiliary energy use, as well as 'unregulated' energy use associated with occupiers of buildings, are trends identified in some Member States.

From a top down sectoral perspective, the study carried out for the European Resource Efficiency Platform (EREP) provides the most comprehensive overall view of the sector. The findings recommend a focus on large flows of materials. This would entail a focus on life cycle impacts associated with mineral and metals flows, with concrete, brick, ceramic, steel, copper and aluminium having been identified. Notably, timber is not addressed because of difficulties evaluating the environmental impacts associated with forestry using current LCA methodologies.

As was noted in Section 5.1, material flow accounting using indicators such as DMC or TMC cannot reflect the distinct range of impacts associated with these construction materials. The most significant impacts associated with each of these major material flows should form the basis for macro-objectives. At a simple level, and as a starting point for discussion, this could focus on the following hot spots:

- Concrete: Greenhouse gas emissions from the production of cement production and, to a lesser extent, material flows and the transport of the mineral (abiotic) resources such as coarse aggregate.
- Steel, copper and aluminium: Greenhouse gas emissions from the production of steel, as well as 'hidden' (abiotic) resource flows, GHG emissions and toxicity arising from the extraction and processing of ore.
- Timber: Total biotic resource flows, as well as the ecosystem damage that may be caused by the harvesting of the raw material. Engineered timber may also be energy intensive to manufacture.

At a building level, the importance of impacts related to the materials used for structures was clearly highlighted by all the studies reviewed. As well as macro-objectives relating to the distinct impacts of these materials, the potential to define macro-objectives from a design and engineering perspective could also be considered. For example, the comparative improvement potential of the re-use of existing concrete structures and the light weighting of new structures can be as significant as changes in mix design to reduce the cement content. The fundamental structural design parameters and intended lifespan should be used when evaluating the life cycle impacts of different material options.

A further area of improvement relates to the efficiency and intensity of use of structures, space and land. There is significant evidence that for domestic buildings, more compact building forms such as apartments and terraces are more land, material and energy efficient. In contrast, taller building forms also require more

material intensive structures in function of the number of floors. The choice of functional unit is therefore critical in defining how the intensity of resource use will be addressed.

Linked to these issues, the efficiency with which space is used within building designs – both on a temporal and spatial basis - and future flexibility in the ability to change layouts and uses can also have a significant influence on comparative LCA performances. For example, depth of floor plates and floor to ceiling heights have been identified as a factor influencing the future potential for changes of use.

Externalised, 'induced' effects beyond the conventional LCA boundary of a building could also be a considered. Decisions relating to the location of buildings are identified as being of significance. This is because the accessibility of a home or commercial building to public transport networks and amenities, in combination with the overall urban density, tend to have a strong correlation with transport energy use.

'Indirect' health & wellbeing factors that may influence the performance, service life and value of a building are increasing seen as a proxy for 'green buildings'. Whilst there is increasing evidence for the quantifiable benefits in terms of the satisfaction, productivity and health of building occupiers, in order to warrant their inclusion within the macro-objectives there should be a clear link between these factors and the resource efficiency of the building.

There is clear evidence from post occupancy studies of buildings that health & wellbeing aspects such as thermal comfort and natural lighting are critical to the performance and occupant satisfaction of low energy buildings. However, it is to be explored further with stakeholders whether this, together with potential health and productivity benefits, justify having specific macro-objectives.

Questions to stakeholders on macro-environmental 'hot spots'

4.1 Which building uses/ typologies should be prioritised at an EU level based on their environmental significance? *Please share any further evidence or studies that may be available e.g. top down extended I/O or LCA studies.*

4.2 How should the resource efficiency of the most common structural materials be addressed within the macro-objectives?

4.3 Are there other aspects of building resource efficiency that justify consideration based on their environmental significance?

4.4 To what extent should 'induced' impacts be included as macro-objectives?

4.5 Are the links between health and wellbeing aspects and the resource efficiency of buildings strong enough to justify their inclusion as macro-objectives? (*See also the specific questions on page 43)*

5.3 Macro-objectives identified from existing assessment and reporting tools

Two broad type of tools were analysed in Chapter 4. Five building assessment schemes used to carry out 'asset ratings' for new building designs and four investor reporting tools used to carry out 'operational ratings' for existing buildings and renovations.

In the majority of cases the scoring or weighted contribution of criteria areas within these tools is determined by panels of experts, as well as wider stakeholder consultations. Only one of the tools examined is directly informed by LCA evidence for building environmental hot spots and incorporates a weighting designed to reflect the spatial and temporal significance of environmental impacts.

Based on this initial comparison of the assessment and reporting tools, the following macro-objectives were identified on the basis of having been weighted as being significant, whilst taking into account major differences in emphasis that may reflect the original national context in which tools were developed:

Building assessment tools, 'asset ratings'

- Life cycle impacts within the building boundary: Primary energy use or CO_2 emissions in the use phase are weighted as the most significant in all tools followed by aggregated scores or combinations of criterion for construction material impacts (embodied energy, CO_2 footprint or a weighted

aggregation of LCA indicator scores). Water can be included on the basis of resource scarcity in a country or location.

- 'Induced' impacts outside of the building's boundary: Location close to public transport connections is weighted significantly in one scheme and is addressed to a lesser extent in two others. Public transport linkages and proximity to amenities is a pre-design consideration in one tool.
- In-direct influences on the performance, service life and value: The aggregated scores for common combinations of occupant comfort and wellbeing criteria – typically IAQ, thermal comfort, daylighting and acoustics - are weighted significantly in all schemes, but in two examples is weighted close to or equal to what can be considered as 'hot spot' life cycle impacts.

Investor reporting tools, 'operational ratings'

- Life cycle impacts within the building boundary: Primary energy use, CO_2 emissions, water use, waste arisings are reported in all four tools with energy being the most highly weighted in one tool.
- 'Induced' impacts outside of the buildings boundary: Site selection for public transport connections and employee related journeys and impacts are reported in three tools and are weighted significantly by at least one tool.
- In-direct influences on the design, service life and value: Occupant wellbeing relating to lighting, ventilation, HVAC, occupant controls and outside views are weighted significantly in one tool and are a general consideration in another.

Although there is a general move towards standardisation according to EN 15978 and EN 15804, as well as the work of the SB Alliance and CESBA, these standards are reporting frameworks and do not as such provide a set of macro-objectives. The extent to which these indicator sets reflect the distinct resource efficiency hot spots associated with common building materials will be analysed in the next stage of this study. For example, abiotic resource depletion is more appropriate for critical raw materials than high volume construction materials and an accepted indicator for biotic resources such as timber is not currently available.

Questions to stakeholders on assessment and reporting tools

5.1 To what extent should the weightings and priorities of the tools analysed inform the macro-objectives?

5.2 How might the findings from collaborative projects such as the SB Alliance, CESBA, SuperBuildings and OpenHouse inform the macro-objectives?

5.3 Are there examples of tools where the criteria have been strongly informed by LCA and resource efficiency hot spots?

5.4 Are there any other tools not analysed in this paper which have distinct criteria areas that should be considered further?

6. Initial considerations for macro-objectives

6.1 Thematic clustering of possible macro-objectives

Whilst the Commission's 2014 Communication on resource efficient buildings did not prescribe priority areas of focus, it is important within the frame of this study that the boundary, scope and priority for the macro-objectives are now discussed and agreed on with stakeholders.

Based on the findings of this working paper, the following themed clusters are put forward for discussion and consideration. The first three address, based on the evidence reviewed, building related resource use and pressures on natural capital. The fourth addresses indirect factors for which there may be a justification for inclusion within the macro-objectives because of links to resource use.

The scope of the building uses/typologies, as well as the points in the life cycle of buildings (e.g. new-build, existing stock, renovation activities), which the macro-objectives would target is to be discussed further with stakeholders. Specific questions for stakeholders on the scope can be found on page 8.

A building structure's performance

- The prioritisation of the re-use of existing primary structures before the construction of new structures
- The optimisation of material use and composition so as to achieve the same structural performance, lifespan and function with reduced material flow, GHG emissions and ecosystem damage

Overall building performance, including structures

- The reduction of Green House Gas emissions along the life cycle of buildings, with a focus on the product and use phases;
- Primary energy consumption should be minimised as far as possible, with a priority focus on the renovation of existing buildings
- The minimisation of material flow (including hidden flows) associated with building construction, with a priority focus on structural materials
- The substitution of primary material flows with re-used, recycled and by-product material flows from within the construction and industrial sectors in order to reduce landfill
- Extension of the service life of new and existing building structures, whilst ensuring that primary energy consumption in the use phase is progressively minimised as far as possible
- Water consumption should be minimised as far as possible in river catchment areas with water stress

Urban development form and location

- The re-use of 'brownfield' land with existing infrastructure connections so it can serve new buildings and developments
- The optimisation of building form and intensity of use in order to minimise material impacts in the production phase and achieve inherently more energy efficiency performance in the use phase
- The optimisation of public transport accessibility and development density in order to minimise 'induced' transport related impacts in the use phase

The performance, productivity and comfort of building assets

- The optimisation of light, temperature and air quality in order to ensure that resource efficient buildings are valued, healthy and comfortable
- The minimisation of Life Cycle Costs and future exposure to risks whilst maximising a building's value and occupier productivity during its service life
- The optimisation of location and setting in order to create attractive, vibrant and well-connected buildings

6.2 'Rules' for translating macro-objectives into building level indicators

The review of LCA evidence and the work of the European Reosurce Efficiency Platform (EREP) highlighted the importance of the functional unit when seeking to analyse intensity of resource use. It is therefore for discussion whether some rules should be set when translating macro-objectives into measurable indicators of building performance.

From the technical literature reviewed to date three possible rules can be identified:

- The functional unit shall relate the buildings use to the unit of consumption for the utility e.g. household (homes), workstation or employee (offices), pupil or class (school);
- For building structures, the resource efficiency of material options shall be related to the design lifespan and fundamental engineering design parameters;
- The building form should always be compared with other building form typologies in order to benchmark resource use intensity.