European Environment Agency

STUDY ON LAND RECYCLING

Final report

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MediTerra consultors ambientals, s.l.

LEITAT Technological Center — managing your technologies — member of TECNIO

…on of:

ARCADIS

LQM Sound science: Defensible decisions

Contents

LIST OF ACRONYMS AND GLOSSARY

List of Acronyms
BF: Brownfield
CABERNET: Concerted Action on Brownfield and Economic Regeneration Network
CF: Common Forum
CTU: Comparative Toxicity Units
EEA: European Environment Agency
EIONET: European Environment Information and Observation Network
GF: Greenfield
ILCD: The International Reference Life Cycle Data System
LCA: Life Cycle Assessment
LCIA: Life Cycle Impact Assessment
LCT: Life Cycle Thinking
NICOLE: Network for Industrial Contaminate Land in Europe
NRC LUSP: National Reference Centres Land Use and Spatial Planning
SETAC: Society of Environmental Toxicology and Chemistry
TPH: Total Petroleum Hydrocarbon
UST: Underground Storage Tank

Glossary
Brownfield: sites that have been affected by former uses of the site or surrounding land; are derelict or underused; occur mainly in fully or partly developed urban areas; require intervention to bring them back to beneficial use; and may have real or perceived contamination problems (CABERNET,2007)

Greenfield: usually land located in a (semi-)rural area that is undeveloped except for agricultural use; especially land considered as site for expanding urban development.

Land take: the change of agriculture, forest and semi-natural/natural land, wetlands or water to urban land cover as a consequence of urban residential sprawl, sprawl of economic sites and infrastructures (including creation of industrial, ommercial and transport units, but excluding the conversion of previously developed land to sport and leisure facilities) and development of green urban areas over previously undeveloped land (EEA Land take indicator (CSI 014/LSI 001): http://www.eea.europa.eu/data-andmaps/indicators/land-take-2/). It is also referred to as land consumption (SWD (2012), and describes an increase of settlement areas over time. This process includes the development of scattered settlements in rural areas, the expansion of urban areas around an urban nucleus (including urban sprawl). Depending on local circumstances, a greater or smaller part of the land take will result in actual soil sealing.

Land recycling: the reuse or regeneration of artificial (usually urban) land that was previously developed, but is currently not in active use or available for re-development (so-called brownfields) (EC, 2012).

Soil sealing: the permanent covering of an area of land and its soil by impermeable artificial material (e.g. asphalt and concrete), for example through buildings and roads.

Life Cycle Thinking: Life cycle thinking describes a process that considers environmental impacts over the entire life cycle of a product. The key aim of Life Cycle Thinking is to avoid burden shifting. This means minimising impacts at one stage of the life cycle, or in a geographic region, or in a particular impact category, while helping to avoid increases elsewhere.

Site actuation: activities performed at a site with the purpose of developing for a new use.

1 Introduction

This report presents the results of the Study on Land recycling (EEA/NSV/14/003) awarded to MediTerra by the European Environment Agency (EEA) in July 2014. The study has been developed with the collaboration of Arcadis, LQM and Leitat.

The main purpose of the study is to evaluate wider environmental impacts, i.e. impacts other than those directly related to land use (both on- and off-site), of brownfield (BF) development by applying and then evaluating the Life Cycle Thinking (LCT) approach to three real-world case studies. LCT seeks to identify possible improvements to goods and services in the form of lower environmental impacts including reduced use of resources across all life cycle stages. In the case of brownfield development this includes the remediation, construction, future use and decommissioning stages.

The main phases of the study consisted of:

- An overview of relevant literature (scientific, local strategic documents, etc.), European networks and national policies dealing with land recycling in which environmental aspects other than land use are considered (Chapter 2 and Annex 1).

- The design of the Life Cycle Assessment (LCA) methodology followed in the study considering the feedback from the representatives of the European Environment Information and Observation Network (Eionet), National Reference Centres Land Use and Spatial Planning (NRC LUSP) during the meeting in Copenhagen on the 10th September 2014 (Chapter 3).

- The elaboration of three case studies by contrasting contexts using the LCT approach (Chapters 4, 5 and 6).

- Comparative analysis of the results of the three case studies and main conclusions (Chapter 7)

- Recommendations for land recycling approaches in Europe whilst considering land resource efficiency. According to the information and knowledge available, the recommendations have taken account of specific contexts across Europe (Chapter 8).

2 Literature and experience research

A literature review on the application of the LCA approach to brownfield development was performed in order to define the state-of-the-art as a starting point for the study (See Annex 1). Other studies related to LCA and soil remediation or sustainability assessment of brownfields projects (with methodologies other than LCA) have also been considered as potential sources of information for the study.

This research has included environmental aspects other than land use. Special attention has been given to governance aspects (in relation to land take or other land targets, responsibilities in spatial planning, etc.) that have been taken into consideration in the conclusions and recommendations of the study. New knowledge obtained from the evaluation of land recycling projects has been included in this study.

The research focussed on the following areas:

- Scientific studies on the application of LCA in brownfield development;
- European networks/projects/associations related to brownfields and contaminated site management;
- Case studies where LCA, sustainable development assessments and/or environmental impacts have been applied to brownfield development;
- European, national and regional policies and strategies on land recycling.

For the collection of information and experiences, three of the main European networks on brownfield or contaminated sites have been consulted via a survey document:

- The Network for Industrially Contaminated Land in Europe (NICOLE). MediTerra and ARCADIS are members and active participants in the NICOLE working group on Sustainable Remediation.
- Common Forum on Contaminated land in the European Union. It is a “stakeholder network”, mainly from member state regulators, in the development of an EU soil protection policy (Paul Nathanail (LQM) is a regular attendee).
- The Concerted Action on Brownfield and Economic Regeneration Network (CABERNET) addressing the complex multi-stakeholder issues raised by Brownfield regeneration. Jordi Boronat (MediTerra) and Paul Nathanail (of LQM) are members.

The main documents, studies and experiences consulted are presented in Annex 1 of this report. From this research it can be concluded that:

- Few studies have been identified where an LCA methodology was applied to BF development taking into consideration the impacts of the whole process, including operation of the site after development. Most of the available studies are related to research projects (Lange and Mashayekh, 2003; Lesage et al., 2007a; Brecheisem and Theis, 2013). The methods used in these studies have been evaluated to provide input for the present study, especially the assessment of results but also regarding the data management and interpretation.

- Most of the sustainability frameworks used in quantitative assessment tools (like LCA) applied to development are primarily focussed on building or construction projects, and they have limitations, such as a fixed scope of assessed factors. Relevant information has been applied to the present study, for instance the methodological aspects to be considered when making the data inventory, the processing of the data into the model, and the identification of environmental impacts from building and infrastructure demolition and construction.

- There are several examples from Europe and the United States of the application of LCA into site remediation activities that assessed the overall impact of the soil and groundwater remediation approach. However, the scope of these assessments is limited to the environmental and health impacts of the remediation process; the impacts of the whole development project are not considered (NICOLE, 2012; Eurodemo, 2012; CL:AIRE-SuRF-UK, 2014; US Air force Centre for Engineering and the Environment – AFCEE, 2011). The remediation process is an important stage in the BF development. The present study has benefitted from those examples where LCA has been applied to only the remediation stage of the overall development. The draft ISO document on Sustainable Remediation (ISO/CD 18504: Soil Quality – Guidance on sustainable remediation) recommends a tiered approach to sustainability assessment and only signposts LCA as being useful in a small number of situations where a high degree of resolution is needed to choose between feasible alternative remediation strategies.

- Sustainability monitoring tools have been developed for large-scale land development programmes (e.g. London 2012 Olympics). These tools include key sustainability performance indicators during construction and operations that have been coupled with sophisticated multi-attribute models to optimise sustainability by balancing trade-offs between different attributes and between multiple alternatives. Although these tools do not assess the overall impact of the development, they have been used in the present study to identify potential impacts related to developments.

- Some public authority bodies have evaluated the suitability of using LCA for assessing the sustainability of soil remediation (Flanders, OVAM 2011). In this case the study concluded that LCA is time-consuming and requires a lot of data. LCA was therefore generally considered not to be suitable for the sustainability assessment of every soil remediation project in Flanders, While this may be true for limited duration (about 1 year) and localised impacts of remediation projects, the time and effort may be justified when considering the full lifespan (>20 years) and wider environmental impacts of the development project as a whole (from construction over operation to demolition). Indeed, the emerging evidence from

US EPA suggests that a detailed consideration of the environmental impacts of remediation can deliver reduced costs as well as improved environmental performance.

- Setting and monitoring sustainability performance indicators can be a powerful management tool if contested issues can be readily resolved – or better still avoided altogether. ISO has a working group (TC190/SC7/WG12), chaired by Paul Nathanail, developing a document on sustainable remediation that recognised a specific role and window of application for LCA in remediation option assessment in those cases where a high degree of resolution was needed to select between candidate remediation strategies

In conclusion, the experience from current BF developments shows that the environmental impacts of these projects are not necessarily considered in a holistic and systematic manner; only specific aspects are assessed comprehensively (for example, selected environmental impacts of remediation activities or construction activities). Therefore, the application of LCA to BF developments, considering all stages of the process (perhaps extending into the operation phase of the redeveloped site), could help to assess the overall environmental impacts and identify possible improvements in BF management.For example, the application of LCA could help identify activities with lower environmental impacts, reduced use of non-renewable resources (including energy) and reduced generation of waste, while increasing energy generation or recovery and reuse of waste across all land use life cycle stages.

From the literature review and case studies, it has also been concluded that, in order to compare the impacts of BF with greenfield (GF) developments, LCT should be applied to a GF development in a similar manner to that used in one of the two BF development case studies presented. The results of this comparison will allow assessing the magnitude of the different environmental impacts for each project and the benefits of BF as opposed to GF development, and thus the importance of land recycling as opposed to land take.

3 Methodology

3.1 Introduction

This study presents a streamlined LCA of three case studies: two brownfield sites and one greenfield site. The inclusion of a greenfield site has allowed a better comparative analysis of the impacts of land take in urban developments. For these urban projects the LCA performed allows creating an environmental profile considering all life stages; from the original site status to the operation of the developed site.

LCA is used to perform quantitative environmental analysis, which allows quantifying the potential environmental impacts of a product or service over its life cycle. The most important applications are:

- Analysis of the contribution of different life cycle stages to the overall environmental impact, usually with the aim of prioritising improvements to products or processes.

- Comparison between products/services for internal or external communications.

LCA is a relatively young method that became popular in the early 1990s. In recent years, life cycle thinking has become a key focus point in environmental policy-making. LCA provides the best quantitative and scientific basis for all these new concepts. In many cases, LCA informs internal and external discussions and can be used as a tool to communicate the environmental impacts of products and business processes.

The first definition for LCA was provided by the Society of Environmental Toxicology and Chemistry (SETAC):

> *"A process to evaluate the environmental burdens associated with a product, process, or activity by identifying and quantifying energy and materials used and wastes released to the environment; to assess the impact of those energy and materials used and released to the environment; and to identify and evaluate opportunities to affect environmental improvements. The assessment includes the entire life cycle of the product, process or activity, encompassing, extracting and processing raw materials; manufacturing, transportation and distribution; use, re-use, maintenance; recycling, and final disposal".*

The application of LCA to greenfield and brownfield developments is still innovative. Prospective approaches and special considerations are needed in order to obtain comprehensive results on the direct and indirect environmental impacts of brownfields into different environmental impact categories and indicators.

This chapter presents a streamlined and adapted LCA methodology. This has been applied to the case studies and permits recommendations to be made regarding the environmental evaluation of brownfield and greenfield developments.

3.2 Description of the methodology

The LCA methodology applied to the present study is based on the standard ISO framework (ISO 14040:2006 and ISO 14044:2006) (Figure 3.1), as well as the recommendations of the International Reference Life Cycle Data System (ILCD) Handbook (ILCD, 2012b). Several adaptations have been introduced in order to align this methodology with the goals of the study. Calculations have been carried out for the three case studies using the SimaPro 8 software, based on the Ecoinvent Database v3 and the ILCD impact assessment method, as well as site-specific data in each case.

The four main phases of the methodology are presented in Figure 3.1 and summarised in the sections below.

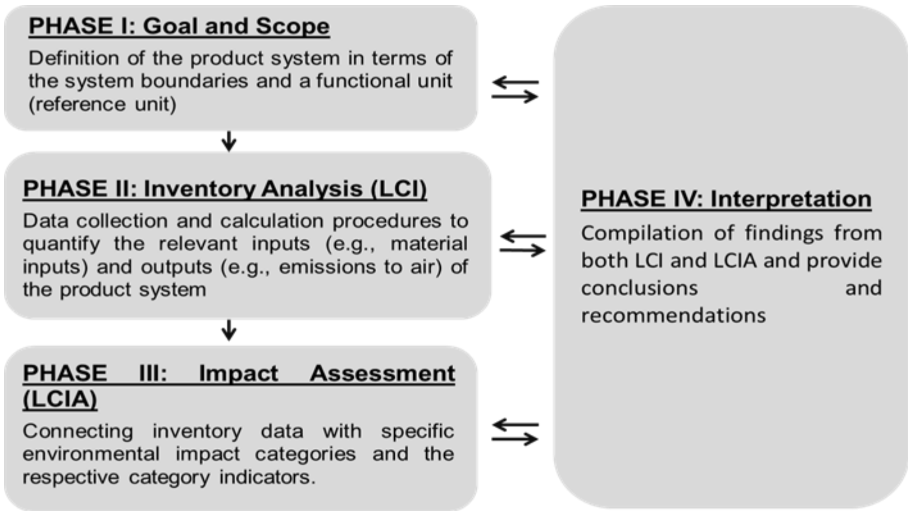

Figure 3.1: Methodology and steps for LCA studies according to ISO:14044:2006

3.2.1 Phase I: Goal and scope definition of LCA studies

The first phase is the goal and scope definition, which defines the general context for the study. In the goal definition, parameters such as the functional unit, the intended application, the reasons for carrying out the study, the target audience and the limitations and assumptions for the study are defined.

The goal of this LCA study is to evaluate the potential environmental impacts of the development or re-use of brownfield sites considering all stages of development. Results will allow identification of stages and parameters that pose the greatest impacts, as well as comparison with other development alternatives, including extending urban developments into greenfield areas.

Scope of the system and boundaries

An innovative approach has been adopted in order to include the different life stages in brownfield development and their associated impacts, which can be classified as

follows:

Figure 3.2. Flowchart of life stages and associated environmental impacts

This classification of impacts was proposed in existing LCAs on brownfields (Lesage et al, 2007a). The innovative approach adopted in this study allows a holistic view of these life stages, whereas conventional studies only cover the impacts related to the intervention stage (secondary impacts) and exclude the primary and tertiary impacts.

Primary impacts are associated with the state of the site and consider the soil and groundwater contamination already existing at the site. Tertiary impacts are associated with the operation or use of the site after development.

All the assessed impacts have a local component (i.e. impacts inside the limits of the developed site) and a regional component (impacts outside the developed site). The assessment has considered both these local and regional dimensions.

In Figure 3.3 the activities assessed for each life stage of the site are presented for the three case studies.

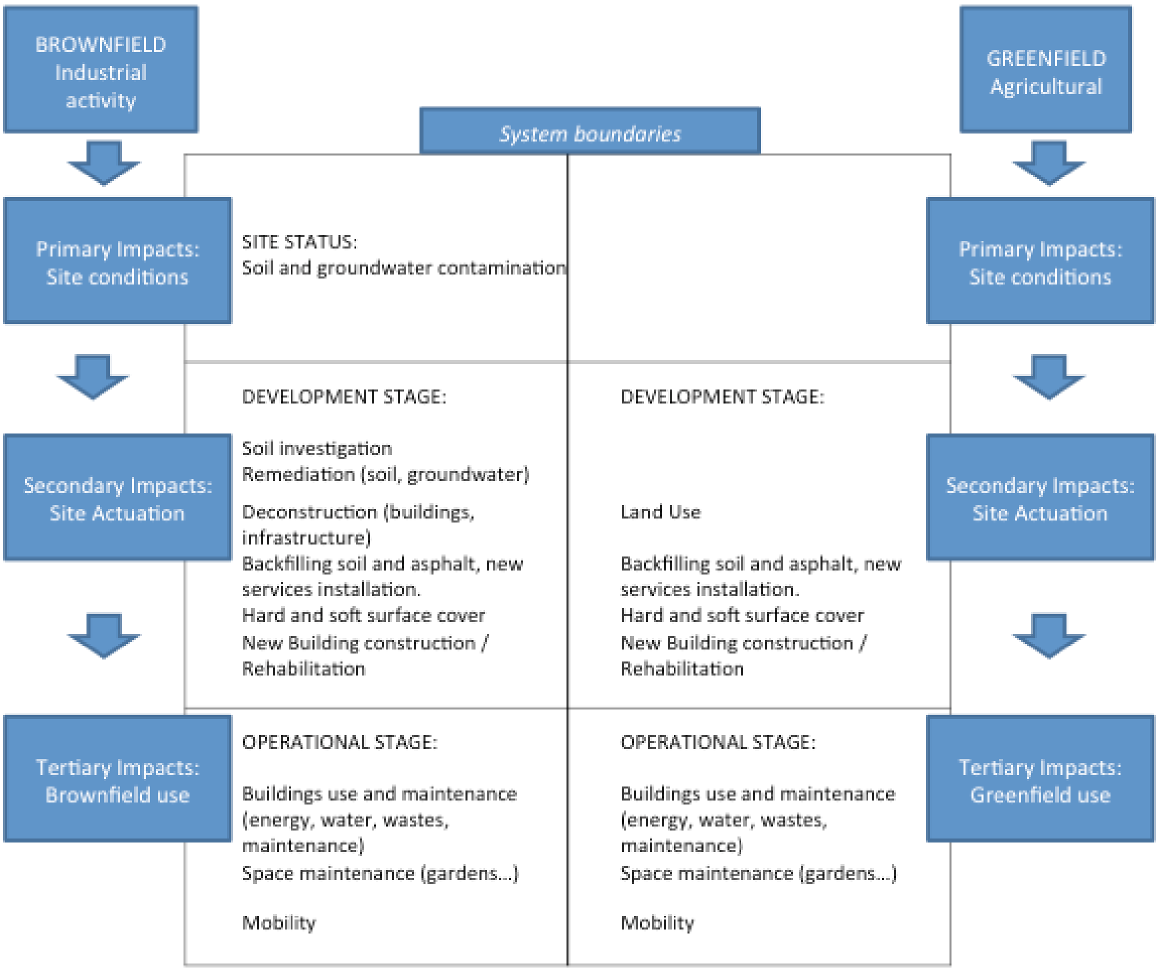

Figure 3.3. Flowchart of life stages and associated environmental impacts

Primary Impacts

Primary impacts refer to the site's degraded physical and chemical state that, for example, can create risks to human and ecosystem health and/or deterioration of life-support services. The fact that the sites are economically inactive (i.e. are currently not in use) but are also not in a state that makes them available for re-use, results in the loss of urban land available for development, and hence increases development pressure on undeveloped land within or at the periphery of the urban footprint (Lesage et al., 2007a).

In this study, previous or present uses have not been included, since the assessment begins at the start of the (re)development process. Only future (re)development activities and soil quality inherited from former industrial activities have been considered. The recently completed FP7 HOMBRE (HOMBRE, 2014) project recommends that planning for the next land use begins before the present one is completed. Switching from current decoupling of land use and management to linking past and future use could enhance the environmental benefit and reduce the environmental impact of transitioning from one land use to another.

When considering primary impacts, reference values and target values are used. Reference values are regulatory thresholds which are used as basic parameters for the assessment/evaluation of soil or groundwater contamination. The reference values are set upon a number of substances which have been grouped according to the use of the soil and their hazard upon the human health and the environment. Usually different uses are considered: industrial use, urban use, green area use, etc. Target values are the concentration of a substance in soil, calculated by means of a risk assessment, which can be left in the soil after applying remediation techniques, even if they are above the regulatory threshold values (reference values).

Concentrations of some substances in the soil remain above regulatory thresholds after site development. Even after soil remediation these concentrations are not generating an unacceptable human health risk for the future use of the site. Therefore, when soil with substances at levels above the reference values remains at the site, the potential environmental impact of this soil is included in the assessment.

Secondary Impacts

Secondary impacts result from the (re)development activities, performed to (re)use the area for urban purposes. The different activities considered are the following:

- Land occupation
- Soil and groundwater investigation
- Soil remediation
- Deconstruction
- Construction of new buildings
- Construction of new infrastructures

Not all of the activities are relevant for all three case studies, as described in each case study assessment.

The assessment of the impacts of the end-of-life of a site has not been included as a separate stage. Yet, the impact of the demolition of new buildings (at their end-of-life) has been considered in the construction stage evaluation.

Tertiary Impacts

Once the site has been (re)developed, the operations considered during the use stage of the developed site are:

- Building use: energy and water consumption, waste production, wastewater production.
- Green areas: water consumption.
- Mobility of users.

The lifespan is a key assumption for the LCA brownfield/greenfield system, since it has a large influence on the final results.

For most LCA on buildings, the lifespan of buildings is considered to be 50 years. However, some LCA on brownfields considered 20 or 40 years (Lange and Mashayekh, 2003; Lesage et al., 2007a; Brecheisem and Theis, 2013). Considering the importance of the use stage and in order to present the results of the different life stages in a proportional manner, the impacts of the use stage have been considered for 20 years in this study. If more than 20 years of lifespan were to be considered, the results would be dominated even more by the use stage of the land. The longer the lifespan of the use stage, the less important the short-term impacts will appear.

Hence, by choosing a short lifespan in the use stage, we allow a balanced insight into all parameters.

The functional units
The functional unit of a development project is the reference unit for impact assessment results. In this study three different functional units have been defined and the results have been compared for each functional unit:

Functional unit 1: hectare of managed brownfield/greenfield

Functional unit 2: m^2 of constructed area (built surface is used with the same meaning)

Functional unit 3: number of residents (inhabitants and habitants are used with the same meaning) in managed brownfield/greenfield

The use of a specific functional unit was found to be critical in order to make a comparison between different sites, not to compare impacts within a site. All the results have been referenced to a functional unit of one hectare in order to compare results within a case study. In addition, the other two proposed functional units (constructed area and number of residents) have been applied to specific impacts in order to compare between different case studies (see Chapter 7).

3.2.2 Phase II: Inventory analysis

In the inventory analysis, each activity in the different life stages is analysed to determine the relevant input flows (energy and materials entering the system) and output flows (emissions and waste from the system to the environment). This information has been collected for the case studies. For each of the three case studies the main information was obtained from the urban planning documents and from authorities, consultants and developers involved in the urban process. Primary data were prioritised, while secondary data from databases and literature were used when needed, with Ecoinvent v3 being the main database used. In each phase the selected inputs (parameters) are indicated, which have associated input and output flows.

3.2.3 Phase III: Impact assessment

In the impact assessment phase, the potential environmental impacts associated with inventory flows are calculated. It is the phase during which the quantified input flows (of energy and materials) are expressed and quantified as output flows (of emissions and waste). The base methodology chosen for the present study is the ILCD 2011 Midpoint method as released by the European Commission, Joint Research Centre in 2012 (ILCD, 2012a). It supports the correct use of impact assessment categories (Table 3.1) as well as the units for the categories identified (Table 3.2). Table 3.1 also specifies if the impact assessment categories are considered to be global, regional or local.

Table 3.1. Impact categories of ILCD LCIA method.

Impact category	Description	Model/Method	Geographical Scales
1 - Climate change	Global Warming Potential calculating the radiative forcing over a time horizon of 100 years. Greenhouse gases such as carbon dioxide and methane can cause climate change.	IPCC 2007.	Global
2 - Ozone depletion	Ozone Depletion Potential (ODP) calculating the destructive effects on the stratospheric ozone layer over a time horizon of 100 years.	World Meteorological Organization (WMO) 1999.	Global
3 - Human toxicity, cancer effects	Comparative Toxic Unit for humans (CTUh) expressing the estimated increase in morbidity in the total human population per unit mass of a chemical emitted (cases per kilogramme). Specific groups of chemicals require further works.	USEtox.	Regional Local
4 - Human toxicity, non-cancer effects	Comparative Toxic Unit for humans (CTUh) expressing the estimated increase in morbidity in the total human population per unit mass of a chemical emitted (cases per kilogramme). Specific groups of chemicals require further works.	USEtox.	Regional Local
5 - Particulate matter	Quantification of the impact of premature death or disability effect that particulates/respiratory inorganic have on the population, in comparison to PM2.5. It includes the assessment of primary (PM10 and PM2.5) and secondary PM (incl. creation of secondary PM due to SOx, NOx and NH3 emissions) and CO.	Rabl and Spadaro 2004.	Regional Local
6 - Ionizing radiation HH (human health)	Quantification of the impact of ionizing radiation on the population, in comparison to Uranium 235.	Frischknecht et al. 2000.	Local
7 - Ionizing radiation E (ecosystems)	[Note: this method is classified as interim; see reference for explanation]: Comparative Toxic Unit for ecosystems (CTUe) expressing an estimate of the potentially affected fraction of species (PAF) integrated over time and volume per unit mass of a radionucleide emitted (PAF m3 year/kg). Fate of radionucleide based on USEtox consensus model (multimedia model). Relevant for freshwater ecosystems.	Garnier-Laplace et al. 2008.	Local
8 - Photochemical ozone formation	Expression of the potential contribution to photochemical ozone formation. Only for Europe. It includes spatial differentiation. Volatile organic compounds react with nitrous oxides and form smog which could have impacts to human health as well as ecosystems	van Zelm et al. 2008.	Regional Local
9 - Acidification	Accumulated Exceedance (AE) characterizing the change in critical load exceedance of the sensitive area in terrestrial and main freshwater ecosystems, to which acidifying substances deposit. European-country dependent. Acids and some compounds that can be converted to acids emitted to the atmosphere can cause regional damage to ecosystems as a result of acid rain..	Seppälä et al. 2006 and Posch et al. 2008.	Regional Local
10 - Terrestrial	Accumulated Exceedance (AE) characterizing the	Seppälä et al.	Regional

Impact category	Description	Model/Method	Geographical Scales
eutrophication	change in critical load exceedance of the sensitive area, to which eutrophying substances deposit. European-country dependent. Nitrogen and phosphor can lead to nutrient enrichment of ecosystems. Regarding soil, low-nutrient eco-systems could disappear.	2006 and Posch et al. 2008.	Local
11 - Freshwater eutrophication	Expression of the degree to which the emitted nutrients reach the freshwater end compartment (phosphorus considered as limiting factor in freshwater). European validity. Averaged characterization factors from country dependent characterization factors. Nitrogen and phosphor can lead to nutrient enrichment of ecosystems. In water, increased algae growth can eventually result in damaged ecosystems.	ReCiPe version 1.05.	Regional Local
12 - Marine eutrophication	Expression of the degree to which the emitted nutrients reach the marine end compartment (nitrogen considered as limiting factor in marine water). European validity. Averaged characterization factors from country dependent characterization factors.	ReCiPe version 1.05.	Regional Local
13 - Freshwater ecotoxicity	Comparative Toxic Unit for ecosystems (CTUe) expressing an estimate of the potentially affected fraction of species (PAF) integrated over time and volume per unit mass of a chemical emitted (PAF m3 year/kg). Specific groups of chemicals require further works.	USEtox.	Regional Local
14 - Land use	Soil Organic Matter (SOM) based on changes in SOM, measured in (kg C/m2/a). Biodiversity impacts not covered by the data set.	Mila i Canals et al. 2007.	Global, Regional Local
15- Water resource depletion	Freshwater scarcity: Scarcity-adjusted amount of water used.	Swiss Eco scarcity 2006.	Global Regional Local
16 - Mineral, fossil & renewable resource depletion	Scarcity of mineral resource calculated as 'Reserve base'. It refers to identified resources that meet specified minimum physical and chemical criteria related to current mining practice. The reserve base may encompass those parts of the resources that have a reasonable potential for becoming economically available within planning horizons beyond those that assume proven technology and current economics.	van Oers et al. 2002.	Global, Regional Local

Source: ILCD Impact impact method (ILCD, 2012a)

Table 3.2 Impact categories, their measurement units and description.

Impact category	Units	Description of units
1 - Climate change	kg CO2 eq	Kilogram of CO2 equivalent
2 - Ozone depletion	kg CFC-11 eq	Kilogram of CFC-11 equivalent
3 - Human toxicity, cancer effects	CTUh	Comparative Toxic Unit for humans (CTUh) expressing the estimated increase in morbidity in the total human population per unit mass of a chemical emitted (cases per kilogramme).
4 - Human toxicity, non-cancer effects	CTUh	Comparative Toxic Unit for humans (CTUh) expressing the estimated increase in morbidity in the total human population per unit mass of a chemical emitted (cases per kilogramme).
5 - Particulate matter	kg PM2.5 eq	Kilograms of Particulate Matter 2.5 equivalent
6 - Ionizing radiation HH (human health)	kBq U235 eq	kilo Becquerel of Uranium235 equivalent
7 - Ionizing radiation E (ecosystems)	CTUe	Comparative Toxic Unit for ecosystems (CTUe) expressing an estimate of the potentially affected fraction of species (PAF) integrated over time and volume per unit mass of a radionucleide emitted (PAF m3 year/kg).
8 - Photochemical ozone formation	kg NMVOC eq	Kilograms of Non- methane VOCs equivalent
9 - Acidification	molc H+ eq	molc H+ equivalent
10 - Terrestrial eutrophication	molc N eq	molc Nitrogen equivalent
11 - Freshwater eutrophication	kg P eq	kg Phosphorus equivalent
12 - Marine eutrophication	kg N eq	kg Nitrogen equivalent
13 - Freshwater ecotoxicity	CTUe	(Comparative Toxic Unit for ecosystems (CTUe) expressing an estimate of the potentially affected fraction of species (PAF) integrated over time and volume per unit mass of a chemical emitted (PAF m3 year/kg).
14 - Land use	kg C deficit	Soil Organic Matter (SOM) based on changes in SOM, measured in (kg C/m2/a).
15- Water resource depletion	m^3 water eq	m^3 water equivalent
16 - Mineral, fossil & renewable resource depletion	kg Sb eq	kg Antimony equivalent

Source: ILCD impact method (ILCD, 2012a).

3.2.4 <u>Phase IV: Interpretation of results</u>

The final step of the LCA is interpretation and critical review of the outputs in order to verify their reliability. In this final step, the completeness, sensitivity and consistency of data collected and results obtained are assessed to ensure their representativeness and suitability for inclusion in the LCA.

Iterations and sensitivity analysis have been performed during the course of the life cycle assessment process to internally control the quality of the data.

3.3 Feedback from the Eionet NRC LUSP meeting

MediTerra attended the meeting of the representatives of the European Environment Information and Observation Network (Eionet), National Reference Centres Land Use and Spatial Planning (NRC LUSP) in Copenhagen. At that event a list of targeted questions was addressed to the participants.

The feedback and answers to the questions obtained during the meeting have been useful in better defining the present methodology. One of the main issues identified during the meeting was the different governance settings within Europe, as well as specific contexts across Europe. Some of the topics discussed during the meeting were:

- The importance of cost/benefit analysis in informing decisions regarding brownfield development.
- The need to assess whether the impacts considered have a positive or negative effect.
- Environmental impact assessments are made in many countries when urban developments are planned, but in general are not as detailed as the one performed in this study.
- The LCA methodology used in this project was considered too complicated to apply to all brownfield developments. It was proposed to develop a simplified software tool that would be more user-friendly with easily understandable outputs. This would also reflect the ISO TC190 Committee Draft where the use of qualitative methods of sustainability assessment is recommended wherever possible.
- The LCA methodology was found to be useful in communicating the potential impacts of a brownfield development.
- In countries with deep financial crisis, aspects other than environmental impacts are prioritised in the decision making process (economics, job creation, promotion of construction sectors, etc.).
- The relevant target groups for the project were discussed (land planners, land developers, authorities, citizens, scientists, etc.).
- According to some participants, the use of LCA as a decision-making tool was not seen as an objective tool because the methodology and the interpretation of the results can introduce subjectivity when introducing the source data and when taking conclusions based on the results. In regions with a low level of planning regulations, this subjectivity could be more relevant than in regions with well-regulated planning policies. .

The feedback from the NRC LUSP representatives is reflected in this report.

3.4 Case studies

The three case studies were selected so as to represent a variety of different scenarios.

Two brownfield sites and one greenfield site have been used for the assessment:

- A brownfield near Nottingham (East Midlands, UK).
- A brownfield in Terrassa, near Barcelona (Catalonia, Spain).
- A greenfield in the same area as the Terrassa BF, selected in order to compare the environmental impacts of these two different types of urban development.

The description of each case study is included in the correspondent chapter, while Table 3.3 presents the main data used for each case study.

Table 3.3 Comparative summary table with the main characteristics of the selected case study sites

Site characteristic	Brownfield site Nottingham (BF_UK)	Brownfield site Terrassa (BF_ES)	Greenfield site Terrassa (GF_ES)
Total surface (ha)	7.7	3	47.5
Residents	700	1,269	13,356
Residential units	600 (2 floors)	423 (5 floors)	4,452 (5 floors)
Construction surface (m^2)	40,000	22,638	130,641
Residents/100 m^2 construction surface	1.75	5.60	10.2
Former use	Opencast coal mine	Industrial Textile	Agricultural, Greenfield
Existing contamination and remediation	Yes	Yes	No
Existing buildings	No	14,443 m^2 (10 industrial units)	16,970 m^2 of rural houses

The different life stages and development and use activities considered for the three case studies are presented in Table 3.4.

Table 3.4: Different life stages and development and use activities considered in the impact assessment of the three case studies

Life stage/Site status, and development and use activities		Considered in brownfield case study (BF_UK)	Considered in brownfield case study (BF_ES)	Considered in greenfield case study (GF_ES)
Primary	Remaining contamination	√ Included	√ Included	χ Not applicable for this site study
Secondary	Soil and Groundwater investigation	√ Included	√ Included	χ Not applicable for this site study

Life stage/Site status, and development and use activities		Considered in brownfield case study (BF_UK)	Considered in brownfield case study (BF_ES)	Considered in greenfield case study (GF_ES)
	Soil remediation	√ Included	√ Included	χ Not applicable for this site study, since no contamination is present on the site.
	Deconstruction	√ Included	χ Not included (not applicable)	χ Deconstruction of the small huts has not been considered in this study.
	Rehabilitation of existing buildings	√ Included	χ Not included (not applicable)	X Existing buildings (16,970 m^2 of Rural houses) are in good conditions. Only minor rehabilitation activities have been carried out and they are not included in the study.
	Land occupation: loss of natural land	χ Not included, considered that it belongs to the previous economic activity system	χ Not included	√ Included as natural land occupation
	Construction of new buildings (including landscaping)	√ Included	√ Included	√ Included
	Construction of new infrastructures	√ Included	√ Included	√ Included
Tertiary	Mobility	√ Included	√ Included	√ Included
	Water supply buildings	√ Included	√ Included	√ Included
	Water supply facilities	√ Included	√ Included	√ Included
	Waste generation	√ Included	√ Included	√ Included
	Wastewater	√ Included	√ Included	√ Included
	Electricity building consumption	√ Included	√ Included	√ Included
	Natural gas consumption	√ Included	√ Included	√ Included

4 Case study 1: Brownfield in Nottingham (UK)

4.1 General description

The third case study is a backfilled former open cast coal mine and landfill site in the area of Nottingham, UK. Some of the data related to soil and groundwater remediation has been estimated due to the lack of information at present time.

Location: In the outskirts Nottingham, UK

Surface: 7.7 Ha.

Uses: The site was used as an opencast coal mine and was afterwards utilized as an inert landfill.

Existing buildings: No

Existing infrastructures: No

Brownfield project: The proposals for the site comprise of a residential development of 200 houses of two floors with associated gardens, access roads, an equipped play area and landscaped areas.

A soil and groundwater investigation was performed. Some of the data related to soil and groundwater remediation have been estimated due to the lack of information at the time of writing.

4.2 Site conditions: primary impacts

As in the case of the brownfield case study in Terrassa, previous or present land occupation has not been included in the system since it occurred in the previous industrial activity. Only future development activities and soil quality inherited from former industrial activities are considered.

From the previous economic activity (coal mining) pollutants are present in the soil and groundwater, which could have an effect on environment and human health. Some pollutants are treated during brownfield development whereas some concentrations of substances in the soil will remain above screening thresholds after BF development. These concentrations are not compromising the suitability for the future use of the site and therefore this soil will remain at the site. These potential impacts have been included in the assessment. Pollutants have been considered as emissions to soil (urban non-industrial soil) and freshwater respectively.

Table 4.1 presents the substances and concentrations that will remain in the soil and groundwater.

Table 4.1 Substance concentrations remaining on-site.

	Quantity of soil /water	**Name**	**Concentration / Quantity (max. concentrations)**	**Input selected (source)**
Site contamination-insitu (potential impacts from pollutants)	2500 t	As	50 mg/kg	Emissions to soil (urban, non-industrial)
		Pb	550 mg/kg	
		Ni	220 mg/kg	
		Zn	500 mg/kg	
		Benzo(a)pyrene	40 mg/kg	
		Naphthalene	9 mg/kg	
		Pyrene	83 mg/kg	
		Benzo(a)anthracene	22 mg/kg	
		TPHs (EC10-EC40)	700 mg/kg	
		Pb	70 µg/l	
		Ni	65 µg/l	
		Zn	670 µg/l	
		Tetrachloroethene (PCE)	75 µg/l	
		Trichloethene (TCE)	450 µg/l	
		cis+trans-DCE	240 µg/l	
		Vinyl chloride	7 µg/l	
		Naphthalene	70 µg/l	
Soil contamination Ex-situ (treatment)	750 t	Tetrachloroethene	1400 mg/kg	Emissions to soil (urban, non-industrial)
		As	760 mg/kg	
		Pb	215000 mg/kg	
		Hg	5 mg/kg	
		Ni	460 mg/kg	
		Zn	3800 mg/kg	
		TPHs	75000 mg/kg	
		Naphthalene	200 mg/kg	
Groundwater contamination site	5000 m3	As	50 µg/l	Emissions to water
Groundwater contamination (treated)	**5000 m^3**	Tetrachloroethene (PCE)	39000 µg/l	Emission to water
		Trichloethene (TCE)	1700 µg/l	
		cis+trans-DCE	9800 µg/l	
		Vinyl chloride	3900 µg/l	
		Naphthalene	1200 µg/l	

Impact assessment

Considering the original site conditions, in-situ pollutants have contributed to toxicity categories: human toxicity and ecotoxicity. The impacts as described in the table below are related to the functional unit (1 ha of brownfield).

Table 4.2 Impact values for soil substances remaining on-site (per ha).

Impact category	Unit	Total	Soil contamination insitu	Soil contamination Exsitu	GWater contamination site	GWater contamination treated
Climate change	kg CO2 eq	0	0	0	0	0
Ozone depletion	kg CFC-11 eq	0	0	0	0	0
Human toxicity, cancer effects	CTUh	2.45E-02	4.86E-03	1.96E-02	1.37E-05	0
Human toxicity, non-cancer effects	CTUh	3.20	0.38	2.82	0.0014	0
Particulate matter	kg PM2.5 eq	0	0	0	0	0
Ionizing radiation HH	kBq U235 eq	0	0	0	0	0
Ionizing radiation E (interim)	CTUe	0	0	0	0	0
Photochemical ozone formation	kg NMVOC eq	0	0	0	0	0
Acidification	molc H+ eq	0	0	0	0	0
Terrestrial eutrophication	molc N eq	0	0	0	0	0
Freshwater eutrophication	kg P eq	0	0	0	0	0
Marine eutrophication	kg N eq	0	0	0	0	0
Freshwater ecotoxicity	CTUe	18807774	4403697	14381259	18895	3921
Land use	kg C deficit	0	0	0	0	0
Water resource depletion	m3 water eq	0	0	0	0	0
Mineral, fossil & ren resource depletion	kg Sb eq	0	0	0	0	0

The quality of the remaining soil has only an impact for the potential toxicity effects into humans using the site and for ecotoxicity to freshwater organisms where contaminants leach from the soil. These impacts are considered to have a local impact localized to the site boundaries for the soil and a regional impact if considering the groundwater. Although there is a measured impact value to human toxicity and freshwater ecotoxicity, the detailed risk assessment performed in relation to the soil investigation and remediation works shows that the risk which these substances can generate is considered acceptable.

4.3 Site actuation: secondary impacts

Secondary impacts are generated from the development activities in order to reuse the area as a new urban development. The different stages considered are the following:

- Soil and groundwater investigation
- Soil and groundwater remediation
- Deconstruction and rehabilitation of existing buildings (in this case this stage does not apply since no buildings are found in the site)
- Construction of new buildings
- Construction of new infrastructures

4.3.1 Soil and groundwater investigation

A soil investigation was performed in this brownfield. Flows are mainly related to the use of machinery and transport, as detailed in Table 4.3:

Table 4.3. Sources of impacts from soil and groundwater investigations.

Input	Quantification	Amount		Information	Input selected (source)
Machines operation trial pits (diesel)	40 hours operation (1 week)	382.5	kWh	Wheeled back hole excavator	Energy, from diesel burnt machinery (ECOINVENT)
Machines operation boreholes (diesel)	80 hours operation (2 weeks)	764.9	kWh	Track mounted archway competitor 130 sampling rig	Energy, from diesel burnt machinery (ECOINVENT)
Transport (car)	1900 km	1900	km		Transport, passenger car, medium size, diesel, EURO 4 (European Light Duty Vehicle standards according to EU Directives) (ECOINVENT)

Impact assessment

Impacts are related to the functional unit (1 ha of brownfield). The impact distribution over the different impact categories during the soil and groundwater investigation stage is given in Figure 4.1.

Table 4.4. Impact values for soil and groundwater investigations (per ha).

Impact categories	Units	Total	Transport (car)	Machines operation trial pits (diesel)	Machines operation boreholes (diesel)
Climate change	kg CO2 eq	129.38	78.70	16.89	33.78
Ozone depletion	kg CFC-11 eq	9.08E-06	5.78E-06	1.10E-06	2.20E-06
Human toxicity, cancer effects	CTUh	6.42E-06	5.21E-06	4.02E-07	8.03E-07
Human toxicity, non-cancer effects	CTUh	2.54E-05	2.32E-05	7.11E-07	1.42E-06
Particulate matter	kg PM2.5 eq	0.12	0.05	0.02	0.04
Ionizing radiation HH	kBq U235 eq	9.01	6.10	0.97	1.94
Ionizing radiation E (interim)	CTUe	4.61E-05	2.79E-05	6.09E-06	1.22E-05
Photochemical ozone formation	kg NMVOC eq	0.91	0.22	0.23	0.46
Acidification	molc H+ eq	0.77	0.27	0.17	0.33
Terrestrial eutrophication	molc N eq	3.03	0.55	0.83	1.65
Freshwater eutrophication	kg P eq	0.02	0.01	0.00	0.00
Marine eutrophication	kg N eq	0.28	0.05	0.08	0.15
Freshwater ecotoxicity	CTUe	2820.45	2775.15	15.10	30.20
Land use	kg C deficit	134.27	104.47	9.93	19.87
Water resource depletion	m3 water eq	36.42	31.04	1.79	3.59
Mineral, fossil & renewable resource depletion	kg Sb eq	0.01	0.01	0.00	0.00

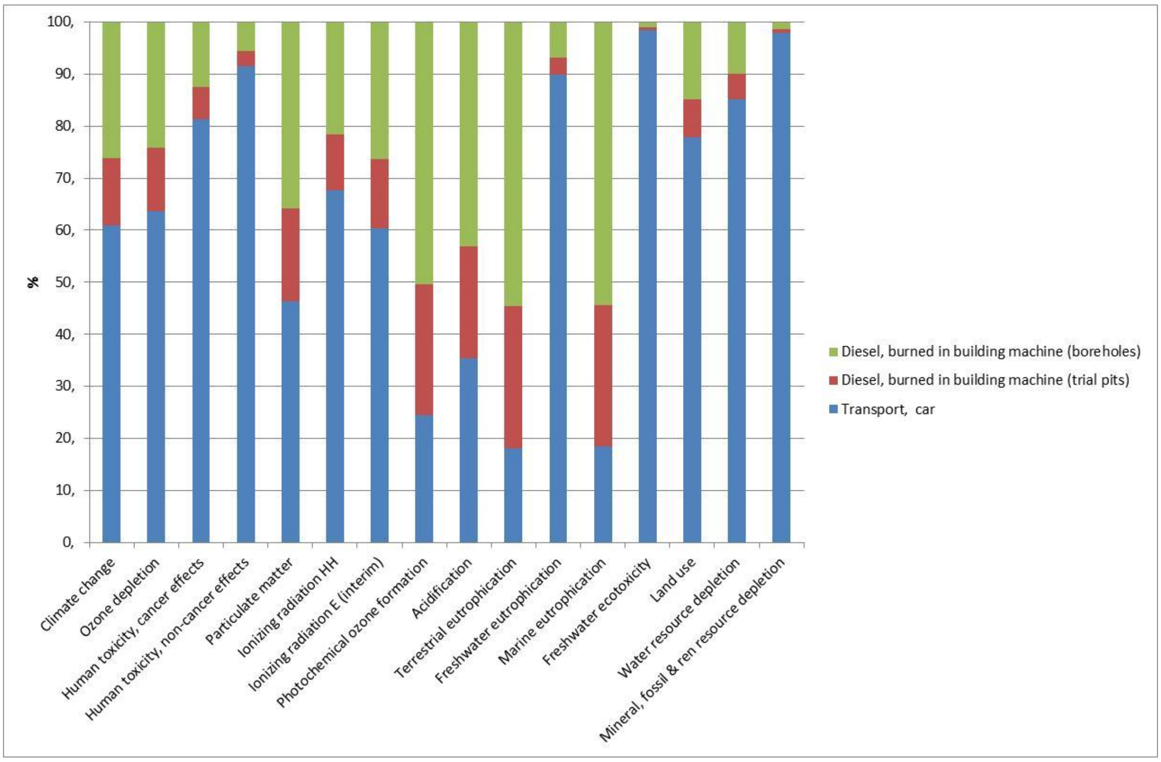

Figure 4.1. Impacts distribution for soil and groundwater investigation stage (in percentages)

The main conclusions of the impact assessment from Investigation phase are:

- The impacts are associated to the use of the machinery and vehicles.

- The use of the transportation to the site has the highest impact in most of the impact categories, whereas for the acidification, eutrophication and photochemical ozone the use of the machinery on-site has the highest impact. This may relate to the higher NOx and particulate emissions expected from the diesel engines of on-site machinery rather than those in passenger vehicles complying with Euro 4 requirements.

4.3.2 Soil and groundwater remediation

A soil remediation was performed, which consisted of the excavation and transport of debris and soil for final disposal in a licenced landfill site. For the groundwater an in-situ chemical oxidation with the application of an oxidation product directly in the excavation hole was performed combined with soil vapour extraction onsite.

Table 4.5. Sources of impacts from soil and groundwater remediation activities.

Input	Quantification	Amount		Information	Input selected (source)
Groundwater remediation					
Machine, In situ chemical oxidation (product directly applied in the excavation hole)	Machinery 3 days = 10x3= 30 hours	882,6	kWh		Electricity (UK mix production) (ECOINVENT)
Soil Vapour Extraction	Vacuum blower	54000	kWh		Electricity (UK mix production) (ECOINVENT)
	Off-gas treatment system	45000	kWh		Electricity (UK mix production) (ECOINVENT)
	Aboveground treatment structure	900	kWh		Electricity (UK mix production) (ECOINVENT)
	Data monitoring and processing	16000	kWh		Electricity (UK mix production) (ECOINVENT)

Input	Quantification	Amount		Information	Input selected (source)
Soil remediation					
Diesel, machine (Excavation)	3 weeks = 5x10x3= 150 hours	4413	kWh		Energy, from diesel burned in machinery (ECOINVENT)
Soil waste landfill (disposal with Metals, chlorinated solvents, PAHs and oils)	750 tones of	750	t	waste managed on hazardous landfill located 25 km	Hazardous waste treatment of, sanitary landfill (ECOINVENT)
Transport, car (technician)	1000 km	1000	km		Transport, passenger car, medium size, diesel, EURO 4 (ECOINVENT)
Transport, lorry (of runes and soil to landfill)	2236 km	2236	km	15 tonnes truck, 25km	Transport, freight, lorry 7.5-16 metric ton, EURO4 (ECOINVENT)

Impact assessment

Impacts are related to the functional unit (1 ha of brownfield).

The impact distribution over the different impact categories during the soil and groundwater remediation phase is given in Figure 4.2. and the impact values for soil remediation activities in ha are presented in table 4.6.

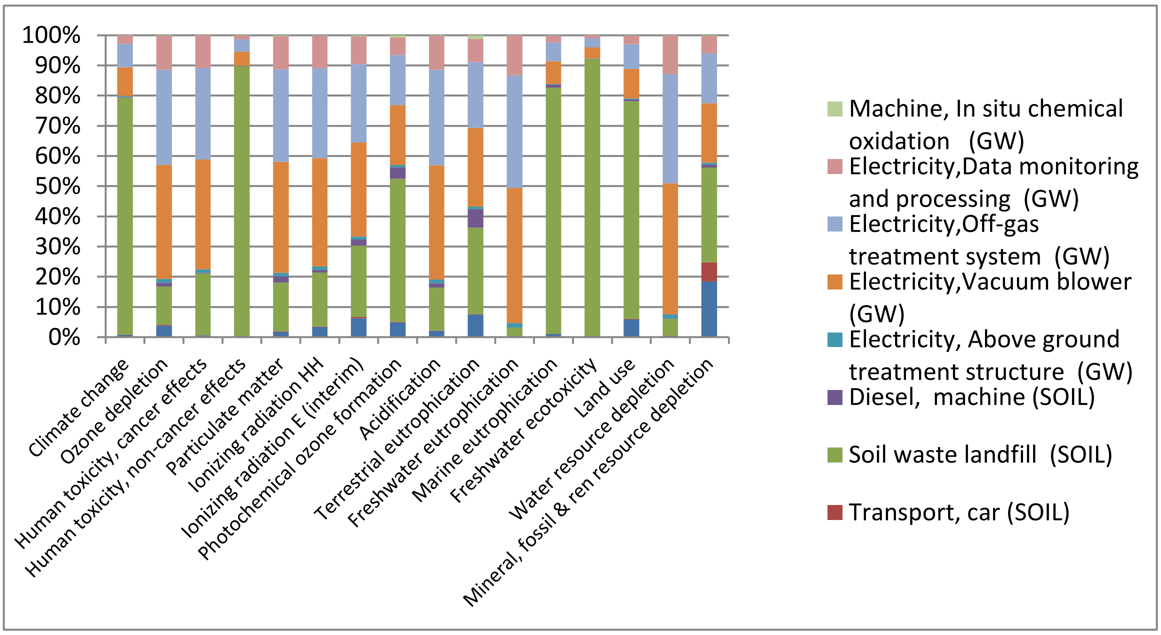

Figure 4.2. Impacts distribution for soil and groundwater remediation stage (in percentages)

Table 4.6 Impact values for soil remediation activities per ha.

Impact category	Unit	Total	Soil remediation	Groundwater remediation
Climate change	kg CO2 eq	80423	64055	16367
Ozone depletion	kg CFC-11 eq	9.94E-04	1.79E-04	8.15E-04
Human toxicity, cancer effects	CTUh	0.003	0.001	0.003
Human toxicity, non-cancer effects	CTUh	0.13	0.11	0.013
Particulate matter	kg PM2.5 eq	12.16	2.44	9.71
Ionizing radiation HH	kBq U235 eq	1310	291	1018
Ionizing radiation E (interim)	CTUe	0.004	0.001	0.002
Photochemical ozone formation	kg NMVOC eq	68.57	38.62	29.95
Acidification	molc H+ eq	137.348	24.482	112.87
Terrestrial eutrophication	molc N eq	155.05	65.80	89.26
Freshwater eutrophication	kg P eq	41.15	1.31	39.84
Marine eutrophication	kg N eq	99.51	83.20	16.31
Freshwater ecotoxicity	CTUe	4257781	3924650	333130
Land use	kg C deficit	18680	14713	3966
Water resource depletion	m3 water eq	30204	1850	28354
Mineral, fossil & ren resource depletion	kg Sb eq	0.101	0.058	0.043

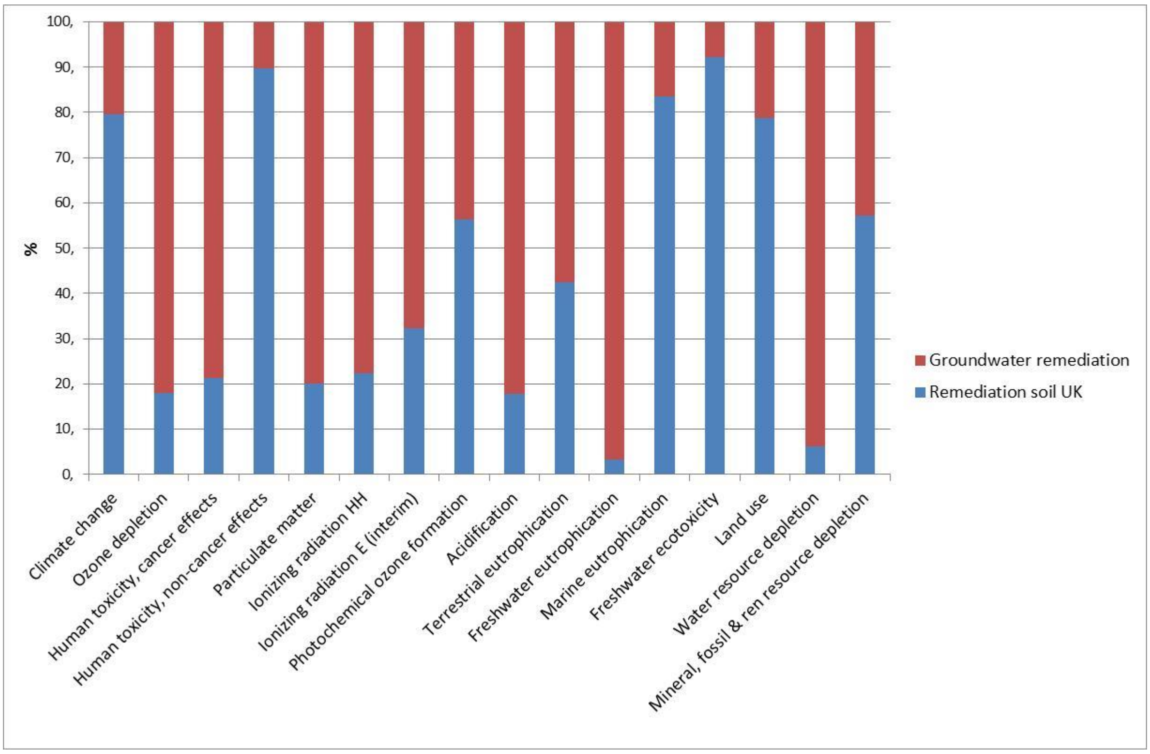

Figure 4.3 Impacts distribution for soil remediation stage (in percentage)

The main conclusions of the impact assessment from the remediation stage are:

- Groundwater remediation has the biggest impact for the impact categories Ozone depletion, cancer human toxicity, particulate matter, ionizing radiations, acidification, terrestrial and freshwater eutrophication and water resource depletion, due to the electricity consumption of the treatment plant.

- The soil remediation has the major impact for the other impact categories and especially for climate change, non-cancer human toxicity, freshwater ecotoxicity, land use and marine eutrophication with more than 80% of impact, due to the impact of the disposal of soil into the landfill.

4.3.3 Construction of new buildings

For the construction of new buildings, detailed information on typology of buildings, materials and construction solutions is still not available in the detailed construction project. For this reason a simplified approach was taken using a standard two-floor building in Europe.

At this stage the impacts on new land occupation have not been considered since the area was an open cast mine and it is not considered as a Greenfield.

Building construction activities are described in Table 4.7.

Table 4.7. Sources of impacts from construction of new buildings activities.

Input	Quantification	Amount		Information	Input selected (source)
Residential zone (Total buildings)	-	40000	m^2	200 dwellings (200 m^2, 2 floors)	Building, multi-storey construction (ECOINVENT) *(Included activities: the most important materials used and their disposal, the transportation of the parts to the building site and to the final disposal at the end of life. Also included is the requirement of electricity for construction, maintenance and demolition. Operation is not included)*

Impact assessment

Impacts are related to the functional unit (1 ha of Brownfield) and their distribution over the different categories is given in Figures 7 and 7bis.

Table 4.8. Impact values for construction of new buildings activities (per ha).

Impact category	Units	Total buildings
Climate change	kg CO2 eq	3568103.80
Ozone depletion	kg CFC-11 eq	0.32
Human toxicity, cancer effects	CTUh	1.02
Human toxicity, non-cancer effects	CTUh	17.80
Particulate matter	kg PM2.5 eq	4974.25
Ionizing radiation HH	kBq U235 eq	230266.22
Ionizing radiation E (interim)	CTUe	0.69
Photochemical ozone formation	kg NMVOC eq	18903.55
Acidification	molc H+ eq	60417.11
Terrestrial eutrophication	molc N eq	62156.32
Freshwater eutrophication	kg P eq	9561.50
Marine eutrophication	kg N eq	6910.30
Freshwater ecotoxicity	CTUe	388240050
Land use	kg C deficit	8637376
Water resource depletion	m3 water eq	4062939
Mineral, fossil & renewable resource depletion	kg Sb eq	517.44

The main conclusions of the impact assessment from the construction stage are:

- The most significant impacts are related to the management of the construction materials. The impact from their use and disposal during construction are considered, as well as the transportation of the parts to the building site and to the final disposal at the end of life (with almost 99% of the impacts). The electricity for construction, maintenance and demolition have a relatively low impact compared to the materials. Operations are included in the tertiary impacts.

- The different materials have different impacts but it is relevant to mention that copper materials have the highest impact followed by the aluminium materials (mainly due to the impact of the manufacturing process).
- It is worth mentioning that lumber/timber has the highest land use impacts due to wood harvesting.

4.3.4 Construction of new infrastructure

For the construction of infrastructure, new land occupation has not been considered. At this stage, fewer infrastructure is needed compared with Greenfields, since supporting infrastructure for electricity, gas, wastewater drainage, roads, etc. already exists in the vicinity because of the Brownfield's location in an urban area.

Uncontaminated soil backfilling for the excavated area has been considered in the assessment.

Table 4.9. Sources of impacts from construction of new infrastructures activities.

Input	Quantification	Amount		Information	Input selected (source)
Green area	19250	19250	m2		Planting soil market (ECOINVENT) Grass seed, organic, for sowing production (ECOINVENT)
Soil backfilling	Clean soil from quarry (30 km)	350	t		
	Machinery works. Total days: 2 weeks	2941.99	kWh	Digger excavator Yanman VIO 40 + compactor	Energy, from diesel burned in machinery (ECOINVENT)
	Transport (350 t x 30 km)	30x350	tkm	23 Trucks (15 tonnes) used for the transport of the clean soil to the site (30 km)	Transport truck (ECOINVENT)
Roads (Internal roads)	2km x 5 m width	2	km	Asphalt	Road construction (ECOINVENT)
Road and street (complements+ play area)	17750	17750	m2		Road construction (ECOINVENT) (Km)
Sewer grid (Wastewater pipelines)	4km	4	km		Sewer grid (ECOINVENT)
Water supply network (Drinking water pipelines)	4km	4	km		Water Supply network (ECOINVENT)

Impact assessment

Impacts are related to the functional unit (1 ha of Brownfield) and quantification of impacts has been done for the different infrastructures to be built (Table 14). Their distribution in percentages over the different categories is presented in Figure 4.4.

Table 4.10. Impact values for construction of new infrastructures activities (per ha).

Impact category	Unit	Total	Green area	Soil backfilling	Road	Road and street	Sewer grid	Water supply network
Climate change	kg CO2 eq	385305.88	37.05	441.66	2837.38	6295.43	344412.42	31281.94
Ozone depletion	kg CFC-11 eq	1.24E-02	1.94E-06	2.98E-05	3.91E-04	8.67E-04	9.45E-03	1.64E-03
Human toxicity, cancer effects	CTUh	9.18E-02	2.00E-06	1.34E-05	1.22E-04	2.72E-04	5.99E-02	3.15E-02
Human toxicity, non-cancer effects	CTUh	1.30E-01	1.51E-04	5.17E-05	4.24E-04	9.41E-04	9.20E-02	3.68E-02
Particulate matter	kg PM2.5 eq	277.31	0.03	0.27	2.43	5.39	240.81	28.38
Ionizing radiation HH	kBq U235 eq	20743.43	2.58	32.20	920.06	2041.38	15592.48	2154.73
Ionizing radiation E (interim)	CTUe	0.07	0.00	0.00	0.00	0.01	0.05	0.01
Photochemical ozone formation	kg NMVOC eq	1584.87	0.32	3.66	35.47	78.70	1304.13	162.59
Acidification	molc H+ eq	1920.65	0.63	2.90	22.42	49.73	1649.80	195.17
Terrestrial eutrophication	molc N eq	4818.35	2.57	12.85	79.98	177.45	4060.06	485.43
Freshwater eutrophication	kg P eq	74.29	0.01	0.03	0.41	0.91	64.18	8.75
Marine eutrophication	kg N eq	442.21	0.20	1.17	7.29	16.18	370.45	46.92
Freshwater ecotoxicity	CTUe	5409845	315.06	1434.25	45359.22	100640.76	2902446	2359649
Land use	kg C deficit	549694.18	-7868.86	682.78	38755.27	85988.25	404792.94	27343.79
Water resource depletion	m3 water eq	212857.10	16.06	85.08	3270.13	7255.59	186502.19	15728.05
Mineral, fossil & ren resource depletion	kg Sb eq	41.44	0.01	0.01	0.15	0.34	14.02	26.91

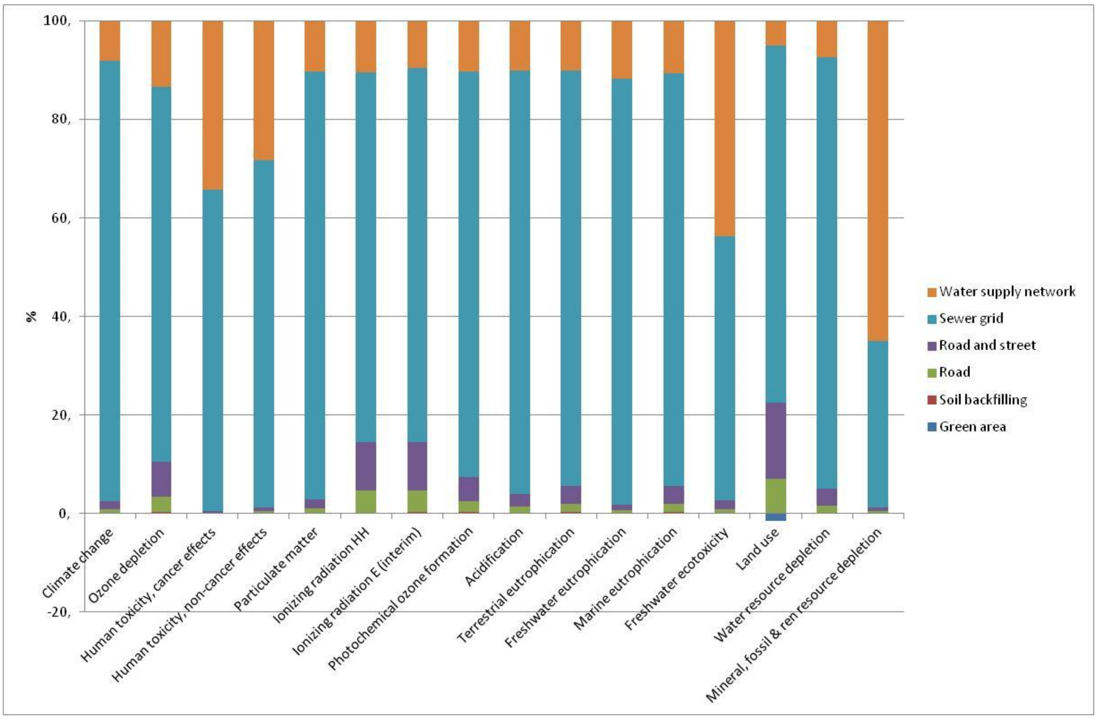

Figure 4.3. Impacts distribution for infrastructure construction stage (in percentage)

The main conclusions of the impact assessment from the construction of infrastructures stage are:

- The highest overall impacts are distributed for the installation of water supply and the wastewater and storm water sewage system.
- The development of green areas has a positive impact in land use because there is an increase of soil organic matter and thus an apportionment of carbon reservoir to the system. Note that negative values imply net environmental benefits.

4.4 Site operation: Tertiary impacts

The operation of the redeveloped Brownfield can be considered the stage of use of the new buildings and infrastructure.

End-of-life of the site has not been included as a separate stage, but the impact of demolition of new buildings (at their end-of-life) has been considered in the construction stage.

Regarding the use of the redeveloped brownfield, the operations considered are:

- Building use: energy and water consumption, waste production, wastewater production.
- Green areas: water consumption.
- Mobility of users.

The lifespan is a key hypothesis for the LCA Brownfield/Greenfield system, since it has a high repercussion in the final results. For this study the use duration has been defined as 20 years.

The inventory data and impact assessment results for the scenario of 20 years are detailed in Table 4.11.

Table 4.11. Sources of impacts from site operation activities.

Input	Quantification.	Amount	Information	Input selected (source)
Mobility			1200 trips/day	
Car	55188000	km	42%	Transport, passenger car(ECOINVENT)
Transport public	49932000	km	38%	Transport, passenger bus/train (ECOINVENT)
Bike/walking	26280000	km	20%	
Water building	1788	m3	149 l/day ·person	Tap water (ECOINVENT)
Waste generation	6000	t	500 kg/year/person	Waste treatment (ECOINVENT)
biodegradable	2460	t	41% biodegradable	
paper	1080	t	18% paper	
glass	420	t	7% glass	
plastic	420	t	7% plastic	
metal	180	t	3% metal	
other	1440	t	24% other	
Energy building - electricity	16800000	kWh	4200 kWh/home year	Electricity UK country mix (Ecoinvent)
Energy building - Natural gas	62000000	kWh	15500 kWh/home year	Heat, natural gas (ECOINVENT)
Wastewater building	1440	m3	120l/day ·person	
Water green area, facilities	193358	m3	9667,90 m3/y	Tap water (ECOINVENT)

Impact assessment (20 years)

Impacts are related to the functional unit (1 ha of Brownfield) and their distribution over the different categories is given in Figure 4.5 Table 16 includes the quantification of impacts for the different aspects assessed during the use of the site.

Table 4.12 Impact values for site operation activities per ha over 20 years.

			Input						
Impact category	**Unit**	Total	Mobility	Water building	Waste generation	Electricity	Heat, natural gas	Wastewater	Water, green area
Climate change	kg CO2 eq	6279800	2942144	82.77	550338.64	1046197	1740909	128.26	8950.90
Ozone depletion	kg CFC-11 eq	3.65E-01	2.07E-01	6.35E-06	1.54E-02	1.35E-01	7.53E-03	5.13E-06	6.87E-04
Human toxicity, cancer effects	CTUh	2.24E-01	1.62E-01	1.01E-05	2.56E-02	2.62E-02	1.02E-02	2.68E-05	1.10E-03
Human toxicity, non-cancer effects	CTUh	1.19E+00	7.04E-01	2.79E-05	3.13E-01	1.22E-01	5.07E-02	3.26E-04	3.02E-03
Particulate matter	kg PM2.5 eq	2462.38	1764.54	0.05	225.01	423.98	48.70	0.11	4.88
Ionizing radiation HH	kBq U235 eq	868775.94	258335	32.40	43850.09	527909.90	38635.41	12.22	3504.06
Ionizing radiation E (interim)	CTUe	2.36	1.08	5.71E-05	1.09E-01	1.11E+00	6.47E-02	3.03E-05	6.18E-03
Photochemical ozone formation	kg NMVOC eq	16513.96	11546.97	0.24	1182.29	3087.88	696.02	0.56	25.86
Acidification	molc H+ eq	22775.30	12910.05	0.47	2129.16	6927.61	806.79	1.22	50.81
Terrestrial eutrophication	molc N eq	51690.49	33357.82	0.82	4984.42	10799.36	2545.22	2.84	88.75
Freshwater eutrophication	kg P eq	870.92	517.49	0.05	98.39	190.28	64.51	0.21	4.93
Marine eutrophication	kg N eq	5243.31	3087.96	0.08	887.62	1019.31	244.46	3.87	9.00
Freshwater ecotoxicity	CTUe	103358600	74202170	1296.93	24612366	3414361	1126126	2278.32	140253.11
Land use	kg C deficit	5303180	3711777	359.88	879435.76	666749.19	44589.34	269.08	38918.13
Water resource depletion	m3 water eq	11662365	1336027	244.41	310379.34	9773060	242536.26	118.15	26431.32
Mineral, fossil & ren resource depletion	kg Sb eq	361.85	336.03	6.04E-03	7.28	5.93	12.61	3.45E-03	0.65

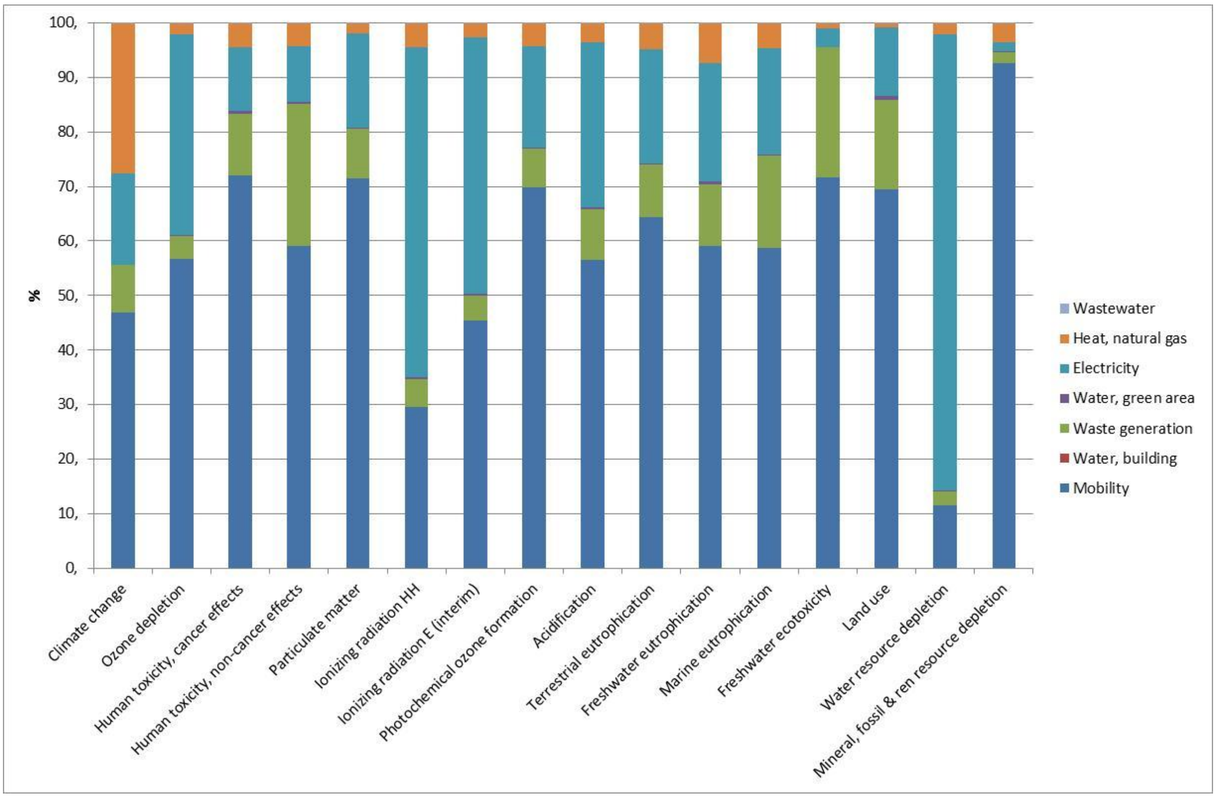

Figure 4.5. Impacts distribution for site operation (in percentage)

The main conclusions of the impact assessment from the use of the redeveloped site are:

- The highest global impact is related to the mobility of the people living in the site and using the site, with more than 50% of the impact for the categories Ozone depletion, human cancer and non-cancer toxicity, particulate matter, photochemical ozone formation, acidification, terrestrial, freshwater and marine eutrophication, freshwater ecotoxicity, land use and fossil resource depletion.

- The second major global impact is for the energy consumption which is relevant for ionizing radiations and water resource depletion.

- Natural gas heating has a relevant impact in climate change (30%).

- Waste generated has relevant impacts especially in toxicity categories.

4.5 Life cycle impacts across the brownfield system

A general environmental profile can be obtained for the brownfield considering the different life stages and a scenario for 20 years of use duration.

Table 4.13. Summary of impact values comparing the different life stages for an operation of the site during 20 years.

			Inputs					
			Primary	Secondary				Tertiary
Impact category	**Unit**	Total	in-situ contamination	Soil analysis	Soil and GW remediation	Construc. Infrastructures	Construction buildings	Use (20years)
Climate change	kg CO2 eq	10322714	0	129.38	80423.72	385305.88	3568103	6288751
Ozone depletion	kg CFC-11 eq	0.70	0	9.08E-06	9.94E-04	1.24E-02	3.24E-01	0.37
Human toxicity, cancer effects	CTUh	1.37	0.02	6.42E-06	3.42E-03	9.18E-02	1.02E+00	0.23
Human toxicity, non-cancer effects	CTUh	22.46	3.20	2.54E-05	1.28E-01	1.30E-01	17.80	1.19
Particulate matter	kg PM2.5 eq	7731.09	0	1.18E-01	12.16	277.31	4974.25	2467.26
Ionizing radiation HH	kBq U235 eq	1124608	0	9.01	1310.10	20743.43	230266.22	872280.00
Ionizing radiation E (interim)	CTUe	3.13	0	4.61E-05	3.55E-03	6.72E-02	6.93E-01	2.37
Photochemical ozone formation	kg NMVOC eq	37097.72	0	0.91	68.57	1584.87	18903.55	16539.82
Acidification	molc H+ eq	85302.00	0	0.77	137.35	1920.65	60417.11	22826.11
Terrestrial eutrophication	molc N eq	118911.98	0	3.03	155.05	4818.35	62156.32	51779.23
Freshwater eutrophication	kg P eq	10552.80	0	0.02	41.15	74.29	9561.50	875.85
Marine eutrophication	kg N eq	12704.61	0	0.28	99.51	442.21	6910.30	5252.31
Freshwater ecotoxicity	CTUe	520217120	18807774	2820.45	4257781	5409845	388240050	103498850
Land use	kg C deficit	14547984.12	0	134.27	18680.17	549694.18	8637376	5342098.70
Water resource depletion	m3 water eq	15994834	0	36.42	30204.80	212857.10	4062939	11688797
Mineral, fossil & ren resource depletion	kg Sb eq	921.49	0	1.26E-02	1.01E-01	41.44	517.44	362.51

Main impacts are generated during the use stage and the construction of buildings. Construction of infrastructures is the third more impacting stage. In-situ contamination has relevant contribution in toxicity categories. Soil investigation and soil remediation stages are the life stages with lower values.

It is of note that the contribution of the use stage would be expected to be even greater if the assessment had assumed the lifespan of the development to be 50 years, for example, rather than 20 years. The standard lifetime of a mortgage in the UK is 25 years and modern housing stock from the 1960s onwards shows little signs of degradation.

Table 4.14. Summary of percentage contributions comparing the three different life stages for an operation of the site during 20 years.

Impact category	In-situ contamination	Soil analysis	Soil and GW remediation	Construc. Infrastructures	Construction buildings	Use (20years)
Climate change	0%	0.001%	0.78%	4%	35%	61%
Ozone depletion	0%	0.001%	0.14%	2%	46%	52%
Human toxicity, cancer effects	2%	0.000%	0.25%	7%	75%	16%
Human toxicity, non-cancer effects	14%	0.000%	0.57%	1%	79%	5%
Particulate matter	0%	0.002%	0.16%	4%	64%	32%
Ionizing radiation HH	0%	0.001%	0.12%	2%	20%	78%
Ionizing radiation E (interim)	0%	0.001%	0.11%	2%	22%	76%
Photochemical ozone formation	0%	0.002%	0.18%	4%	51%	45%
Acidification	0%	0.001%	0.16%	2%	71%	27%
Terrestrial eutrophication	0%	0.003%	0.13%	4%	52%	44%
Freshwater eutrophication	0%	0.000%	0.39%	1%	91%	8%
Marine eutrophication	0%	0.002%	0.78%	3%	54%	41%
Freshwater ecotoxicity	4%	0.001%	0.82%	1%	75%	20%
Land use	0%	0.001%	0.13%	4%	59%	37%
Water resource depletion	0%	0.000%	0.19%	1%	25%	73%
Mineral, fossil & ren resource depletion	0%	0.001%	0.01%	4%	56%	39%

Note: The contributions for each stage are detailed by percentage. The stage with the highest contribution is highlighted in red; while the rest of the stages with relevant contributions (≥5%) are marked in orange.

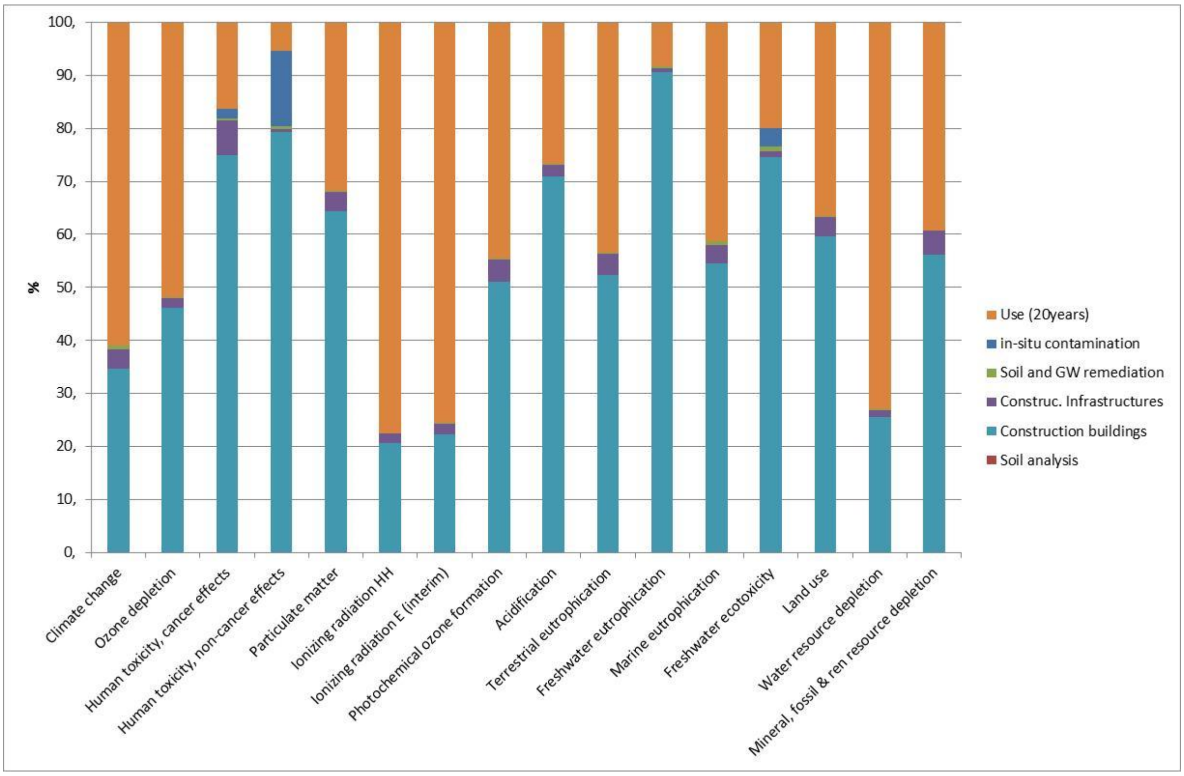

Figure 4.6 Impacts distribution by category impacts

Contribution of each life stage to global warming (20-year scenario)

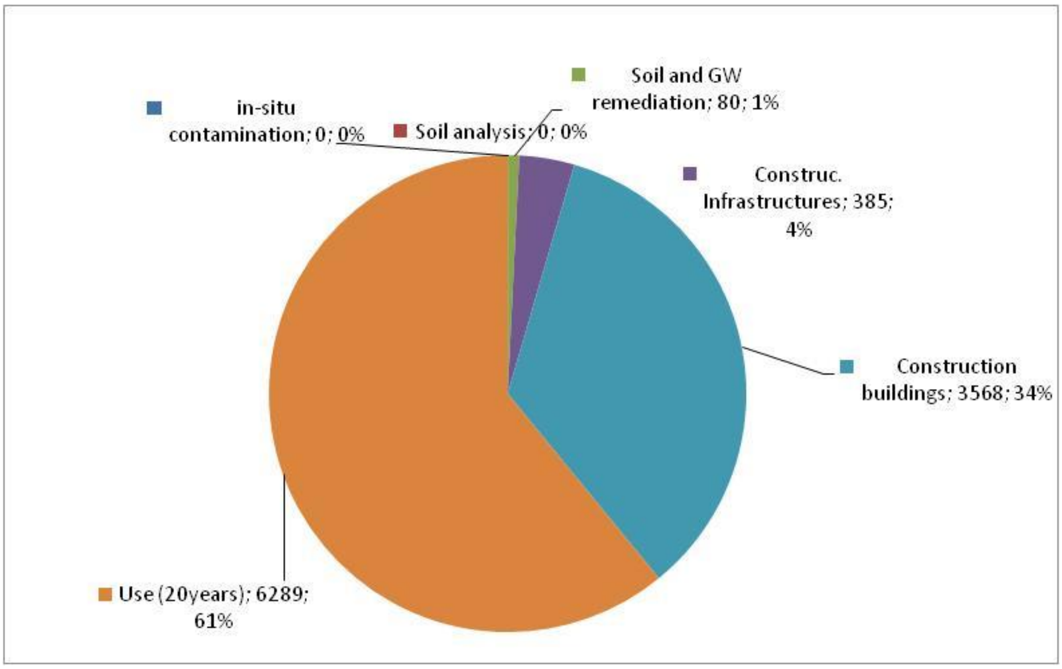

Figure 4.7 Impacts distribution for climate change category (20-year scenario)

If not considering the tertiary impacts from the use of the site, the construction of buildings counts for more than 90% of all impact categories and the third activity of impact importance would be for the construction of infrastructures, but far away from the construction of buildings. The in-situ contamination has special contributions to human on-cancer toxicity but very low if compared with building construction. The stages of soil remediation and soil investigation are less relevant with lower impacts.

5 Case study 2: brownfield in Terrassa (Catalonia, Spain)

5.1 General description

In the first instance, the LCA method has been applied to a site located in the city of Terrassa (Catalonia, Spain). The main information is summarised below.

Location: In the city centre of Terrassa (20 km north of Barcelona), Spain (former Sala i Badrinas).

Surface: 30,692 m^2 (3.07 ha)

Uses: Textile factory (wool) from 1870 until the early 1980s. Later the industrial units were divided and occupied by small industrial activities and workshops: dyes, mechanisation of metals, metallic carpentry, car repair shop, chemical products, etc., all of which ceased by 2005 approximately.

Currently the site is not in use. Some buildings are occupied by squatters.

Existing buildings: Approximately 10 industrial units of different sizes.

Constructed area: 22,638 m^2

Status of existing site: Moderate condition

Existing infrastructures: One Underground Storage Tank (UST) used for fuel storage from the previous industrial activity. It was emptied and cleaned in April 2014. Original storm water infrastructures still exist, and the site is connected for water supply, and access to the natural gas and electricity grids.

Brownfield development project: Of the total area, approx. 5,600 m^2 is destined for educational facilities (preschool and primary); the rest will be used for residential purposes (423 residential homes with 5 floors and basement), economic activities (1,015 m^2) and a pneumatic waste collection centre.

Some of the buildings will be kept (4 buildings and a chimney that will remain as industrial heritage, which occupy 7,756 m^2).

In the following sections the quantification of the different impacts following the three main stages of impact (primary, secondary, tertiary) and using the impact categories as defined in the LCA methodology is presented. At the end of this chapter an assessment of the different impact categories across all stages of impact considered, is presented.

5.2 Site conditions: primary impacts.

As explained in Chapter 3, primary impacts refer to the site's degraded physical and chemical state. In this case study, soil contamination was present, but groundwater contamination was absent. The maximum concentrations of each pollutant within the approximately 1000 tonnes of soil that will remain on-site after remediation have been taken account of in the assessment. These pollutants are above regulatory reference values for multifunctional use, but below the remediation target values (see chapter 3 of Methodology). This means that they do not pose a risk to the future use of the site, but have been considered in the assessment due to exceeding regulatory soil reference values.

Table 5.1. Concentrations of substances remaining on-site.

Name	Concentration / Quantity (maximum concentrations)
As	54 mg/kg
Pb	440 mg/kg
Benzo(a)pyrene	32 mg/kg
Naphthalene	8.4 mg/kg
Pyrene	83 mg/kg
Benzo(a)anthracene	22 mg/kg
Chrysene	27 mg/kg
Benzo(b)fluoranthene	33 mg/kg
Dibenzo(ah)anthracene	4.8 mg/kg
Indeno(123cd)pyrene	44 mg/kg
TPHs (EC10-EC40)	19.00 mg/kg

TPH EC (Total Petroleum Hydrocarbon) refers to the Equivalent Carbon numbers as developed by the TPH Criteria Working Group

Impact assessment

Considering the original site conditions, in-situ pollutants have contributed to toxicity categories: human toxicity and ecotoxicity. The impacts described in Table 5.2 are related to the functional unit (1 ha of brownfield).

Table 5.2. Impact values for soil substances remaining on-site (per ha).

Impact category	Units	Impact value
Climate change	kg CO2 eq	0.00
Ozone depletion	kg CFC-11 eq	0.00
Human toxicity, cancer effects	CTUh	3.46E-03
Human toxicity, non-cancer effects	CTUh	2.65E-01
Particulate matter	kg PM2.5 eq	0.00
Ionizing radiation HH	kBq U235 eq	0.00
Ionizing radiation E (interim)	CTUe	0.00
Photochemical ozone formation	kg NMVOC eq	0.00
Acidification	molc H+ eq	0.00
Terrestrial eutrophication	molc N eq	0.00

Impact category	Units	Impact value
Freshwater eutrophication	kg P eq	0.00
Marine eutrophication	kg N eq	0.00
Freshwater ecotoxicity	CTUe	4.24E+05
Land use	kg C deficit	0.00
Water resource depletion	m3 water eq	0.00
Mineral, fossil & ren resource depletion	kg Sb eq	0.00

The quality of the remaining soil only has an impact related to potential toxicity effects for site users and ecotoxicity to freshwater organisms when soil leaching occurs. These impacts are considered to be local, i.e. confined to the site boundaries. Although the impact to human toxicity and freshwater ecotoxicity is expressed as a measured value, the detailed risk assessment performed in relation to the soil investigation and remediation activities shows that the risk generated by these substances is considered acceptable.

5.3 Site actuation: secondary impacts

Secondary impacts are those resulting from the development activities themselves including:

- Soil and groundwater investigation
- Soil remediation
- Deconstruction
- Construction of new buildings
- Construction of new infrastructures

Contrary to the greenfield case study, land occupation is not relevant here, as the site is already occupied by the industrial installations, even though no longer in use.

5.3.1 Soil and groundwater investigation

Two surveys were performed in relation to the site:

- A soil and groundwater investigation performed in September 2009, with 22 boreholes drilled and one monitoring well installed (4 days of work considered).
- A soil survey performed in July 2012, with 29 boreholes drilled (7 days of work considered).

Flows are mainly related to the use of machinery and transport during both investigations, as detailed in Table 5.3.

Table 5.3. Sources of impacts from soil and groundwater investigations.

Input	Quantification	Amount	Information	Input selected (source)

Input	Quantification	Amount		Information	Input selected (source)
Transport (car)	712+1246 km	1958	km	Renault Kangoo	Transport, passenger car, medium size, diesel, EURO 4 (ECOINVENT)
Machines operation (diesel) e	32+48 hours operation	764.9	kWh	ML-76-A drilling rig. Power 13 CV	Energy, from diesel-burning drilling machinery (ECOINVENT)

Impact assessment

Impacts are related to the functional unit (1 ha of brownfield). The impact values for activity inputs per impact category are presented in Table 5.4; distribution of the environmental impacts of the soil and groundwater investigations across the different impact categories is given in Figure 5.1.

Table 5.4. Impact values for soil and groundwater investigations (per ha).

Impact categories	Units	Total	Transport (car)	Machines operation (diesel)
Climate change	kg CO2 eq	288.34	203.54	84.79
Ozone depletion	kg CFC-11 eq	2.05E-05	1.49E-05	5.52E-06
Human toxicity, cancer effects	CTUh	1.55E-05	1.35E-05	2.02E-06
Human toxicity, non-cancer effects	CTUh	6.36E-05	6.00E-05	3.57E-06
Particulate matter	kg PM2.5 eq	0.25	0.14	0.11
Ionizing radiation HH	kBq U235 eq	20.65	15.78	4.88
Ionizing radiation E (interim)	CTUe	0.00	0.00	0.00
Photochemical ozone formation	kg NMVOC eq	1.72	0.57	1.15
Acidification	molc H+ eq	1.55	0.71	0.84
Terrestrial eutrophication	molc N eq	5.56	1.42	4.15
Freshwater eutrophication	kg P eq	0.04	0.04	0.00
Marine eutrophication	kg N eq	0.51	0.13	0.38
Freshwater ecotoxicity	CTUe	7252.97	7177.18	75.80
Land use	kg C deficit	320.04	270.18	49.86
Water resource depletion	m3 water eq	89.28	80.28	9.01
Mineral, fossil & renewable resource depletion	kg Sb eq	3.23E-02	3.19E-02	4.35E-04

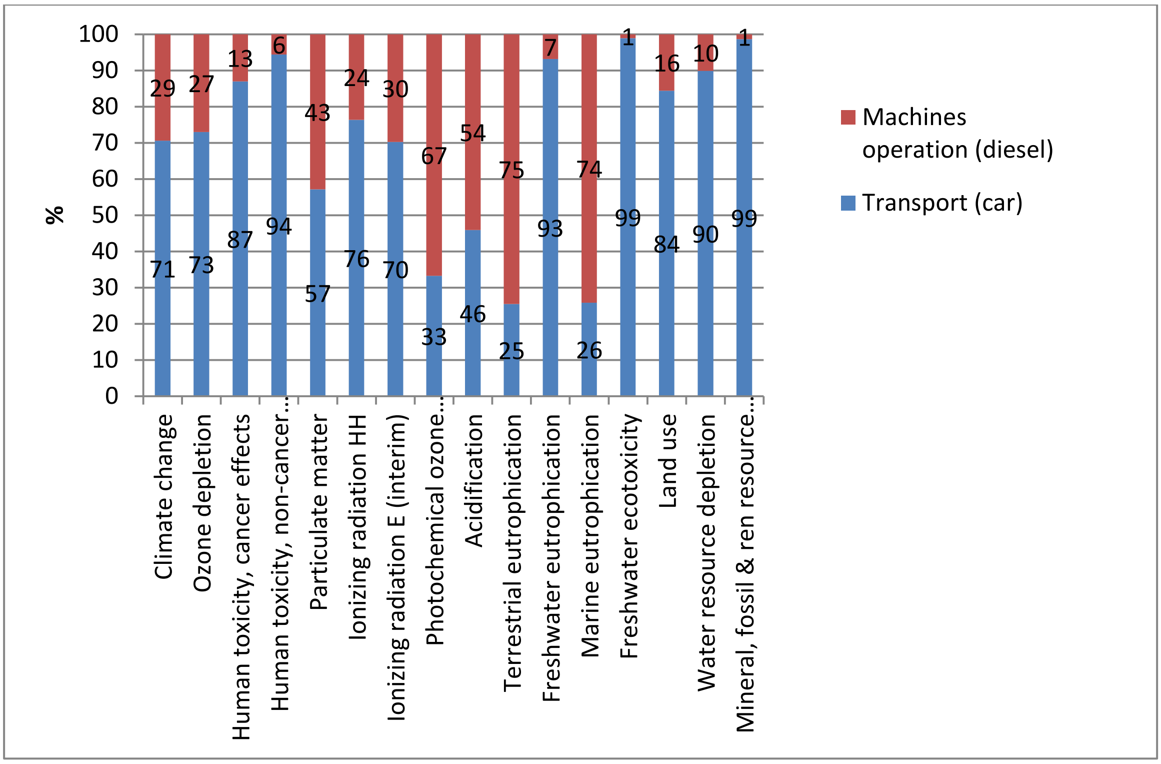

Figure 5.1. Impact distribution across impact categories for the soil and groundwater investigation stage (in percentage).

The main conclusions relating to the soil and groundwater investigation phase are:

- The impacts are primarily associated with the use of machinery (on site) and vehicles (transport to and from the site).
- Transportation to the site has the highest contribution to all impact categories except for the acidification, eutrophication and photochemical ozone formation categories, where the main contributor is the use of the machinery on-site. The latter may relate to higher NOx and particulate emissions expected from diesel engines of the on-site machinery compared to those in passenger vehicles complying with Euro 4 requirements.

5.3.2 Soil remediation

Limited soil remediation occurred at the site. This consisted of the excavation, transport and reuse or disposal of soil and debris. Some materials were disposed of to a licenced landfill, while the remaining part was reused in the construction of a new harbour.

The environmental impacts of all activities presented in Table 5.5 have been assessed.

Table 5.5. Sources of impacts from soil remediation activities.

Input	Quantification	Amount	Information	Input selected (source)

Input	Quantification	Amount		Information	Input selected (source)
Waste transport (lorry) of debris and soil to landfill	2236 km (15 tonnes truck), (472,34 t x 35 km)	2236	km	4 Trucks (15 tons)	Transport, freight, lorry 7.5-16 metric ton, EURO4 (ECOINVENT)
Debris disposal	104.16 tonnes of debris	104.16	t	104.16 tonnes of debris managed on Barcelona Harbour (used for filling)	Not considered as waste because it is used as filling material (only transport)
Transport (car)	1068 km	1068	km	Renault Kangoo	Transport, passenger car, medium size, diesel, EURO 4 (ECOINVENT)
Landfill soil (disposal)	368.18 tonnes of soil	368.18	t	368.18 tonnes of soil managed on Gavà landfill (managed as inert waste*)	Inert waste* treatment of sanitary landfill (ECOINVENT)
Machinery operation (Excavation)	6 days = 6x10= 60 hours	3278.9	kWh	Digger excavator Yanman VIO 40 (31-40CV) and Bobcat S130 (34.3CV)	Energy, from diesel burnt in machinery (ECOINVENT)

*Inert waste: refers to the waste classification before disposal. In Spain the wastes are classified as inert, non-hazardous and hazardous. Inert waste typically requires lower disposal fees as it is neither chemically or biologically reactive and will not decompose.

Impact assessment

Impacts are related to the functional unit (1 ha of brownfield).

All flows related to the inputs of the previous inventory tables have been converted into the associated impacts. The contribution of each activity during the soil remediation phase to the various impact categories is presented in Table 5.6 and the percentage contributions are given in Figure 5.2.

Table 5.6. Impact values for soil remediation activities (per ha).

Impact category	Unit	Total	Waste Transport (lorry)	Transport (car)	Landfill soil	Machinery operation
Climate change	kg CO2 eq	3259.66	1407.69	111.02	1377.52	363.43
Ozone depletion	kg CFC-11 eq	2.54E-04	9.65E-05	8.15E-06	1.25E-04	2.37E-05
Human toxicity, cancer effects	CTUh	4.72E-04	4.64E-05	7.35E-06	4.10E-04	8.64E-06
Human toxicity, non-cancer effects	CTUh	2.25E-02	2.09E-04	3.28E-05	2.22E-02	1.53E-05
Particulate matter	kg PM2.5 eq	2.44E+00	5.05E-01	7.68E-02	1.41E+00	4.53E-01
Ionizing radiation HH	kBq U235 eq	288.76	111.67	8.61	147.59	20.90
Ionizing radiation E (interim)	CTUe	1.47E-03	5.62E-04	3.93E-05	7.39E-04	1.31E-04
Photochemical ozone	kg NMVOC eq	26.34	8.54	0.31	12.55	4.93

Impact category	Unit	Total	Waste Transport (lorry)	Transport (car)	Landfill soil	Machinery operation
formation						
Acidification	molc H+ eq	22.97	7.30	0.39	11.69	3.59
Terrestrial eutrophication	molc N eq	90.07	29.36	0.77	42.16	17.77
Freshwater eutrophication	kg P eq	4.97E-01	1.04E-01	2.05E-02	3.61E-01	1.18E-02
Marine eutrophication	kg N eq	8.24	2.68	0.07	3.86	1.62
Freshwater ecotoxicity	CTUe	491939.40	5952.27	3914.82	481747.43	324.87
Land use	kg C deficit	19366.14	2738.27	147.37	16266.78	213.71
Water resource depletion	m3 water eq	1143.54	321.85	43.79	739.29	38.61
Mineral, fossil & ren resource depletion	kg Sb eq	9.88E-02	4.69E-02	1.74E-02	3.27E-02	1.87E-03

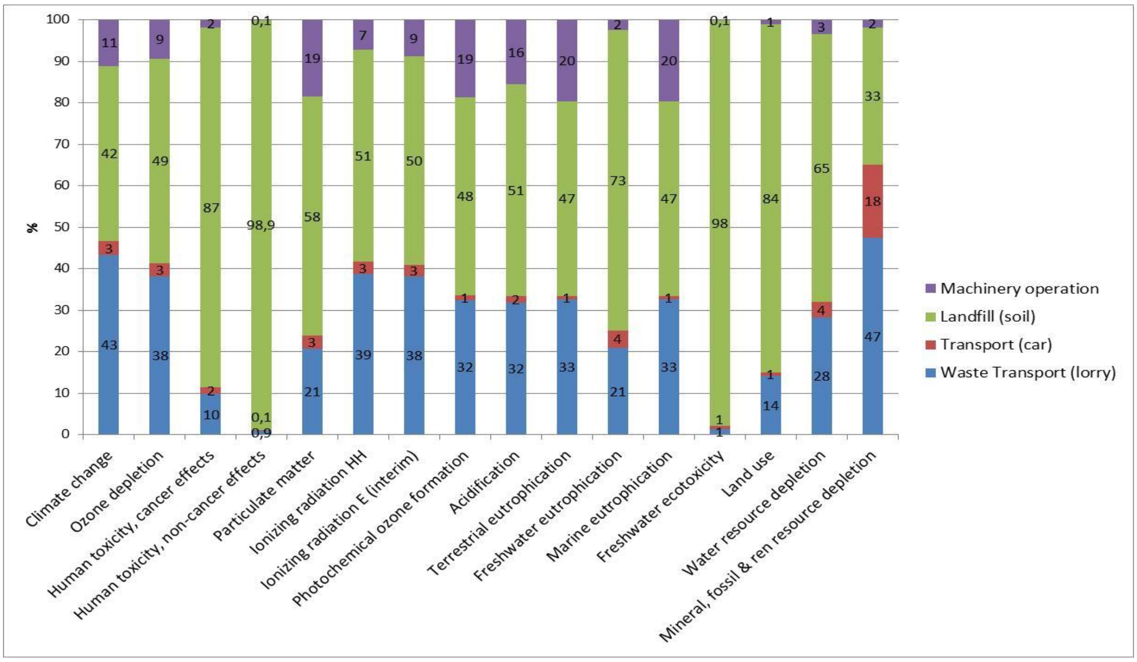

Figure 5.2. Impacts distribution for soil remediation stage (in percentage)

The main conclusions relating to the remediation stage are:

- The highest contribution to almost all impact categories is from the treatment of the soil in the landfill site, with relatively high impacts relating to human and freshwater toxicity, eutrophication and also to land use. These impacts are primarily regional in nature with only limited on-site effects.

- The transport of soils to the landfill makes the second largest contribution, including significant impacts to climate change and resource depletion due to the use of fuel.

5.3.3 Deconstruction (demolition, decommissioning, material recovery)

According to available information, only 46% (6,687 m^2) of the total built area of the site (14,443 m^2) was subject to deconstruction. The remaining 54% (7,756 m^2) did not require such activities.

The deconstruction activities considered in the assessment include use of deconstruction machinery (machine consumption and air emissions), direct particulate matter emissions from deconstruction, transport to dismantling facilities and final disposal of each waste material. These aspects were considered for each type of waste material, and environmental impacts for each type of waste material generated were thus calculated (see Table 5.7). The quantities of each waste type were estimated based on the surface area of the various buildings.

Demolition of the school area has already occurred and real quantitative data on the waste generated is available. For the rest of the site, estimations were made according to the surface area occupied by each material and the density of materials.

Table 5.7. Sources of impacts from deconstruction activities.

Input	Quantification	Amount		Information	Input selected (source)
Machinery Energy	hours: 30 daysx8=240h	7060.8	kWh	Heavy machinery. Considered 40 CV	Diesel, burnt in building machine (ECOINVENT)
Waste Aluminium	For the rest of the area	79.57	tonnes	Considering 0,2 m of depth. density = 961 kg /m3	Waste aluminium treatment of, sanitary landfill (ECOINVENT)
Stone waste	From the school area	1014.61	tonnes	Inert waste	Inert waste | treatment of, sanitary landfill (ECOINVENT)
Brick, tiles and ceramics debris	From school area (2452,5t) and rest of the area(725.29t)	3177.79	Tonnes	For the rest of area: Considering brick 0,3 m of depth. Brick density = 1922 Considering tile 0,2 m of depth. density = 1540	Waste brick| treatment of, collection for final disposal (ECOINVENT)*(energy for dismantling, particulate matter emissions from dismantling and handling, transport to dismantling facilities, final disposal of waste material)*
Waste Glass	From school area (3.43t) and rest of the area (96.71t)	100.14	tonnes	Considering 0,05 m of depth. Glass density = 2579 (http://www.simetric.co.uk/si_materials.htm)	Waste glass sheet treatment of, collection for final (ECOINVENT)disposal *(energy for dismantling, particulate matter emissions from dismantling and handling, transport to dismantling facilities, final disposal of waste material)*

Input	Quantification	Amount		Information	Input selected (source)
Waste Concrete	From the school area	1390.49	tonnes	Inert waste	Waste concrete, not reinforced {CH}| treatment of, collection for final disposal *(energy for dismantling, particulate matter emissions from dismantling and handling, transport to dismantling facilities, final disposal of waste material)*
Waste Metal	From the school area	32.49	tonnes	Non-hazardous waste	Waste bulk iron, excluding reinforcement treatment of, sorting plant (ECOINVENT)
Waste Wood	From the school area	101.42	tonnes	Non-hazardous waste	Waste building wood, chrome preserved treatment of, municipal incineration (ECOINVENT)
Waste Plastic	From the school area	3.57	tonnes	Non-hazardous waste	Waste polyethylene/polypropylene product treatment of, collection for final disposal (ECOINVENT) *(energy for dismantling, particulate matter emissions from dismantling and handling, transport to dismantling facilities, final disposal of waste material)*
Waste Bitumen	From the school area	397.02	tonnes	Hazardous waste	Waste bitumen market for (ECOINVENT)
Waste cement	From the school area	35.59	tonnes	Hazardous waste	Waste cement-fibre slab treatment of, collection for final disposal (ECOINVENT) *(energy for dismantling, particulate matter emissions from dismantling and handling, transport to dismantling facilities, final disposal of waste material)*

Impact assessment

Impacts are related to the functional unit (1 ha of brownfield).

The contribution of each activity to each impact category is presented in Table 5.8 and the percentage contributions are given in Figure 5.3.

Table 5.8. Impact values for deconstruction activities (per ha).

Impact category	Total	Waste alumni	Stone waste	Waste brick, tiles, cer.	Waste glass	Waste concrete	Waste metals	Waste wood	Waste plastics	Waste bitumen	Waste cement	Machinery Energy
Climate change	43308.92	232.04	3147.49	13370.53	310.65	6184.41	19.68	368.24	3534.28	15177.25	181.74	782.62
Ozone depletion	2.33E-03	1.14E-05	3.03E-04	1.18E-03	2.99E-05	5.37E-04	7.88E-07	2.40E-05	5.19E-06	1.71E-04	1.47E-05	5.10E-05
Human toxicity, cancer effects	5.12E-02	1.08E-05	1.20E-04	4.58E-04	1.18E-05	2.09E-04	1.46E-06	4.97E-02	2.69E-05	6.22E-04	4.10E-05	1.86E-05
Human toxicity, non-cancer effects	9.83E-03	2.33E-04	4.10E-04	1.43E-03	4.05E-05	6.41E-04	4.09E-06	6.14E-04	1.94E-04	4.67E-03	1.55E-03	3.29E-05
Particulate	1.09E+02	2.25E-01	2.66E+00	7.00E+01	2.63E-01	3.10E+01	1.98E-02	9.75E-01	6.33E-02	2.28E+00	9.86E-01	9.75E-01

Impact category	Total	Waste alumni	Stone waste	Waste brick, tiles, cer.	Waste glass	Waste concrete	Waste metals	Waste wood	Waste plastics	Waste bitumen	Waste cement	Machinery Energy
matter												
Ionizing radiation HH	2399.14	29.70	319.05	1201.25	31.49	544.83	4.48	18.08	5.60	223.04	-23.38	45.00
Ionizing radiation E (interim)	1.32E-02	8.71E-05	1.73E-03	6.70E-03	1.71E-04	3.05E-03	9.65E-06	6.35E-05	2.31E-05	1.04E-03	5.16E-06	2.82E-04
Photochemical ozone formation	297.41	1.19	30.04	141.76	2.97	66.56	0.07	14.66	0.97	22.71	5.85	10.62
Acidification	249.76	1.85	25.96	115.96	2.56	54.04	0.16	11.02	0.82	25.73	3.93	7.72
Terrestrial eutrophication	1023.71	4.07	102.67	493.29	10.13	232.17	0.23	56.05	3.59	61.66	21.57	38.26
Freshwater eutrophication	2.45E+00	6.59E-02	2.99E-01	1.05E+00	2.96E-02	4.71E-01	8.37E-03	2.06E-01	9.03E-03	2.76E-01	7.67E-03	2.55E-02
Marine eutrophication	3.17E+02	3.78E-01	9.39E+00	4.51E+01	9.26E-01	2.12E+01	2.21E-02	5.16E+00	3.33E-01	2.29E+02	1.89E+00	3.49
Freshwater ecotoxicity	2519040	8913.28	10719.36	36713.15	1057.98	16362.90	102.32	1015113	55637.16	1341981	31739.31	699.58
Land use	347670.45	908.04	57686.90	182742.62	5693.58	80158.16	111.57	523.73	119.32	18596.49	669.84	460.21
Water resource depletion	8380.84	222.55	1122.21	3887.94	110.76	1736.70	43.38	161.77	28.63	1154.78	-171.00	83.14
Mineral, fossil & ren resource depletion	6.69E-01	2.15E-03	9.98E-02	3.31E-01	9.85E-03	1.46E-01	9.84E-05	1.04E-02	2.30E-03	5.53E-02	8.02E-03	4.02E-03

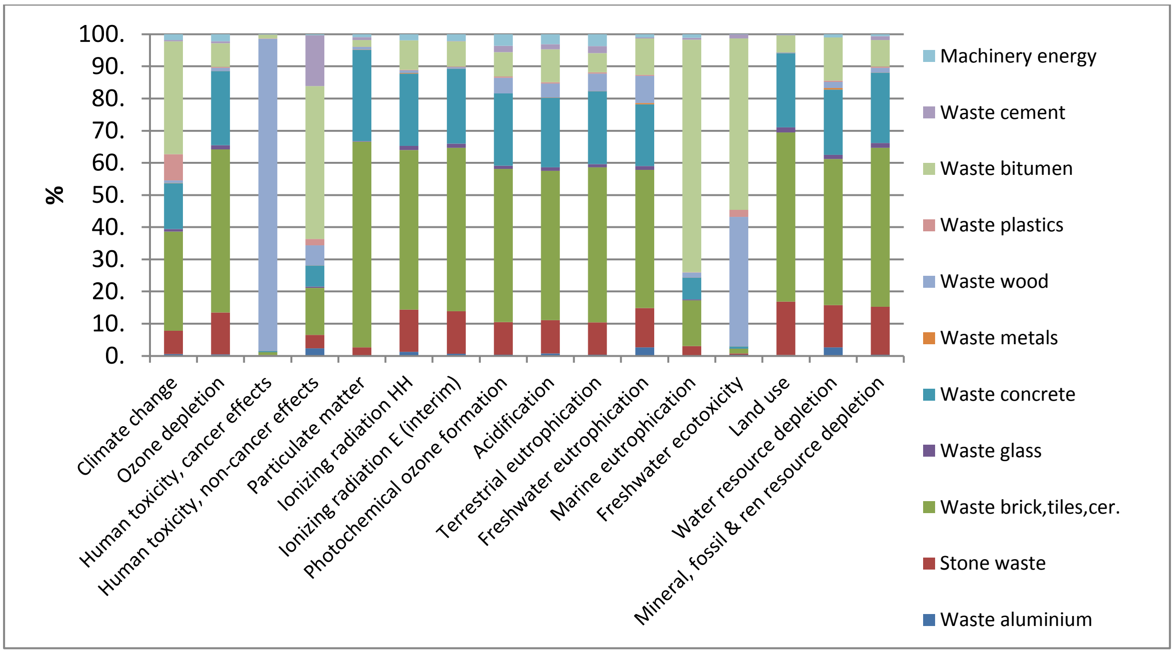

Figure 5.3. Impacts distribution for the deconstruction stage (in percentage)

The main conclusions relating to the deconstruction stage are:

- The highest impacts relate to the management of the deconstruction materials including energy for dismantling, particulate matter emissions from dismantling and handling, transport to dismantling facilities, and final disposal of waste material.

- The different materials have different impacts. However, waste cement, concrete and stone constitute approximately 75% of the effects associated with most of the impact categories.

- Highest impacts of bitumen waste were determined in relation to climate change (35%), non-cancer human toxicity (47%), marine eutrophication (72%) and freshwater ecotoxicity (53%). Waste wood has the highest impact for cancer-related human toxicity (97%), possibly due to the potential presence of chromium VI, a known carcinogen, in wood preservatives.

5.3.4 Construction of new buildings

Detailed information on the types of buildings, construction materials and engineering solutions was not available at the time of writing. For this reason a simplified approach was adopted involving assumptions about standard European buildings.

The impacts of new land occupation have not been considered as the area is already urbanised (contrary to the construction on greenfields where new land is occupied).

Three building construction activities have been defined, as described in Table 5.9.

Table 5.9. Sources of impacts from construction of new buildings.

Input	Amount		Information	Input selected (source)
Building, Residential area	15345.35	m2	423 residential homes with 5 floors and basement	Building, multi-storey construction (ECOINVENT) *(Included activities: Includes the most important materials used and their disposal, the transportation of the parts to the building site and to the final disposal at the end of life. Also included is the requirement of electricity for construction, maintenance and demolition. Operation is not included)*
Building, Preschool and primary school	1027	m2	-	Building, multi-storey construction (ECOINVENT) *(Included activities: Includes the most important materials used and their disposal, the transportation of the parts to the building site and to the final disposal at the end of life. Also included is the requirement of electricity for construction, maintenance and demolition. Operation is not included)*

Input	Amount		Information	Input selected (source)
Building, Economic activities	1015	m2	-	Building, multi-storey construction (ECOINVENT) *(Included activities: Includes the most important materials used and their disposal, the transportation of the parts to the building site and to the final disposal at the end of life. Also included is the requirement of electricity for construction, maintenance and demolition. Operation is not included)*

Impact assessment

Impacts are related to the functional unit (1 ha of brownfield) and expressed for different building components and impact categories; the distribution over which is visualised in Figures 5.4 and 5.5.

Table 5.10. Impact values for construction of new buildings (per ha)

Impact category	Units	Total	Building, residence	Building, school	Building, economic
Climate change	kg CO2 eq	3892338	3435206	229909.22	227222.84
Ozone depletion	kg CFC-11 eq	0.35	0.31	0.02	0.02
Human toxicity, cancer effects	CTUh	1.12	0.99	0.07	0.07
Human toxicity, non-cancer effects	CTUh	19.42	17.14	1.15	1.13
Particulate matter	kg PM2.5 eq	5426.26	4788.98	320.51	316.77
Ionizing radiation HH	kBq U235 eq	251190.57	221689.73	14837.10	14663.74
Ionizing radiation E (interim)	CTUe	0.76	0.67	0.04	0.04
Photochemical ozone formation	kg NMVOC eq	20621.32	18199.47	1218.04	1203.81
Acidification	molc H+ eq	65907.23	58166.82	3892.95	3847.46
Terrestrial eutrophication	molc N eq	67804.48	59841.24	4005.02	3958.22
Freshwater eutrophication	kg P eq	10430.35	9205.37	616.09	608.89
Marine eutrophication	kg N eq	7538.24	6652.92	445.26	440.06
Freshwater ecotoxicity	CTUe	423519540	373779680	25016079	24723778
Land use	kg C deficit	9422257	8315669	556545.62	550042.65
Water resource depletion	m3 water eq	4432139	3911611	261793.71	258734.78
Mineral, fossil & renewable resource depletion	kg Sb eq	564.46	498.17	33.34	32.95

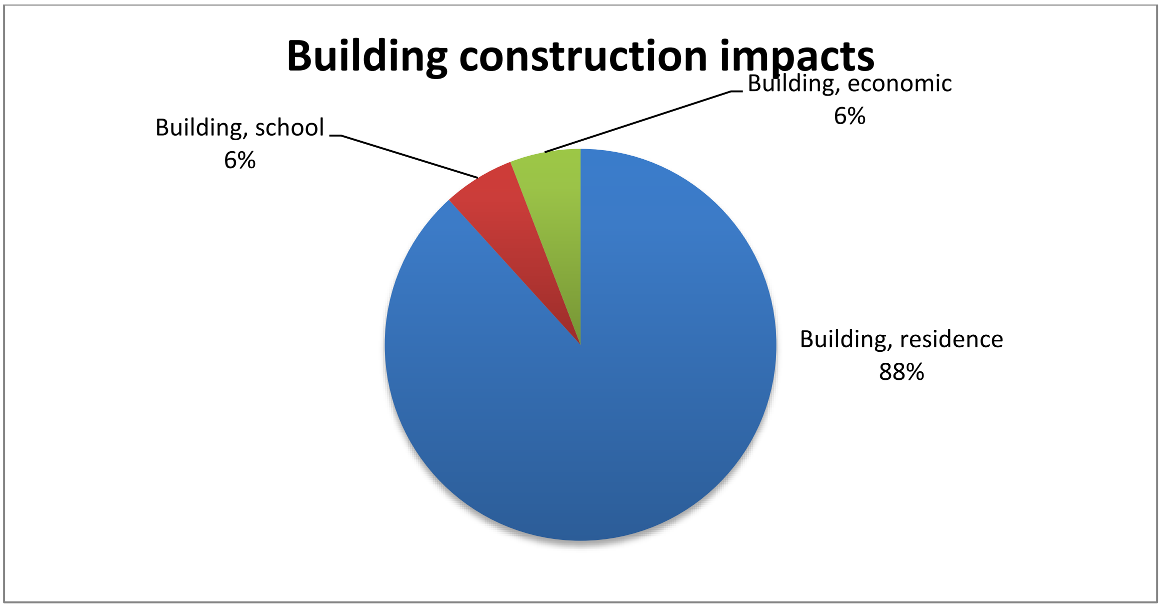

Figure 5.4. Impacts distribution over the different building components (in percentages)

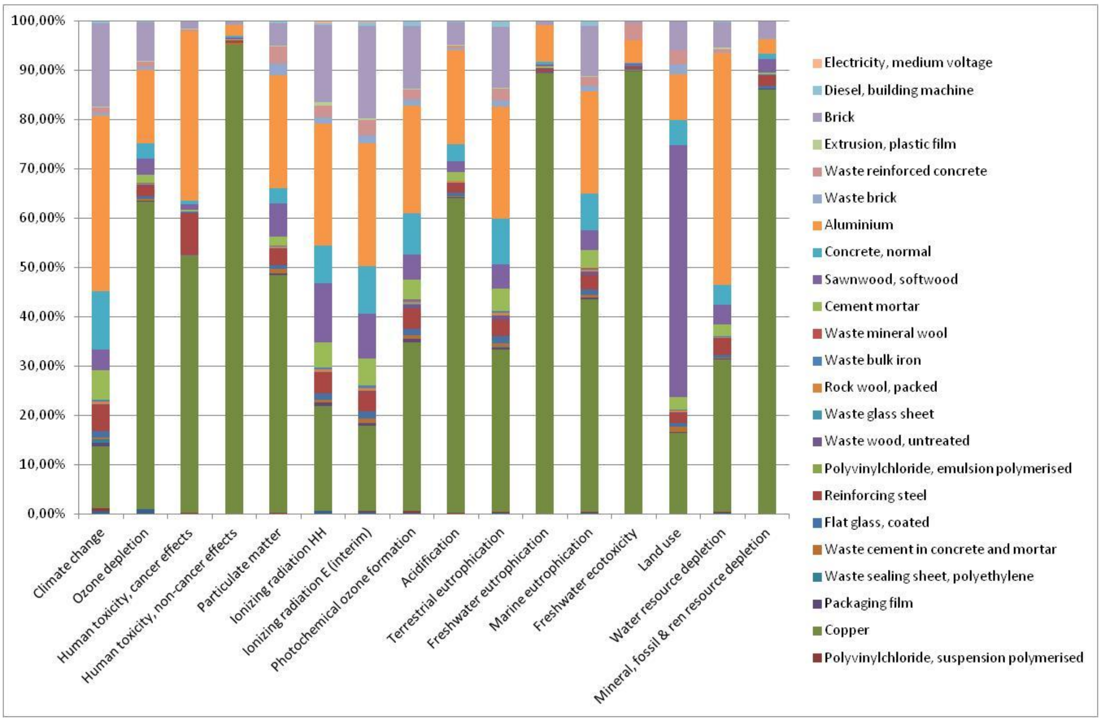

Figure 5.5. Impacts distribution across impact categories and building activities (by materials where relevant) (in percentages)

The main conclusions relating to the construction stage are:

- Overall, the highest impact results from the construction of the residential buildings, mainly due to the large volume of materials used.

- The most significant impacts relate to the management of construction materials, including their use and disposal during construction, transportation to the building site and final disposal at the end of their life (accounting for almost 99% of the impacts). Impacts associated with electricity used during construction, maintenance and demolition have a relatively low impact compared with the materials. Impacts associated with the operation of the buildings are included in the tertiary impacts.

- Different materials have different impacts. Copper has the highest impact followed by aluminium; this impact is mainly associated with their manufacturing.

- It is worth mentioning that lumber/timber marked the greatest contribution to 'land use' impacts (51%) due to effects of wood harvesting.

5.3.5 Construction of new infrastructure

New land occupation has not been considered for the construction of new infrastructure. On a site that was developed previously and is already connected (electricity, gas, wastewater drainage, roads, etc.) to an urban area, less new infrastructure is needed compared with greenfields.

Table 5.11. Sources of impacts from construction of new infrastructure activities.

Input	Quantification	Amount		Information	Input selected (source)
Streets	-	30465.55	m2	-	Road construction (ECOINVENT) (Km)
Road complements	-	4451.8	m2	-	Road construction (ECOINVENT) (Km)
Underground Transformer station (UST)	-	150	m2	-	Transmission network, electricity, medium voltage construction (ECOINVENT). *It describes the infrastructure (poles, cables etc.) of the electricity transmission network. It includes the high-to-medium voltage switching stations.*
Waste facility (Pneumatic waste collection centre)	-	342	m2	-	Scrap preparation facility construction ECOINVENT)
Green area	-	4451.8	m2	-	Planting soil market (ECOINVENT)
		9	kg	20 kg /ha (average)	Grass seed, organic, for sowing production (ECOINVENT)

Impact assessment

Impacts are related to the functional unit (1 ha of Brownfield) and quantification of impacts has been done for the different infrastructure components to be built (Table 5.12). Their distribution in percentages over the different impact categories is presented in Figure 5.8.

Table 5.12. Impact values for construction of new infrastructures activities (per ha).

Impact category	Unit	Total	Streets	Road complem.	Underground transformer	Waste facility	Green area
Climate change	kg CO2 eq	91573.58	36155.57	5283.35	4753.490	45211.75	169.41

Impact category	Unit	Total	Streets	Road complem.	Underground transformer	Waste facility	Green area
Ozone depletion	kg CFC-11 eq	1.03E-02	4.98E-03	7.27E-04	8.55E-04	3.74E-03	1.01E-05
Human toxicity, cancer effects	CTUh	2.44E-02	1.56E-03	2.28E-04	8.41E-03	1.42E-02	9.24E-06
Human toxicity, non-cancer effects	CTUh	0.27	5.40E-03	7.90E-04	0.063	1.98E-01	4.76E-04
Particulate matter	kg PM2.5 eq	106.92	30.97	4.52	10.919	60.42	0.10
Ionizing radiation HH	kBq U235 eq	16605.84	11723.96	1713.20	307.36	2849.11	12.20
Ionizing radiation E (interim)	CTUe	0.05	3.78E-02	5.52E-03	8.78E-04	8.67E-03	5.36E-05
Photochemical ozone formation	kg NMVOC eq	787.47	451.99	66.05	33.43	234.32	1.67
Acidification	molc H+ eq	1201.45	285.63	41.74	160.96	711.43	1.69
Terrestrial eutrophication	molc N eq	2104.22	1019.12	148.92	106.27	823.41	6.50
Freshwater eutrophication	kg P eq	144.67	5.20	0.76	32.33	106.33	0.04
Marine eutrophication	kg N eq	204.53	92.94	13.58	13.91	83.53	0.57
Freshwater ecotoxicity	CTUe	6399576	577994.78	84461.42	1383695	4351963	1462.03
Land use	kg C deficit	674184.77	493843.27	72164.50	9129.22	103093.14	-4045.35
Water resource depletion	m3 water eq	104678.24	41669.95	6089.16	7296.15	49551.69	71.30
Mineral, fossil & ren resource depletion	kg Sb eq	19.67	1.93	0.28	1.72	15.71	0.04

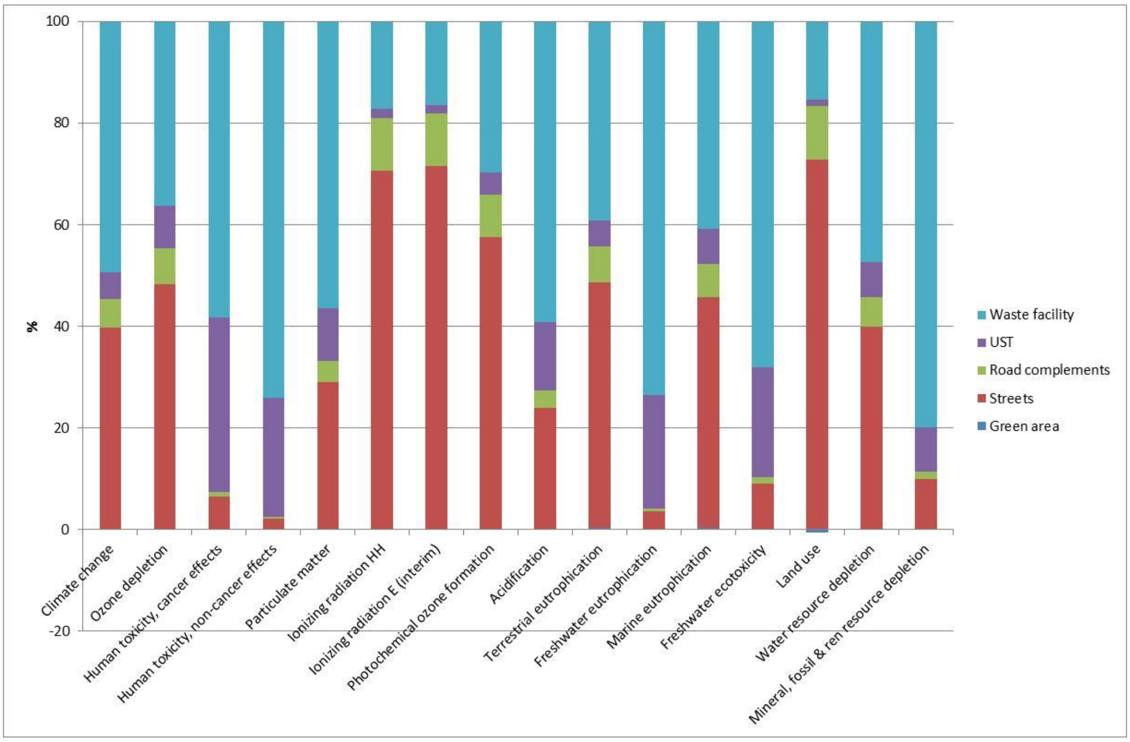

Figure 5.6. Impacts distribution across impact categories for construction of new infrastructure components (in percentages)

The main conclusions of the impact assessment from the construction of new infrastructure components are:

- The highest impacts are attributed to the construction of streets and the installation of the waste facility. Had the site been located outside the urban area, the impact of developing new infrastructure would have been higher.

- The development of green areas has a positive impact in land use because there is an increase of soil organic matter and thus an apportionment of carbon reservoir to the system. Note that negative values imply net environmental benefits.

5.4 Site operation: Tertiary impacts

Tertiary impacts during the operational stage include use of the buildings and infrastructure.

Regarding the use of the remodelled brownfield, the operations considered are:

- Building use: energy and water consumption, waste production, wastewater production.

- Green areas: water consumption.

- Mobility of users.

The choice of the lifespan is crucial for the LCA brownfield system, since it influences the final results to a high degree. In this study the impacts of the use of the brownfield have been considered for 20 years. Were longer periods of use to be considered, the increase of the total tertiary impact would be directly proportional (i.e. for 40 years the total tertiary impact would be twice as high as for 20 years). When extrapolating the conclusions of 20 years towards 40 years, the general conclusions of impacts remains the same for 20 or 40 years.

The inventory data and impact assessment results for the 20-year period are detailed in the Table 5.13.

Table 5.13. Sources of impacts from site operation activities.

Input	Quantification	Amount	Information	Input selected (source)
Mobility			From Mobility Study of the Site Total trips: 3385 trips/day	
Car	78455838	km	25% of trips Average distance=12.7	
Motorbike	15691168	km	5% of trips. Average distance=12.7	
Transport public	31382335	km	10% of trips. Average distance=12.7	
Bike/walking	188294010	km	60% of trips. Average distance=12.7	
Water building	1046820	m^3	52341 m3/year	Tap water, at user (ECOINVENT)
Water facilities (green area)	193358	m3	9667,90 m3/y. 50 years	Tap water, at user (ECOINVENT)
Waste generation			From Environmental Impact Assessment of the Urban Plan	
Paper/cardboard	157	t	7.85 t/y. 50 years	
Glass	230.2	t	11.51 t/y. 50 years	
Packaging	27.2	t	1.36 t/y. 50 years	
Organic fraction	293	t	14.65 t/y. 50 years	
Rest fraction	10468.2	t	523.41 t/y. 50 years	
Electricity building (Energy)	31773040	kWh	1878 kWh/hab·y Statistics Terrassa City (2008). Occupation: 2 peers/res.	Electricity, medium voltage {ES}| market for (ECOINVENT)
Natural gas (Energy building)	36215026	kWh	118 kWh /m2 (heating, warming water, cooking). Source: Catalan Building Agency (http://www.agenciahabitatge.cat)	Heat, central or small-scale, natural gas (ECOINVENT)
Wastewater building	837456	m3	80% of water consumption	Wastewater, from residence treatment of (ECOINVENT)

Impact assessment (20 years)

Impacts are related to the functional unit (1 ha of Brownfield) and their distribution over the different site operational activities and impact categories is given in Figure 5.7. Table 5.14 includes the quantification of impacts for the different aspects assessed during the use of the site.

Table 5.14. Impact values for site operation activities over 20 years (per ha).

			Input						
Impact category	**Unit**	**Total**	**Mobility**	**Water buildings**	**Water facilities**	**Waste generation**	**Electricity building**	**Natural gas**	**Wastewater building**
Climate change	kg CO2 eq	19586232	9862887	121614.47	22463.40	1874464	4965596	2552006	187198.26
Ozone depletion	kg CFC-11 eq	1.37	0.69	9.34E-03	1.72E-03	1.52E-02	6.38E-01	1.10E-02	7.49E-03
Human toxicity, cancer effects	CTUh	0.92	0.55	1.49E-02	2.75E-03	1.73E-01	1.25E-01	1.49E-02	3.90E-02
Human toxicity, non-cancer effects	CTUh	7.74	2.44	0.04	0.01	4.12	0.58	0.07	0.48
Particulate matter	kg PM2.5 eq	8214.38	5717.17	66.24	12.24	179.10	2012.35	71.39	155.88
Ionizing radiation HH	kBq U235 eq	3451090	787462.93	47609.03	8793.86	27116.10	2505634	56635.80	17837.79
Ionizing radiation E (interim)	CTUe	9.10	3.50	0.08	0.02	0.08	5.28	0.09	0.04
Photochemical ozone formation	kg NMVOC eq	64696.29	45850.77	351.33	64.89	1929.69	14656.08	1020.30	823.22
Acidification	molc H+ eq	76721.65	38241.06	690.40	127.52	1815.42	32880.70	1182.68	1783.87
Terrestrial eutrophication	molc N eq	155326.30	89276.91	1205.78	222.72	5485.36	51257.35	3731.05	4147.13
Freshwater eutrophication	kg P eq	3143.52	1643.96	66.97	12.37	114.67	903.14	94.57	307.85
Marine eutrophication	kg N eq	23935.79	8258.17	122.35	22.60	4684.98	4837.97	358.36	5651.36
Freshwater ecotoxicity	CTUe	6.36E+08	2.63E+08	1905595	351982.39	349257420	16205689	1650793	3325234
Land use	kg C deficit	17028434	12083397	528774.15	97669.81	695894.75	3164611	65363.70	392723.06
Water resource depletion	m3 water eq	51477634	3943218	359118.01	66332.65	194813.19	46386170	355534.90	172447.59
Mineral, fossil & ren resource depletion	kg Sb eq	1285.60	1218.69	8.87	1.64	4.74	28.13	18.48	5.04

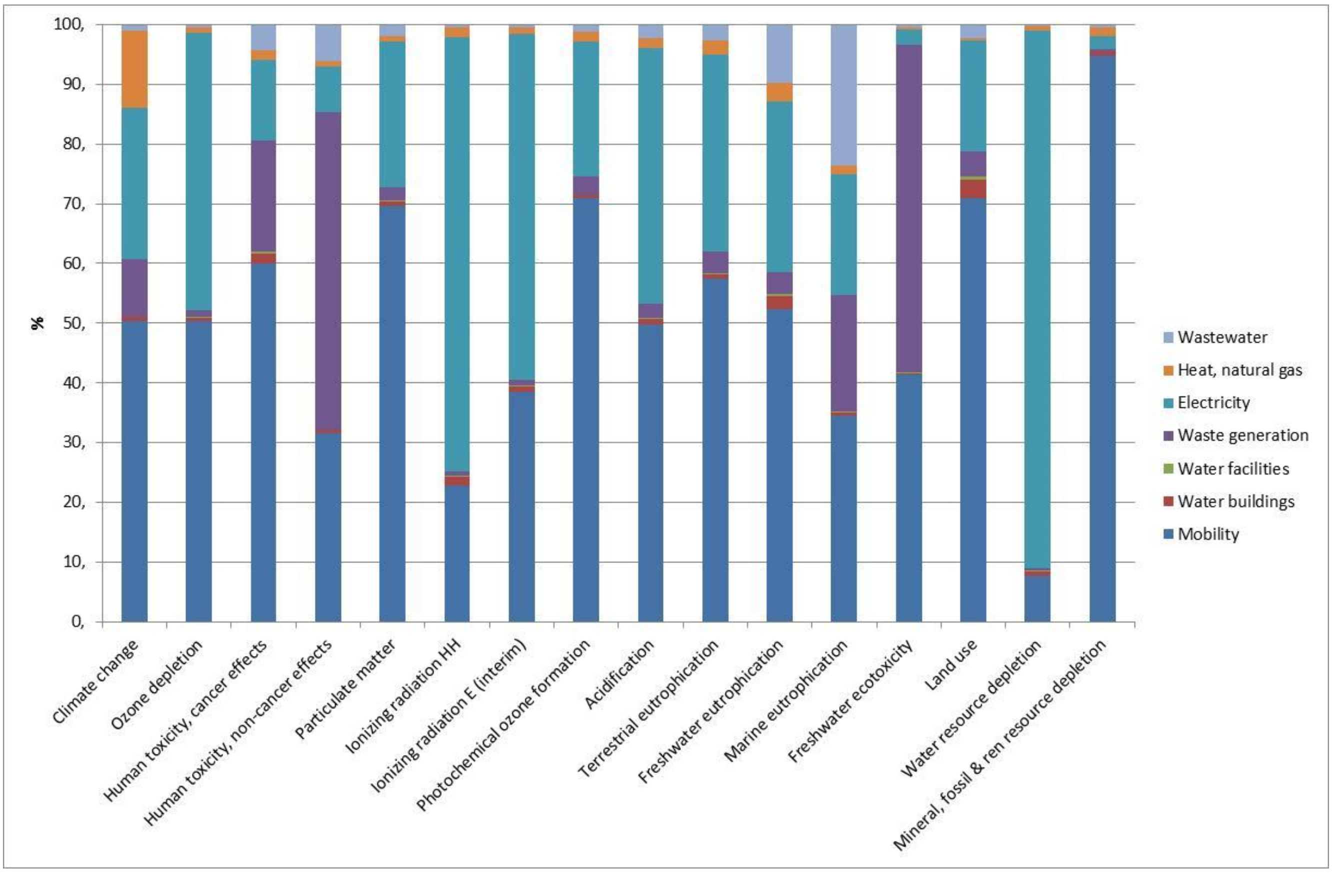

Figure 5.7. Impacts distribution across impact categories for site operation (in percentages)

The main conclusions of the impact assessment from the use of the redeveloped site are:

- The highest impact is related to the mobility of the people living on the site and using the site, with more than 50% of the impact for the categories climate change, ozone depletion, human cancer toxicity, particulate matter, photochemical ozone formation, acidification, terrestrial and freshwater eutrophication, land use and fossil resource depletion.

- The second major impact is for the energy consumption which is relevant for ionizing radiations and water resource depletion.

- Waste generation has the highest impacts for human non-cancer toxicity and freshwater ecotoxicity.

5.5 Life cycle impacts across the brownfield system

A general environmental profile can be obtained for the brownfield considering the different life stages, for which a scenario of 20 years of use has been considered.

Table 5.15. Summary of impact values comparing the three different life stages for an operation of the site during 20 years.

			Inputs						
			Primary	Secondary					Tertiary
Impact category	Unit	Total	In-situ contamination	Soil investigation	Remediation soil	Deconstruction	Construction buildings	Construc. Infrastruct.	Use
Climate change	kg CO2 eq	23617000	0.00	288.34	3259.66	43308.92	3892338	91573.58	19586232
Ozone depletion	kg CFC-11 eq	1.74	0.00	2.05E-05	2.54E-04	2.33E-03	3.54E-01	1.03E-02	1.37
Human toxicity, cancer effects	CTUh	2.12	3.46E-03	1.55E-05	4.72E-04	5.12E-02	1.12E+00	2.44E-02	9.23E-01
Human toxicity, non-cancer effects	CTUh	27.73	2.65E-01	6.36E-05	2.25E-02	9.83E-03	19.42	0.27	7.74
Particulate matter	kg PM2.5 eq	13859.72	0.00	0.25	2.44	109.47	5426.26	106.92	8214.38
Ionizing radiation HH	kBq U235 eq	3721595	0.00	20.65	288.76	2399.14	251190.57	16605.84	3451090
Ionizing radiation E (interim)	CTUe	9.92	0.00E+00	1.03E-04	1.47E-03	1.32E-02	7.56E-01	0.05	9.10
Photochemical ozone formation	kg NMVOC eq	86430.55	0.00	1.72	26.34	297.41	20621.32	787.47	64696.29
Acidification	molc H+ eq	144104.60	0.00	1.55	22.97	249.76	65907.23	1201.45	76721.65
Terrestrial eutrophication	molc N eq	226354.34	0.00	5.56	90.07	1023.71	67804.48	2104.22	155326.30
Freshwater eutrophication	kg P eq	13721.53	0.00	0.04	0.50	2.45	10430.35	144.67	3143.52
Marine eutrophication	kg N eq	32004.13	0.00	0.51	8.24	316.82	7538.24	204.53	23935.79
Freshwater ecotoxicity	CTUe	1068963157	424037.6	7252.97	491939.4	2519040	423519540	6399576	635601770
Land use	kg C deficit	27492233	0.00	320.04	19366.14	347670.4	9422257	674184.77	17028434
Water resource depletion	m3 water eq	56024065	0.00	89.28	1143.54	8380.84	4432139	104678.24	51477634
Mineral, fossil & ren resource depletion	kg Sb eq	1870.53	0.00	3.23E-02	9.88E-02	0.67	564.46	19.67	1285.60

Table 5.16. Summary of percentage contribution comparing the three different life stages for an operation of the Terrassa brownfield site during 20 years.

	Inputs						
	Primary	Secondary					Tertiary
Impact category	In-situ contamination	Soil investigation	Remediation soil	Deconstruction	Construction buildings	Construc. infrastructures	Use
Climate change	0.000%	0.001%	0.014%	0.2%	16.5%	0.4%	82.9%
Ozone depletion	0.000%	0.001%	0.015%	0.1%	20.3%	0.6%	78.9%
Human toxicity, cancer effects	0.163%	0.001%	0.022%	2.4%	52.7%	1.2%	43.5%
Human toxicity, non-cancer effects	0.957%	0.000%	0.081%	0.0%	70.0%	1.0%	27.9%
Particulate matter	0.000%	0.002%	0.018%	0.8%	39.2%	0.8%	59.3%

	Inputs						
	Primary	Secondary					Tertiary
Impact category	In-situ contamination	Soil investigation	Remediation soil	Deconstruction	Construction buildings	Construc. infrastructures	Use
Ionizing radiation HH	0.000%	0.001%	0.008%	0.1%	6.7%	0.4%	92.7%
Ionizing radiation E (interim)	0.000%	0.001%	0.015%	0.1%	7.6%	0.5%	91.7%
Photochemical ozone formation	0.000%	0.002%	0.030%	0.3%	23.9%	0.9%	74.9%
Acidification	0.000%	0.001%	0.016%	0.2%	45.7%	0.8%	53.2%
Terrestrial eutrophication	0.000%	0.002%	0.040%	0.5%	30.0%	0.9%	68.6%
Freshwater eutrophication	0.000%	0.000%	0.004%	0.0%	76.0%	1.1%	22.9%
Marine eutrophication	0.000%	0.002%	0.026%	1.0%	23.6%	0.6%	74.8%
Freshwater ecotoxicity	0.040%	0.001%	0.046%	0.2%	39.6%	0.6%	59.5%
Land use	0.000%	0.001%	0.070%	1.3%	34.3%	2.5%	61.9%
Water resource depletion	0.000%	0.000%	0.002%	0.0%	7.9%	0.2%	91.9%
Mineral, fossil & ren resource depletion	0.000%	0.002%	0.005%	0.0%	30.2%	1.1%	68.7%

Note: The contributions for each stage are detailed by percentage. The stage with the highest contribution is highlighted in red; while the rest of the stages with relevant contributions (≥5%) are marked in orange.

The following Figure 5.8 presents these results in a graphical mode.

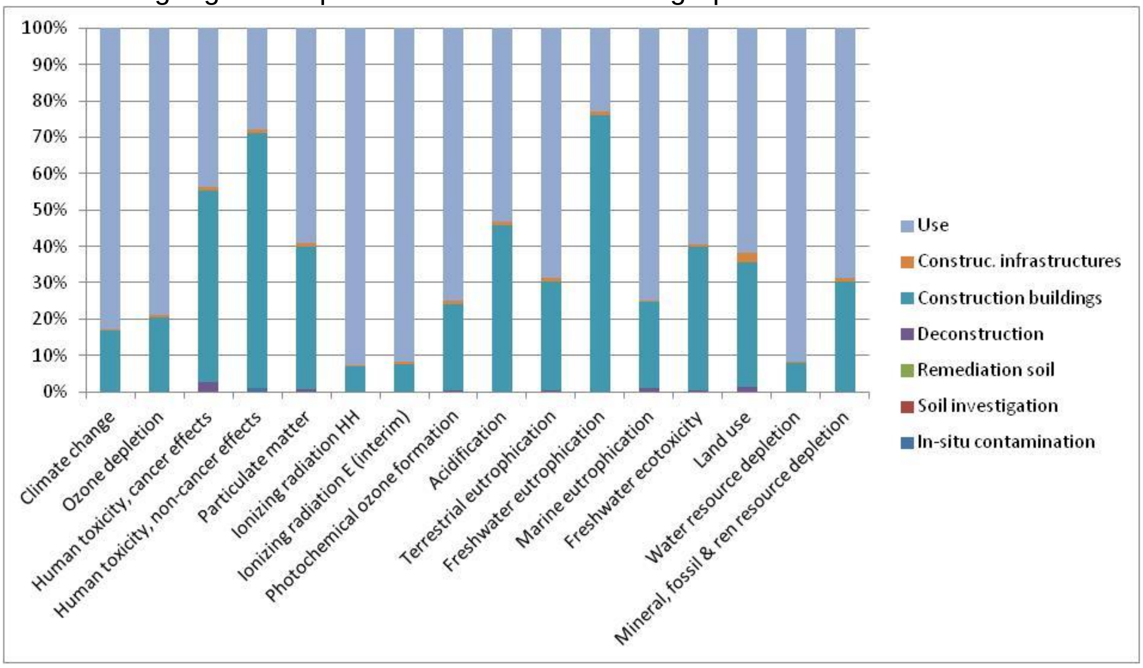

Figure 5.8. Impacts distribution for the Terrassa brownfield system for a 20-year use scenario (in percentages)

The main impacts are generated by the use stage, with highest percentages of impacts for all impact categories, except for human toxicity and freshwater eutrophication, where the construction of new buildings results in higher impacts due to emissions during the manufacture of the construction materials used. It is noteworthy that the contribution of the use stage is expected to be even bigger had the assessment assumed the lifespan of the development to be 50 years, for example, rather than 20 years.

Contribution of each life stage to global warming per ha (20-year scenario)

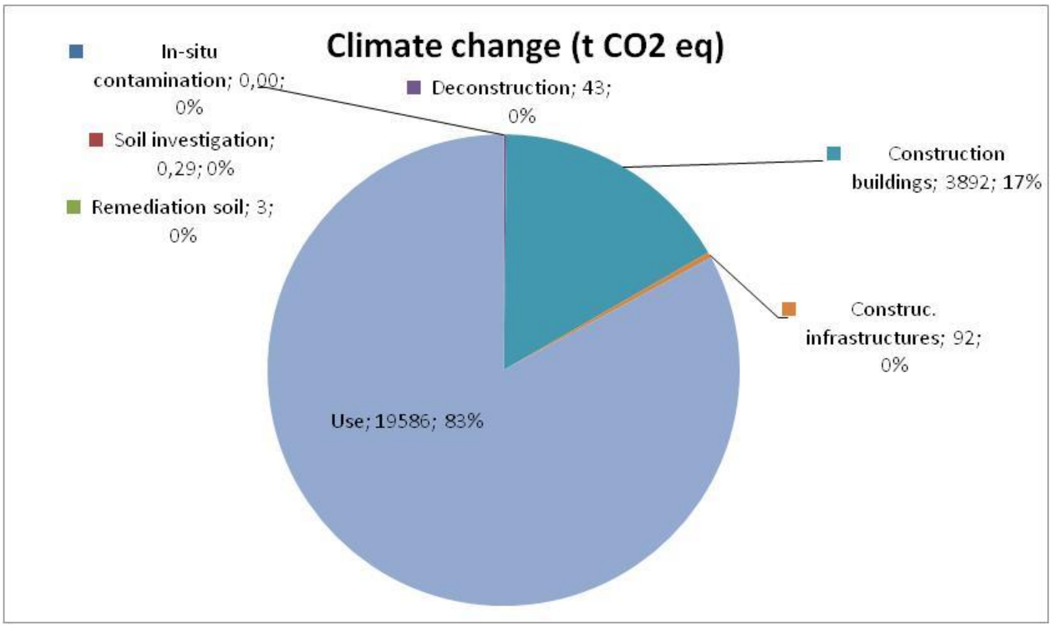

Figure 5.9. Impacts distribution for climate change category (20-year scenario)

Ignoring the tertiary impacts from the use of the site, the construction of buildings counts for more than 90% of all impact categories, while the third activity of impact importance would be the construction of infrastructures, however to a much lesser degree than the construction of buildings. The deconstruction has special contributions to human toxicity, particulate matter, land use and eutrophication, but very low compared with the construction of new buildings. The stages of soil remediation and soil investigation are less relevant, with lower impacts for this site. In situ contamination only contributes to the toxicity impact categories, but has very low relevance compared with the activities for the construction of new buildings.

6 Case study 3: Greenfield in Terrassa (Catalonia, Spain)

6.1 General description

The LCA method has also been applied to a greenfield site located in the city of Terrassa (Catalonia, Spain). The main information is summarised below.

Location: Terrassa (20 km north of Barcelona). Spain (Can Colomer)

Surface: 474,892 m^2 (47.49 ha).

Uses: It is an undeveloped area on the North border of Terrassa city (200,000 residents). The former use was agricultural/rural and undeveloped area.

Existing building: There are two listed buildings, which will remain. The existing buildings are in good condition.

Existing infrastructures: There is a transformer substation which will remain, but new water supply lines, wastewater sewage system, natural gas network and communication and electricity networks need to be developed.

Urban project: Partial Plan in Can Colomer Torrent Mitger. The partial plan exists since 2006, and it was initiated with the development of the roads and services in the area but it was stopped due to the financial crisis in Spain. The project includes 4,452 residential homes. The maximum intended height corresponds to 5 floors + basement. It also includes school, sports area and waste collection area.

49,868 m^2 will be destined to equipment areas (school, sports area, waste collection point) and the remaining area will be a residential zone with green areas.

The area has been topographically modified with earth movements during urbanisation of the land.

6.2 Site conditions: primary impacts

Primary impacts are referred to as the site's degraded physical state. For this greenfield previous uses are limited to agriculture and undeveloped area. Therefore, soil or groundwater contamination are not present on the site; thus no primary impacts have been evaluated.

6.3 Site actuation: secondary impacts

Secondary impacts are generated from the development activities in order to use the area as a new urban area. The different stages considered are the following:

- Land occupation
- Deconstruction
- Construction of new buildings

- Construction of new infrastructures

Contrary to the other two brownfields, the stages soil and groundwater investigation, soil remediation and deconstruction are not relevant in this case. However, land occupation is relevant compared to brownfields developments.

6.3.1 Land occupation

In greenfield projects, the project execution in non-urban areas results in the occupation and loss of natural land (differently from brownfield, where the redeveloped area is already urbanised). This land occupation has environmental consequences since the ecological role of this area is affected and land use is completely changed (from agricultural or forest land to urbanised soil).

To model this process, a generic process from the Ecoinvent database was selected, called *unknown land use* (Table 6.1). This process refers to the impacts of recent occupation of different types of natural land (including primary forest, secondary forest, agricultural land, grassland...). This process includes the activities to transform the land (clear-cutting forest) and also the ecological consequences in terms of carbon sequestration, deforestation and carbon content lost from the soil.

Table 6.1: Quantification of land occupation.

Input	Quantification	Amount		Information	Input selected (source)
Land occupation	Total area (deducting already built area)	457,922	m^2	Forest and agricultural land	Unknown land use (corresponding with the future land use). (ECOINVENT database) Land recently transformed from primary, secondary forest and agricultural land. The activity takes account of the changes in soil organic carbon (SOC) resulting from the land use.

Impact assessment

Impacts are related to functional unit (1 ha of Greenfield) and its quantification for each impact category is presented in the Table 6.2.

Table 6.2: Quantification of impact categories for land occupation (per ha).

Impact categories	Units	Total
Climate change	kg CO_2 eq	620187.6
Ozone depletion	kg CFC-11 eq	0.00026
Human toxicity, cancer effects	CTUh	0.00052
Human toxicity, non-cancer effects	CTUh	0.00019
Particulate matter	kg PM2.5 eq	172.62
Ionizing radiation HH	kBq U235 eq	232.75
Ionizing radiation E (interim)	CTUe	0.0014

Photochemical ozone formation	kg NMVOC eq	594.57
Acidification	molc H+ eq	330.47
Terrestrial eutrophication	molc N eq	1394.21
Freshwater eutrophication	kg P eq	0.17
Marine eutrophication	kg N eq	53.29
Freshwater ecotoxicity	CTUe	8749.12
Land use	kg C deficit	5580740.1
Water resource depletion	m3 water eq	436.59
Mineral, fossil & ren resource depletion	kg Sb eq	75.16

6.3.2 Topographic modification

This life stage includes the earth movements during urbanisation of the area in order to modify the topographic profile. It was assessed that the excavated soil is reused on the site, as a consequence of which the total soil balance is zero. The main impacts are associated with the use of machinery and the internal transport of the soil, as explained in Table 6.3.

Table 6.3: Sources of impacts from topographic modification

Input	Quantification	Amount		Information	Input selected (source)
Transport Lorry (Soil internal)	2 trucks for 6 months (1200 km)	1200	km	2 Trucks (15 tonnes)	Transport, freight, lorry 7.5-16 metric ton, EURO4 (ECOINVENT)
Diesel Machine	Work of machine for 6 months (960 hours)	24218.5	kWh	Digger excavator and Bobcat: 34,3 CV	Energy, from diesel burned in machinery (ECOINVENT)

Impact assessment

Impacts are related to functional unit (1 ha of greenfield) and quantification for each activity and impact category are presented in Table 6.4.

Table 6.4: Impact values for topographic modification (per ha)

Impact category	Unit	Total	Transport, lorry	Diesel, machine
Climate change	kg CO2 eq	179.19	5.77	173.41
Ozone depletion	kg CFC-11 eq	1.17E-05	3.96E-07	1.13E-05
Human toxicity, cancer effects	CTUh	4.31E-06	1.90E-07	4.12E-06
Human toxicity, non-cancer effects	CTUh	8.16E-06	8.56E-07	7.30E-06
Particulate matter	kg PM2.5 eq	2.18E-01	2.07E-03	2.16E-01
Ionizing radiation HH	kBq U235 eq	10.430	0.458	9.97
Ionizing radiation E (interim)	CTUe	6.48E-05	2.31E-06	6.25E-05
Photochemical ozone formation	kg NMVOC eq	2.39E+00	3.51E-02	2.35E+00
Acidification	molc H+ eq	1.741	0.030	1.71
Terrestrial eutrophication	molc N eq	8.598	0.120	8.48
Freshwater eutrophication	kg P eq	0.006	0.000	0.006
Marine eutrophication	kg N eq	0.785	1.10E-02	0.77
Freshwater ecotoxicity	CTUe	179.437	24.422	155.01
Land use	kg C deficit	113.209	11.235	101.97
Water resource depletion	m3 water eq	19.744	1.321	18.42
Mineral, fossil & ren resource depletion	kg Sb eq	1.08E-03	1.92E-04	8.90E-04

The main impact from the topographic modification is related to the use of machinery, whereas internal transport has a lower contribution. It is worth recalling that no net soil is imported or exported and the excavated soil is reused on the same site.

6.3.3 Construction of new buildings

The typology of buildings for the greenfield development in Terrassa is expected to be similar to those on the brownfield site. For the construction of new buildings, detailed information on typology of buildings, materials and constructive solutions is not available. For this reason a simplified approach has been taken, using a standard building (as it was defined for the brownfield in Terrassa). In Table 6.5 the input inventory of activities with impact on the construction of new buildings is presented.

Table 6.5: Sources of impacts from construction of new buildings

Input	Quantification	Amount		Information	Input selected (source)
Primary School	-	8148	m^2	-	Building, multi-storey construction (ECOINVENT) *(Included activities: the most important materials used and their disposal, the transportation of the parts to the building site and to the final disposal at the end of life. Also included is the requirement of electricity for construction, maintenance and demolition. Operation is not included here)*
Secondary School	-	18014	m^2		Building, multi-storey construction (ECOINVENT) *( )*
Residential area (new)	-	104479	m^2	Includes 4,452 residential homes with green area. The maximum intended height corresponds to 5 floors + basement	Building, multi-storey construction (ECOINVENT) *(Included activities: Includes the most important materials used and their disposal, the transportation of the parts to the building site and to the final disposal at the end of life. Also included is the requirement of electricity for construction, maintenance and demolition. Operation is not included here)*

Impact assessment

The quantification of impacts presented in Table 6.6 per impact category are related to the functional unit (1 ha of greenfield).

Table 6.6. Impact values for construction of new buildings (per ha)

Impact category	Units	Total	Primary school	Secondary school	Residential
Climate change	kg CO_2 eq	1889322	117835.93	260517.48	1510969
Ozone depletion	kg CFC-11 eq	0.17	0.01	0.02	0.14
Human toxicity, cancer effects	CTUh	0.54	0.03	0.07	0.43
Human toxicity, non-	CTUh	9.43	0.59	1.30	7.54

Impact category	Units	Total	Primary school	Secondary school	Residential
cancer effects					
Particulate matter	kg PM2.5 eq	2633.88	164.27	363.18	2106.42
Ionizing radiation HH	kBq U235 eq	121926.74	7604.50	16812.40	97509.84
Ionizing radiation E (interim)	CTUe	0.37	0.02	0.05	0.29
Photochemical ozone formation	kg NMVOC eq	10009.49	624.29	1380.20	8005.00
Acidification	molc H+ eq	31991.06	1995.26	4411.23	25584.57
Terrestrial eutrophication	molc N eq	32911.98	2052.70	4538.21	26321.07
Freshwater eutrophication	kg P eq	5062.85	315.77	698.11	4048.97
Marine eutrophication	kg N eq	3659.03	228.21	504.54	2926.27
Freshwater ecotoxicity	CTUe	205574410	12821552	28346518	164406340
Land use	kg C deficit	4573520	285247.67	630639.62	3657632
Water resource depletion	m^3 water eq	2151339	134177.77	296646.82	1720515
Mineral, fossil & ren resource depletion	kg Sb eq	273.99	17.09	37.78	219.12

Figure 6.1 represents the distribution of the total impact of the building construction for each of the three building types: primary school, secondary school and residential building.

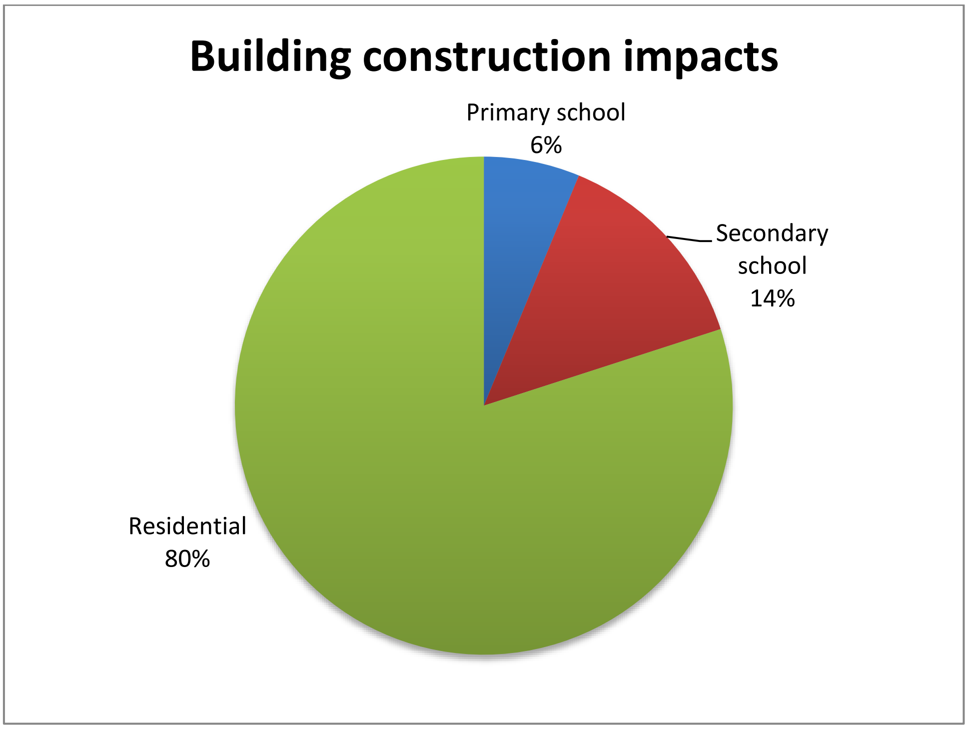

Figure 6.1. Impacts distribution per building type (in percentage)

6.3.4 Construction of new infrastructures

As opposed to brownfield development, urban development in greenfields generally requires more infrastructure (streets, water and energy networks, etc.).Greenfields are new urban areas outside the cities, normally implying that there are no existing infrastructures. In Table 6.7 the quantification for each activity and impact category are presented for the construction of new infrastructures.

Table 6.7. Sources of impacts from construction of new infrastructures.

Input	Quantification	Amount		Information	Input selected (source)
Green areas (Free spaces)	190537 m^2	190537	m^2	-	Planting soil activities (ECOINVENT)
		381	kg	20 kg /ha (average)	Grass seed, organic, for sowing production (ECOINVENT)
Road and street system	-	97937	m^2		Road construction (ECOINVENT)
Transformer station	-	14717	m^2	-	Transmission network, electricity, medium voltage construction (ECOINVENT). *It describes the infrastructure (poles, cables etc.) of the electricity transmission network. It includes the high-to-medium voltage switching stations.*
Distribution Electricity network		0.5	km		Transmission network, electricity (ECOINVENT)
Sewer grid network		7	km		Sewer grid construction (ECOINVENT)
Pipeline Natural gas network		5	km		Pipeline, natural gas, low pressure distribution network { (ECOINVENT)
Communication/data network		5	km		Transmission network, electricity (ECOINVENT)
Waste collection point	-	4501	m^2	-	Scrap preparation facility onstruction ((ECOINVENT)
Pneumatic waste collection centre	-	1141	m^2	-	Scrap preparation facility construction (ECOINVENT)
Water supply network		5	km		Water supply network construction (ECOINVENT)
Sport area	-	14669	m^2	-	*Not considered since it is based on existing facilities*

Impact assessment

The quantification of impacts presented in the Table 6.8 per impact category are related to the functional unit (1 ha of greenfield).

Table 6.8 Impact values for construction of new infrastructures (per ha)

Impact category	Total	Green area	Roads and streets	Trans-former station	Distri. network electricity	Sewer grid	Pipelinen atural gas	Network communications	Waste collection point	Pneumatic waste collection centre	Water supply network
Climate change	214724.97	59.33	12076.46	37660.96	322.44	97716.09	10176.35	2190.30	38439.25	9744.32	6339.49
Ozone depletion	0.02	3.11E-06	1.58E-03	6.77E-03	5.80E-05	2.68E-03	4.85E-04	5.18E-04	3.18E-03	8.06E-04	3.33E-04
Human toxicity, cancer effects	0.11	3.21E-06	8.58E-04	6.66E-02	5.71E-04	1.70E-02	3.71E-03	4.21E-03	1.21E-02	3.06E-03	6.38E-03
Human toxicity, non-cancer effects	0.80	2.42E-04	2.06E-03	4.97E-01	4.25E-03	2.61E-02	1.23E-02	3.87E-02	1.68E-01	4.27E-02	7.46E-03
Particulate matter	249.58	4.38E-02	1.03E+01	8.65E+01	7.41E-01	6.83E+01	7.33E+00	6.17E+00	5.14E+01	1.30E+01	5.75E+00
Ionizing radiation HH	14754.13	4.12	3694.17	2435.11	20.85	4423.87	546.14	156.83	2422.33	614.06	436.65
Ionizing radiation E (interim)	0.05	1.71E-05	1.19E-02	6.95E-03	5.95E-05	1.45E-02	1.89E-03	4.29E-04	7.37E-03	1.87E-03	1.31E-03
Photochemical ozone formation	1122.26	0.52	144.21	264.84	2.27	370.01	38.80	18.94	199.22	50.50	32.95
Acidification	2805.87	1.01	93.37	1275.22	10.92	468.08	66.61	92.91	604.86	153.33	39.55
Terrestrial eutrophication	3475.38	4.12	326.27	841.98	7.21	1151.91	110.32	57.67	700.07	177.47	98.38
Freshwater eutrophication	419.90	0.02	1.98	256.18	2.19	18.21	6.53	19.69	90.40	22.92	1.77
Marine eutrophication	363.70	0.31	29.77	110.18	0.94	105.10	11.07	7.80	71.02	18.00	9.51
Freshwater ecotoxicity	18346787	504.47	190903	1096274	93857.82	823477.0	321165.6	837912.5	3700060	937962.3	478196.8
Land use	1673378	-12627.7	206319.6	72329.00	971.82	114847.1	25537.8	5997.16	1000767	253693.8	5541.39
Water resource depletion	189572.28	25.72	13555.79	57805.94	494.91	52914.07	5497.85	3281.92	42129.09	10679.69	3187.30
Mineral, fossil & ren resource depletion	42.25	0.01	0.65	13.61	0.12	3.98	0.64	1.05	13.36	3.39	5.45

The following figure represents the distribution of impacts in percentage for each activity and category of impact.

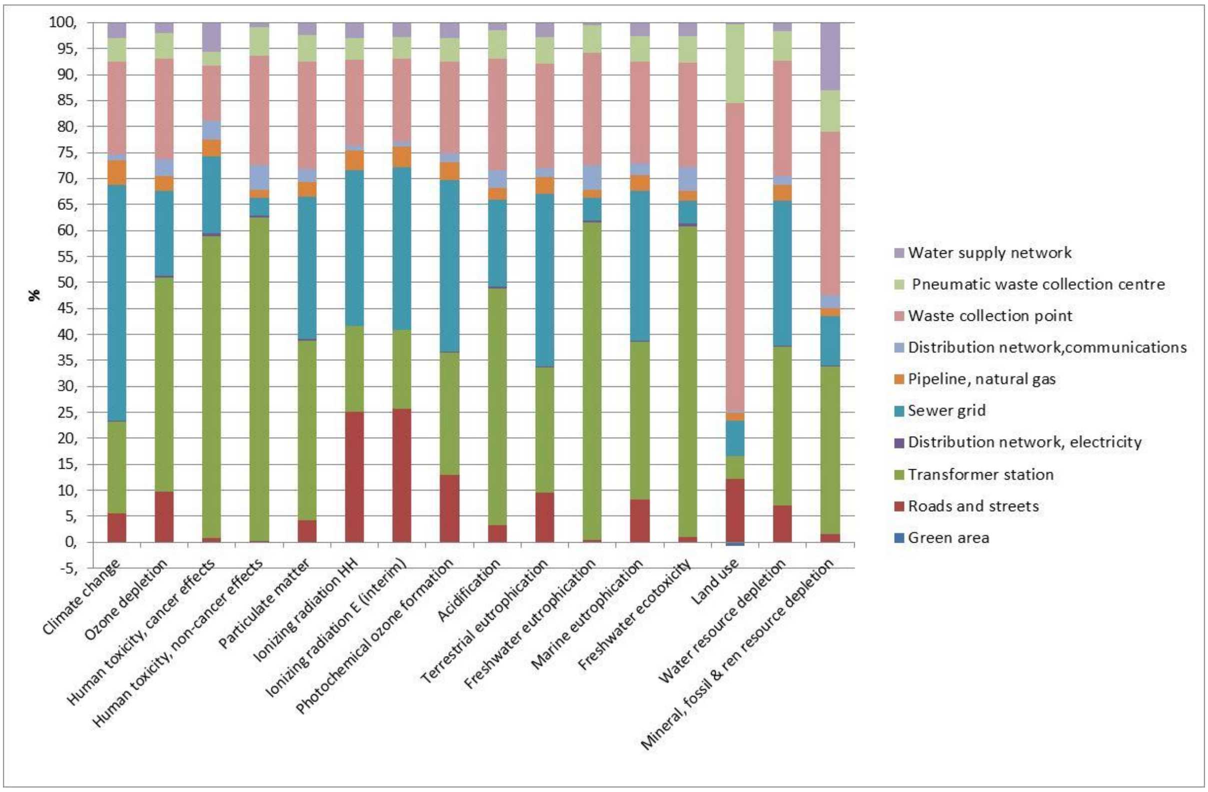

Figure 6.1. Impacts distribution for infrastructure construction stage (in percentage)

The main conclusions of the impact assessment from the construction of new infrastructures stage are:

- The highest overall impacts are identified for the construction of the transformer (specially for human toxicity and freshwater ecotoxicity and eutrophication), the construction of the waste collection facility (with highest impact for land use), the wastewater and storm water sewer grid (with highest impact on climate change) and the construction of streets (with relevant impacts on ionizing radiations).

- The development of green areas has a positive impact on land use.

6.4 Site operation: Tertiary impacts

The operation of the newly urbanised greenfield can be considered the stage of use of the buildings and infrastructures built.

Regarding the use of the greenfield, the operations considered are:

- Building use: energy and water consumption, waste production, wastewater production.

- Green areas: water consumption.

- Mobility of users.

The choice of the lifespan is crucial for the LCA brownfield system, since it influences the final results to a high degree. In this study the impacts of the use of the brownfield have been considered for 20 years. Were longer periods of use to be considered, the increase of the total tertiary impact would be directly proportional (i.e. for 40 years the total tertiary impact would be twice as high as for 20 years). When extrapolating the conclusions of 20 years towards 40 years, the general conclusions of impacts remains the same for 20 or 40 years. The inventory data and impact assessment results for the scenario of 20 years are detailed in Table 6.8.

Table 6.8 inventory data and impact assessment results for the scenario of 20 years

Input	Quantification.	Amount	Information	Input selected (source)
Mobility			14188 trips /day	
Car	2071448000	km	7591 trips/day (80%). Average distance=25	
Transport public	388396500	km	4058 trips/day (15%). Average distance=25	
Bike/walking	129465500	km	2525 trips/day (5%). Average distance=25	
Tap Water building	17734.1	m3	886.705 m3/year (including domestic, equipment and green areas consumption)	Tap water, at user (ECOINVENT)
Waste generation	116998.56	t	3.6 kg/home/day = 36 l/home day	
Electricity (Energy building)	334434240	kWh	1878 kWh/hab.y Statistics Terrassa City (2008). Occupation: 2 pers/res (4452 residences)	Electricity, medium voltage {ES}| market for (ECOINVENT)
Heat Natural gas (Energy building)	246570440	kWh	118 kWh /m2 (heating, warming water, cooking). Source: Catalan Building Agency (http://www.agenciahabitatge.cat)	Heat, central or small-scale, natural gas (ECOINVENT)
Wastewater building	14187.28	m3	80% of water consumption	Wastewater, from residence treatment of (ECOINVENT)

Impact assessment (20 years)

Impacts are related to the functional unit (1 ha of greenfield) and their distribution over the different categories is given in Figure 6.9.

Table 6.9 quantification of impacts for the different aspects assessed during the use of the site (per ha)

			Input					
Impact category	Unit	Total	Mobility	Tap water	Waste generation	Electricity	Heat natural gas	Wastewater
Climate change	kg CO2 eq	207526	149926	159.71	1260707	337647	1122470	204.87

			Input					
Impact category	Unit	Total	Mobility	Tap water	Waste generation	Electricity	Heat natural gas	Wastew ater
		38	16			9		
Ozone depletion	kg CFC-11 eq	1.50	1.06	1.23E-05	7.07E-03	4.34E-01	4.86E-03	8.20E-06
Human toxicity, cancer effects	CTUh	1.10	0.89	1.96E-05	1.21E-01	8.47E-02	6.56E-03	4.27E-05
Human toxicity, non-cancer effects	CTUh	7.31	3.92	5.39E-05	2.96E+00	3.95E-01	3.27E-02	5.21E-04
Particulate matter	kg PM2.5 eq	10271.99	8798.23	8.70E-02	73.76	1368.35	31.40	0.17
Ionizing radiation HH	kBq U235 eq	2905446	1168675	62.52	8010.59	1703768	24910.59	19.52
Ionizing radiation E (interim)	CTUe	8.94	5.28	1.10E-04	0.03	3.59	4.17E-02	4.83E-05
Photochemical ozone formation	kg NMVOC eq	57642.88	46100.96	0.46	1126.03	9965.76	448.77	0.90
Acidification	molc H+ eq	78253.63	54571.77	0.91	800.76	22358.05	520.19	1.95
Terrestrial eutrophication	molc N eq	154602.84	115276.23	1.58	2825.74	34853.70	1641.06	4.54
Freshwater eutrophication	kg P eq	3288.39	2572.32	0.09	59.94	614.11	41.60	0.34
Marine eutrophication	kg N eq	17383.06	10689.64	0.16	3239.76	3289.70	157.62	6.18
Freshwater ecotoxicity	CTUe	705584120	442239250	2502.59	251593190	11019458	726081.99	3639.15
Land use	kg C deficit	21244314	18770035	694.43	292549.89	2151855.8 0	28749.45	429.80
Water resource depletion	m3 water eq	376 416 91	588 250 4	471 .62	6072 8.04	315 414 20	1563 77.8 4	188.73
Mineral, fossil & ren resource depletion	kg Sb eq	204 3.32	201 4.44	1.1 7E- 02	1.61	19.1 2	8.13	5.52E- 03

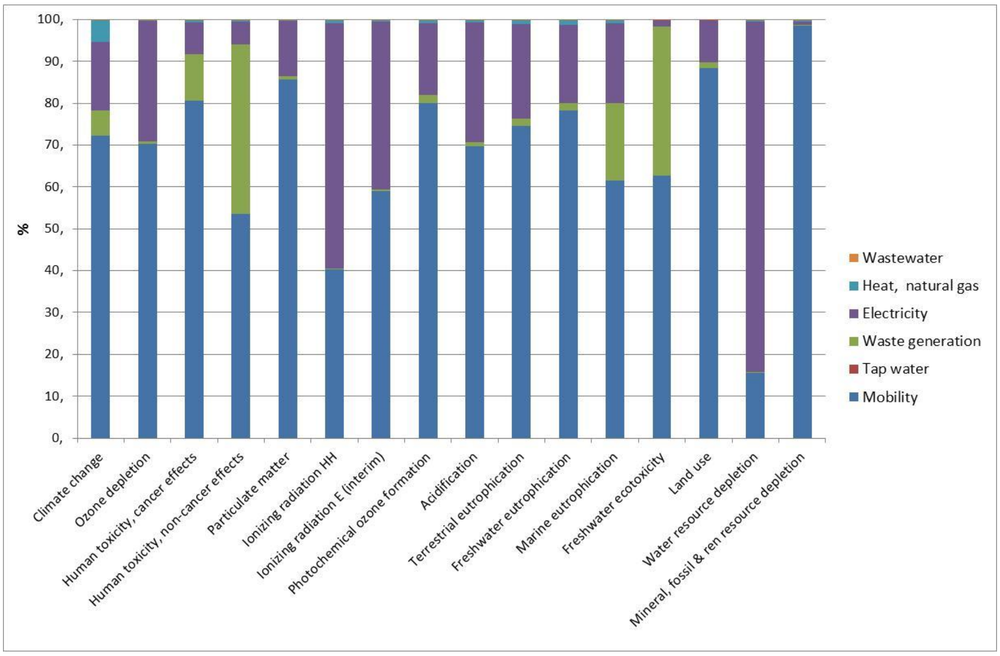

Figure 6.2 Impacts distribution for use stage (in percentages)

The main conclusions of the impact assessment from the use of the redeveloped site are:

- The highest contribution to overall impact is related to the mobility of the people living on and using the site, with more than 70% of the impact for the categories climate change, ozone depletion, human cancer toxicity, particulate matter, photochemical ozone formation, acidification, terrestrial and freshwater eutrophication, land use and fossil resource depletion.

- The second major contribution to overall impact originates from the energy consumption, which is relevant for ionizing radiation (60%) and water resource depletion (85%).

- Waste generation has relevant impacts on human non-cancer toxicity (40%) and freshwater ecotoxicity (35%).

6.5 Life cycle impacts across the greenfield system

A general environmental profile can be obtained for the greenfield considering the different life stages with a scenario for 20 years of use duration.

Table 6.10 Summary of impact values comparing the three different life stages for an operation of the site during 20 years.

			Inputs				
			Secondary				Tertiary
Impact category	**Unit**	Total	Land occupation	Topographic modification	Construction buildings	Construc. infrastructures	Use_20years_GF
Climate change	kg CO2 eq	23477052.66	620187.60	179.19	1889322.90	214724.97	20752638
Ozone depletion	kg CFC-11 eq	1.69	2.64E-04	1.17E-05	0.17	0.016	1.50
Human toxicity, cancer effects	CTUh	1.76	5.22E-04	4.31E-06	0.54	0.11	1.10
Human toxicity, non-cancer effects	CTUh	17.54	1.88E-04	8.16E-06	9.43	0.80	7.31
Particulate matter	kg PM2.5 eq	13328.29	172.62	2.18E-01	2633.88	249.58	10271.99
Ionizing radiation HH	kBq U235 eq	3042370.65	232.75	10.43	121926.74	14754.13	2905446.6
Ionizing radiation E (interim)	CTUe	9.35	0.00	6.48E-05	0.37	0.046	8.94
Photochemical ozone formation	kg NMVOC eq	69371.59	594.57	2.39E+00	10009.49	1122.25	57642.88
Acidification	molc H+ eq	113382.78	330.48	1.74	31991.06	2805.87	78253.63

Terrestrial eutrophication	molc N eq	192393.01	1394.21	8.60	32911.98	3475.38	154602.84
Freshwater eutrophication	kg P eq	8771.30	0.17	0.006	5062.85	419.90	3288.39
Marine eutrophication	kg N eq	21459.87	53.29	0.78	3659.03	363.70	17383.06
Freshwater ecotoxicity	CTUe	929514245	8749.12	179.44	205574410	18346787	7.06E+08
Land use	kg C deficit	33072065	5580740	113.21	4573520	1673378	21244314
Water resource depletion	m3 water eq	39983059	436.59	19.74	2151339	189572.28	37641691
Mineral, fossil & ren resource depletion	kg Sb eq	2434.71	75.16	1.08E-03	273.99	42.24	2043.32

Table 6.11. Summary of percentages contribution comparing the three different life stages for an operation of the greenfield during 20 years

	Inputs				
	Secondary				Tertiary
Impact category	Land occupation	Topographic modification	Construction buildings	Construc. infrastructures	Use (50years)
Climate change	3%	0,001%	8%	1%	88%
Ozone depletion	0%	0,000%	10%	1%	89%
Human toxicity, cancer effects	0%	0,000%	31%	7%	63%
Human toxicity, non-cancer effects	0%	0,000%	54%	5%	42%
Particulate matter	1%	0,000%	20%	2%	77%
Ionizing radiation HH	0%	0,000%	4%	0%	95%
Ionizing radiation E (interim)	0%	0,000%	4%	0%	96%
Photochemical ozone formation	1%	0,000%	14%	2%	83%
Acidification	0%	0,000%	28%	2%	69%
Terrestrial eutrophication	1%	0,000%	17%	2%	80%
Freshwater eutrophication	0%	0,000%	58%	5%	37%
Marine eutrophication	0%	0,000%	17%	2%	81%
Freshwater ecotoxicity	0%	0,001%	22%	2%	76%
Land use	17%	0,000%	14%	5%	64%
Water resource depletion	0%	0,000%	5%	0%	94%
Mineral, fossil & ren resource depletion	3%	0,000%	11%	2%	84%

Note: The contributions for each stage are detailed by percentage. The stage with the highest contribution is highlighted in red; while the rest of the stages with relevant contributions (≥5%) are marked in orange.

The main impacts are generated by the use stage (between 94-21% depending on the impact category), followed by the construction of new buildings. As the impact related to the use stage has a direct correlation to the years of operation, considering longer and more realistic periods of use (up to 50 years) would result in a proportional increase of the impact of this stage. The construction of infrastructures has less impact. Land/Site occupation makes a significant contribution only in the land use category. Regarding the land use impact category, it has to be commented that the model only accounts for the loss of organic carbon content from land use, while other impacts from natural land occupation, such as the loss of diversity or ecological role of the area occupied/taken, are not reflected in the results.

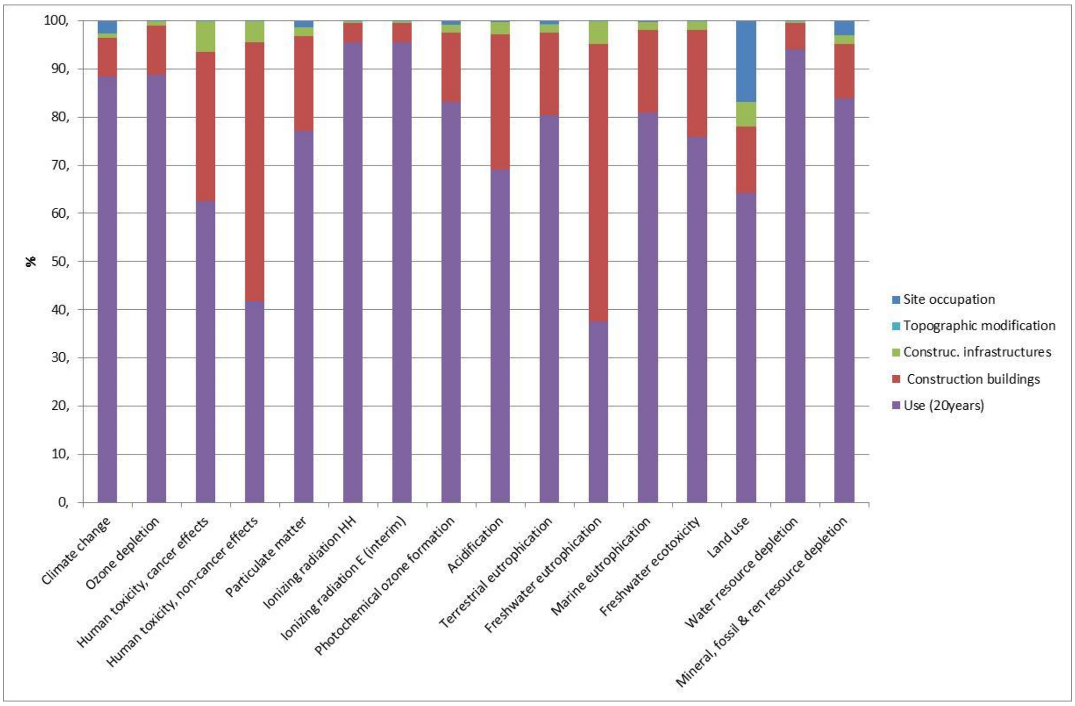

Figure 6.3. Impacts distribution for greenfield system for 20 years scenario (in percentage)

If not considering the tertiary impacts from the use of the site, the construction of buildings has the second biggest impact and counts for more than 80% of most of the impact categories. The third activity of impact importance is the land occupation (with 47% impact for land use, 23% impact for climate change and 19% for resource depletion). The construction of infrastructures has an average impact of approximately 10%.

Contribution of each life cycle stage to specific impact categories (20 years scenario)

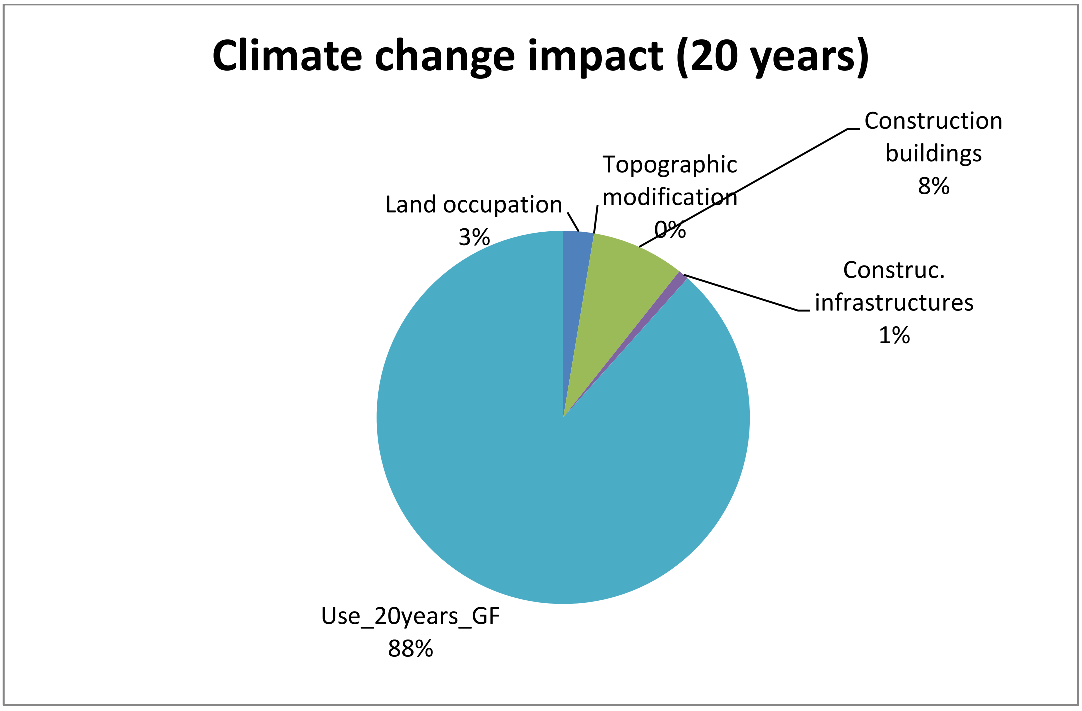

Figure 6.4. Impacts distribution for climate change category (20 years scenario)

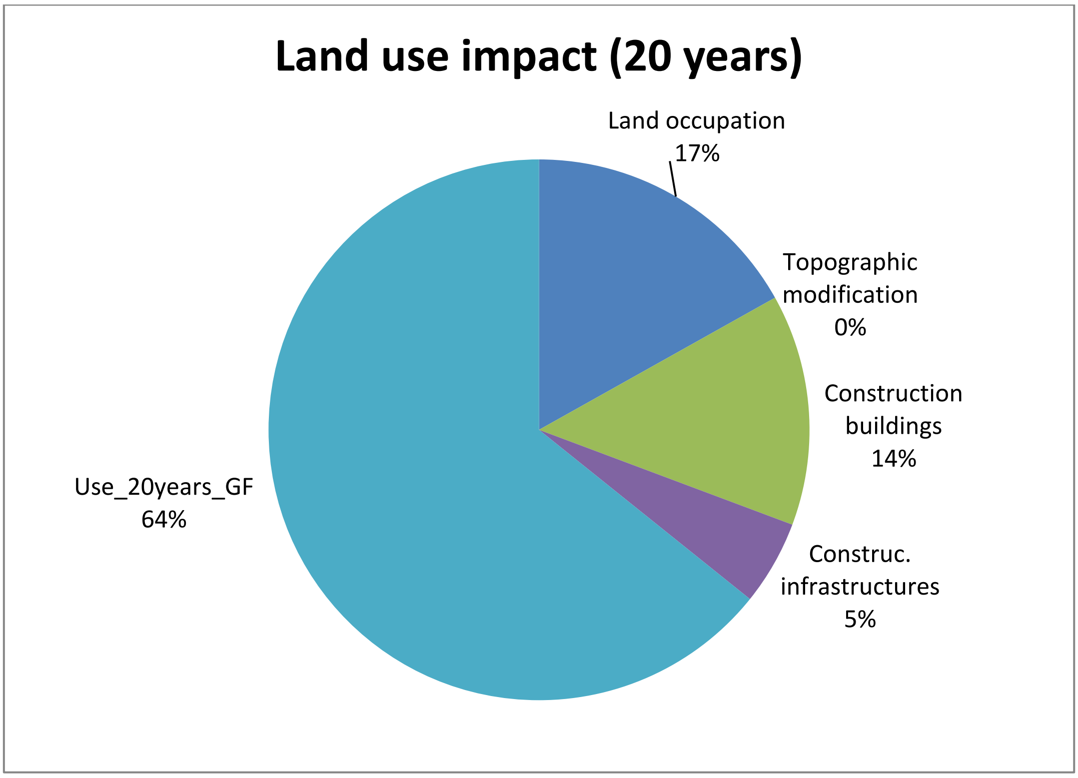

Figure 6.5. Impacts distribution for land use category (20 years scenario)

7 Comparative analysis

The assessment per case study has been done considering one hectare of the site as a functional unit. However, the use of a specific functional unit has an important impact upon the comparative results. For example, the three case studies have a different intensity regarding the ratio of constructed area/total area surface, and consequently a different population density. Thus, the common functional unit (ha) used in the analysis of each case may be not representative when comparing the three case studies, but it is suitable for comparing results inside an individual site. Therefore, additional functional units have been used for parts of the comparative analysis between the three case studies in the present chapter: the constructed area and the number of residents.)

7.1 Comparative analysis of total impacts across all life cycle stages and activities

A first exercise has been done in comparing the three case studies using the three functional units defined in the methodology. Table 7.1 shows the total impact per case study considering one hectare of site.

Table 7.1 Comparative analyses for 1 hectare functional unit for each of the three case study sites.

Impact category	Units	Total BF UK	Total BF Spain	Total GF Spain
Climate change	kg CO2 eq	10322714	23617000	23477053
Ozone depletion	kg CFC-11 eq	0.70	1.74	1.69
Human toxicity, cancer effects	CTUh	1.37	2.12	1.76
Human toxicity, non-cancer effects	CTUh	22.46	27.73	17.54
Particulate matter	kg PM2.5 eq	7731	13859	13328
Ionizing radiation HH	kBq U235 eq	1124608	3721595	3042370
Ionizing radiation E (interim)	CTUe	3.13	9.92	9.35
Photochemical ozone formation	kg NMVOC eq	37097	86430	69371
Acidification	molc H+ eq	85302	144104	113382
Terrestrial eutrophication	molc N eq	118911	226354	192393
Freshwater eutrophication	kg P eq	10552	13721	8771
Marine eutrophication	kg N eq	12704	32004	21459
Freshwater ecotoxicity	CTUe	520217120	1068963157	929514246
Land use	kg C deficit	14547984	27492233	33072065
Water resource depletion	m3 water eq	15994834	56024065	39983060
Mineral, fossil & ren resource	kg Sb eq	921.49	1870.53	2434.71

depletion				

In order to represent the total impact across all impact categories for the three case studies in the same figure, a normalisation of the data is necessary, as presented in the following figures. Normalisation is done by attributing the 100% value to the highest absolute value across all case studies and impact categories. In Figure 7.1 data is compared to a functional unit of 1 hectare of the site's area.

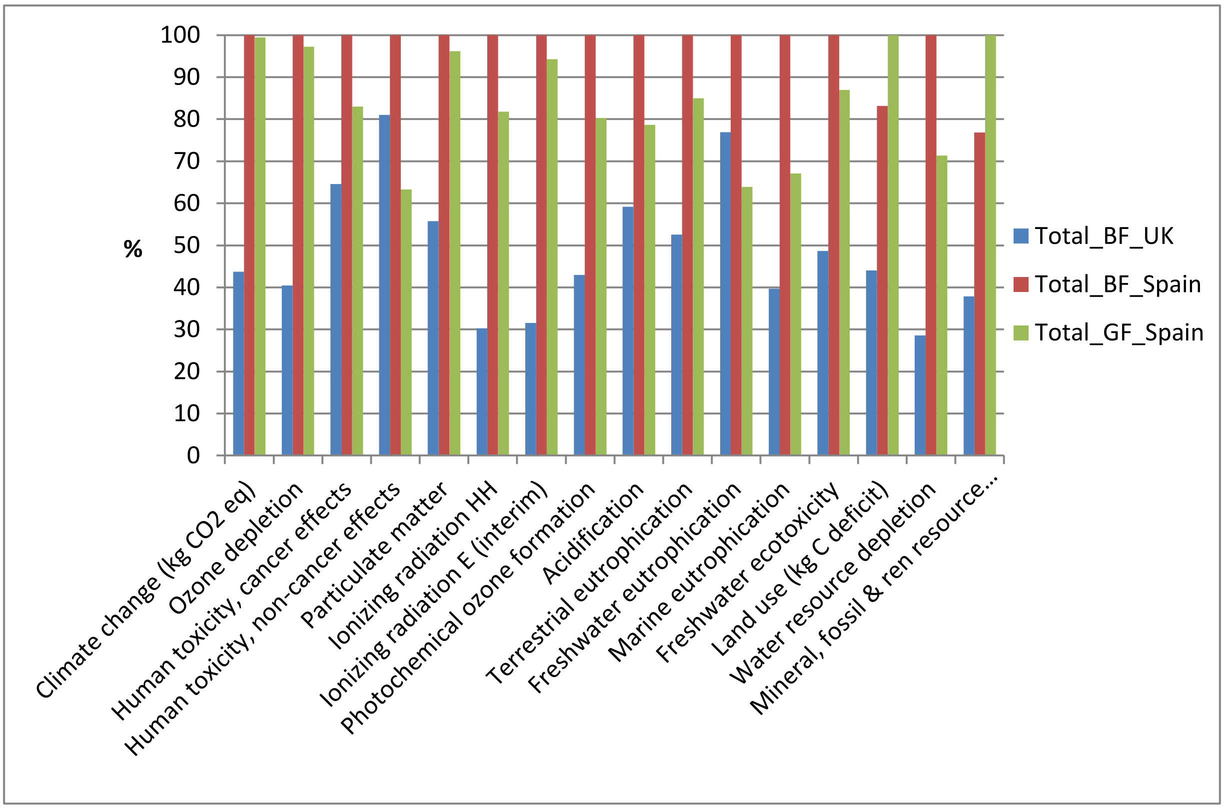

Figure 7.1 Comparative analyses across the three case studies for 1 hectare functional unit.

Figure 7.1 shows that, when comparing all the impacts on a one hectare basis, the brownfield site in Terrassa has the highest impact across almost all impact categories, which can be explained by the small surface (3 ha) of the site compared with the other two sites. Even considering that the greenfield has the biggest surface, the impacts for land use and resource depletion are nevertheless highest compared with the two brownfields and many of the impact categories show impacts above 80%.

In Table 7.2 and Figure 7.2 the same comparative analyses have been done but with 1 resident as the functional unit.

Table 7.2 Comparative analyses across the three case studies for 1 resident functional unit

Impact category	Units	Total BF UK	Total BF Spain	Total GF Spain
Climate change	kg CO2 eq	132470	57086	83607
Ozone depletion	kg CFC-11 eq	9.03E-03	4.21E-03	6.03E-03
Human toxicity, cancer effects	CTUh	1.76E-02	5.13E-03	6.27E-03
Human toxicity, non-cancer effects	CTUh	2.88E-01	6.70E-02	6.25E-02
Particulate matter	kg PM2.5 eq	99.21	33.50	47.46
Ionizing radiation HH	kBq U235 eq	14432	8995	10834
Ionizing radiation E (interim)	CTUe	4.02E-02	2.40E-02	3.33E-02
Photochemical ozone formation	kg NMVOC eq	476.07	208.92	247.05
Acidification	molc H+ eq	1094.67	348.32	403.78
Terrestrial eutrophication	molc N eq	1525.99	547.14	685.16
Freshwater eutrophication	kg P eq	135.42	33.16	31.23
Marine eutrophication	kg N eq	163.04	77.36	76.42
Freshwater ecotoxicity	CTUe	6675919	2583874	3310235
Land use	kg C deficit	186693	66453	117778
Water resource depletion	m3 water eq	205260	135420	142389
Mineral, fossil & ren resource depletion	kg Sb eq	11.82	4.52	8.67

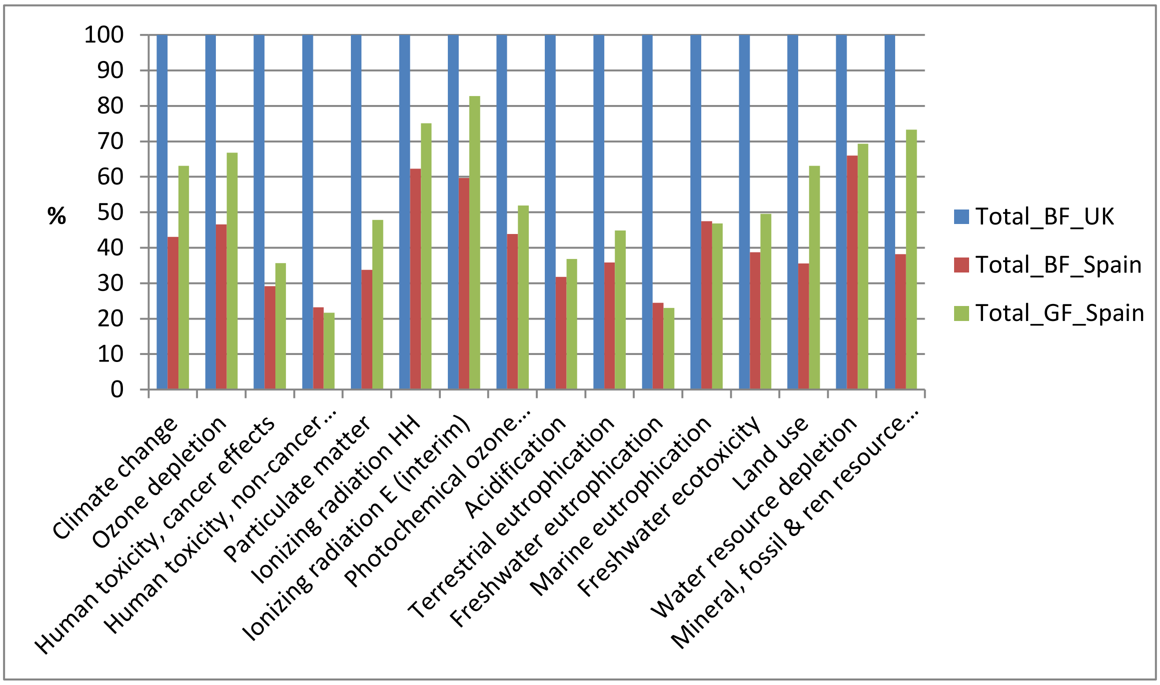

Figure 7.2 Comparative analyses across the three case studies for 1 resident functional unit.

Figure 7.2 shows that, when comparing all the impacts to resident unit, the brownfield site in UK has the highest impact across all impact categories, which can be explained by the small number of residents expected (600 residents compared with 1,300 and 13,300 residents in Terrassa BF and GF, respectively). When comparing both sites in Terrassa, the greenfield site has the highest impacts across almost all impact categories, despite its population being 10 times higher than that of the BF.

Finally in Table 7.3 and Figure 7.3 similar comparative analyses have been done with 1 m^2 of constructed area as the functional unit.

Table 7.3 Comparative analyses across the three case studies for 1 m^2 of constructed area functional unit.

Impact category	Units	Total BF UK	Total BF Spain	Total GF Spain
Climate change	kg CO2 eq	1987	3188	8918
Ozone depletion	kg CFC-11 eq	1.35E-04	2.35E-04	6.43E-04
Human toxicity, cancer effects	CTUh	2.64E-04	2.86E-04	6.68E-04
Human toxicity, non-cancer effects	CTUh	4.32E-03	3,74E-03	6.66E-03
Particulate matter	kg PM2.5 eq	1.48	1.87	5.06
Ionizing radiation HH	kBq U235 eq	216.43	502.30	1155

Impact category	Units	Total BF UK	Total BF Spain	Total GF Spain
Ionizing radiation E (interim)	CTUe	6.03E-04	1.34E-03	3.55E-03
Photochemical ozone formation	kg NMVOC eq	7.14	11.66	26.35
Acidification	molc H+ eq	16.41	19.44	43.07
Terrestrial eutrophication	molc N eq	22.88	30.55	73.08
Freshwater eutrophication	kg P eq	2.03	1.85	3.33
Marine eutrophication	kg N eq	2.44	4.32	8.15
Freshwater ecotoxicity	CTUe	100119	144277	353092
Land use	kg C deficit	2800	3711	12563
Water resource depletion	m3 water eq	3078	7562	15188
Mineral, fossil & ren resource depletion	kg Sb eq	1.77E-01	2.52E-01	9.25E-01

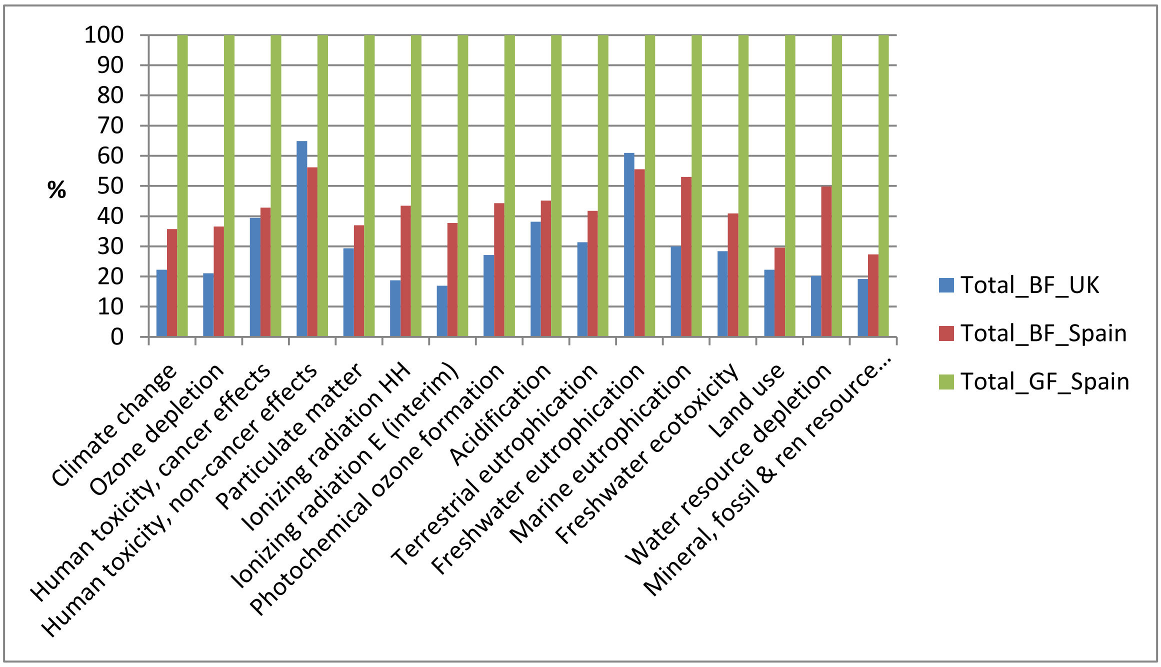

Figure 7.3 Comparative analyses across the three case studies for 1 m^2 of constructed area functional unit.

The main conclusion from Figure 7.3 indicates that, when comparing all the impacts on the basis of 1 m^2 of constructed area, the greenfield site in Terrassa has the highest impact across all impact categories, even though it has the largest built area (approximately 130,000 m^2 in comparison with the BF in Terrassa with 22,600 m^2 and the 40,000 m^2 of the BF in UK).

In Figure 7.4 the total impact per site across the impact categories with global impacts (climate change, ozone depletion, land use, water resource depletion and mineral, fossil & removable resources depletion) are presented together and compared on the basis of one hectare of site as functional unit (absolute values).

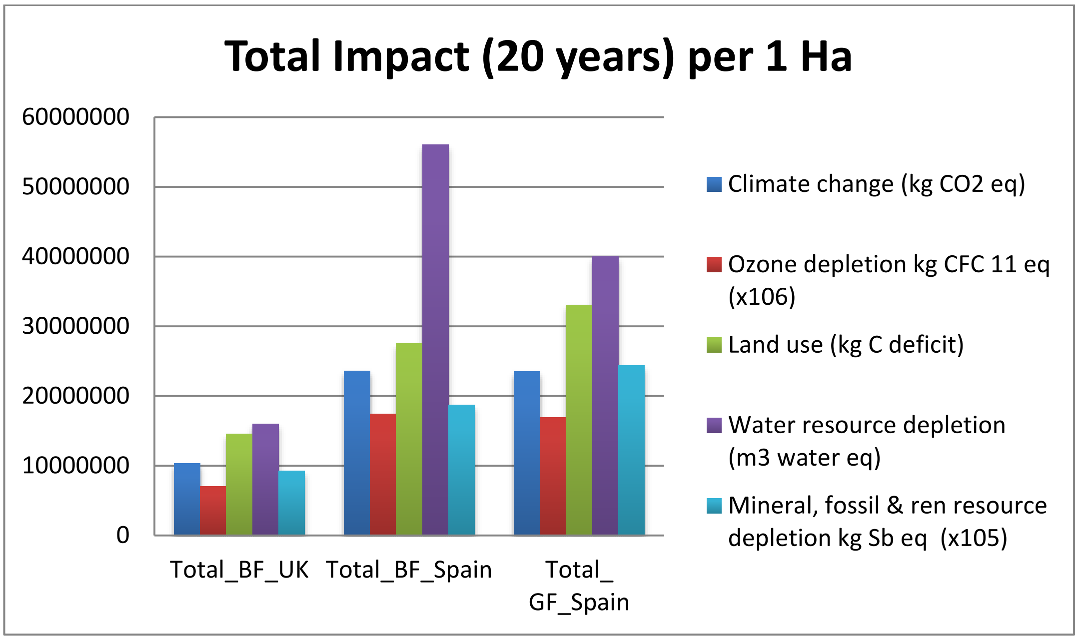

Figure 7.4 Comparative analyses across the three case studies for 1 ha of constructed area functional unit for impact categories

A similar analysis for the same impact categories has been done with one resident as functional unit.

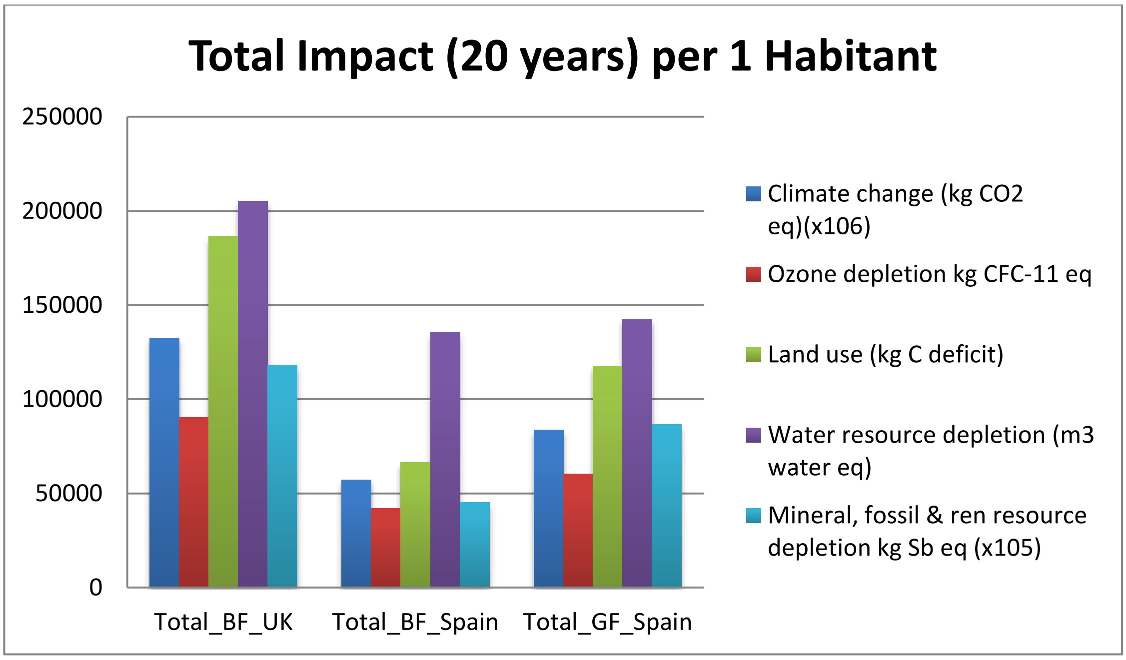

Figure 7.5 Comparative analyses across the three case studies for 1 resident functional unit for selected impact categories.

Finally the analyses for the functional unit of 1 m^2 of constructed area is presented in Figure 7.6.

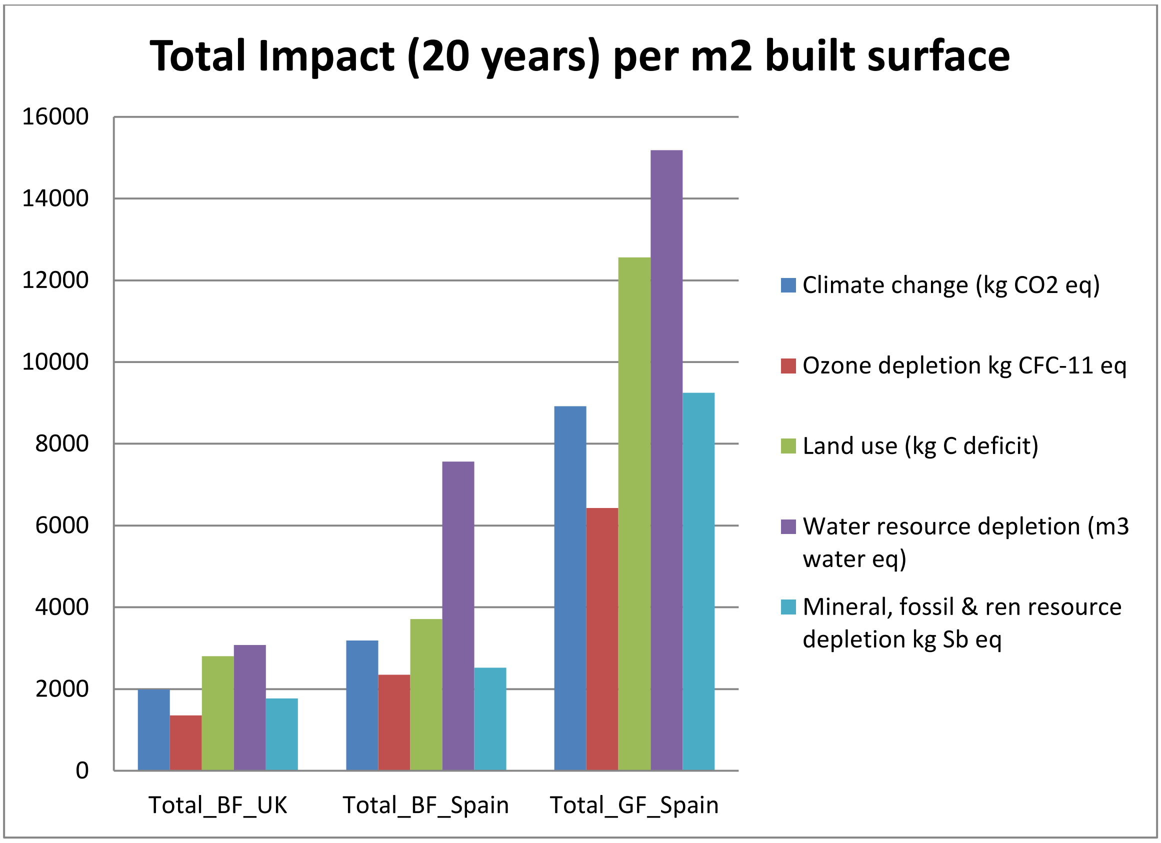

Figure 7.6 Comparative analyses across the three case studies for 1 m^2 of constructed area functional unit for selected impact categories.

The same comparison is being presented for the local/regional impact categories in the following figures (Figures 7.7 to 7.9): human toxicity –cancer effects, human toxicity – non-cancer effects, particulate matter, ionizing radiation for human health, ionizing radiation for ecosystems, photochemical ozone formation and acidification, terrestrial eutrophication, freshwater eutrophication, marine eutrophication, or freshwater ecotoxicity (depending on the relevance to the respective functional unit).

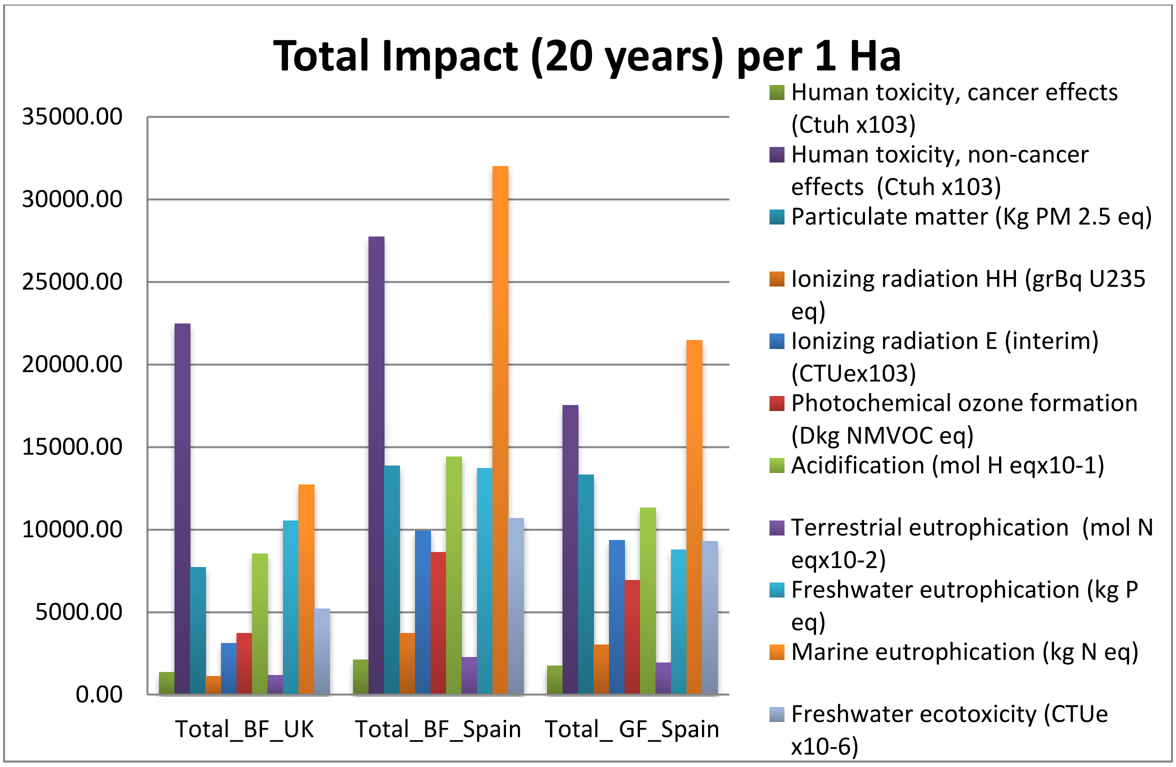

Figure 7.7 Comparative analyses across the three case studies for 1 ha of site functional unit for local/regional impact categories.

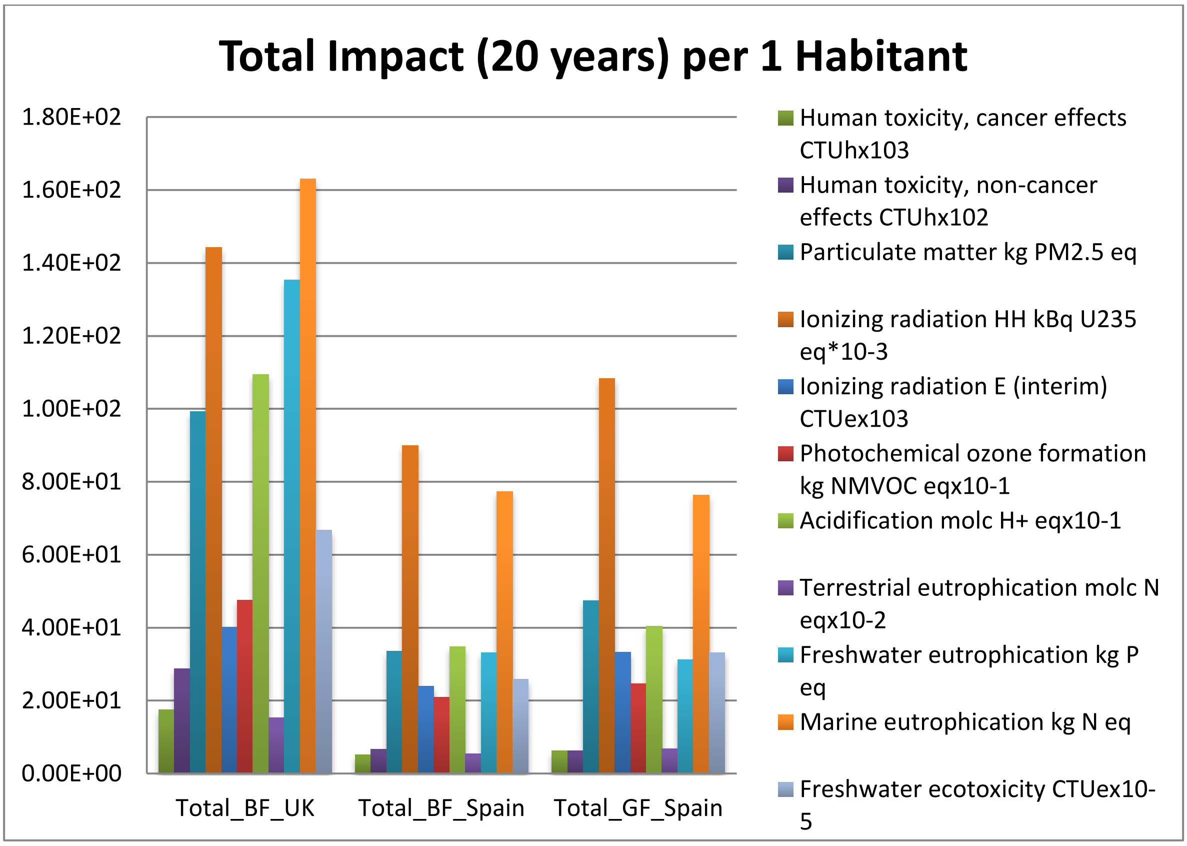

Figure 7.8. Comparative analyses across the three case studies for 1 habitant of site functional unit for local/regional impact categories

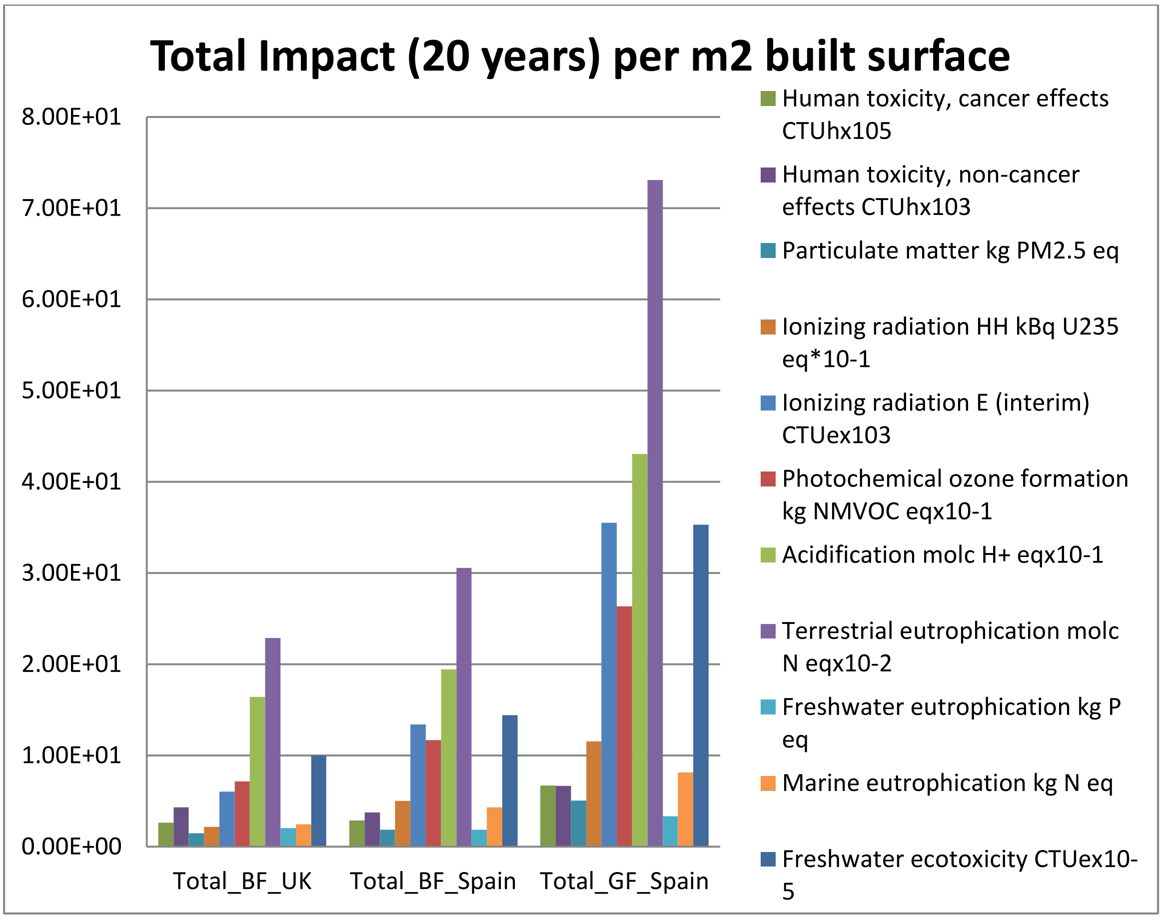

Figure 7.9 Comparative analyses across the three case studies for 1 m2 of constructed area of site functional unit for local/regional impact categories

From the above analysis it can be concluded that:

- Total impacts across all impact categories are higher in the greenfield when using the functional unit of 1 m^2 of constructed area, but not when using the other functional units.
  When considering the functional unit of one resident, the impact is higher for the brownfield site in UK, because the number of residents is comparatively lower than for the other sites. However, when comparing the greenfield and brownfield sites in Terrassa, the total impact for the selected categories is higher in the greenfield, despite the higher number of residents in the greenfield, except for the freshwater eutrophication and human toxicity (non-cancer) categories, for which the impact is is higher in the brownfield.

In conclusion, it is apparent that the choice of the functional unit is a critical parameter for the environmental analysis and can cause significant variations in the final results. The choice of the functional unit is especially important for comparative analysis among different brownfield cases with different characteristics of: surface, use (operational stage), surface covered with constructions (buildings, infrastructure) and expected residents/users. In addition, using built area as the basis for the functional unit shows particular relevance when comparing brownfields with greenfields. This is particularly relevant considering that the evaluation of land use impacts has its limitations in taking account of some effects only (e.g. no ecological effects considered).

For the purpose of this study (including the comparison of brownfields and greenfields) it is considered that the comparison on the basis of the constructed area is the most appropriate. Expressing the impacts per unit area or per resident results in distortions (e.g. the highest impact per resident for the site with the lowest number of residents). However, using the constructed area as functional unit results in the greenfield having the highest impacts, despite having the highest constructed surface of the three sites.

A similar comparison has been done grouping the activities according to primary (when relevant, depending on the impact category as well as the type of site: BF or GF), secondary and tertiary impacts across all impact categories as shown in Figures 7.10 to 7.25.

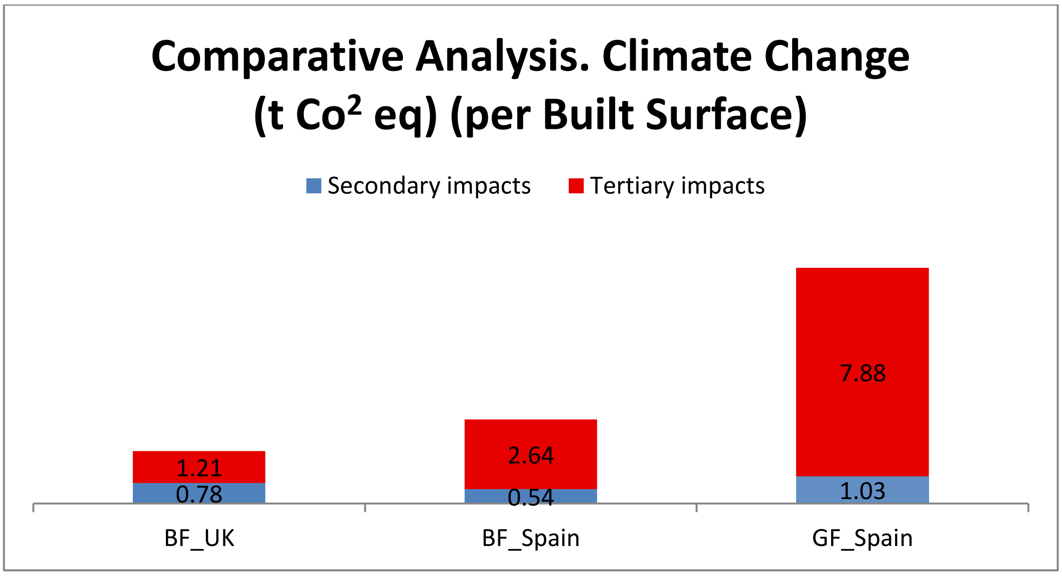

Figure 7.10. Comparative analyses across the three case studies for constructed area functional unit for Climate Change

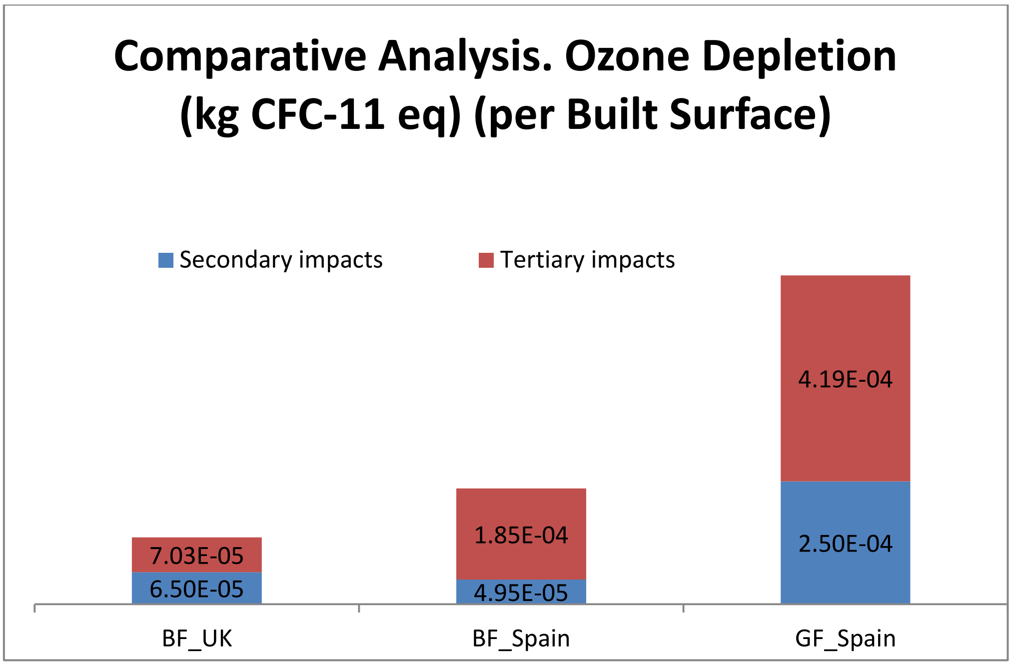

Figure 7.11 Comparative analyses across the three case studies for constructed area functional unit for Ozone depletion

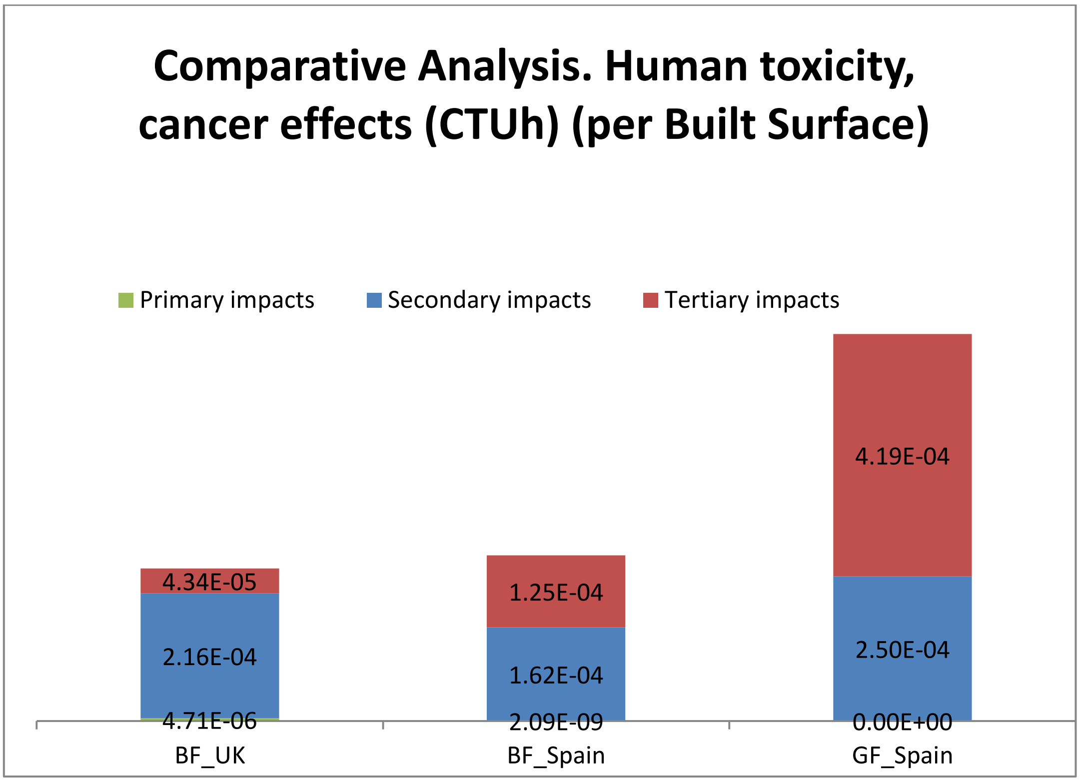

Figure 7.12 Comparative analyses across the three case studies for constructed area functional unit for Human toxicity, cancer effects.

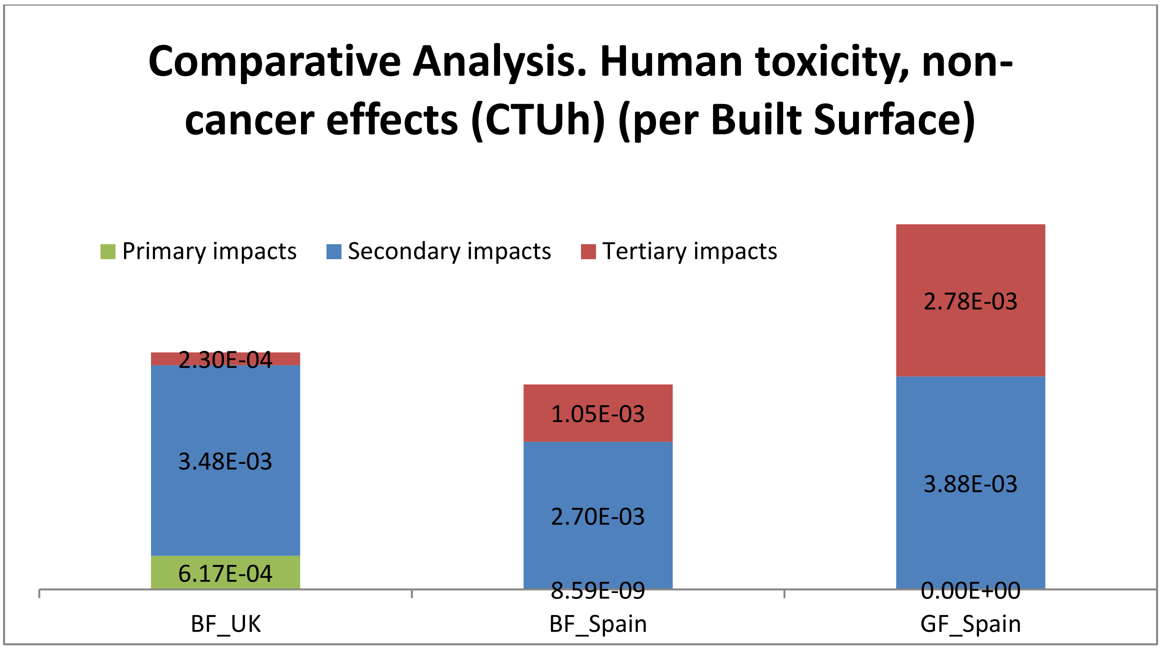

Figure 7.13 Comparative analyses across the three case studies for constructed area functional unit for Human toxicity, non- cancer effects.

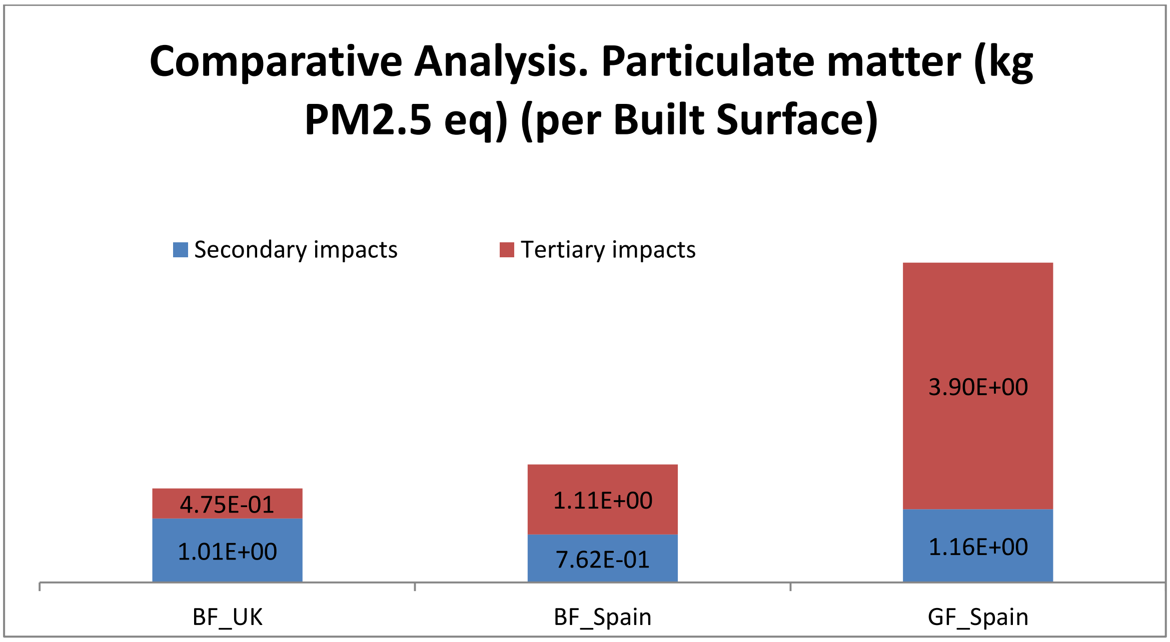

Figure 7.14 Comparative analyses across the three case studies for constructed area functional unit for Human toxicity, particulate matter.

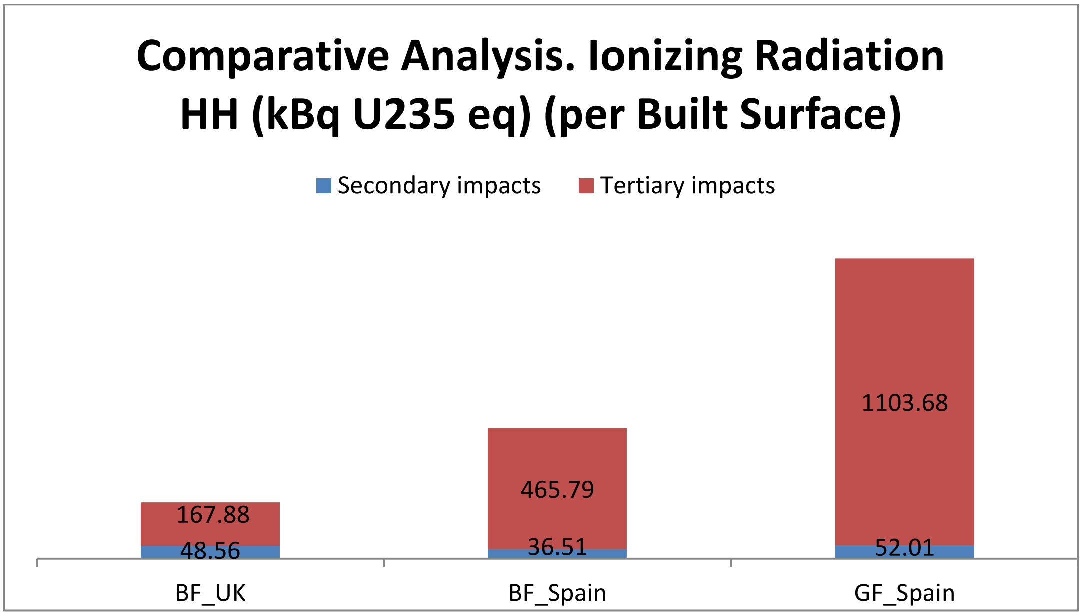

Figure 7.15 Comparative analyses across the three case studies for constructed area functional unit for Ionizing Radiation HH

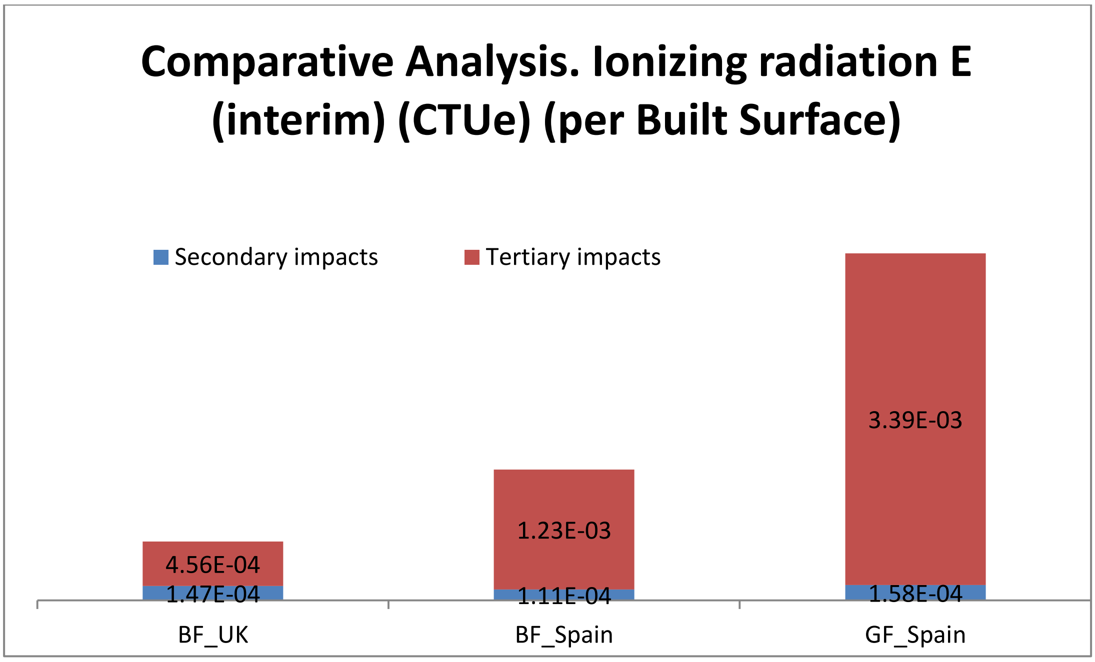

Figure 7.16 Comparative analyses across the three case studies for constructed area functional unit for Ionizing Radiation E

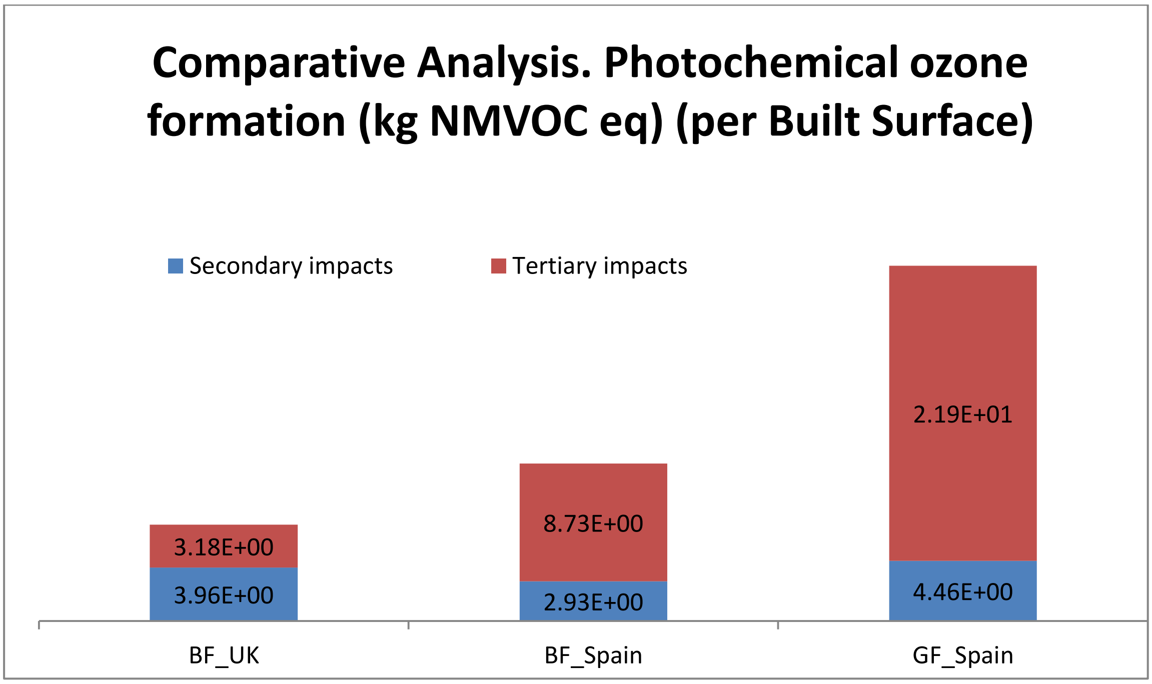

Figure 7.17 Comparative analyses across the three case studies for constructed area functional unit for photochemical ozone formation

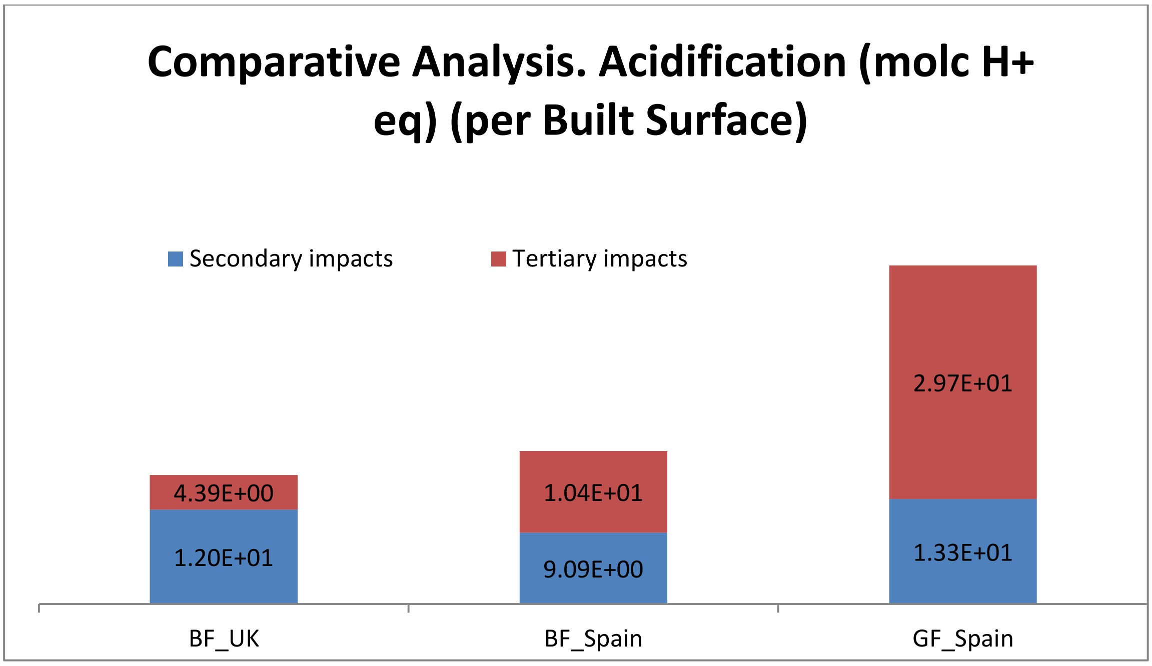

Figure 7.18 Comparative analyses across the three case studies for constructed area functional unit for Acidification

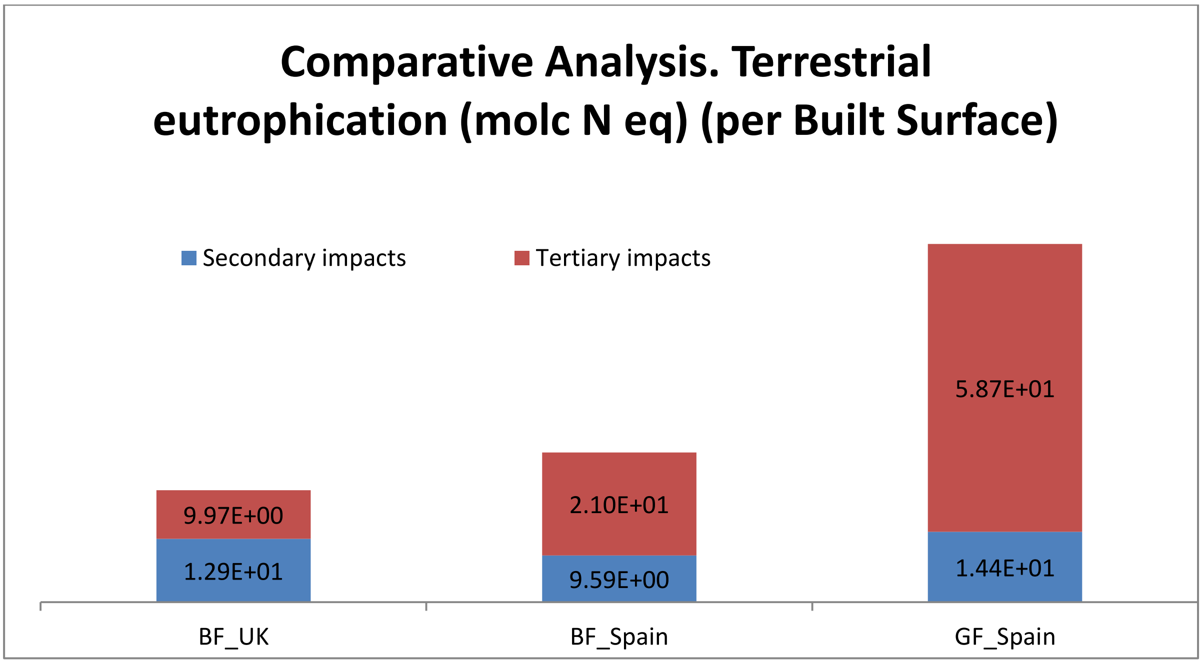

Figure 7.19 Comparative analyses across the three case studies for constructed area functional unit for Terrestrial eutrophication

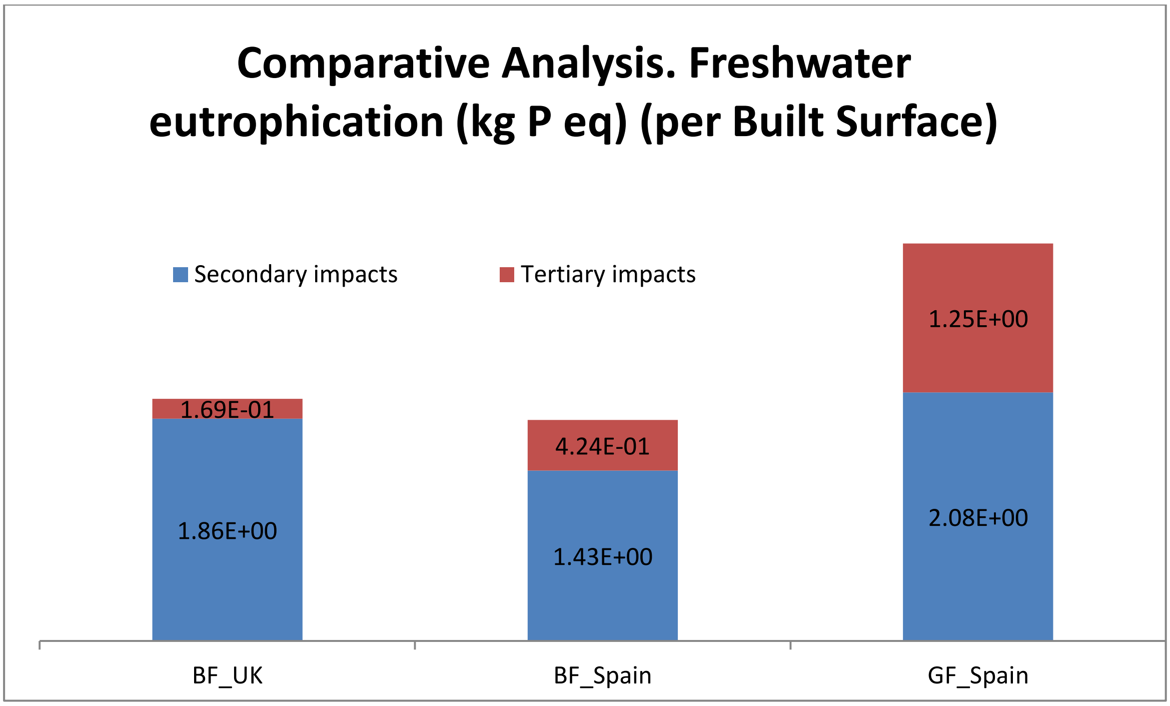

Figure 7.20 Comparative analyses across the three case studies for constructed area functional unit for Freshwater eutrophication

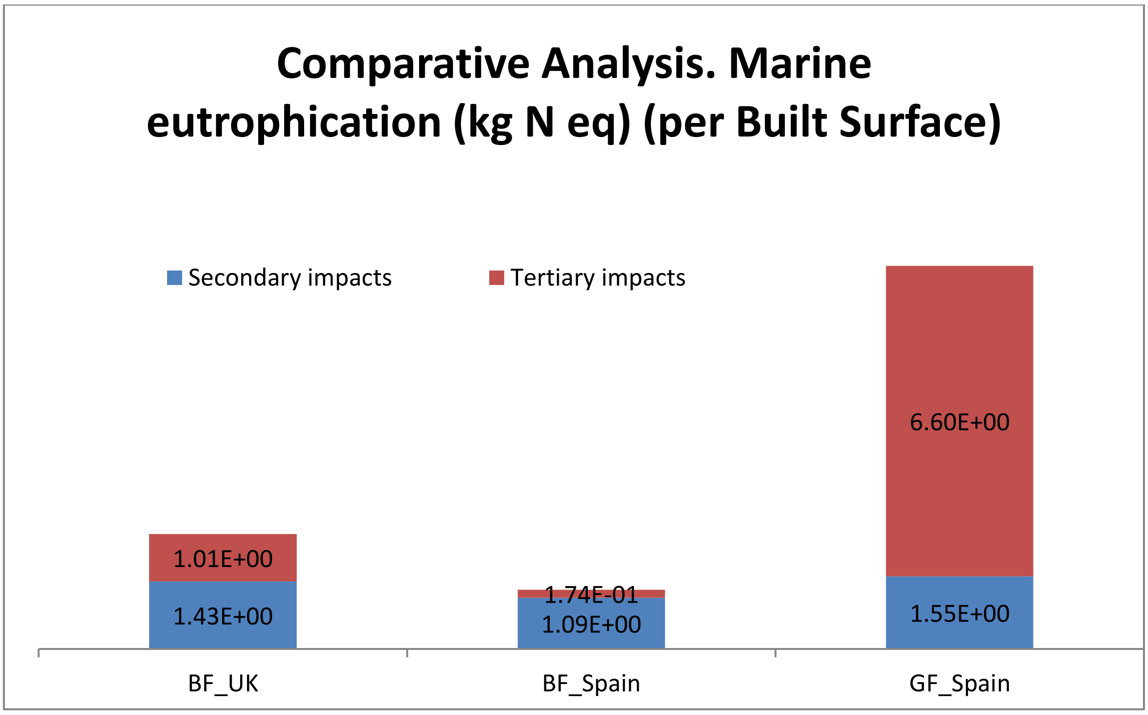

Figure 7.21 Comparative analyses across the three case studies for constructed area functional unit for Marine eutrophication

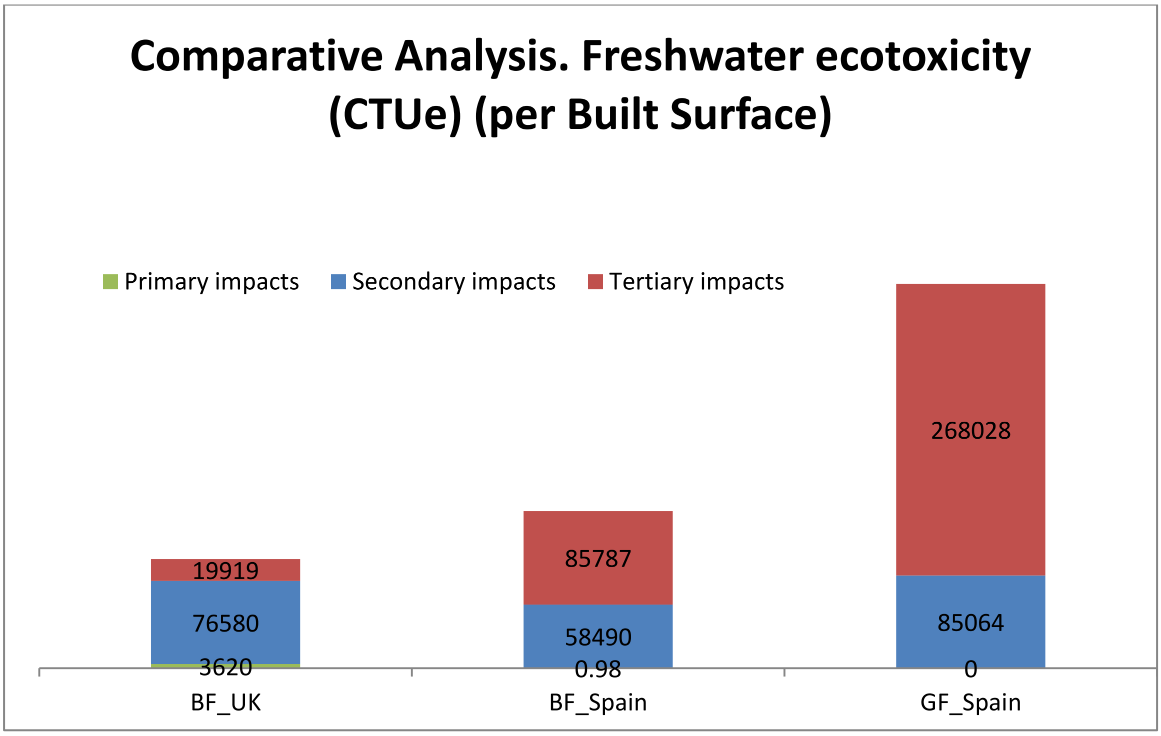

Figure 7.22 Comparative analyses across the three case studies for constructed area functional unit for Freshwater Eco toxicity

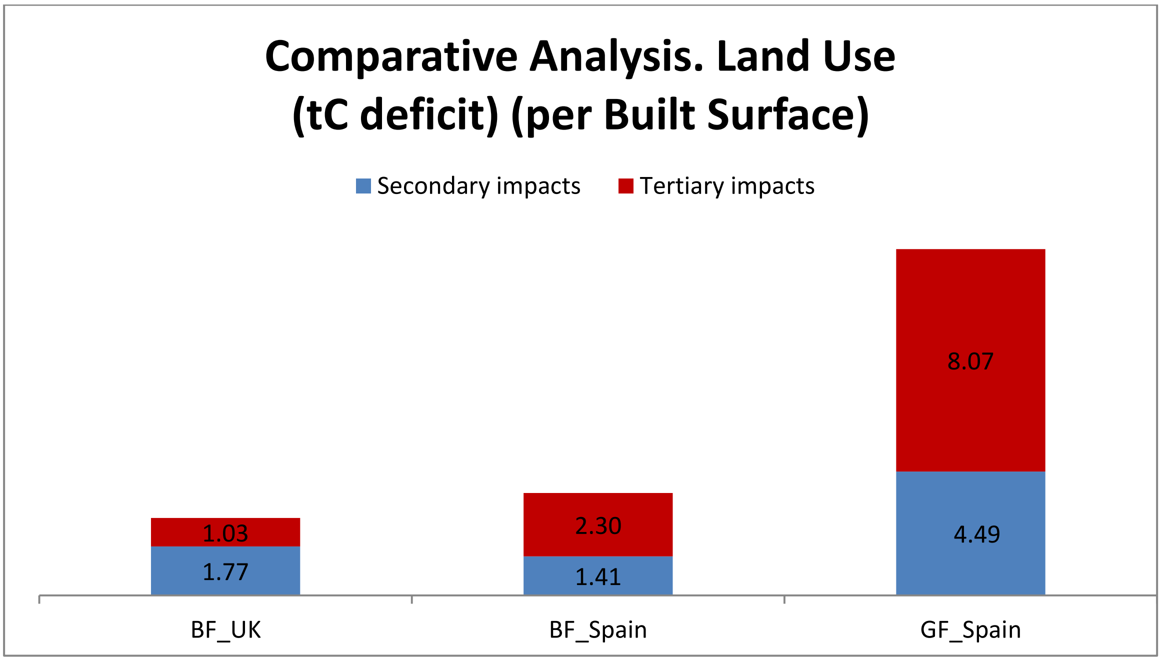

Figure 7.23 Comparative analyses across the three case studies for constructed area functional unit for Land Use

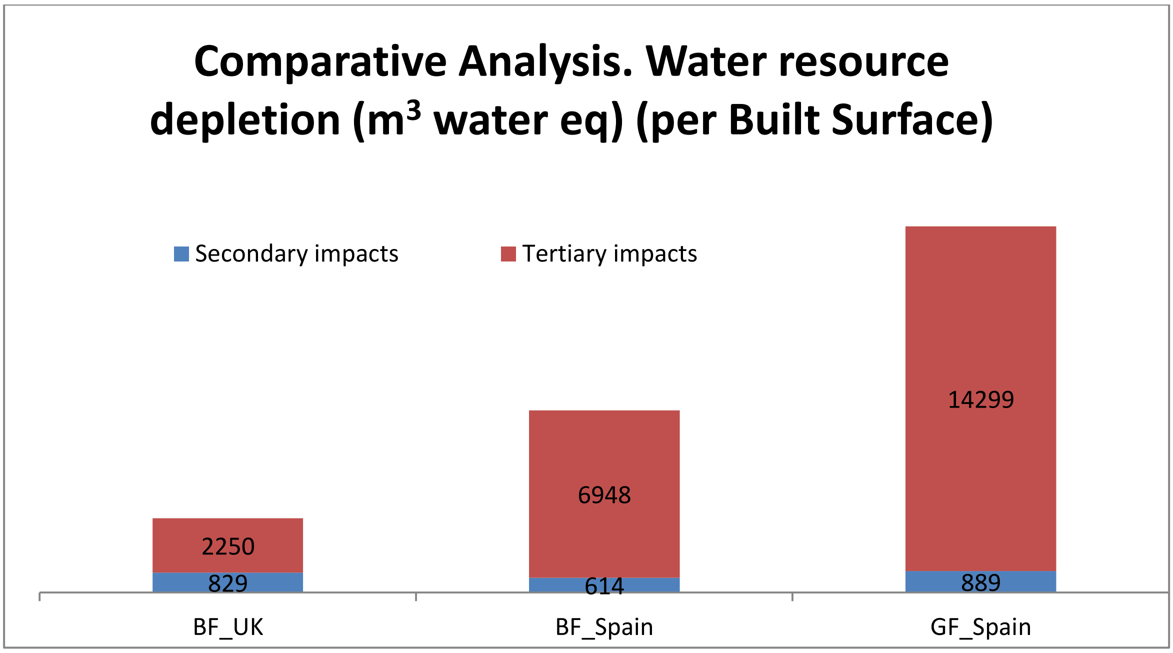

Figure 7.24 Comparative analyses across the three case studies for constructed area functional unit for Water Resource Depletion

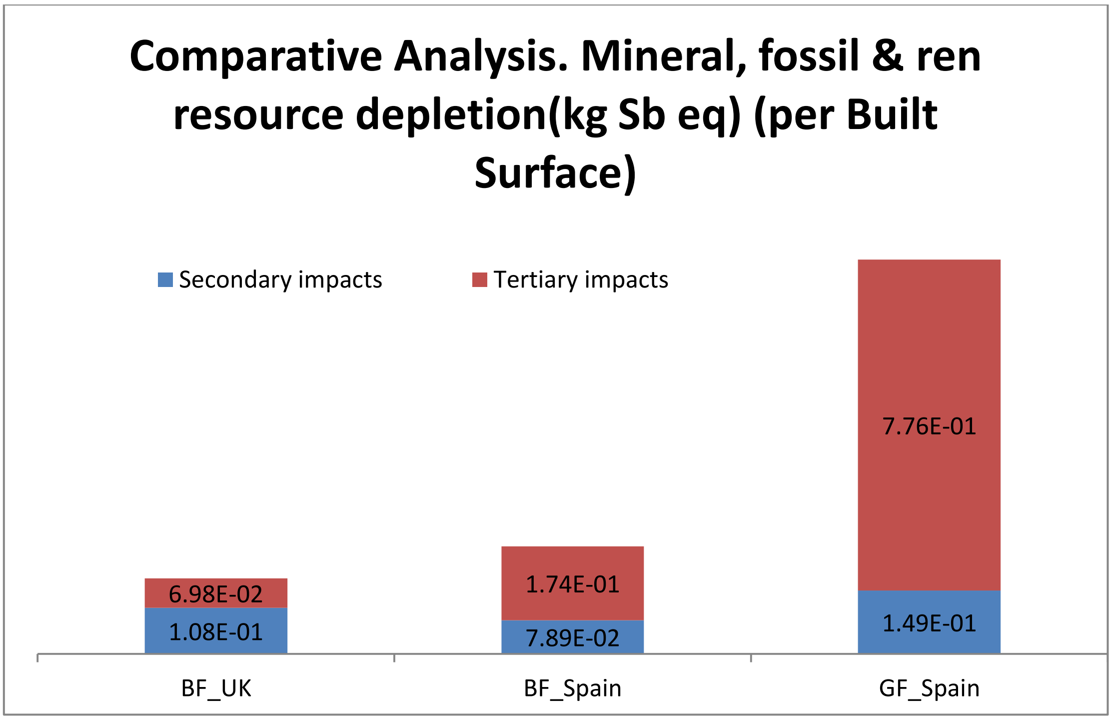

Figure 7.25 Comparative analyses across the three case studies for constructed area functional unit for Mineral, fossil & ren resource depletion

From the above comparative figures it can be concluded that, when comparing both brownfields, the BF in UK generates higher secondary impacts (site development), while the BF in Spain generates higher tertiary impacts (use stage of the site).

For the BF and GF in Spain, tertiary impacts are clearly bigger than secondary impacts for almost all the impact categories. Meanwhile for BF in UK, in 70% of the impact categories the secondary impacts are bigger than the tertiary impacts. This is due to the low number of residents/low population density in the UK BF, also when seen in relation to the construction surface (see Table 3.4), resulting in a lower impact of the use stage compared to the other sites.

It is also remarkable that secondary and primary impacts on human toxicity and freshwater eutrophication are higher than tertiary impacts for the three sites, mainly due to the relevance of these impact categories in construction activities (secondary), as well as to in-situ contamination (only for the brownfield sites).

For the impact categories relevant for global impacts (climate change, ozone depletion, water resources depletion and resources depletion), tertiary impacts are clearly dominant (over secondary impacts).

7.2 Comparative analysis of relevant impact categories for selected activities

Figures representing all impact categories are done with normalised values since the different impact categories have different units; accordingly, the values are represented as relative contributions (percentages). When the comparative analysis is presented for a single impact category, the graphics can be represented using the real values (characterisation factors/units).

The comparison has been done for the activities that were present in the three case studies: construction of buildings, construction of infrastructures (secondary impacts), and site use (tertiary impacts).

Building construction impact

In Table 7.4 and figures 7.14 and 7.15 a comparative analysis for the impacts of the building construction stage/activity across all impact categories for the three case studies is presented, standardised to the functional unit 1 m^2 of constructed area. It can be seen that the greenfield has the highest impacts, followed by the UK brownfield. The Spanish brownfield (Terrassa) has the lower impacts. For the two brownfields this matches with the conclusions drawn from Figures 7.10 to 7.25 (results also expressed per m^2 of built surface), according to which the secondary impacts (related to site actuation) for most impact categories in the UK BF are proportionally higher than the tertiary impacts, and are also higher than those in the ES BF.

Table 7.4 Comparative analyses of impacts from building construction for 1 m^2 of constructed area functional unit across the three case studies.

Impact category	Units	BF UK	BF Spain	GF Spain
Climate change	kg CO2 eq	686.70	525.35	717.69
Ozone depletion	kg CFC-11 eq	6.24492E-05	4.77754E-05	6.52675E-05
Human toxicity. cancer effects	CTUh	1.97E-04	1.51E-04	2.06E-04
Human toxicity. non-cancer effects	CTUh	3.43E-03	2.62E-03	3.58E-03
Particulate matter	kg	9.57E-01	7.32E-01	1.00E+00

Impact category	Units	BF UK	BF Spain	GF Spain
	PM2.5 eq			
Ionizing radiation HH	kBq U235 eq	44.32	33.90	46.32
Ionizing radiation E (interim)	CTUe	1.33E-04	1.02E-04	1.39E-04
Photochemical ozone formation	kg NMVOC eq	3.64	2.78	3.80
Acidification	molc H+ eq	11.63	8.90	12.15
Terrestrial eutrophication	molc N eq	11.96	9.15	12.50
Freshwater eutrophication	kg P eq	1.84	1.41	1.92
Marine eutrophication	kg N eq	1.33	1.02	1.39
Freshwater ecotoxicity	CTUe	74719	57162	78091
Land use	kg C deficit	1662	1272	1737
Water resource depletion	m3 water eq	781.94	598.20	817.22
Mineral. fossil & ren resource depletion	kg Sb eq	9.96E-02	7.62E-02	1.04E-01

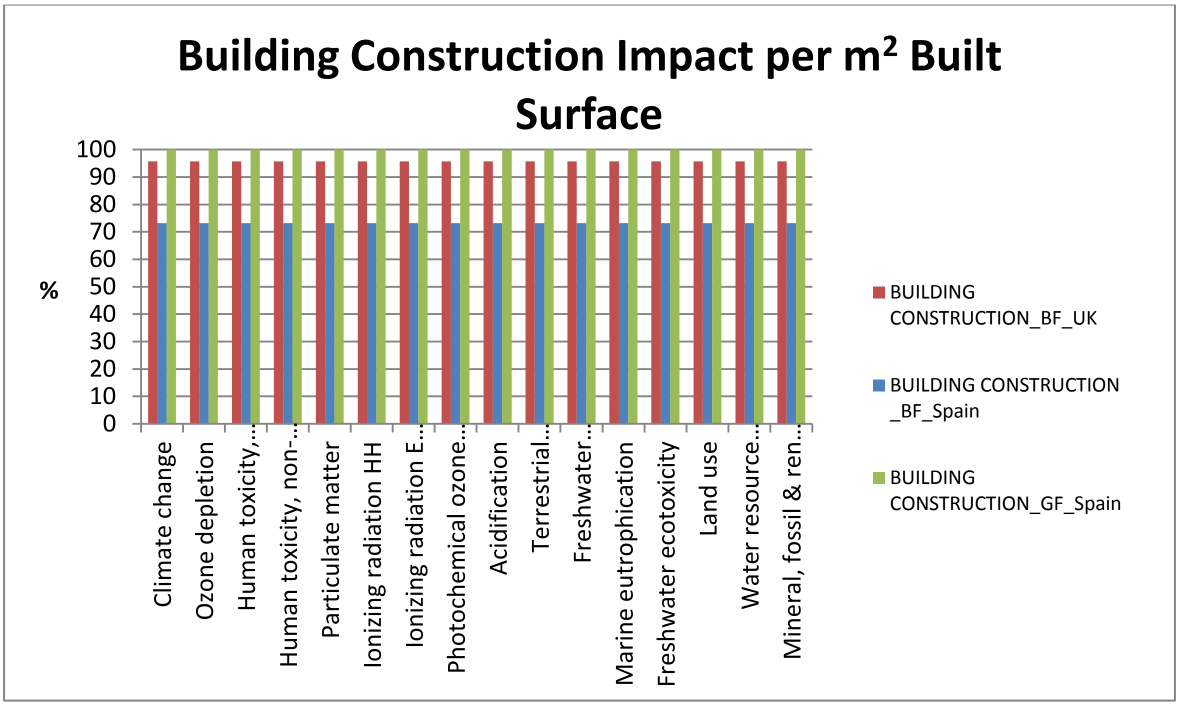

Figure 7.26 Comparative analyses of impacts from building construction for 1 m² of constructed area functional unit across the three case studies.

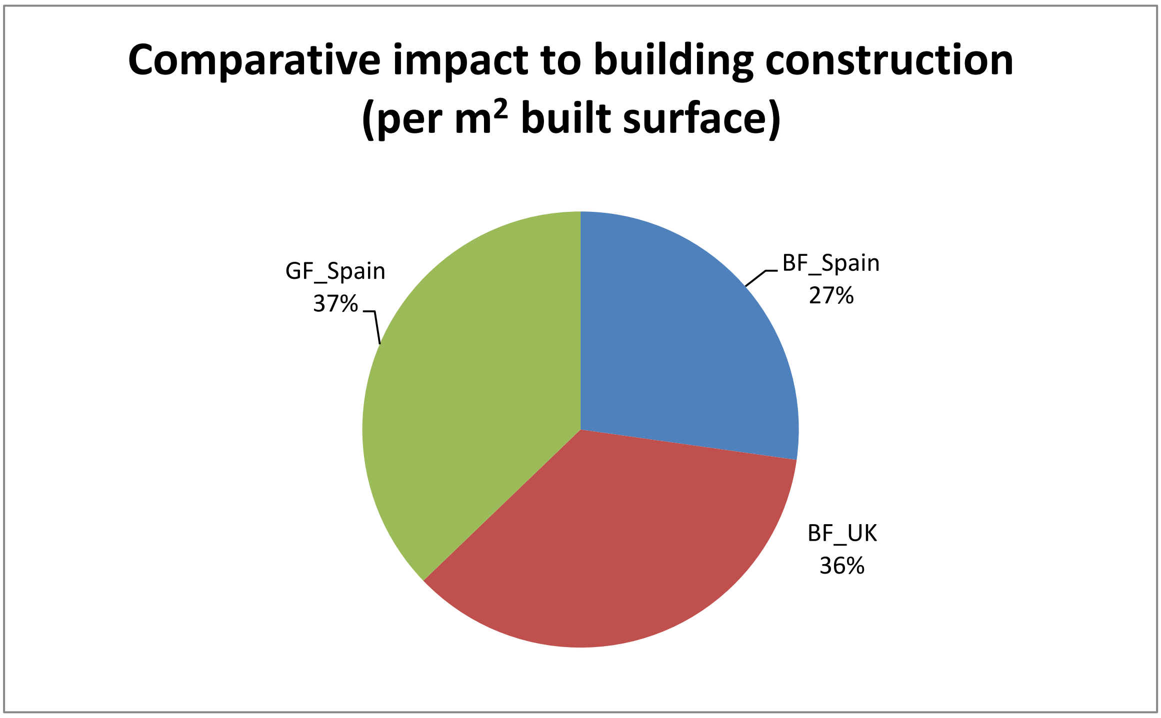

Figure 7.27 Comparative analyses of climate change impacts from building construction for 1 m² of constructed area functional unit across the three case studies.

Differences in climate change impacts across the three sites due to the construction activity are considered irrelevant (Figure 7.27), as the type of construction material has been considered the same for the three sites (due to the lack of detailed information on the construction projects).

Construction of infrastructure impact

Table 7.5 Comparative analyses across the three case studies of impacts from infrastructure construction for 1 m^2 of constructed area functional unit.

Impact category	Units	BF UK	BF Spain	GF Spain
Climate change	kg CO2 eq	74.15	12.36	81.57
Ozone depletion	kg CFC-11 eq	2.38E-06	1.39E-06	6.24E-06
Human toxicity, cancer effects	CTUh	1.77E-05	3.30E-06	4.35E-05
Human toxicity, non-cancer effects	CTUh	2.51E-05	3.61E-05	3.03E-04
Particulate matter	kg PM2.5 eq	5.34E-02	1.44E-02	9.48E-02
Ionizing radiation HH	kBq U235 eq	3.99	2.24	5.60
Ionizing radiation E (interim)	CTUe	1.29E-05	7.14E-06	1.76E-05
Photochemical ozone formation	kg NMVOC eq	3.05E-01	1.06E-01	4.26E-01
Acidification	molc H+ eq	3.70E-01	1.62E-01	1.07E+00
Terrestrial eutrophication	molc N eq	9.27E-01	2.84E-01	1.32E+00
Freshwater eutrophication	kg P eq	1.43E-02	1.95E-02	1.60E-01
Marine eutrophication	kg N eq	8.51E-02	2.76E-02	1.38E-01
Freshwater ecotoxicity	CTUe	1041.16	863.75	6969.34
Land use	kg C deficit	105.79	90.99	635.66
Water resource depletion	m3 water eq	40.97	14.13	72.01
Mineral, fossil & ren resource depletion	kg Sb eq	7.97E-03	2.66E-03	1.60E-02

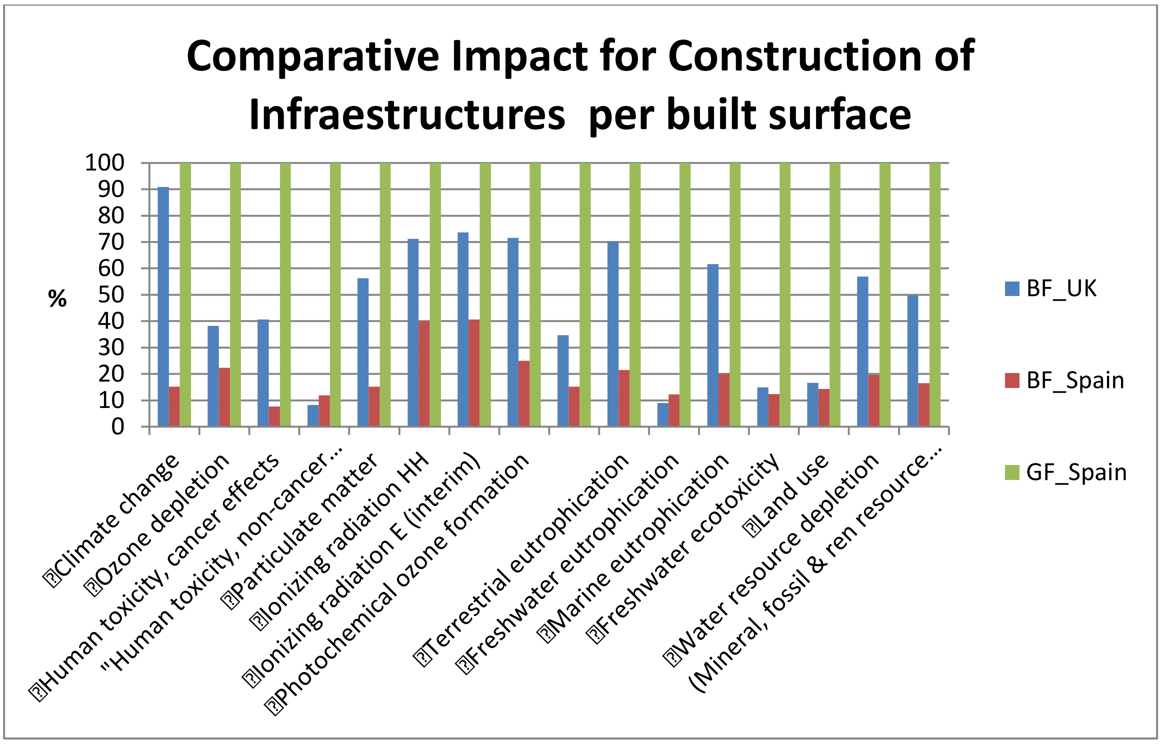

Figure 7.28 Comparative analyses across the three case studies for 1 m^2 constructed area functional unit for construction of infrastructures

For the construction of infrastructures the impacts on the greenfield are highest due to the necessity of building new roads, water supply and wastewater pipelines, as well as electricity, gas and communication networks. When comparing both brownfields, the impact for the BF in the UK is higher due to the necessity to build new infrastructures, while most of the infrastructure could be reused in the Spanish BF.

Use of the site impact

In Table7.6 and Figure 7.29 a comparative analysis for the total impact of the use of the site over 20 years, standardised to functional unit 1 m^2 constructed area, is presented.

Table 7.6 Comparative analyses across the three case studies of impacts from Land Use for 1 m^2 of constructed area functional unit.

Impact category	Units	BF UK	BF Spain	GF Spain
Climate change	kg CO2 eq	1210	2644	7883
Ozone depletion	kg CFC-11 eq	7.03E-05	1.85E-04	5.71E-04
Human toxicity, cancer effects	CTUh	4.34E-05	1.25E-04	4.19E-04
Human toxicity, non-cancer effects	CTUh	2.30E-04	1.05E-03	2.78E-03
Particulate matter	kg PM2.5 eq	4.7E-01	1.11	3.90
Ionizing radiation HH	kBq U235	167.88	465.79	1103.68

Impact category	Units	BF UK	BF Spain	GF Spain
	eq			
Ionizing radiation E (interim)	CTUe	4.56E-04	1.23E-03	3.39E-03
Photochemical ozone formation	kg NMVOC eq	3.18	8.73	21.90
Acidification	molc H+ eq	4.39	10.36	29.73
Terrestrial eutrophication	molc N eq	9.97	20.96	58.73
Freshwater eutrophication	kg P eq	1.69E-01	4.24E-01	1.25E+00
Marine eutrophication	kg N eq	1.01	3.23	6.60
Freshwater ecotoxicity	CTUe	19919	85787	268028
Land use	kg C deficit	1028	2298	8070
Water resource depletion	m3 water eq	2250	6948	14299
Mineral, fossil & ren resource depletion	kg Sb eq	6.98E-02	1.74E-01	7.76E-01

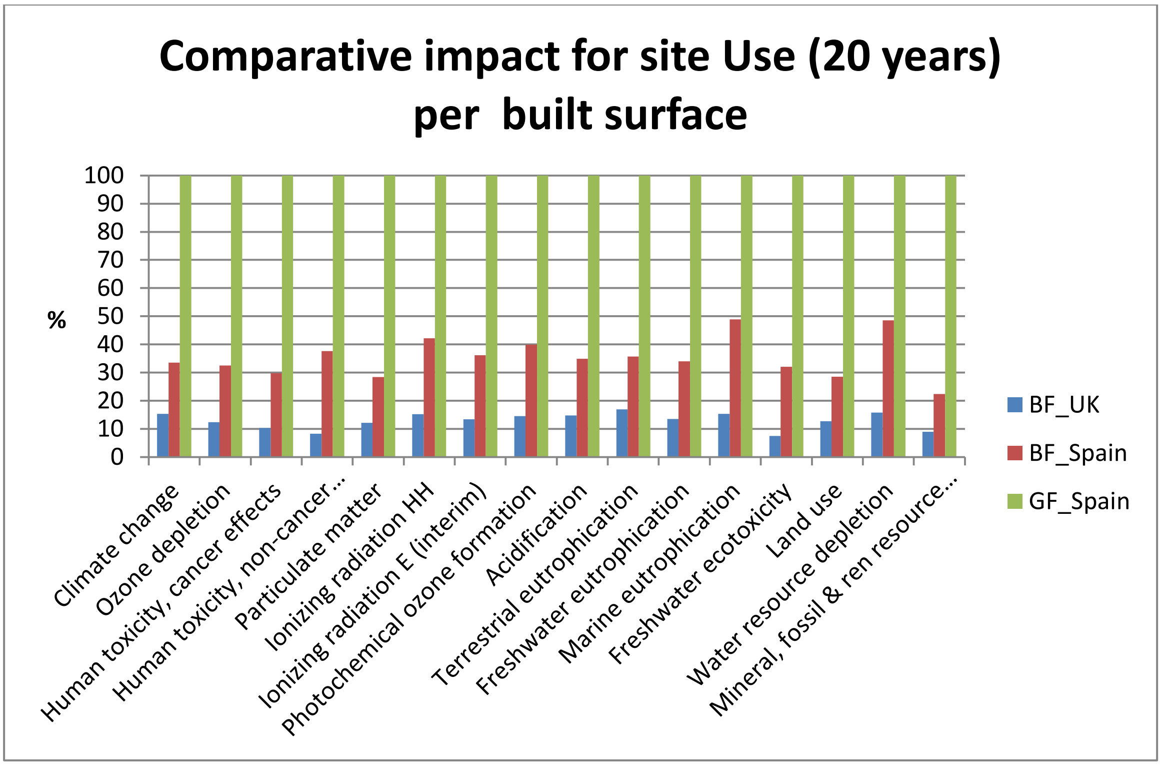

Figure 7.29 Comparative analyses across the three case studies for constructed area functional unit for site use

Once the land/site is developed, the use impact of the greenfield is clearly higher than that of the two brownfields. The impact is related to the mobility of residents living in the developed area. As mentioned earlier, the greenfield site has the highest density of residents per area of construction. Comparing the two brownfields, the higher number and density of residents in the Spanish BF explains the higher impact during the use stage.

8 Conclusions and recommendations

Justification of the study

The way land is occupied, transformed and used has an impact on the local, regional and global environment (toxicity, ecosystem services, climate change, etc.) as shown in the present study. This study has focussed on urban land uses, where most of the human activities are concentrated.

Recent studies have demonstrated that increase of land take and urban sprawl are a tendency in most of the European countries, albeit with regional and local differences. The area where land recycling of artificial surfaces occurred (between 2000 and 2006), which coincides with brownfield development, was on average less than 20 % of the total area of land taken, suggesting sprawl (Soer, 2010).

Land take for urban development and infrastructure results in soil sealing and thus the loss of soil resources and functions due to the covering of land for housing, roads or other construction work, and is generally irreversible. Urban land take is mostly consuming agricultural land, but also reduces space for habitats and ecosystems that provide important services like regulation of the water balance and protection against floods, particularly if the soil is sealed. Thus, when greenfields are urbanized, the level of organic matter and organisms in soil, as well as CO2 sequestration capacity, generally decrease.

In addition, lower population densities (a result of urban sprawl) require more energy for transport (Soer, 2010). This has also been observed in this study when comparing the environmental impact of site use between the greenfield and brownfield case studies.

In countries with deep financial crisis, aspects other than environmental impacts are prioritised in the decision making process. For example, in some countries, the development of new urban areas is seen as a positive economic indicator and the authorities avoid putting barriers to those developments (i.e. limiting such developments with environmental constraints). The same financial crisis, especially in the construction sector, is forcing some countries (Spain, Germany) to develop new policies promoting the reuse and revitalization of existing buildings, which could have a positive impact on reducing land take and thus on reducing environmental impacts of new developments.

Both land take and land recycling activities need to consider adaptation to climate change and future environmental conditions. Climate change risks like water scarcity or risk of flooding can be faced when taking land use decisions. Especially new urban developments in greenfield areas have a potential to impact runoff streams and increase the risk of flooding in the area downstream, and can also modify the infiltration of rainwater into the aquifer reservoirs. In addition, when greenfields are urbanized, the level of organic matter, as well as CO2 sequestration capacity, generally decrease.

The suitability of the LCA tool

This chapter includes the main conclusions from the present study and some recommendations for the use of LCT and LCA in the context of land take and land recycling in order to assess alternatives for a sustainable urban development.

In general, this study represents an initial exploration of how to apply LCT and the LCA methodology to the environmental assessment of developing brownfields and greenfields. Probably, the use of this tool would need to be adapted to the specific purpose of land development through the design of specific software which would include databases and processes relevant to the activities of land take and land recycling. The study has identified possible improvements on how to minimize environmental impacts and reduce the use of resources across all life cycle stages when considering local, regional and global impact categories, and thus how to make urban developments more sustainable. Three case studies have been analysed using a streamlined approach that could be used for future studies and included in future guidance to assist decision makers in selecting (re)development strategies based on a better understanding and hence possible optimisation of the environmental impacts. The assessment of three case studies with different characteristics has identified shortcomings in the methodology and issues that should be considered in future LCA assessments of urban planning and development projects.

LCA can be considered as a tool for performing comprehensive environmental assessment in a holistic manner (across all life cycle stages). This study shows the importance of considering all life cycle stages from the beginning of the (re)development activities (including the site status) to the use of the final development, since impacts can occur during all life stages and can be transferred across stages. This issue is especially important for large urban projects with several actuations (re-development stages) in the territory over a longer time scale.

The study has been limited to three case studies. At this stage it is not possible to conclude that one development alternative is better than the others when assessing environmental impacts, due to the uncertainty in the final results, and the impact of other aspects such as economic and social issues that have not been considered in this study.

The use of the LCA tool

From the results of the study, it can be concluded that the LCA process has to be seen as a tool that can provide decision-makers with a better understanding of the potential environmental impacts associated with a site development at different scales (local, regional and global), taking into consideration a life cycle perspective of environmental impacts associated with each process or activity in a site development project.

The European Union has promoted regulations that require considering environmental impacts in urban developments in the Member States (Environmental Impact Assessment Directive, EIA and Strategic Environmental Assessment Directive, SEA). LCA can be helpful in those stages of urban planning when detailed development alternatives are assessed for a specific location. The overall impact of different urban development alternatives for a specific site can be assessed and can help the decision making process. That, of course, must also include aspects not considered in LCA such as economic, political and social issues, as well as specific local impacts. In the design of the detailed urban planning, the LCA methodology can also be used to define the lower environmental impact action: for example, the remediation technology, the building construction project or the energy sources with less impact. However, there is no single solution, and different approaches and materials will suit different circumstances.

At a global scale, the LCA methodology can also be useful for urban planners to define the global impact of developments in greenfield areas instead of development of existing brownfield areas. At a regional scale, the application of LCA methodology could prioritize brownfield sites based on their potential for sustainable urban development.

As mentioned before, there are social and economic aspects that are not considered in the LCA tool. Final decisions on urban developments can depend on local contexts and the responsibility of local authorities. Here, income generated by urbanization fees and levies, as well as a general lack of appreciation of the value of soil (and landscape) as a limited resource, may influence decision-making. Urbanization fees and levies (e.g. building and business taxation) combined with strong competition between municipalities trying to maximize their local revenues make them promote the construction of new residential, commercial or industrial areas, offering cheap land for development (EC, 2012[14]).

Governance settings within Europe determine regional differences in land use patterns and intensity (for example how brownfields are developed). In regions with low urban density patterns, the development of brownfield areas are restrained by contamination issues, as it is perceived that there is enough land available, and it is thus cheaper to take new land than to invest in existing brownfield sites that would require remediation. On the contrary, in regions with high urban density, the development of brownfield areas can be driven by the scarcity of urban land to be developed, and by economic and social issues.

Provided that the characteristics of the site (including the drivers and patterns of spatial planning) are known, this tool helps to get insight in different impacts and to improve a sustainable development. As a tool that is based on a modelization and thus simplification of the reality, it implies a certain degree of user subjectivity, especially when there are different political and social priorities (for example, in the selection of the functional unit). Probably, the more the tool is included in the regulation and decision-making process, the less “subjectively” it will be used.

Conclusions and recommendations of the application of LCA into the case studies

From the conclusions of the comparative analyses between the three case studies, it can be seen that the greenfield has an overall bigger environmental impact, especially when the functional unit of built surface is used, mainly due to the occupation of land (land take), the site development activities (not only from the site construction, but also from new infrastructure construction) and to the use stage of the site with a relevant impact of mobility.

The brownfield developments have shown impacts that are not present in the greenfield development, e.g. those associated to existing contamination. In order to bring brownfield land back into productive use, remedial intervention may be required in relation to soil and groundwater (including site investigation and remediation activities). The impacts of such activities are not normally encountered in greenfield developments.

Remediation of the contamination has a positive environmental impact due to a reduction of the impact categories ‘human toxicity’ and ‘freshwater ecotoxicity’ for the brownfield area. However, remediation can also have a negative impact for the same toxicity categories if the contamination is transferred to other sites (*e.g.* landfills).

As it has been observed in the application of LCA in the two brownfield developments, impacts associated with site remediation are relatively low compared with the total impacts. Optimisation of remediation activities in these and similar cases are therefore mainly cost driven when compared with the overall environmental impact and social acceptability of the proposed form of redevelopment.

Residual contamination after remediation activities also has an environmental impact that needs to be assessed in conjunction with the remediation activities and local soil regulations. The environmental impact of increasing remediation efforts has to be compared with the impact of leaving higher concentrations of substances in the environment (nevertheless at concentrations that are below the remediation target value and thus without unacceptable risks).

Demolition of existing buildings and infrastructure is also a necessary activity during brownfield development; an activity that is generally not applicable to greenfields. On the other hand, if existing buildings and infrastructure at brownfield sites can be renovated and reused, impacts can be ‘saved’/reduced compared to the construction of new buildings and infrastructure in greenfields.

Besides these remediation and demolition/renovation activities, construction processes (of buildings and infrastructures) are also sources of secondary impacts (i.e. impacts derived from the actuation/(re)development of the site). In that sense, construction of buildings appears as the activity with the highest secondary impacts, being highly dependent on the type of construction project and proposed use. The results of the study have shown that construction of infrastructure can have more impact for greenfields, requiring new infrastructures, compared to brownfields, located in urban areas and already provided with infrastructure.

LCA provides insight into both the short-term (*i.e.* secondary impacts during redevelopment) and long-term impacts (*i.e.* tertiary impacts during use and operation) of a development, but it is clear from the three case studies that it is the long-term impacts (operational phase) that dominate. Nevertheless, consideration of both secondary (particularly those associated with construction) and tertiary impacts are important in optimizing a given development. Therefore, careful consideration of the design of buildings and infrastructure during the construction phase can have a big effect on reducing impacts during the future use of the site (use of construction materials with low environmental impact during its life, use of renewable energy, introducing energy efficiency measures, developing public transport networks, etc.).

However, for the given examples, the impacts relating to site investigation and remediation activities are relatively low compared to the impacts relating to the construction and subsequent use of the site. Hence, in these cases, there is little benefit in optimizing the environmental performance of these activities, when assessing the overall impact of an urban development, including the use stage. The selection of site investigation and remediation methods may be primarily cost-driven on sites with levels of contamination that do not pose a high health risk to the users of the site. In such cases, the environmental optimization of a development is best served by designing and constructing buildings and infrastructure that promote lower environmental impacts during the subsequent use and operation of the resulting development.

Based on the results of the case studies, when comparing the overall impact of a site development, LCA should probably be used at two stages, especially if the main purpose is to use the LCA as a decision making tool for development:

- For evaluating the short term impacts (excluding life span). In this case the relevance of activities like site remediation could have a higher weight in the total impact of the urban development.
- For evaluating life span use (hence optimize use, etc.)

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Project HOMBRE (Holistic Management of Brownfield Regeneration). http://www.zerobrownfields.eu

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ILCD, 2012b
European Commission Joint Research Centre. ILCD Handbook: General guide for Life Cycle Assessment (http://lct.jrc.ec.europa.eu/assessment/publications)

ISO/CD 18504: Soil Quality – Guidance on sustainable remediation

ISO 14040:2006 Environmental management—Life cycle assessment—Principles and framework.

ISO 14044:2006 Environmental management—Life cycle assessment—Requirements and guidelines

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Deborah Lange, Yeganeh Mashayekh. Estimation of Comparative Life Cycle Costs and Greenhouse Gas Emissions of Residential Brownfield and Greenfield Developments. Department of Civil & Environmental Engineering, Carnegie Mellon University, Pittsburgh, PA 15213: residential Brownfield developments. Shakweer, A. 2003, University of Nottingham, UK (Unpunlished thesis)

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Lesage P, Ekvall T, Deschênes L, Samson R. CIRAIG Interuniversity Reference Center for the LCA (Montréal). Environmental Assessment of Brownfield Rehabilitation Using two different Life Cycle Inventory Models. Int J LCA 12(7) 497-513 (2007b).

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EEA lead authors: Andrus Meiner, Birgit Georgi, Jan-Erik Petersen, Ronan Uhel. 2010. The European environment — state and outlook 2010 (SOER 2010). Land use. www.eea.europa.eu/soer

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ANNEX 1: Research on State of the art of the application of LCA into Brownfield developments

1) LCA studies applied on brownfields

In some cases LCA methodology has been applied to brownfield projects. Information regarding the type of the study, the scope and the impact categories are detailed in the following table.

Reference	Type of study /description	Scope	Impact categories
Brecheisem T, Theis T. The Chicago Center for Green Technology: life-cycle assessment of a brownfield development project. Environ. Re. Lett. 8 (2013) 015038 (13pp)	LCA of a brownfield development project	1) Brownfield assessment and remediation 2) building rehabilitation and site development 3) Ten years of operation	Cumulative energy
Lesage P, Deschênes L, Samson R. CIRAIG Interuniversity Reference Center for the LCA (Montréal). Evaluating Holistic Environmental Consequences of Brownfield Management Options Using Consequential Life Cycle Assessment for Different Perspectives. Environ Manage (2007a) 40:323-337	Consequential LCA. Proposal of LCA framework. 1 case study: comparison of rehabilitation and exposure minimization	Primary impacts (site's environmental quality), Secondary impacts (intervention stage), Tertiary impacts (land use)	Method used: IMPACT 2002+ 4 endpoint: damage to human health (DALYs), damage to ecosystem quality (PDF·m2·yr), damage to climate change (Kg CO2 eq), damage to resources (MJ)
Lesage P, Ekvall T, Deschênes L, Samson R. CIRAIG Interuniversity Reference Center for the LCA (Montréal). Environmental Assessment of Brownfield Rehabilitation Using two different Life Cycle Inventory Models. Int J LCA 12(7) 497-513 (2007b) Presentation "Life Cycle Assessment of Brownfield Management" P. Lesage, L. Deschênes, R. Samson CIRAIG – Interuniversity Reference Center for the Life Cycle Analysis, Interpretation and Management of Products, Processes and Services: http://www.lcacenter.org/InLCA-LCM03/Lesage-presentation.pdf	Attributional and Consequential LCA to compare 2 scenarios: rehabilitation for residential development vs. exposure minimization. Inventory data	Primary impacts (site's environmental quality), Secondary impacts (intervention stage), Tertiary impacts (land use)	Method used: IMPACT 2002+ Midpoints indicators (carcinogens, non-carcinogens, aquatic and terrestrial ecotoxicity, land use). Normalised damages: Human Health, Ecosystem quality, climate change and resources.
Deborah Lange, Yeganeh Mashayekh. Estimation of Comparative Life Cycle Costs	Life cycle costs and greenhouse gas	Secondary impacts (remediation, building	Development of a spread sheet tool

Reference	Type of study /description	Scope	Impact categories
and Greenhouse Gas Emissions of Residential Brownfield and Greenfield Developments. Department of Civil & Environmental Engineering, Carnegie Mellon University, Pittsburgh, PA 15213: residential brownfield developments. http://www.cmu.edu/steinbrenner/brownfields/index.html	emissions for residential brownfield and greenfield developments to estimate the overall life cycle costs and GHG emissions resulting from residential brownfield developments relative to traditional (Greenfield) developments.	construction, infrastructure). Tertiary impacts (utilities and maintenance, travel)	which includes default and ranges of values for five different impact categories based upon a sample of brownfield and greenfield sites and other data from the literature. Economic-Input-Output Life Cycle Assessment (EIOLCA) tool (www.eiolca.net) was used to estimate greenhouse gas emissions based upon these remediation costs
Presentation "Life Cycle Analysis of Residential brownfield and Greenfield Developments: Case Studies of Summerset (Phase 1) at Frick Park & Cranberry Heights in Cranberry Township". Ronell Auld. Carnegie Mellon University: April 2010 http://www.eswp.com/brownfields/Present/Auld%205B.pdf	Case Study	Greenhouse gas (GHG) emissions associated with a residential brownfield and greenfield development in South western Pennsylvania. GHG emissions resulting from their initial construction, yearly utility consumption and vehicle usage.	GHG emissions
Presentation "Evaluating Brownfield Development Sustainability ". Jeff Roberts & Peter Dollar. Presentation for Federation of Canadian Municipalities 2012: https://www.fcm.ca/Documents/presentations/2012/webinars/Evaluating_Brownfield_Development_Sustainability_EN.pdf	Case Study	To determine environmental impacts of performing various remedial technologies. To identify sustainable remedial options that are better for the environment and community	CO2-Climate Change, NOX-Eutrophication, SOX-Acidification, PM10 -Respiratory Problems, Energy Consumed (All Types), Capital Cost (Technology), Safety/Accident Risk, Change in Ecosystem Service Value

2) LCA studies of soil remediation

The literature on LCA for soil remediation is abundant. An exhaustive research has been carried out in order to have a framework of the different technologies and their potential impacts, and the framework to assess these processes through LCA methodologies. The most relevant studies have been included in the following table:

Reference	Type of study /description	Scope	Impact categories
Harbottle a M.J, A. Al-Tabbaa, C.W. Evans. A comparison of the technical sustainability of in situ stabilisation/solidification with disposal to landfill. Journal of Hazardous Materials 141 (2007) 430–440	Assessment of remediation technologies with a life cycle approach. Comparison between In-situ stabilization / solidification (S/S) and landfilling)	Remediation process and waste treatment	Human health and safety, local environment, 3rd party/stakeholder concern, site use, global environment (global warming)
Lemming G, Hauschild M.Z, Bjerg P.L. Life cycle assessment of soil and groundwater remediation technologies: literature review. Int J Life Cycle Assess (2010) 15:115–127	Paper review. LCA to compare different soil remediation technologies (12 reviewed Studies)	In-situ and ex-situ remediation technologies	Not applicable
Lemming G , Hauschild M , Chambon J , Binning P.J , Bulle C , Margni M, Bjerg P.L. Environmental Impacts of Remediation of a Trichloroethene-Contaminated Site: Life Cycle Assessment of Remediation Alternatives. Environ. Sci. Technol. 2010, 44, 9163–9169	LCA. Comparison among remediation options: (i) *in situ* bioremediation by enhanced reductive dechlorination (ERD), (ii) *in situ* thermal desorption (ISTD), and (iii) excavation of the contaminated soil followed by off-site treatment and disposal.	Primary impacts (local toxic impacts from the residualsite contamination) and secondary impacts (impacts generated by the remediation activities)	EDIP2003 method for the categories global warming, ozone formation, acidification, and eutrophication. Particulate matter (PM) from Humbert et al. USEtox used for human toxicity and ecotoxicity.
Morais S.A, Delerue-Matos C. A perspective on LCA application in site remediation services: Critical review of challenges. Journal of Hazardous Materials 175 (2010) 12–22	Critical review of LCA studies	In site remediation services	Not applicable

Reference	Type of study /description	Scope	Impact categories
Sparrevik M,, Saloranta T, Cornelissen G, Eek E, Fet A.M,Breedveld G.D, and Igor Linkov. Use of Life Cycle Assessments To Evaluate the Environmental Footprint of Contaminated Sediment Remediation. Environ. Sci. Technol. 2011, 45, 4235–4241	LCA. Environmental footprint of the active and passive capping materials as remediation alternatives and compares them with a natural recovery scenario.	Production, use, and disposal phases	ReCipe impact model

3) Other studies related to brownfield and sustainability

Some papers dealing with the topic of sustainability and brownfields have been identified. They propose some approaches in order to assess and promote the sustainability of the brownfields projects and interventions. These papers present a theoretical approach for qualitative assessment, but they can provide useful information to establish the framework of the project.

Reference	Description
Chen Y, Hipel K.W ,Kilgour D.M, Yuming Zhu Y. A strategic classification support system for brownfield development. Environmental Modeling & Software 24 (2009) 647–654	Approach for classification of brownfields
De Sousa C.A. Turning brownfields into green space in the City of Toronto. Landscape and Urban Planning 62 (2003) 181–198	Review of 10 pertinent “greening” case studies
Doick K.J, Sellers G,Castan-Broto V, Silverthorne T. Understanding success in the context of brownfield greening projects: The requirement for outcome evaluation in urban green space success assessment. Urban Forestry&Urban Greening(2009)163–178	Model to assess brownfield projects (six UK case studies)
Nijkamp P, Rodenburg C.A., Wagtendonk A.J. Success factors for sustainable urban brownfield development. A comparative case study approach to polluted sites. Ecological Economics 40 (2002) 235–252	Identification of the critical success factors for an effective clean-up policy for brownfield areas
Pediaditi K, Wehrmeyer W,Chenoweth J. Monitoring the sustainability of brownfield development projects: the Development Assessment Framework. Land Contamination & Reclamation / Volume 13 / Number 2 / 2005	Theoretical / methodological approach: Development Assessment Framework (RAF)
Pediaditia K, Doick K.J,Moffat A.J. Monitoring and evaluation practice for brownfield, regeneration to greenspace initiatives A meta-evaluation of assessment and monitoring tools. Landscape and Urban Planning 97 (2010) 22–36	Evaluation of 28 tools considered potentially relevant to Brownfield regenerated greenspaces (monitoring and assessment)

Reference	Description
Thornton G, Franz M, Edwards D, Pahlen G, Nathanail, P. The challenge of sustainability: incentives for brownfield regeneration in Europe. Environmental science & policy 10 (2007)116 – 134	Revision of incentives at European Union level for the promotion of sustainable brownfield regeneration
Wedding G.C, Crawford-Brown D. Measuring site-level success in brownfield developments: A focus on sustainability and green building. Journal of Environmental Management 85 (2007) 483–495	Definition of a tool to assess sustainability of brownfields. 40 indicators (environmental-health, financial, social-economic and liability)
Williams K, Dair C. (2007) A framework for assessing the sustainability of brownfield developments, Journal of Environmental Planning and Management, 50:1, 23-40, DOI: 10.1080/09640560601048275	Assessment Framework description. Qualitative assessment based on pre-defined objectives

4) Land take and land recycling strategic and regulatory documents

Reference	Description
Ludlow, D., Falconi, M., Carmichael, L., Croft, N., Di Leginio, M., Fumanti, F., Sheppard, A., Smith, N., 2013. Land Planning and Soil Evaluation Instruments in EEA Member and Cooperating Countries (with inputs from Eionet NRC Land Use and Spatial Planning). Final Report for EEA from ETC SIA (EEA project managers: G. Louwagie and G. Dige).	UNPUBLISHED Please do not disseminate this work any further; it is only intended for internal use.
Study supporting potential land and soil targets under the 2015 Land Communication. Draft final Report. European Commission, DG Environment BIO by Deloitte (BIO), AMEC, Institute for Environmental Studies - VU University Amsterdam (IVM) and Vienna University of Economics and Business (WU)	UNPUBLISHED Please do not disseminate this work any further; it is only intended for internal use.
COMMISSION STAFF WORKING DOCUMENT Guidelines on best practice to limit, mitigate or compensate soil sealing. Brussels, 15.5.2012. SWD(2012) 101 final/2	The objective of this Commission Staff Working Document is to provide information on the magnitude of soil sealing in the European Union (EU), its impacts and examples of best practice for its limitation, mitigation or compensation with a view to ensuring better land management.
The European environment — state and outlook 2010 (SOER 2010). Land use. www.eea.europa.eu/soer EEA lead authors: Andrus Meiner, Birgit Georgi, Jan-Erik Petersen, Ronan Uhel. EEA contributors: Robert Collins, Paul Csagoly, Philippe Crouzet, Gorm Dige, Markus Erhard, Josef Herkendell, Ybele. Hoogeveen, Stéphane Isoard, Karina Makarewicz, Branislav Olah, Rania Spyropoulou, Jean-Louis Weber. EEA's European Topic Centre on Land use and spatial information	The European environment — state and outlook 2010 (SOER 2010) is aimed primarily at policymakers, in Europe and beyond, involved with framing and implementing policies that could support environmental improvements in Europe. It includes an EEA analysis of land-cover type change across 36 European countries, the state and trends and the environmental impacts and the outlook

Reference	Description
(ETC/LUSI): Jaume Fons, Alejandro Iglesias-Campos, Andreas Littkopf, Walter Simonazzi, Tomas Soukup	2020.
OECD KEY ENVIRONMENTAL INDICATORS 2004. OECD Environment Directorate. Paris, France	It presents key environmental indicators endorsed by OECD Environment Ministers in 2001 as a tool for use by OECD. These indicators give a broad overview of environmental issues of common concern in OECD countries, and inform policy makers and the public about progress made and to be made.
"LCA toepassingen in bodemsaneringsprojecten –Literatuurstudie". OVAM 2011. http://www.ovam.be/sites/default/files/LCA%20toepassingen%20in%20bodemsaneringsprojecten%20-%20Literatuurstudie.PDF The Flemish Institute for Technical Research (VITO) has conducted a study commissioned by OVAM in 2011 in order to examine the suitability of LCA to assess the sustainability of soil remediation.	Conclusion was that executing LCA is time-consuming and requires a lot of data. LCA was therefore considered not to be suited for general use or application to assess the sustainability of every soil remediation project in Flanders.
Bal, Nele, Paulus, Dirk, Piljs, Charles, Bruneel, Nick, van Gestel, Griet. "Improved MultiCriteria Analysis in Remediation Plans in Flanders: Quantifying Sustainability by Introduction of the CO2-footprint" http://www.umweltbundesamt.at/fileadmin/site/aktuelles/veranstaltungen/2012/sustrem2012/13_Dirk_Paulus_abstract_MCA_in_Remediation_Plans_in_Flanders_CO2-footprint.pdf Nick Bruneel, Griet Van Gestel, Sven De Mulder, Bavo Peeters, Nele Bal, Dirk Paulus, Kaatje Touchant, Richard Lookman. "Green and Sustainable Remediation in Flanders". OVAM, Belgium http://www.umweltbundesamt.at/fileadmin/site/aktuelles/veranstaltungen/2012/sustrem2012/05_Nick_Bruneel_abstract_OVAM_Green_and_Sustainable_Remediation_Flanders.pdf	OVAM has developed a tool to calculate the carbon footprint of soil remediation. The use of this CO2-calculator is mandatory in the planning of a soil remediation project. Impacts on water depletion aren't considered or assessed yet.
Nick Bruneel, OVAM – Public Waste Agency of Flanders. Department of "Soil management Green and Sustainable Remediation in Flanders. SustRem 2012, Vienna Conceptual frameworks (session 2)". November 14, 2012 http://www.umweltbundesamt.at/fileadmin/site/aktuelles/veranstaltungen/2012/sustrem2012/present/05_Bruneel_N_Green_and_Sustainable%20Remediation_in_Flanders_SustRem2012.pdf	Use of Multi Criteria Analysis is mandatory in Flanders to evaluate the sustainability of different remediation strategies. More information and the content of this MCA can be found on page 5 of following presentation.
OVAM has recently (2014) assigned Witteveen+Bos with the development of an extensive sustainability barometer for soil remediation and development projects (no further information available at this stage).	The goal is to assess different remediation and development options and their sustainability, and present the results in a visually attractive way through a web-tool.

Reference	Description
"How to implement sustainable remediation in a contaminated land management project?". Nicole sustainable remediation work group 2012 report	UNPUBLISHED Please do not disseminate this work any further; it is only intended for internal use.
Information from C-sequestration is pending from David Manning, from Newcastle University, and at present president of the Geological Society of London.	Pending to receive information.
Tand and Nathanail (2012) Sticks and Stones: The Impact of the Definitions of Brownfield in Policies on Socio-Economic Sustainability	OPEN ACCESS peer review paper (http://www.mdpi.com/2071-1050/4/5/840/pdf) which concludes that " a definition of brownfield in regeneration policies should focus on previously developed land that is now vacant or derelict if land recycling is to contribute to sustainable communities."

5) European brownfield and site contamination networks/projects/associations

The following existing and former networks have been contacted/accessed information via internet in order to obtain relevant information applicable to this study. Most of them are pending to answer (expected in September), but their webpages have been checked at this stage:

Network/project	Description
HOMBRE Project (Holistic Management of Brownfield Regeneration). http://www.zerobrownfields.eu	Aiming to create a paradigm shift to 'Zero brownfields' where brownfields become areas of opportunity that deliver useful services for society, instead of derelict areas that are considered useless. Looking at how synergies between different types of services might leverage change where none was possible before.
TIMBRE Project (Tailored Improvement of brownfield Regeneration in Europe). http://www.timbre-project.eu	Focussed on megasites brownfield development
COBRAMAN Project. http://www.cobraman-ce.eu	This project is implemented through the CENTRAL EUROPE Programme co-financed by ERDF. The project has developed a Database containing information about cases related to the revitalization projects carried out in Central European countries and has elaborated a Guide to brownfield management.
NICOLE, Network for Contaminated Land in Europe. l. http://www.nicole.org/	Started as a FP4 funded project, is a now a self-supporting network since February 1999. It is the principal forum where industry, service providers and academia cooperate to develop and influence the state of the art in contaminated land management in Europe. The network has 141 members, representing industrial companies, technology developers/service providers, academics, non-profit organisations, and other networks related to contaminated soil.

CABERNET: (Concerted Action on Brownfield and Economic Regeneration Network). http://www.cabernet.org.uk/index.asp?c=1124	Started as FP5 project, Key Action 4, (2002-2004, built up from CLARINET) is now a self-supporting European Expert Network addressing the complex multi-stakeholder issues that are raised by brownfield regeneration. CABERNET has a LinkedIn group; email forum (www.jiscmail.ac.uk CABERNET) and a twitter account providing brownfield news items from around the world (@cabernet_4eu).
Common Forum on Contaminated land in the European Union. http://www.commonforum.eu/	It is a “stakeholder network” in the development of an EU soil protection policy. The general objectives are to develop strategies for the management and treatment of contaminated sites and for land recycling with respect to “sustainable resource protection” for contaminated land and groundwater. It holds regular meetings to discuss important and current issues in these fields. When possible, common views are developed and expertise is offered to the European Commission, relevant stakeholder networks and EU research projects. Member from 27 European countries
LUDA(“Improving the quality of life in Large Urban Distressed Areas”) http://www.luda-project.net/	The LUDA consortium joins together six cities as well as ten research institutions from eight different European countries in a common quest of interdisciplinary research. It is a research project under the 5th Framework 4 Programme within the “Energy, Environment and Sustainable Development” programme.
RESCUE, Regeneration of European sites in cities and urban environments (2002-2005) http://www.rescue-europe.com/	Aimed to improve the quality of derelict land recycling and develop tools for the practical work involved in the complex processes of brownfield regeneration projects. It is a research project under the 5th Framework Programme within the “Energy, Environment and Sustainable Development” programme.
NORISC, Network oriented risk-assessment by in-situ screening of contaminated sites (2001-2003). http://www.norisc.com	FP5 project, Key Action 4, “Energy, Environment and Sustainable Development” programme. Aimed at the redaction of standard guideline in the form of a decision support software system for environmental assessment of contamination profiles in urban areas
SNOWMAN ERA-NET (Working together in research and development for sustainable land management in Europe. http://www.snowmanera.net/index.php	The FP6 ERA-NET project on cooperative research on sustainable soil pollution management, SNOWMAN, has organized a coordinated call for research projects, co-funded by organizations in the SNOWMAN partner countries (Austria, Belgium, France, Germany, Netherlands, Sweden and the United Kingdom).
URBS PANDENS (Urban Sprawl: European Patterns, Environmental Degradation and Sustainable Development, 2001 – 2005, http://www.iclei-europe.org/)	In the frame of the ICLEI (Local Governments for Sustainability) was funded under the EC’s 5th Environmental Framework Programme
PECOMINES project. http://viso.ei.jrc.it/pecomines_ext/index.html	Carried out by the JRC/IES in the context of FP6-FP7, focuses on methods and techniques for inventories and rehabilitation of historical mine waste sites.

GLOCOM ("Global Partners in Contaminated Land Management"). (FP7/2007-2013)	A knowledge and staff exchange programme.
REVIT http://www.revitnweurope.org/	Within North-West Europe six partners have come together to improve regenerating their brownfield sites by sharing experience and developing new concepts and innovative approaches
INTERREG project CONVERNET http://www.conver.net/	The network was run within INTERREG IIIB. Partners from the Baltic Sea Region and the Czech Republic exchanged knowledge about the conversion of former military sites (2003-2006).
INTERREG project TUSEC-IP. (Technique of Urban Soil Evaluation in City Regions – Implementation in Planning Procedures). http://www.tusec-ip.org	It developed a procedure to evaluate soils in city regions of the Alpine Region working out strategies for its implementation in regional and municipal planning procedures. The participating countries were Austria, Germany, Switzerland, Italy and Slovenia.
INTERREG III B - project PROSIDE. www.proside.info	Promoting Sustainable Inner urban Development, funded by the CADSES program (Central European Adriatic Danubian South-Eastern European Space).
RETINA	Revitalisation of traditional Industrial Areas in South-east Europe
REKULA (Restructuring Cultural Landscapes)	LIFE Project that addressed rehabilitation issues in 3 former quarrying and mining regions (Upper Silesia-PL, Lusatia-Brandenburg- DE, Veneto-IT).
ACR+ Association of Cities and Regions for Recycling and Sustainable Resource Management) http://www.acrplus.org/	It is an international network of cities and regions who share the aim of promoting smart resource consumption and sustainable management of municipal waste through prevention at source, reuse and recycling
The European Construction Technology Platform (ECTP). http://www.ectp.org/	It is one of the environmental technology platforms foreseen by ETAP http://cordis.europa.eu/technology-platforms/individual_en.html). It aims at formulating research and innovation strategies for the European construction sector. It is constituted by representatives from industry, academics, stakeholders, the European Commission. It has so far elaborated a vision paper, a Strategic Research Agenda and an Implementation of the research agenda (August 2007, http://www.ectp.org/documentation/SRA_IAPv1.pdf). Several priorities areas have been identified. Under Priority D, Reduce Environmental and Man-made Impacts of Built Environment and Cities. One of the main development issues the regeneration of Brownfield sites
ICCL, International Committee on Contaminated Land (former Ad Hoc International Working Group on Contaminated Land), http://www.iccl.ch/index.html	It is an informal forum for international exchange and cooperation. Its principal purpose is to provide a forum, open to any country, in which issues and problems of contaminated land and groundwater can

	be discussed and information freely exchanged to the benefit of all participants.
EUGRIS is a web portal offering information and services on topics related to soil and waterhttp://www.eugris.info/	EUGRIS operates as a community of collaborating projects, people and organisations who co-operate to supply information for the benefit of everyone and also to promote themselves and disseminate their work. EUGRIS began as a project supported by the European Commission under the Fifth Framework Programme and other supporters.
CONTAMINATED LAND MANAGEMENT LinkedIn group	Over 4000 members from around the world – an online forum for exchanging news, activities and employment opportunities.
CONTAMINATED-LAND-STRATEGIES	An email forum (join via www.jiscmail.ac.uk) with over 1000 members – mainly with news from the UK but some EU and global information as well.