The Housing and Regeneration Agency

Homes England – Measuring Social Value

Paper 5: Environmental Impact of New Housing Development

Background Research Compendium

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Introduction

Purpose

An appraisal guidance document – Environmental Impacts of New Housing Development – has been developed to provide guidance for Homes England appraisal practitioners. This supplements existing guidance on the economic appraisal of Homes England's interventions and the creation of business cases for funding in line with departmental and government policy. The main framing for this guidance is economic appraisal that uses Cost Benefit Analysis (CBA) to compare benefits and costs to identify the impact of different (short-listed) intervention options on public value and overall societal welfare. Accompanying this guidance is a practical tool – ENvironmental Impact of Housing development Appraisal Tool (ENHAT) – which has been developed for use by appraisal practitioners to identify, quantify and value the environmental impacts of new housing developments. The tool provides a series of methods and approaches that utilise existing evidence on the value of environmental impacts. Outputs from ENHAT are monetary value estimates for environmental impacts that should be included in the overall economic appraisal for a project or intervention.

To enable the development of the guidance document and the ENHAT, a number of research projects have been undertaken, to fill in some of the existing evidence gaps that have been identified by the study team. This document provides an overview of the research reports undertaken as part of this exercise.

Note on this document

- All of the research contained within this research compendium is not to be used by appraisers in valuing the environmental impacts associated with new housing development; appraisers should use the ENHAT tool and the appraisal guidance document for these purposes.
- This research compendium is intended as a source of information for appraisers to refer to if they are trying to understand more about particular topics identified through the guidance/ ENHAT tool.
- **The methods for various outcome and impact areas have been progressed (either improved upon or adjusted to be fit for use in later stages of the project) since these research streams were conducted. Where the method in the Environmental Impact of New Housing Development (eftec and SQW, 2023) and ENHAT (eftec and SQW, 2023) differs from that presented in this compendium, please refer to those documents.**

Structure

The document includes the following research papers that have been developed as part of this research:

- **Literature Review**: provides an overview of the conceptual basis for valuing the environmental impacts associated with housing development and shows the existing evidence/tools that already exist for appraisal purposes.

- **Improved Performance (Design) Standards**: provides a methodology and a set of evidence that can be used to estimate the impacts of improved performance standards associated with the development of new housing.

- **Embodied Carbon**: provides a methodology and tool for calculating the emissions associated with the construction of housing and the implications of different design decisions.

- **Climate Change Adaptation**: this research identifies the benefits and costs associated with adapting housing now to cope with the expected future climate and environmental conditions.

- **Population Adjustment Factors**: provides population adjustment values to ensure that per person environmental benefits / disbenefits are applied correctly within appraisals.

Literature Review

Purpose of Document

- The literature review provides an overview of the conceptual basis for valuing the environmental impacts associated with housing development and shows the existing evidence/tools that already exist for appraisal purposes.
- The review also identifies impact areas that cannot be reliably or robustly assessed at present and overall gaps with respect to informing value for money assessments.
- The literature review has identified current evidence gaps and therefore supported the development of future research streams that have informed the development of the appraisal guidance and ENHAT tool.

Date Completed: April 2021

Introduction

Purpose

The objective of the project is to improve and expand on the methodology and evidence currently available to appraise the impacts of housing interventions. It aims to develop a framework for assessing environmental impacts that will support value for money assessments within Homes England business cases for housing developments. This initial phase of the project has two main workstreams:

- **Literature review:** providing an overview of the conceptual basis for valuing environmental impacts along with a review of existing evidence and tools. The review takes into consideration the features of housing developments such as location and size that may affect the scope and materiality of environmental impacts. Outputs from the review include identification of evidence/tools that can be readily applied in appraisals, areas where impacts cannot be reliably or robustly assessed at present, and overall gaps with respect to informing value for money assessments.

- **Case studies:** intended to demonstrate the environmental impact 'logic chain' for housing developments and provide an illustration of the use of existing evidence in a business case context (identifying benefit types and if these are quantifiable/non-quantifiable). The two case studies examine whether the valuation of environmental impacts may have led to variation in the project BCR/appraisal findings, and any potential areas of duplication/over-lap in the existing methods employed.

The intention is that project outputs will inform subsequent phases of work that will fill gaps in the evidence base and prepare guidance that is consistent with the HMT Green Book and can be used consistently to reliably estimate environmental impacts in a housing development context.

Structure of report

This report focuses on the literature component of the project. It is structured as follows:

- **Section 2**: Provides the conceptual overview for the environmental valuation.

- **Section 3**: Defines the scope of the literature review in relation to the appraisal of housing interventions.

- **Section 4**: Details the findings from the literature review.

- **Section 5**: Concludes and provides recommendations for future phases of work.

- **Annex A**: Provides detailed valuation methodologies.

- **Annex B**: Compares the natural capital logic chain to the housing intervention theory of change.

Conceptual overview

Economic valuation

The valuation of environmental impacts in monetary terms helps understand the trade-offs between costs and benefits in economic analyses. With this, value for money assessments reflect a wider range of impacts and changes in overall social wellbeing.

To a large extent, the value of environmental impacts – changes in the provision of goods/services to individuals, communities and society overall derived from natural assets and the environment – are non-market in nature. This means that they are not traded in conventional markets, which form the basis for understanding individuals' preferences and the value they place on different outcomes. Instead, 'economic valuation methods' are needed to measure preferences and establish the value of non-market outcomes in monetary terms. More information on the concept of economic value is given in Error! Reference source not found.**1**.

Box 1: Concept of economic value

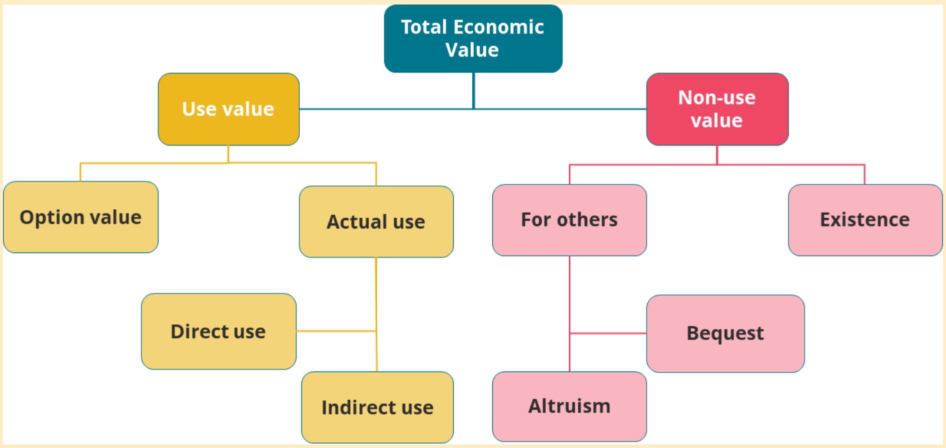
Economic analysis is concerned with measuring the wellbeing of individuals and society overall. Trade-offs made between different goods and services reveal the value placed on those goods and services and their contribution to wellbeing. The existence of a trade-off is the key point; economic value is concerned with what is 'given up' (or 'foregone' or 'exchanged') to obtain a good or service, rather than seeking to estimate the absolute value for a resource.

When considering trade-offs between different goods and services, if the resource that is given up is measured in monetary terms it is possible to express economic value in monetary terms. Money, therefore, is simply a 'unit of measure' that enables a common comparison of outcomes in economic analysis; for example, comparing the environmental impact of air pollution to that of noise pollution.

The trade-off between money and changes in the provision (quantity or quality) of goods and services – i.e. their economic value – is defined through individuals' willingness to pay (WTP) for securing a gain or avoiding a loss, or their willingness to accept compensation (WTA) for foregoing a gain or tolerating a loss. Economic valuation methods estimate WTP and WTA using different types of data depending on whether the good or service is traded in actual markets or not.

Both market and non-market goods and services may confer economic value for a variety of reasons. These relate to the uses or services provided and are summarised by the concept of total economic value (TEV) (see **Figure 1**). The TEV framework distinguishes between use value, which arises from either a direct or indirect interaction with a good/service, and non-use value, which arises due to altruistic motives (for others' wellbeing), bequest motives (for the wellbeing of future generations) and/or for the sake of the resource itself (existence). The extent to which different valuation methods capture the components of TEV differs.

Figure 1: Components of Total Economic Value



Source: eftec.

Natural capital approach

'Natural capital' is the prevailing perspective for conceptualising the value of the environment in economic terms. The concept of natural capital has been in use for decades but has risen to greater prominence in the UK in recent years, for example:

- The Department for Environment, Food and Rural Affairs (Defra) published the 25 Year Environment Plan in 2018 (Defra, 2018) setting out the government's approach to improving the environment and a draft Environment Bill in 2019. These introduce the ambition to enhance biodiversity through integrating a 'net gain' approach into the planning system for new developments. Natural capital accounting is one option for measuring net gain.

- Defra have announced that natural capital will be a fundamental component of the Environmental Land Management Scheme (ELMS) as part of the UK agricultural policy following leaving the EU.

- Defra published their online resource 'Enabling a Natural Capital Approach' (ENCA) in 2020 (Defra 2020a). ENCA is an extensive source of information and guidance on the natural capital approach and aims to allow users to assess and value the natural environment in a consistent manner (see **Section 2.4**).

The traction of the natural capital perspective stems from, amongst other things a greater focus on ecosystem services and attention on the environment's capacity to provide them. Added to this is the need to use business and economics compatible language and frameworks to influence decision-makers in the public and private sector – in particular the idea of stocks of capital assets that provide flows of benefits (**Box 2**).

Box 2: Defining the 'natural capital approach'

Figure 2 summarises the 'natural capital approach', describing how the stock/flow distinction and explicit recognition of impacts and dependencies goes beyond other environmental analysis. Collectively, these aspects define the 'natural capital approach' and in combination support more integrated systems-based thinking that can give greater insight into environment and natural resource challenges.

A key component of the natural capital approach is the inclusion of both the current flow of ecosystem services provided, as well as the future flows which are dependent on the condition (and extent) of natural assets and the productive capacity/ability to sustain benefits over time. Further considerations for future flows are the resilience of natural assets and their adaptability, in light of external pressures and shocks (for example climate change or population growth).

Figure 2: Natural capital approach

Features of natural capital approach	Other approaches
Focuses on **stocks** of natural capital assets (quality and quantity) as well as **flows** of benefits	Ecosystem services approach, and indeed most economic analysis, focus on flows of benefits – as such they are inputs to a natural capital approach
Incorporates both **biotic and abiotic** natural resources	Ecosystem services approach considers biotic resources only
Assesses how both stocks and flows are likely to change in the **future**	Environment Social and Governance analysis and financial accounting mainly consider past performance
Considers both **dependencies** of an economic activity on natural capital and its **impacts** on natural capital	Most environmental regulation is about controlling the impacts of activities (such as reducing emissions); the implications of the impacts are considered separately
Uses **valuation*** of impacts and dependencies	Different approaches use different measures, mostly of impacts
Makes the links between all of the above, to support **systems-based thinking**	Research & decision making tend to be developed separately for different sectors or issues (like agriculture, water, biodiversity) even when they depend on the same natural capital assets

*Valuation is the process of estimating the relative importance, worth, or usefulness of natural capital to people (or to a business), in a particular context. Valuation may involve qualitative, quantitative, or monetary approaches, or a combination of these.

Source: eftec (2019)

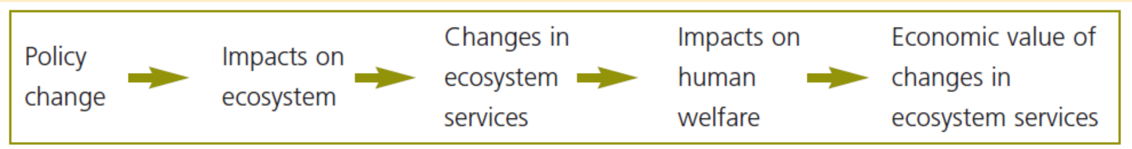
Logic chains are increasingly used as analytical tools to represent the relationships between natural assets, flows of ecosystem services, and the provision of final goods and services. These characterisations of asset > service > benefits relationships are synonymous with the ecosystem services approach that attempts to understand the processes that affect the provision of final goods and services. In effect, logic chains combine familiar impact assessment tools such as the 'impact pathway' or 'pressure-state-response' models that are used to describe the change in the provision of final goods and services that results from a management or policy action. Further details and examples of logic chains are provided in Error! Reference source not found.**3**.

Complex bio-physical relationships underpin asset > services > benefits relationships. Invariably practical assessments – whether for economic appraisals or natural capital accounting – are constrained due to evidence gaps and uncertainty by the extent to which they can adequately or reliably represent these relationships and assess the impact of changes (e.g. from housing development). A critical assessment of the validity of evidence as well as the use of sensitivity analysis and qualitative assessments is necessary in order to better understand the order of magnitude of the costs and benefits as well as the key sensitivities. These constraints, however, are not unique to environmental valuation and apply to various other aspects of value for money assessments and business cases.

Box 3: Logic chains

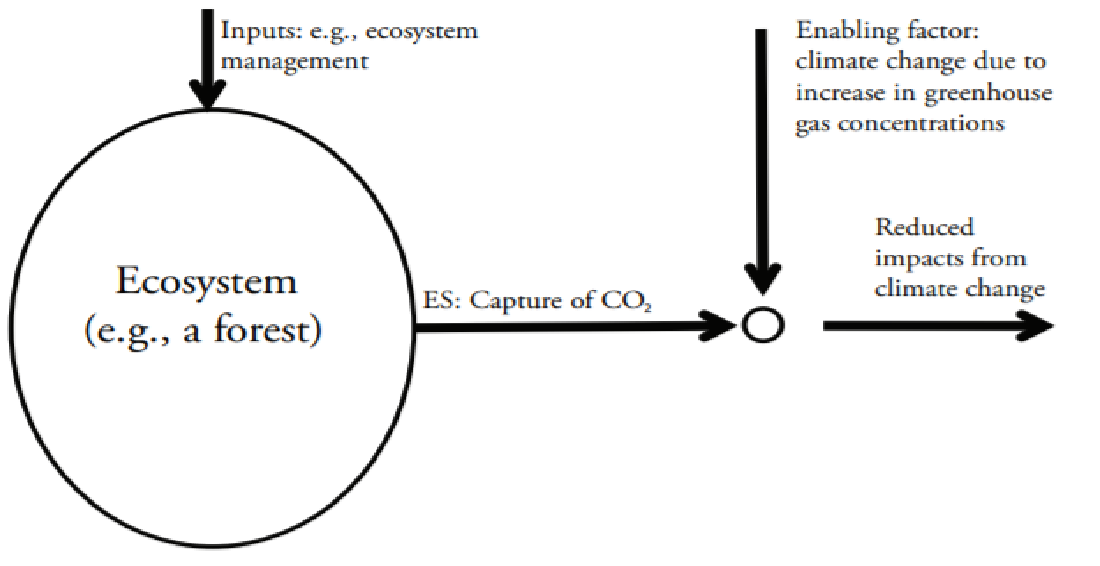
Defra (2007) sets out the impact pathway approach to value ecosystem services in a policy appraisal context. Error! Reference source not found.**3** illustrates how a policy change will affect human welfare through changes in ecosystems and ecosystem services. For example, a policy change in pollutant emissions restrictions will impact ecosystems through a change in pollutant concentrations, causing a change to species composition which can impact human welfare through altering aesthetic benefits.

Figure 3: Impact pathway approach from Defra (2007)



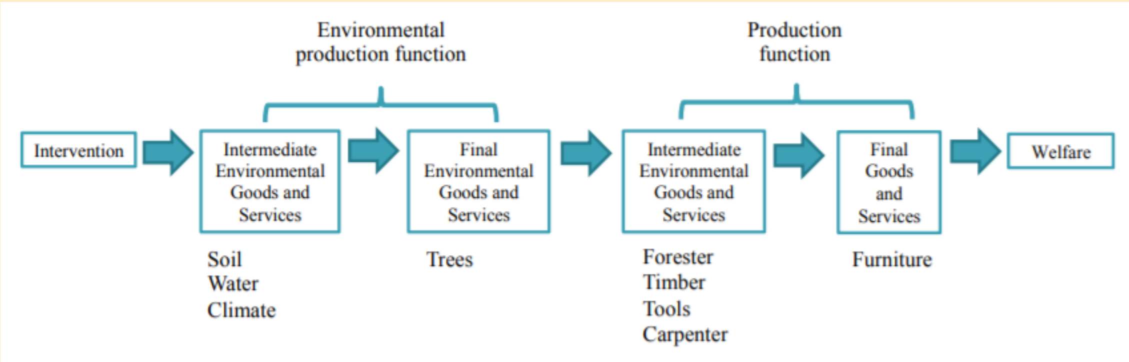
The SEEA EEA (United Nations et al. 2014) framework considers the stock of ecosystem assets and the flows of ecosystem services through the use of chain models. **Figure 4** shows how a management intervention will affect an ecosystem asset, in turn impacting the level of sequestration of carbon, resulting in an impact on climate change. Reduced impacts from climate change provide economic benefits to society through avoided damages now and in the future.

Figure 4: Logic chain from SEEA EEA (2014)



Binner et al. (2017) adopts the ecosystem service approach to recognise the role of nature in human wellbeing. The form of logic chain in this approach combines environmental production functions and economic production function and recognises human welfare comprises of natural capital assets and other capitals. For example, the quality and quantity of trees are dependent on the underlying condition of the natural capital assets. These environmental factors impact the final goods and services provided by the woodland, e.g. furniture, and ultimately affecting human welfare. **Figure 5** illustrates how a management intervention impacts an environmental production function, impacting a production function, ultimately effecting human welfare.

Figure 5: Production function logic chain from Binner et al. (2017)



Practical application

Economic valuation focuses on changes in provision of final goods and services. This is consistent with underlying analytical principles that are concerned with measuring changes in individual and social welfare (Error! Reference source not found.**1**). In economic appraisals the objective therefore is to value the outcomes – i.e. changes in the provision of final goods and services – due to policy interventions.

At the basic level, an appraisal of a specific impact or outcome quantifies two items:

- The change in the provision of the final good or service (Q), which could be a quantity change or quality change.

- The (marginal) value or 'price' (P) of that change, which measures the change in individual or social welfare. Ordinarily this is calculated as an annual flow value that is aggregated over: (a) the affected population (i.e. users and non-users); and (b) the time. The basic formula (Benefit = P x Q), however, underplays the intricacy of developing a practical benefits assessment that accounts for the dependency of economic values on natural assets.

On the value side of the formula, (*P*), there is the need to consider the factors that influence economic values, particularly in terms of the beneficiary population and their characteristics, including:

- Use of the final goods/services, socio-economic and demographic profile, and the availability and quality substitute goods and services. All of these factors influence the marginal value of the change and, in principle, should be accounted for in benefits assessments; for example, by applying a 'distance-decay' function in the aggregation across the beneficiary population (eftec, 2010) (see also **Box 4).**

- The choice of the economic valuation method or evidence source, which determines the extent of TEV that is captured within an assessment (Error! Reference source not found.**1**). Of note too, is that the measures of this value, such as WTP to secure the change (or avoid the change) in provision of the final good or service are defined by individuals' current preferences and income constraints. Typically, it is assumed that these underlying preferences hold over the timescale of the assessment, although adjustment can be made for expected growth in income and how this may result in real changes in WTP[1].

Reducing the change in provision of the final good that results from a management or policy action to simply '*Q',* significantly understates the multi-disciplinary analytical requirement that is often needed for a benefits assessment that accounts for the dependency of economic values on natural assets. Often, the science linking the action (e.g. changes in land-use or management) to the changes in the environment and the changes in final goods and services (the end-points) relevant to valuation is missing. For example, understanding how the construction of a housing development will affect the local biodiversity. Without these scientific linkages in place to represent the relationships between natural assets, flows of ecosystem services, and the provision of final goods and services (assets > services > benefits), the scope of economic valuation to meaningfully inform benefits assessment can be limited.

Box 4: Value transfer

"Value transfer" is the most common way in which environmental values are applied in practical assessments. In short, it is an approach where existing valuation evidence is applied in a new policy context – for example the appraisal of environmental impacts arising from housing developments – rather than commissioning new bespoke evidence via primary research. The robustness of value transfer evidence depends on the process of reviewing available evidence and selecting the most suitable estimates. This requires that analysis takes into account the context sensitivity of economic values (and adjusts if necessary) when judging the suitability of the existing evidence, particularly with respect to the:

- Definition of the environmental impact.

[1] Real' values are adjusted for inflation, hence WTP can be compared across time periods to understand how factors such as relative scarcity and income growth result in change in the value of final goods and services. 'Nominal values' measure the value of a good or service in current price terms.

- The scale of the change in impact.
- Location and time period of the impact as well as the affected population (e.g. socio-economic and demographic profile).
- Availability and quality of substitutes.
- Institutional framing (e.g. whether the valuation is concerned with a private consumption good or a public good, and therefore the component of total economic value that is captured).

Practical guidelines for using value transfer approaches are provided by Defra (see eftec, 2010). In practice, the criteria for establishing if available evidence is suitable are demanding and valuations can vary between different contexts due to multiple factors. For housing development, spatial and location context is particularly material, in particular the:

- The baseline condition of local environment/natural assets.
- The beneficiary population and their characteristics, such as their use of goods/services, socio-economic/demographic profile (relevant to 'levelling-up').
- The availability/quality of substitute goods/services. These factors influence the marginal value of benefits (costs) and should be accounted for in economic appraisals.

Developing and refining a practical approach for treatment of these factors will be key to subsequent stages of work, particularly with regards to: (a) how the characteristics of the local area and features of the development influence the benefit (cost) values at an individual site/project level; and (b) how to 'scale' benefits appropriately to estimate benefits (costs) at the national level (e.g. accounting for diminishing marginal benefits).

Current guidance

This section details the current guidance on appraising environmental impacts.

DCLG Appraisal Guide, 2016

The DCLG Appraisal Guide (DCLG, 2016) states the importance of including all costs and benefits associated with an intervention, including both the private and external impacts.

"An economic appraisal should seek to capture all the benefits and costs associated with an intervention. This will include both private and external impacts. For many DCLG interventions, land value uplift will capture the net private impacts of a development. However, external impacts also need to be captured and can be fundamental to the case for intervention".

While environmental, air quality and energy use and greenhouse gas emissions impacts are all listed as important external impacts to be included, no framework is given to understand the link between the intervention and the environmental impacts, nor how to account for context dependent factors such as the baseline condition of the local environment or the beneficiary population and their characteristics. Usefully the DCLG guidance could be updated to refer to the subsequent release of Defra's 'Enabling a Natural Capital Approach' and revisions on the HM Treasury Green Book.

HM Treasury Green Book

The Green Book sets out the Government's overarching guidance on appraising policies, programmes and projects. The guidance states that the appraisal of social value should include all "significant costs and benefits that affect the welfare and wellbeing of the population, not just market effects" listing environmental impacts as one such category of costs and benefits (HM Treasury, 2020, p.5).

Moreover, it states that "costs or benefits of options should be valued and monetised where possible in order to provide a common metric" and recommends a range of valuation techniques where there is no reasonable market price available. These non-market valuation techniques are detailed in Annex A (p. 75) of the guidance along with some generic environmental values for use in appraisal. These cover environmental impacts such as; i) air quality; ii) noise; iii) waste, iv) recreation; v) amenity value; vi) landscape; vii) water quality and resources; viii) biodiversity; and ix) GHG emissions.

The guidance further suggests using Defra's Enabling a Natural Capital Approach (ENCA) guidance (see below) for "initial estimates of environmental impacts, or valuing secondary impacts" which should be used in combination with "changes in the physical quantity of the environmental good or impact under consideration" (p. 77).

Defra Enabling a Natural Capital Approach (ENCA) guidance

Defra published their online resource 'Enabling a Natural Capital Approach' (ENCA) in 2020. ENCA is an extensive source of information and guidance on the natural capital approach and aims to allow users to assess and value the natural environment in a consistent manner. As well as the guidance document, ENCA contains a Service Databook which:

- Gives data sources for available studies and metrics (physical and monetary data) for 24 ecosystem services.
- Discusses limitations of the data, its use in appraisal, and in natural capital accounting.

ENCA, however, is not presented as a comprehensive and prescriptive source of guidance. In particular, it does not advise on the validity of each value presented for all contexts.

The guidance aligns with the requirements for economic analysis within Government as described in HM Treasury's Green Book, as well as other Natural Capital guidance such as the Office for National Statistics (ONS) Principles of Natural Capital Accounting (ONS, 2017) and Defra's Value Transfer Principles (eftec, 2010).

Department for Transport Appraisal Guidance (WebTAG)

DfT's Transport Analysis Guidance (WebTAG) provides guidance on the appraisal of transport interventions with the aim to inform the business case for a transport investment proposals. The appraisal of environmental impacts should be undertaken as part of this transport appraisal process, with specific guidance detailed in Section A3.

Specific values referenced in the guidance when appraising the environmental impacts of transport interventions are presented in the accompanying TAG Data Book which includes the following impacts: i) noise; ii) air quality; iii) greenhouse gases; iv) landscape; v) townscape; vi) the historic environment; vii) biodiversity; and viii) the water environment.

Wider use of the natural capital approach

It is worth noting the difference between the natural capital approach and Environmental Impact Assessments and Strategic Environmental Assessments. These tend to focus on legal obligations and the adverse environmental impacts of a project or programme, as opposed to the natural capital approach which can provide a more strategic basis for how the natural environment can be integrated with and deliver wider objectives (Defra, 2020a).

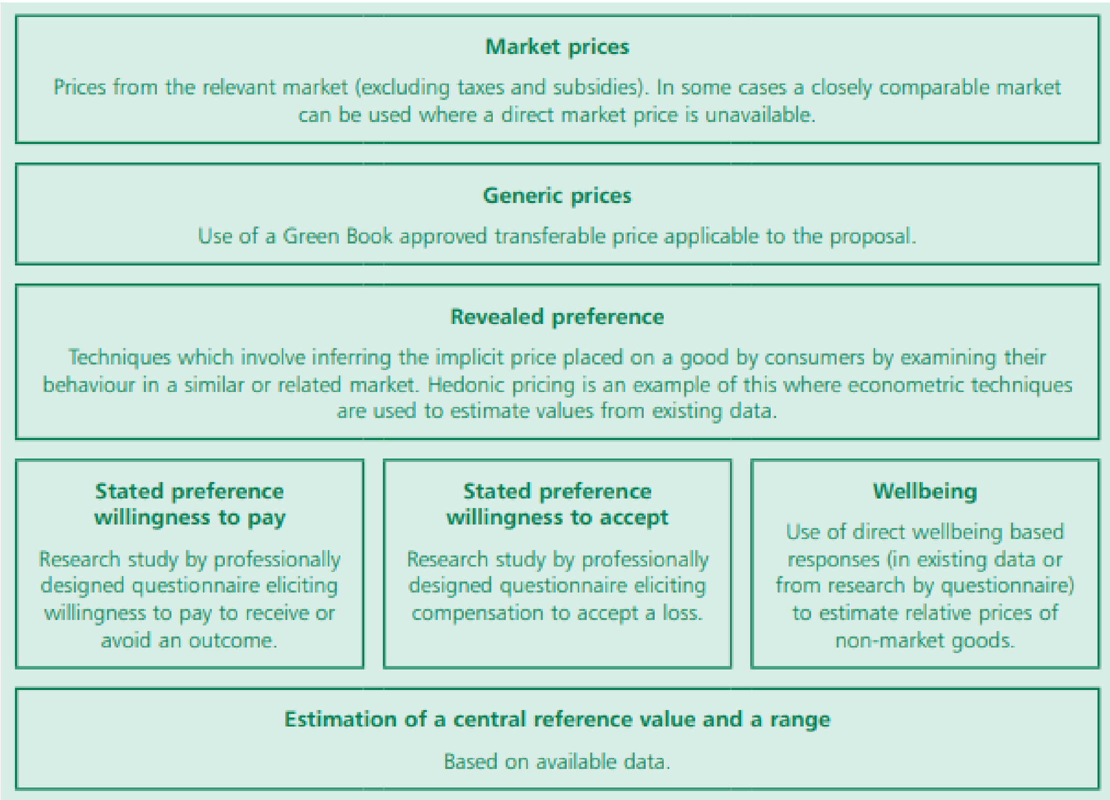
It is also important to distinguish between natural capital "accounting" which assesses the baseline provision of assets, flows and benefits (i.e. what is currently provided) from conventional economic "appraisal" which assesses a change in costs and benefits (i.e. from a policy intervention) relative to a baseline. A more detailed comparison between the two analytical contexts is provided in the ENCA Guidance (Defra, 2020a, p.39).

The majority of work in the UK on natural capital has been on accounting rather than appraisal. Recent examples include Natural England's natural capital account of their National Nature Reserves (Natural England, 2020) and the Environment Agency's recently published Natural Capital Register and Account Tool (Environment Agency, 2021).

Valuation methodologies

The notion of a 'valuation hierarchy' is well-rehearsed in relevant guidance concerning the use of economic valuation methods. It shows a notional hierarchy of preference for methods to estimate values (to be used as a guide only and not without considering the validity of individual methods and their application). The hierarchy is explicitly drawn-out in the Green Book (**Figure 6**).

Figure 6: Valuation Hierarchy



Source: HM Treasury (2020, p.59)

These valuation methodologies are summarised in Table 1 and detailed in **Appendix A**.

Table 1: Valuation methodologies

Approach	**Description**	**Examples**
Market based	Market-based methods use evidence from markets in which environmental goods and services are traded, markets in which they enter into the production functions for traded goods and services, or markets for substitutes or alternative resources.	Market values Production functions Cost of illness methods Replacement cost methods Resource rent method
Revealed preference	Revealed preference methods analyse relationships between demand for some market goods and preferences for related non-market goods/services. These methods only work if changes in provision of the non-market good have an observable impact on the demand for a market good.	Averting behaviour Hedonic property pricing method Hedonic wage method Travel expenditure based method
Stated preference	Stated preference methods are based on surveys which create simulated markets for respondents to express their preferences.	Contingent valuation Discrete choice experiments
Subjective wellbeing	Estimates value for outcomes, goods and services based on inferring the impact on an individual's subjective wellbeing. Impact can then be converted into a monetary amount by estimating the equivalent amount of income they would be willing to pay to receive the proposed positive change in an outcome (or avoid a proposed negative change).	Subjective wellbeing valuation

Scope of evidence review

This section defines the scope of the literature review in relation to the appraisal of housing interventions. The first section provides a high-level summary of Homes England interventions, the second section defines the categorisation of impacts used in the literature review and the third section sets out the drivers of scope and materiality of impacts.

High-level context

In order to cover the full scope of environmental impacts, the scope of the literature review is based on a large greenfield or brownfield development. Retrofitting existing properties and other types of housing interventions will have a different profile of impacts, with some relatively more important than for new developments. Overall, however, the scope of impacts is likely to be a subset of those covered in this literature review. When determining the scope of impacts it is important that economists and analysts engage with the relevant experts.

Categorisation of impacts

The literature review is framed around three broad categories of impact from housing developments:

- **Land take**: Permanent net changes to ecosystem service provision resulting from the land use change.
- **Construction**: One-off / temporary impacts from the production, use, transport and waste of materials used in the construction of housing.
- **Occupation**: On-going impacts of the occupants energy use, water consumption, transport and waste for the duration of the properties' life.

At this stage, the focus is on approaches for valuing impacts (e.g. methodology, existing studies, tools), rather than issues for appraisal, such as attribution, additionality and establishing the net effect against a baseline position or counterfactual scenario. Whilst these considerations are critical for robust appraisal practice, they are secondary to the main objective for the literature review which is to identify evidence/tools that can be readily applied in appraisals and establish the main gaps for future work to address.

The individual impacts within these are described in the sections below.

Land take

Land take considers the permanent net changes to ecosystem service provision resulting from the land use change. Depending on the housing intervention type and design this can result in negative or positive outcomes for the environment. The ecosystem services relevant to housing developments are listed in **Table 2.** Note that ecosystem service classification detailed in ENCA is used throughout this report.

Table 2: Land take impacts

Type of Impact	Impact
Land use change *(net change to ecosystem service provision)*	Carbon sequestration
	Air pollution removal
	Recreation
	Landscape
	Local temperature regulation
	Food (crops & livestock)
	Timber
	River flood regulation
	Heritage
	Biodiversity

Construction

Construction is separated into four main types of impact; i) aggregates; ii) construction activity; iii) transport; and iv) waste. The individual environmental impacts within these are listed in **Table 3** below.

Table 3: Construction impacts

Type of Impact	Impact
Aggregates *(embodied impacts from the extraction and production of construction materials)*	GHG emissions (embodied and stored carbon)
	Air pollution
	Noise
	Landscape
Construction activity (*direct impacts of the construction*)	GHG emissions
	Air pollution
	Noise
Transport (*of construction materials and workers to and from the housing development)*	GHG emissions
	Air pollution
	Noise
Waste *(transport, treatment and disposal of waste generated by construction)*	GHG emissions
	Air pollution
	Noise
	Landscape

Occupation

Occupation is separated into four main types of impacts; i) energy use; ii) water consumption; iii) transport; and iv) waste. The individual environmental impacts within these two types are listed in **Table 4** below.

Table 4: Occupation impacts

Type of Impact	Impact
Energy use *(for living and transport by occupants - including communal areas)*	GHG emissions*
	Air pollution
	Light pollution
Water consumption *(impacts of abstraction, transportation and treatment of occupants use)*	GHG emissions
	Landscape
	Biodiversity
	Water quality
Transport *(direct use by occupants and additional long-term demand placed on local transport infrastructure)*	GHG emissions
	Air pollution
	Noise
	Landscape
	Biodiversity
	Heritage
Waste *(transport, treatment and disposal of waste generated by occupants)*	GHG emissions
	Air pollution
	Noise
	Landscape

** Note: for energy use, GHG emissions are outside the scope of the literature review as these impacts are being covered by a separate study for Homes England.*

Drivers of scope and materiality of impacts

Following from above, the value of environmental impacts is context dependent, and ideally the valuation evidence applied in economic appraisals needs to be sensitive to the factors that influence values (**Box 4**). With respect to the environmental impacts of housing developments, there are a range of factors to consider, both in terms of establishing the scope of environmental impacts (i.e. the number of impacts to be included in the assessment) and their materiality (the scale of impacts). These include:

- **Development size**: given the same baseline land cover, the size of the development is unlikely to change the scope of the land take impacts (the same land use change will occur), however the materiality of these impacts will vary in some proportion to the development scale. Similarly, while the scope of construction and occupation impacts are unlikely to change (all will still be relevant to some extent), the materiality of these will depend on the development scale.

- **Development location and condition**: the location of the development and baseline condition of the existing land cover will affect the scope of land take impacts due to the spatial differences in the net change in ecosystem services provisions. The scope of construction and occupation impacts however is likely to be independent (all will be relevant to some extent). In terms of materiality, all impact types are likely to be affected by the location, for instance, due to differences in transport access.

- **Intervention type**: The intervention type can affect both the scope and materiality of all impact groups. For instance, compared to a new build, retrofitting will not require land take and will have a smaller construction impact. The scope and materiality of occupation impacts could also vary depending on the type of intervention.

- **Housing type**: given the same size, location and type of development, the housing type is unlikely to affect the scope of any of the impact groups (all will be relevant to some extent). Unlike the materiality of land take impacts (which would not be expected to change), those relating to construction and occupation will however depend on the housing type through construction requirements and differences in building efficiencies.

- **Construction method**: given the same size, location and type of development, the construction method is unlikely to affect the scope of construction and occupation impacts (few impacts would be completely eliminated), however there would be changes to the size of the impact, for example through increased building efficiencies. However, the scope and materiality of land take impacts could be affected through incorporating sustainable drainage systems (SuDs) into the housing design.

- **Standards and benchmarks:** a further consideration is the build standards. For instance, the scale of occupation impacts[2] will depend upon the reference point to which they are assessed. Note that this will not affect the scope of impacts.

Table 5 and Table 6 below summarises these effects (factor vs. type of impact).

Table 5: Scope of impacts

Factor	Land take	Construction	Occupation
Development size	-	-	-
Development location and condition	Y	-	-
Intervention type	Y	Y	Y
Housing type	-	-	-
Construction method	Y	-	-
Standards and benchmarks	-	-	-

Note: "Y" indicates that the factor is likely to affect the scope of impacts.

[2] Such as water use. Note that GHG emissions from energy use in occupation are outside the scope of the literature review

Table 6: Materiality of impacts

Factor	Land take	Construction	Occupation
Development size	Y	Y	Y
Development location and condition	Y	Y	Y
Intervention type	Y	Y	Y
Housing type	-	Y	Y
Construction method	-	Y	Y
Standards and benchmarks	-	-	Y

Note: "Y" indicates that the factor is likely to affect the scope of impacts.

The summary of findings from the literature review (**Section 4**) notes the extent to which these considerations are reflected in the evidence. In addition, they are taken into account in terms of the suggestions for further work in subsequent phases of the project.

Findings

This section details the findings from the literature review.

Land take impacts

This section presents the evidence relating to land take (permanent net changes to ecosystem service provision resulting from the land use change). When the literature distinguishes between different values according to spatial factors (such as location in the UK or habitat type and condition), a range of values is presented. Suggested indicative values to use in appraisal are presented following the sections on valuation and physical flow.

Carbon sequestration

Habitats naturally sequester carbon dioxide from the atmosphere and store it as carbon in their biomass and the soil. Therefore, any net change in land use as a result of housing developments, such as the conversion of agricultural to urban land or the planting of trees around a property, has an impact on the quantity of carbon sequestered (and stored) per hectare. This sequestration and storage provides a benefit to humans through the contribution to meeting national GHG targets to avert the possible consequences of climate change (Defra 2020a, p. 63).

Valuation

The Green Book (HM Treasury, 2020, p. 84) recommends using the BEIS carbon prices (BEIS 2020a) to value the sequestration and emission of carbon dioxide. These values are based on the economic cost of mitigating a unit of carbon emission (abatement cost) and distinguishes between two types of emissions depending on the sector from which the emissions occur[3]:

- **Traded sector**: is defined as those activities covered by the EU Emissions Trading System (EU ETS) which sets a market price for carbon. It generally covers all power generation, many energy-intensive industries, and intra-EU aviation. Therefore, all electricity consumption is covered by the EU ETS and is in the traded sector.

- **Non-traded sector**: includes all other energy consumption, including all household and non-aviation transport fuel use (excluding electricity).

As stated in BEIS (2020a, p. 17), emissions from land use, land use change, and forestry (LULUCF) falls outside the scope of the EU Emissions Trading Scheme and should be valued using the non-traded carbon price (see **Table 7** where these values are denoted in bold font).

Note that BEIS is currently updating its carbon prices to reflect:

- Changes in international targets: More ambitious targets following Paris Agreement (keep global temperature rise well below 2°C above pre-industrial levels and to pursue efforts to limit the temperature increase even further to 1.5°C).

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[3] Note that From 2030 onwards, the two prices converge under the assumption of a comprehensive global carbon market (increasing to £355/tCO2e by 2075).

- Changes in domestic targets: The new carbon price will reflect the marginal abatement costs to meet the strengthened UK net zero GHG emissions target by 2050.

- EU Exit: Short-term traded (EU ETS) carbon values may be revisited depending on the outcome of EU Exit.

Until the new values become available, BEIS considers that the "current published central carbon values may undervalue policy impacts on GHG emissions, although the scale of undervaluation is unclear" (DfT, 2020a). It therefore recommends, until the updated carbon values are available to illustrate the potential impact of placing a higher value on GHG emissions by "reporting scheme GHG impacts using the current published high carbon values series as a required sensitivity test (in addition to any use of central values)".

Table 7 details the BEIS traded and non-traded carbon prices which are valued in terms of £ per tonne of carbon dioxide equivalent (tCO2e). Note that all studies in the literature review have used these values or their predecessor which was based on the social cost of carbon. Note also that these values can be used nationally as all sequestration and emission of greenhouse gases contribute to the UK carbon target.

Table 7: Valuation - carbon sequestration

Description	Source	Price year	2021 Value (£ / tCO2e)		
			Low	Central	High
Traded carbon price*	BEIS (2020a)	2018	4	21	37
Non-traded carbon price*	BEIS (2020a)	2018	**35**	**70**	**106**

** Note: both sets of prices rise over time to reflect the increasing difficulty in abating marginal emissions (i.e. once the "low hanging fruit" has been addressed).*

Physical flow

Table 8 summarises the evidence on the physical sequestration of carbon dioxide, presenting the carbon sequestration rates per hectare of different habitats. These are listed in ENCA (Defra, 2020a) and are understood to be widely used in practical assessments. For completeness, all habitats listed in ENCA have been included below though not all will be relevant for the appraisal of housing developments. Conversion of habitat types due to housing development should be calculated using the values below. Note that sealed surfaces provide zero carbon sequestration ONS (2019).

Table 8: Physical flow - carbon sequestration

Description	Source	Original source	Value (tCO2e / hectare / yr)		
			Low	Central	High
Woodland	Defra (2020a)	ONS (2019), Forestry Commission (2017a)	-	5.7	-
Semi-natural grassland	Defra (2020a)	Christie et al. (2011, p.104)	-	0.4	-
Enclosed farmland (cropland)	Defra (2020a)	Christie et al. (2011, p.104)	-	0.1	-
Upland and lowland bog, fen and marsh	Defra (2020a)	Christie et al. (2011, p.104)	-	0.7	-

Heather grassland and montane habitats	Defra (2020a)	Christie et al. (2011, p.104)	-	0.7	-
Salt marsh	Defra (2020a)	Cannell et al. (1999, p514)	2.3	5.1	8.0

** Note: all values refer to annual flows of carbon sequestration and do not consider permanent storage.*

The rate of carbon sequestration per tree is calculated in eftec (2019b) at 6.8kg CO2e per tree per year using the woodland sequestration figure in **Table 8** and an assumption of 833 trees per hectare on average (based on case study data).

Alternative values to those in **Table 8** can be produced using NEVO tool developed by the University of Exeter (2019a) whereby the land cover for the housing development site can be altered to urban to show the indicative impact of land-take on carbon sequestration. Note however that the minimum scale of analysis is 2km and that it is not possible to specify type of landcover beyond broad habitats.

Suggested indicative values to use in appraisal (carbon sequestration)

a. Valuation: non-traded carbon price *(BEIS, 2020a)* - Table 7
b. Physical flow: national per hectare sequestration rates *(Defra, 2020a)* - Table 8

Context dependent factors

As with the valuation of carbon sequestration, the values in **Table 7** can be used nationally, however the exact volume of carbon sequestration will depend on the condition of the habitat.

Air pollution removal

Habitats and their vegetation remove air pollutants from the atmosphere, lessoning the exposure and therefore impact that these have to humans in terms of health and wellbeing. The scale of this benefit is positively related to i) the existing concentration of air pollutants; ii) the amount of vegetation, and iii) the population density in the area of interest (Defra 2020a, p. 62). By removing habitats which provide this service to free up land for housing developments, these benefits are lost and should be accounted for in appraisal. Conversely, if features are added to housing developments, such as the planting of trees or the construction of green roofs, the benefits provided by these should be accounted for. The literature distinguishes between five main air pollutants, each of which are considered in this section:

- Particulate Matter 2.5 (PM2.5)[4].
- Nitrogen Dioxide (NO2).
- Sulphur Dioxide (SO2).
- Ozone (O3).

[4] Of the air pollutants listed, PM2.5 has been found to be the most harmful to human health as stated in ONS (2019) and Jones et al., (.2017) and highlighted in the tables below.

- Nitrous Oxide (NOx).

Valuation

Valuation evidence for the benefits of air pollutant removal focuses on reduced healthcare costs due to the lower exposure to the harmful air pollutants relative to a counterfactual of zero vegetation (e.g. a sealed surface). Table 9 summarises the national level valuation evidence on the health damages associated with exposure to these air pollutants, measured in terms of their mass (tonnes). This is consistent with the Green Book which states that for impacts likely to be less than £50 million and do not affect compliance with legal limits then a "damage cost" approach is appropriate (HM Treasury, 2020, p.77)[5]. Note that only Jones et al. (2017) states the components included in the cost (reduced respiratory and cardiovascular hospital admissions as well as life years lost) which are detailed in the footnotes below.

It is also important to note that these values only relate to physical health effects and do not take into account wider impacts on:

- Mental health.
- Ecosystems.
- Agriculture and crop yield.
- Damage to buildings and cultural heritage, such as cathedrals.
- Changes to visibility.

Table 9: Valuation – air pollution removal

Description	**Source**	**Price year**	**Value (£ / tonne)**		
			Low	**Central**	**High**
Particulate Matter 2.5 (PM2.5)					
Avoided health costs	Defra (2020b, Table 10)	2017	**15,888**	**73,403**	**227,323**
Avoided health costs[6]	CIRIA (2019)	2015	45,510	58,125	66,052
Avoided health costs	DfT (2020a)	2020	26,857	125,835	389,894
Avoided health costs[7]	Jones et al. (2017)	2012	-	42,059	-
Sulphur dioxide (SO2)					

[5] The Green Book goes on to state that "if impacts are greater than £50 million then the "impact pathway" approach should be considered. This involves bespoke modelling specific to the intervention". Furthermore in the limited instances where a proposal could affect compliance with legal limits, an "abatement cost" approach should be used.
[6] Includes impacts from all sizes of particulate matter.
[7] Respiratory hospital admissions, Cardiovascular hospital admissions, Life years lost.

Avoided health costs	Defra (2020b)	2017	**2,893**	**13,026**	**37,611**
Avoided health costs	Office of the Deputy Prime Minister (2005)	Not stated	744	-	2,296
Avoided health costs[8]	Jones et al. (2017)	2012	-	32	-
Nitrogen dioxide (NO2)					
Avoided health costs[9]	Jones et al. (2017)	2012	-	2,797	-
Ozone (O3)					
Avoided health costs[10]	Jones et al. (2017)	2012	-	42	-
Nitrogen oxides (NOx)					
Avoided health costs	Defra (2020b, Table 10)	2017	**611**	**6,385**	**24,174**
Avoided health costs	Office of the Deputy Prime Minister (2005)	Not stated	154	565	977
Avoided health costs	CIRIA (2019)	2015	10,101	25,252	40,404
Avoided health costs	DfT (2020a)	2020	754	7,370	25,727

** Note: when multiple values are available in the literature, the suggested indicative value for each air pollutant is bolded. In all cases the Defra (2020b) values are recommended since they are based on the most recent science.*

As stated in the Green Book (HM Treasury, 2020, p. 77), the latest damage cost estimates are available from Defra (as in **Table 9**) and so these should be used. With the exception of Jones et al. (2017), the remaining values in the table are derived from previous versions of the Defra air quality damage cost guidance which was withdrawn in 2020.

The benefit provided from removing pollutants from the atmosphere depends on the existing concentration of air pollutants in the area since the rate of removal by vegetation and hence overall quantities will be larger. Similarly, it also depends on the population density in the area of interest since a greater number of people stand to benefit. For this reason, when the location of housing developments is known, more accurate estimates can be made using spatially specific values.

Spatial variations depending on the location and habitat type are derived from Jones et al. (2017) and presented in ENCA, looking at PM2.5, NO2, SO2 and O3 combined as a per hectare value (see **Table 10**). Specific values for each pollutant can also be derived from the report using the methodology presented in ENCA.

[8] Respiratory hospital admissions.
[9] Respiratory hospital admissions, Cardiovascular hospital admissions, life years lost.
[10] Respiratory hospital admissions, Cardiovascular hospital admissions, deaths.

Table 10: Valuation - air pollution removal (spatial variations)

Description	Source	Price year	2021 value – PM2.5, NO2, SO2 and O3 (£ / hectare)		
			Low	Central	High
Urban woodland	Jones et al (2017)	2012	-	771	-
Rural woodland	Jones et al (2017)	2012	-	245	-
Urban grassland	Jones et al (2017)	2012	-	149	-
Enclosed farmland	Jones et al (2017)	2012	-	14	-
Coastal margins	Jones et al (2017)	2012	-	26	-

A more detailed spatial breakdown for solely PM2.5 is provided in the eftec and CEH air pollution removal tool (eftec and CEH, 2019) (see **Figure 7**). This tool calculates and values the human health benefits provided by trees removing PM2.5 for each local authority in the UK, taking into consideration differences in pollution levels, local population, tree cover and climate. One-hundred-year asset values are given per hectare which include the health benefits from avoided cases of respiratory hospital admissions, cardiovascular hospital admissions, and life years lost[11]. Note that this tool only values the removal of PM2.5 as opposed to other air pollutants and does not include the full range of health benefits associated with reduced levels of PM2.5.

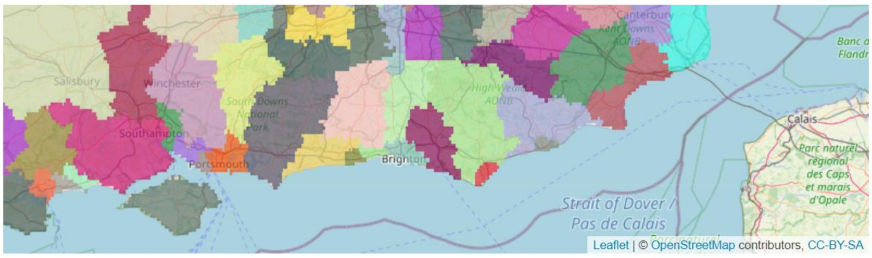
Figure 7: Valuation – air pollution removal (eftec and CEH, 2019)

Area of woodland planted or removed (negative number) in hectares:

1

Existing Woodland (ha)	1945
Woodland planted (ha)	1
Change in asset value (£, PV 100, 2019 prices)	37078

Local Authority	Bromley
Area of woodland (ha)	1945
Total area of Local Authority (ha)	15013
Population	325000



Choose your Map:

- Local Authorities
- PM2.5 Removed
- Value

Local Authority	PM2.5 removed by woodland (kg/year)	PM2.5 removal rate per ha woodland (kg/ha year)	Asset value of PM2.5 removal (£ million, 2019 prices)	Asset value of PM2.5 removal per ha (£/ha, 2019 prices)
Bromley	13433	6.9	111.8	57465

Source: eftec and CEH (2019)

[11] Note that annual values are not included in the tool as these are expected to change over time as background air pollution levels fall due to reduced emissions at source.

Spatial variation of value is also considered in the Air Quality Appraisal guidance published by Defra (2020b). Values for PM2.5 and NOx are presented in per tonne metrics as opposed to per hectare as above. Note that these relate to road transport impacts though could be applied to the removal of the air pollutants by vegetation.

Table 11: Valuation - air pollution removal (spatial variations)

Location	**Road transport damage cost values (£ / tonne) Defra (2020b, Table 10)**					
	PM2.5			**NOx**		
	Low	**Central**	**High**	**Low**	**Central**	**High**
Average	17,567	81,518	252,695	817	9,066	34,742
Central London	83,689	401,540	1,234,992	4,053	51,178	200,767
Inner London	85,544	410,293	1,273,099	4,161	52,587	206,323
Outer London	46,656	222,205	690,525	2,252	27,741	108,367
Inner Conurbation	32,693	154,672	480,614	1,574	18,913	73,565
Outer Conurbation	20,374	95,108	294,812	979	11,170	43,037
Urban Big	21,067	98,465	305,206	1,007	11,529	44,455
Urban Large	17,712	82,253	254,531	850	9,493	36,427
Urban Medium	14,512	66,797	206,169	706	7,614	29,021
Urban Small	12,231	55,777	171,775	601	6,251	23,646
Rural	7,048	30,697	93,795	364	3,166	11,483

Physical flow

Table 12 summarises the evidence on air pollution removal for PM2.5, NO2, SO2 and O3, presenting the removal rates per hectare of different habitats along with the UK average. These values, derived from Jones et al. (2017), are used in the EA Natural Capital Register and Account Tool (EA, 2021). For completeness, all eight UK National Ecosystem Assessment (UKNEA) broad habitats (with a distinction made between urban sealed surfaces, trees/woodland and grassland) have been included below though not all will be relevant for the appraisal of housing developments. Conversion of habitat types due to housing development should be calculated using the values below. Note that sealed surfaces do not provide air pollution removal.

Table 12: Physical flow – air pollution removal

Broad habitat*	**Value (kg / hectare / year) Jones et al (2017)**			
	PM2.5	**NO2**	**SO2**	**O3**
Average	0.88	0.95	1.52	47.34
Coastal Margins	0.45	1.12	2.25	40.67
Enclosed Farmland	0.18	1.30	1.62	52.36
Freshwaters, Openwaters, Wetlands and Floodplains	0.21	0.21	0.56	33.61
Marine	0.00	0.00	0.00	0.00
Mountains, Moorlands and Heaths	0.23	0.31	0.73	44.83
Semi-natural Grasslands	0.30	0.61	1.19	43.10

Urban (sealed surfaces)	0.00	0.00	0.00	0.00
Urban (trees/woodland)	7.04	4.12	5.94	50.00
Urban (grassland)	0.74	3.83	2.38	40.29
Woodlands	6.06	1.42	3.81	73.90

** Note: Habitat classifications vary depending on the source study, however most presented in this report overlap. For example, "Upland and lowland bog, fen and marsh" and "Heather grassland and montane habitats" from **Table 4.2** overlap with "Mountains, Moorlands and Heaths". Depending on the choice of values used, a mapping exercise may need to be undertaken to ensure consistency when appraising impacts.*

As with the valuation of PM2.5 removal, the physical flows can be calculated for each local authority in the UK using the eftec and CEH (2019) tool, presenting annual kg per hectare values.

Housing developments may however lead to positive impacts with respect to air pollution removal through the construction of green roofs and the planting of trees around the property, both of which have the potential to draw pollutants out of the atmosphere. Both of these are estimated in the B£ST Tool (CIRIA, 2019), the removal rates for which are presented in **Table 13** and **Table 14** below.

Table 13: Physical flow – air pollution removal (green roofs)

Description	Source	Original source	Value (kg / ha / yr)		
			Low	Central	High
PM10	(CIRIA, 2019)	USEPA (2014)	-	6.49	-
PM2.5 (converted)	Calculated	-	-	3.45	-
NO2	(CIRIA, 2019)	USEPA (2014)	-	19.82	-
SO2	(CIRIA, 2019)	USEPA (2014)	-	23.29	-
O3	(CIRIA, 2019)	USEPA (2014)	-	44.92	-

Note: the PM2.5 value has been estimated using a PM10 to PM2.5 conversion factor of 0.53 (Jones et al, 2017, Table S4).

Table 14: Physical flow – air pollution removal (per tree)

Description	Source	Original source	Value (kg / tree / yr)		
			Low	Central	High
PM10	(CIRIA, 2019)	McPherson et al (2002)	0.07	0.13	0.20
PM2.5 (converted)	Calculated	-	0.04	0.07	0.11
NO2	(CIRIA, 2019)	McPherson et al (2002)	0.04	0.08	0.13
SO2	(CIRIA, 2019)	McPherson et al (2002)	0.01	0.03	0.05
O3	(CIRIA, 2019)	McPherson et al (2002)	0.06	0.12	0.20

Note: the PM2.5 value has been estimated using a PM10 to PM2.5 conversion factor of 0.53 (Jones et al, 2017, Table S4). The low, central and high values relate to small, medium and large trees respectively.

Suggested indicative values to use in appraisal (air pollution removal)
Valuation: dependent on the air pollutant and spatial context

- National per tonne values: PM2.5, SO2 and NOx *(Defra, 2020b),* NO2, O3 *(Jones et al., 2017)* – Table 9
- Habitat and spatially specific per hectare values for PM2.5, SO2, NO2 and O3 combined *(Jones et al., 2017)* – Table 10
- Spatially specific (local authority level) PM2.5 per hectare values *(eftec and CEH, 2019)* – Figure 7
- Per tonne values – Table 11
- Physical flow: dependent on the source of air pollution removal
- Habitats: national air pollution removal rates per hectare for PM2.5, NO2, SO2 and O3 *(Jones et al., 2017)* – Table 12
- Green roofs: National air pollution removal rates per hectare for PM10, PM2.5, NO2, SO2 and O3 *(CIRIA, 2019)* – Table 13
- Trees: National air pollution removal rates per tree for PM10, PM2.5, NO2, SO2 and O3 *(CIRIA, 2019)* – Table 14

Context dependent factors

The potential for air pollution removal varies significantly throughout England due to spatial differences in the concentration of pollutants (see above). Furthermore, the damage avoided is dependent on the local population. For this reason, caution should be taken when using national level values.

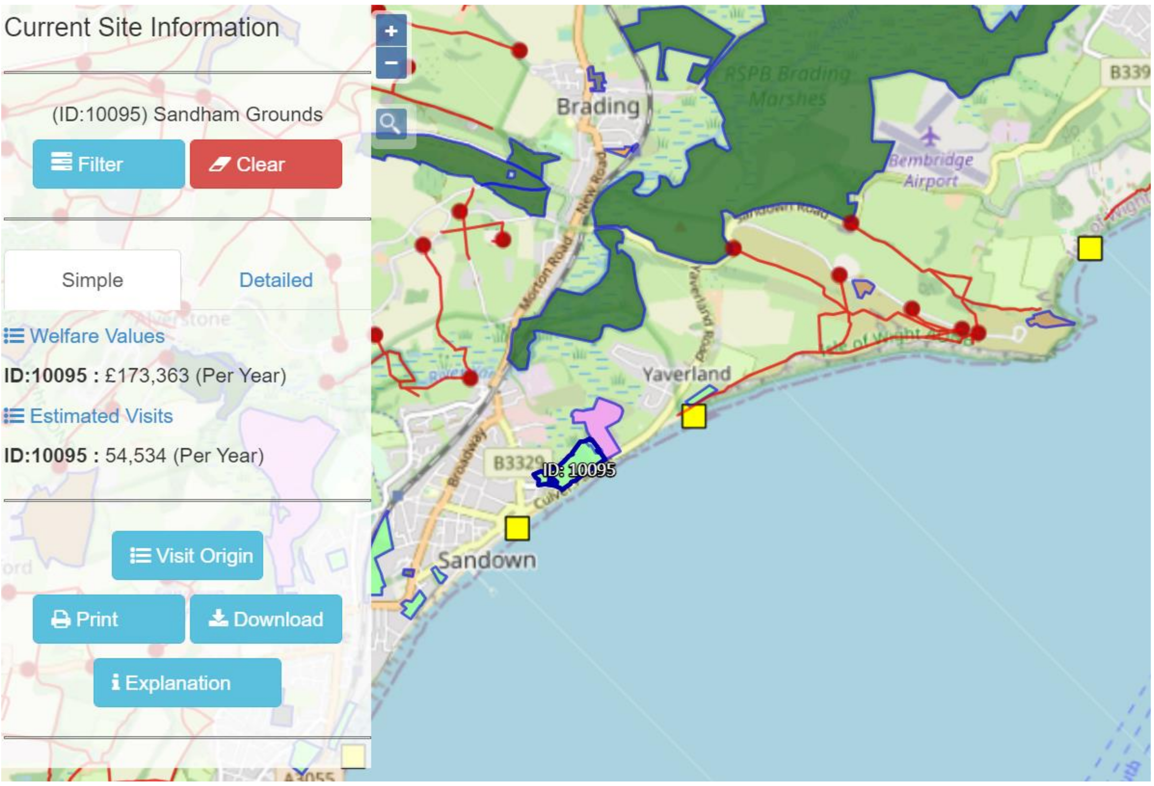
Recreation

Green and blue spaces provide potential for recreational activities, the value of which varies with the location, habitat type, beneficiary population and availability of alternative recreational opportunities (Defra, 2020a, p.65).
Housing developments can lead to both positive and negative effects on recreation depending on the nature of the intervention and resulting land use change. For example, an improvement or increase in accessible areas can increase the potential for recreational use (and vice versa).

Valuation

Both the Green Book and ENCA describe the Outdoor Recreation Valuation (ORVal) Tool developed by the University of Exeter (2019b) as useful for baseline assessments of recreational use (HM Treasury, 2020, p.78; Defra, 2020a, Services Databook – "Recreation"). The tool allows users to estimate visitation rates and recreational welfare benefits that are provided by accessible green space in England and Wales (see **Figure 4.2**). Moreover, it allows for the assessment of changes to these from creating or altering sites, such as from housing development. It is worth noting however that ORVal is based on predictions from a recreational demand model and does not provide actual counts of visits or resulting welfare benefits. Consequently, the figures should be taken as indicative (University of Exeter, 2019b)

Figure 8: Valuation – recreation (University of Exeter, 2019b)



Source: University of Exeter (2019b)

In cases where ORVal cannot be used to estimate values (such as if the site is not picked up or the model fails to account for unique characteristics that influence the visitation and welfare value) or where there is robust pre-existing data on visitor numbers or changes, Defra (2020a) recommends the following values from Sen et al. (2014) as given in **Table 15**. For completeness, all habitats listed in Sen et al. (2014) have been included below though not all will be relevant for the appraisal of housing developments.

Table 15: Valuation – recreation (Sen et al., 2014)

Description	Source	Price year	Value (£ / visit)		
			Low	Central	High
Urban Fringe Farmlands	Sen et al. (2014)	2010	-	£5.36	-
Mountains, Moors and Heathland	Sen et al. (2014)	2010	-	£5.03	-
Woodland and Forests	Sen et al. (2014)	2010	-	£3.96	-
Marine and Coastal	Sen et al. (2014)	2010	-	£3.34	-
Freshwater and floodplains	Sen et al. (2014)	2010	-	£1.82	-
Grasslands	Sen et al. (2014)	2010	-	£1.54	-

Physical flow

As with the valuation of recreation, ORVal can be used to estimate changes in recreational visits to accessible green spaces following housing interventions and the corresponding changes in land use.

Suggested indicative values to use in appraisal (recreation)

a. Valuation: Site specific values can be estimated using the ORVal tool (*University of Exeter, 2019b)* – Figure 8. If visit numbers are known, national per habitat values are given in *(Sen et al., 2014)* – Table 15
b. Physical flow: Site specific values can be estimated using the ORVal tool (*University of Exeter, 2019b)* – Figure 8

Context dependent factors

Whether the housing development delivers benefits or disbenefits in terms of recreation will depend on the change in the pre- and post-intervention land use. Furthermore, the scale of impact will vary according to the location, beneficiary population and availability of alternative recreational opportunities.

Landscape

Landscape and amenity are typically understood to encompass a bundle of cultural services that are associated with being close to nature, including aesthetic and visual benefits, tranquillity, recreational opportunities, and improvements to mental health (HM Treasury, 2020, p.79; Defra, 2020a, p. 67). Given the overlap with other ecosystem services, care is needed not to double count these impacts.

As with the ecosystem services presented above, housing development can lead to both positive and negative landscape impacts depending on the nature of the intervention and resulting land use change. For example, an improvement in the local landscape through the planting of street trees or creation of natural features can improve the aesthetics of the area for local residents. Conversely, the removal of natural green and blue space can lead to a reduction in wellbeing.

Valuation

Table 16 summarises the available information on landscape valuation resulting from changes in the presence of natural features in the local area. Both sets of values are included in the B£ST tool (CIRIA, 2019) however as noted in the tool, these values are likely to cover range of ecosystem services including recreation, biodiversity and health and so care is required to avoid double counting with these benefits.

Table 16: Valuation – landscape (natural features)

Description	Source	Price year	Unit	2021 Value		
				Low	Central	High
Street tree planting	CIRIA (2019)	2011	£ / resident	19.56	22.56	27.96
Creation of sustainable drainage systems ponds	CIRIA (2019)	2011	£ / resident household	67.44	131.4	224.5

Note: The low, central and high values relate to small, medium and large trees respectively.

The B£ST tool also provides per resident estimates of the landscape value provided by parks and green spaces to the local population (within 1km) which can be used when these are created or significantly improved as a result of housing developments[12]. These estimates are provided in **Table 17** for different parts of the UK. Note that as with the values presented in **Table 16**, these values are likely to cover a range of ecosystem services including recreation, biodiversity and health as well as non-use benefits (such as their preservation for future generations) and so care is required to avoid double counting.

Table 17: Valuation – landscape (local parks and green space)

Description	Source	Price year	2021 Value (£ / resident)		
			Low	Central	High
London	CIRIA (2019)	2017	-	47.04	-
North East	CIRIA (2019)	2017	-	27.72	-
North West	CIRIA (2019)	2017	-	26.4	-
East Midlands	CIRIA (2019)	2017	-	30.48	-
East England	CIRIA (2019)	2017	-	32.04	-
West Midlands	CIRIA (2019)	2017	-	31.92	-
Yorks. & Humber	CIRIA (2019)	2017	-	20.16	-
South East	CIRIA (2019)	2017	-	26.76	-
South West	CIRIA (2019)	2017	-	30.72	-
Scotland	CIRIA (2019)	2017	-	27.96	-
Wales	CIRIA (2019)	2017	-	28.92	-
Northern Ireland	CIRIA (2019)	2017	-	27.96	-

Additional values which can be used to assess the landscape impact of housing developments based on changes to the availability of green and blue space are provided in ENCA (Defra, 2020a, Services Databook - "Amenity"). For example, views of green space are valued in Mourato et al (2010) at £135-452 (2010 prices) per person per year, based on the quality-of-life change resulting from a view of green space (compared to no view). Similarly, Morris and Camino (2011) estimated the per hectare aesthetic value of inland and coastal wetlands at between £227-2080 per hectare.

An alternative method to calculate the aesthetic value of green and blue spaces is through hedonic pricing (see **Appendix A** for more details on this methodology). This is a revealed preference approach which measures the price people are willing to pay to live close to green and blue spaces among other variables that affect house prices, for example the rating of the nearest school, travel to work areas for commuting, and other environmental factors (ONS, 2020). Differentials in house prices which arises due to factors related to the green and blue spaces (such as distance, quantity and quality) is attributed to the aesthetic value provided.

This method has been used in the ONS Natural Capital Accounts (ONS, 2020) which found that having a view over a green space or water increased urban house prices by an average of £4,600 (capital value), which the study attributes to the increase in aesthetic value. The overall landscape value attributed to the greenspace can subsequently be calculated by multiplying this estimate by the number of local residents who benefit from the greenspace. Note however that since this value relates to house prices, it is an asset rather than an annual value, and must be used accordingly. As before, if used as a proxy for local environmental amenity/landscape, it also is likely to overlap with

[12] Note that these values could also be used negatively if these are removed as a result of housing developments.

other cultural ecosystem services related to green and blue space such as recreation, physical and mental health and so care must be taken to avoid double counting of ecosystem services.

In part the impact may also be captured in the development appraisal through gross development value (GDV) and therefore also land value uplift (LVU) and caution is advised to avoid double counting.

Physical flow

The number of properties affected by landscape changes as a result of a housing development require bespoke analysis for each separate intervention.

Suggested indicative values to use in appraisal (landscape)

Valuation: dependent on landscape feature to be valued:

- Natural features such as street trees and sustainable drainage systems ponds *(CIRIA, 2019)* – Table 16. Risk of double counting other impacts (see above)
- Local parks and greenspace *(CIRIA, 2019)* - Table 17. Risk of double counting other impacts (see above)
- Additional values provided in ENCA *(Defra, 2020a, Services Databook - "Amenity")*

Physical flow: bespoke analysis required

Context dependent factors

The landscape value will depend upon the beneficiary population as well as the pre- and post-intervention habitat condition which will vary for each intervention. For this reason, caution should be taken when using the values presented above.

River flood regulation

Through their role in retaining and the slow release of rainwater, natural and semi-natural habitats can reduce the risk to downstream populations by slowing the process of rainfall flows entering rivers. This is especially true in urban areas where vegetation can reduce surface water flooding from heavy rainfall, with benefits to surface drainage and sewer capacity (Defra, 2020a). This benefit to local populations can be valued by estimating the reduced flood damage to downstream settlements or the cost saving in investing in greater sewage capacity or water storage.

Note that the evidence presented in this section relates solely to river flooding. No evidence has been identified in the literature on the impact of housing development on surface water or sewer flooding, such as the role of sustainable drainage systems (SuDS).

Valuation

Table 18 summarises the available information on flood regulation resulting from land use change. These per hectare values are referenced in Defra's ENCA and are based on research by Forest Research and the Forestry Commission. Note that the Forest Research (2018) values for flood regulation are national averages as opposed to that presented by the Forestry Commission (2017b) which is based on a case study in the Southwell catchment (and therefore likely to be less transferable). For that reason, the Forest Research (2018) values are suggested.

Table 18: Valuation – river flood regulation

Description	Source	Price year	Unit	2021 Value		
				Low	Central	High
Woodland – water storage	Forest Research (2018)	2018	£ / hectare	-	**89**	-
Floodplain woodland – water storage	Forest Research (2018)	2018	£ / hectare	-	**221**	-
Woodland – flood damages	Forestry Commission (2017b)	2017	£ / hectare	-	250	-

** Note: when multiple values are available in the literature, the suggested indicative value is bolded.*

A per volume of water storage value of £0.42 / m3 (2018 prices) is also given in Forest Research (2018) which allows for compatibility with the figures presented in the physical flow section below.

It is worth noting that the Environment Agency's Flood and Coastal Erosion Risk Management appraisal guidance (Environment Agency, 2010) provides a methodology for valuing damages from flood events. This can be used to value the reduced risk and associated damages provided by the presence of natural features, however bespoke analysis is required. Similarly, an approach to quantify and monetise the benefits is provided in the B£ST tool 2019 guidance (CIRIA, 2019).

Physical flow

Table 19 summarises the available information on the physical flows resulting from land use change. Similarly, these per hectare values are referenced in Defra's ENCA and are based on research by Forest Research (2018). These quantify the flood storage volumes generated by the water use and hydraulic roughness of woodlands and floodplain woodlands. Country breakdowns are provided in section 4 of the Forest Research (2018) report in addition to differentiating between public and private woodlands. The values below relate to the average of all woodlands.

Table 19: Physical flow – river flood regulation

Description	Source	Original source	UK value (m^3 / hectare)		
			Low	Central	High
Woodland canopy interception	Defra (2020a)	Forest Research (2018)	-	10.5	-
Woodland soil water storage	Defra (2020a)	Forest Research (2018)	-	165	-
Floodplain woodland hydraulic roughness	Defra (2020a)	Forest Research (2018)	-	520	-

Suggested indicative values to use in appraisal (river flood regulation)

- Valuation: national values per hectare for multiple habitats (Defra, 2020a) – Table 18
- Physical flow: national flood storage volumes per hectare for multiple habitats (Defra, 2020a) – Table 19

Context dependent factors

The flood regulation value will depend upon the climate conditions, specific catchment and beneficiary population which will vary for each intervention. For this reason, caution should be taken when using the values presented above.

Food (crops & livestock)

Food refers to the provision for human consumption generated from a range of ecosystems (Defra, 2020a, p.61). When undertaken on agricultural land, housing developments remove the potential physical and monetary flows from this ecosystem service.

Valuation

There are several possible approaches to the valuation of food provision, and there are significant pros and cons with each. A key consideration is the attribution of value to natural capital compared to other capital inputs. Ideally the aim is to establish a value for the food provisioning service of agricultural land (i.e. the contribution from its soil, water and minerals)[13].

The ONS accounts (ONS, 2020) have generally favoured a resource rent approach for provisioning services but this is under review. The main approaches include:

- The resource rent approach calculates the value attributable to natural capital by taking gross farm sales and deducting costs of other capital inputs such as direct input costs (e.g. fertilisers), labour (including an allowance for unpaid farm labour) and manufactured capital (e.g. an expected return on farm assets such as harvesting machinery). Under the UK market conditions, this usually means that food production will mostly likely be assigned a negative overall value in an account. Based on the Farm Business Survey (FBS) data (FBS, 2021), typically only dairy has a positive residual value after subtracting all other input costs. This reflects the economic reality that most farm enterprises related to food production do not generate positive returns without public subsidy.

- Gross margin is calculated by deducting variable costs from sales value, and hence excludes fixed costs (such as farm overheads) and allowances for unpaid farm labour and the use of fixed capital assets (e.g. farm machinery). This provides an indication of the value of farm output and avoids the case of negative values for natural capital.

Two possible sources of gross margin data have been identified: the annual series of John Nix Pocketbooks – the latest being the 2020 50th Edition (Nix, 2019) and the FBS (2021). FBS provides regional data for eight English regions

[13] Note that this value may already be included in the calculation of the opportunity cost of land as part of the land uplift value and so care should be taken so as not to double count.

and for nine farming types based on annual survey data. One potential drawback with FBS regional data is that sample sizes can be small, sometimes only a handful of farms by type. At a national level, sample sizes are usually over a hundred farms which should provide more accurate results.

Nix (2019) is a widely recognised farm management guide that gives estimates of output, income and costs for a wide range of farming methods presented on a per hectare basis. It draws upon FBS data at a national level and other sources and has the advantage of being consistent with the physical estimates presented below. It is important to note that as UK market prices can vary significantly from year to year, it is advised to use averages across multiple years for the select food output categories. For this reason, three-year averages are presented in **Table 20** below (2018-2020). For the five agricultural products, the values are given on a per hectare basis.

Table 20: Valuation – food (crops & livestock)

Description	Source	Price year	2021 Value (£ / hectare)		
			Low	Central	High
Feed wheat	(Nix, 2019)	2019	-	765	-
Dairy cow	(Nix, 2019)	2019	-	2,342	-
Beef	(Nix, 2019)	2019	-	180	-
Sheep (lowland)	(Nix, 2019)	2019	-	467	-
Sheep (upland)	(Nix, 2019)	2019	-	-37	-

Alternative values to those in **Table 20** can be produced using the NEVO tool developed by the University of Exeter (2019a) whereby the land cover for the housing development site can be changed to urban to show the indicative impact of land-take on agricultural production and resulting farm profit (i.e. reduction to zero production and profit). Note however that the minimum scale of analysis is 2km and that it is not possible to specify type of landcover beyond broad habitats.

Physical flow

One potential source of physical flows identified in the literature is Nix (2019). As with **Table 20**, physical outputs per hectare are given for the five agricultural products, facilitating the calculation of output for a place, based on input land area and type. The drawback of these values however is that they are based on national averages. Spreads of output are typically in the range +/-15 to 20% around the average values (EA, 2021). For this reason, care should be taken if applying these values, with locally known values used if available.

Table 21: Physical flow – food (crops & livestock)

Description	Source	Unit	2020 value		
			Low	Central	High
Feed wheat	(Nix, 2019)	t/ha/year	-	8.60	-
Dairy cow	(Nix, 2019)	litres/ha/year	-	17,600	-
Beef	(Nix, 2019)	kg/ha/year	-	510	-
Sheep (lowland)	(Nix, 2019)	kg/ha/year	-	400	-
Sheep (upland)	(Nix, 2019)	kg/ha/year	-	181	-

Suggested indicative values to use in appraisal (food - crops & livestock)

- Valuation: national gross margin values per hectare for multiple agricultural products *(Nix, 2019)* – Table 20
- Physical flow: national outputs per hectare for multiple agricultural products *(Nix, 2019)* – Table 21

Context dependent factors

As noted above, farm productivity varies nationally and so care should be taken when applying these values, with locally known values used if available.

Timber

Timber has been the dominant use of woodlands in the UK and remains an important ecosystem service for the forestry sector (Defra, 2020a, p.61). When undertaken on forested land, housing developments remove the potential physical and monetary flows from this ecosystem service.

Valuation

The value of timber has been estimated by Forest Research (2019) at £25.2/m^3 (2019 prices) based on the average for the 3 years (2017-19). This value reflects the contractors expected felling, distribution and selling costs, hence it is a proxy for the resource rent for the production function of growing timber. Note that this value relates to the Coniferous Standing Sales Price Index for Great Britain and so applies to softwood/coniferous trees as opposed to broadleaves/hardwoods which may differ in price.

Alternative values can be produced using the NEVO tool developed by the University of Exeter (2019a) whereby the land cover for the housing development site can be changed to urban to show the indicative impact of land-take on timber production and resulting profit (i.e. reduction to zero output and profit). Note however that the minimum scale of analysis is 2km and that it is not possible to specify type of landcover beyond broad habitats.

Physical flow

To determine the volume of timber removals per hectare of land use change to align with the valuation method above, a national figure can be used. This has been calculated by dividing the total volume of softwood removals in the UK (13.8 million cubic meters) (Forest Research, 2019) by the area of coniferous woodland in the UK (estimated at 1.6 million hectares) (Forestry Commission, 2019). This gives an estimate for the volume of softwood timber removals per hectare in the UK of 8.5 m^3/ha/year.

Suggested indicative values to use in appraisal (timber)

- Valuation: national per cubic metre value of £25.2/m^3 (2019 prices) *(Forest Research, 2019)*
- Physical flow: national per hectare volume of 8.5 m^3/ha/year *(Forest Research, 2019; Forestry Commission, 2019)*

Context dependent factors

Timber productivity varies nationally, and so care should be taken when applying these values, with locally known values used if available.

Local climate regulation

Local climate regulation refers to the cooling effect provided by woodland, grassland, gardens and open waters in urban areas through evapotranspiration. By reducing hot summer temperatures, the presence of these habitats help decrease associated labour productivity losses and air conditioning costs (Defra, 2020a, p.64).

As with the ecosystem services presented above, housing development can lead to both positive and negative local climate regulation impacts depending on the nature of the intervention and resulting land use change. For example, the planting of street trees or creation of blue spaces can increase this benefit, while the removal of natural green and blue space can lead to a reduction.

Valuation

Local temperature regulation has been valued in the UK Natural Capital Accounts (ONS, 2020) and is based on a case study of 11 city regions in the UK using local climate projections. The study monetises the benefit provided by urban green and blue spaces through the estimated cost savings from air conditioning and the number of productive working hours lost due to hot days (which makes up the majority of the value). Total hot days and the cooling effect of green and blue spaces is detailed in the physical flow section below.

Note that there are no standard values which can be applied in the UK due to the context dependent factors required (such as temperatures and the beneficiary populations) and so bespoke modelling should be undertaken to value this impact.

An alternative approach is taken by Moss et al. (2019) which estimates the hourly local climate regulation benefits per tree from the avoided air conditioning costs. For the three locations studied; London, Edinburgh and Wrexham, the value per tree per hour is £0.05, £0.03 and £0.04 respectively. While simpler than the ONS approach, as noted in ENCA (Defra, 2020a, Services Databook – "Temperature Regulation"), it is unclear how many hours or days this unit value should apply over the summer period. Moreover, since the values are location specific, extrapolation should be taken with care.

Physical flow

The ONS details the cooling effect per landcover category in the accompanying workbook to the report, as presented in **Table 22**. These values are multiplied by the percentage of the total urban area for each landcover category to calculate the total cooling effect in degrees centigrade. The number of hot days avoided (needed for the valuation) can be calculated either through using estimates in workbook or bespoke climate modelling.

Table 22: Physical flow – local climate regulation (ONS, 2020)

Landcover	Cooling effect (degrees centigrade)
Woodland <3ha	-3.5
Woodland >3ha	-3.5

Woodland buffer	-0.52
Parks/grass >200m2	-0.95
Gardens >200m2	-0.95
Rivers/canals >25m	-1.4
Rivers/canals buffer	-0.8
Lakes/ponds >700m2	-0.1
Lakes/ponds buffer	-0.057

For the Moss et al. (2019) approach, the resulting benefit will depend on the change in the number of trees as a result of the housing development and the number of hours per summer month the unit values are applied.

Suggested indicative values to use in appraisal (local climate regulation)

- Valuation: bespoke modelling required based on extrapolations from *ONS (2020)*
- Physical flow: bespoke modelling required based on extrapolations from *ONS (2020)*

Context dependent factors

The local climate regulation impacts are inherently context dependent and so bespoke modelling is advised.

Biodiversity

Biodiversity encompasses multiple dimensions reflecting the variation in species (plants, animals, fungi, micro-organisms) and the habitats and natural systems that support them (Defra, 2020a, p.66). It is core to the ecological condition and quality of ecosystems, their resilience to shocks, and capacity to support ecosystem service provision both now and into the future. Stated another way, biodiversity is a critical element of the health of natural assets (i.e. the stock of natural capital).

Since the "value of biodiversity" is likely to be embedded in the final values for many ecosystem services (e.g. recreation, landscape, food and timber), the Green Book advises to only value the service where it "directly impacts human wellbeing and where it is additional to other benefits" in order to avoid double counting (HM Treasury, 2020, p.81). Largely then, this corresponds to non-use values for nature conservation, as well as specific use values, such as nature-based recreation.

As with the ecosystem services presented above, housing development can lead to both positive and negative impacts on biodiversity depending on the nature of the intervention and resulting land use change. For example, changes to either the quantity or quality of habitats can determine the impact.

Valuation

Table 23 summarises the available information on biodiversity valuation. These per hectare values are presented in ENCA (Defra, 2020a, Services Databook – "Biodiversity") and are derived from Christie et al (2011) by combining the willingness to pay values for species numbers and habitat condition for each habitat and dividing these totals by the UK areas of those habitats. For completeness, all habitats listed in ENCA have been included below though not all will be relevant for the appraisal of housing developments. Habitat gain or loss due to housing development should be calculated using the values below. Note that sealed surfaces are presumed to have zero biodiversity value.

Table 23: Valuation – Biodiversity

Description	Price year	2021 Value (£ / ha / year) Defra (2020a)		
		Low	Central	High
Lowland heathland	2010	-	£84	-
Coastal floodplain	2010	-	£75	-
Native woodland	2010	-	£72	-
Upland heath	2010	-	£70	-
Hedgerows	2010	-	£55	-
Blanket bog	2010	-	£53	-
Purple moorland grass	2010	-	£34	-
Improved grassland	2010	-	£8	-
Arable field margins	2010	-	£4	-

As noted in the ENCA guidance however, these values represent a “crude and conservative lower bound measure” of the benefit from improved biodiversity and habitat condition (Defra, 2020a, Services Databook – “Biodiversity”) and so care should be taken when applying them. For instance, these values do not reflect spatial variations in beneficiaries’ characteristics (e.g. population size, demographics, preferences), and do not take into account increasing returns to scale that may be expected from improved connectivity of habitats.

Moreover, as the ENCA guidance also highlights, there is a risk of double counting the biodiversity impacts if included alongside the value of recreation, landscape, food and timber. Whilst it is possible to isolate the specific contribution of biodiversity to these benefits using certain valuation methods, primary research is typically needed to generate site- and context-specific data in order to reliably estimate these contributions. Further details of the challenges surrounding valuing biodiversity are presented in eftec et al. (2015).

One further approach currently being considered to value biodiversity is through the use of the Biodiversity Metric 2.0 developed by Defra and Natural England (Natural England, 2019) (see physical flow section below). This approach uses £11k per biodiversity unit as a proxy value based on the average costs for off-site habitat creation presented in Defra’s 2019 Impact Assessment on biodiversity net gain (Defra, 2019a). In a housing setting, this value would be applied to those biodiversity units which are outside the regulatory 10% net gain requirement. It is important to note however **this is not a published methodology** and that the **actual costs will depend upon the context and the habitat created or enhanced**.

Physical flow

No measures of the physical flow of biodiversity have been identified in the literature.

One method to provide a proxy assessment of the change in biodiversity as a result of a housing development is through the Biodiversity Metric 2.0 developed by Defra and Natural England (Natural England, 2019). This metric is the standard method in England for measuring biodiversity change from development in order to demonstrate that the requirement biodiversity net gain has been met. The Biodiversity metric 2.0 uses habitat as a proxy to describe biodiversity. These habitats are converted into measurable ‘biodiversity units’ (BUs).

Biodiversity units are calculated using the size of a parcel of habitat and its quality. The metric uses habitat area as its core measurement, except for linear habitats where habitat length is used. To assess the quality of a habitat the metric scores habitats of different types, such as woodland or grassland, according to their relative biodiversity value.

Habitats that are scarce or declining typically score highly relative to habitats that are more common and widespread. The metric also takes account of the condition of a habitat.

It is important to note, however, that the metric effectively represents a composite indicator of the extent and condition of the ‘stock’ of biodiversity at each site. This has no direct association with the potential value of biodiversity benefits, since it only accounts for physical environment factors, and not socio-economic factors that also influence economic values.

Alternative indicators for biodiversity can be produced using NEVO tool developed by the University of Exeter (2019a) whereby the land cover for the housing development site can be changed to urban to show the indicative impact of land-take on species richness. A richness score is generated according to the modelled abundance of plants, invertebrates, birds, mammals, lichen, and herptiles. Note however that the minimum scale of analysis is 2km and that it is not possible to specify type of landcover beyond broad habitats.

Suggested indicative values to use in appraisal (biodiversity)

- Valuation: national per hectare values for multiple habitats *(Defra, 2020a)*
- Physical flow: proxy assessment through the Biodiversity Metric 2.0 *(Natural England, 2019)*

Context dependent factors

As detailed above, the biodiversity will depend on the local beneficiaries’ characteristics (e.g. population size, demographics, preferences) as well as returns to scale from changes to connectivity of habitats. For this reason, caution should be taken when the values presented above.

Heritage

No evidence has been identified on the impact to heritage generated from the land take associated with housing developments in the literature.

Construction and occupation

This section details the available evidence on the negative environmental effects as a result of the construction and occupation of housing development.

For each impact (see **Table 3** and **Table 4**), the monetary valuation is presented first as these can be applied regardless of the group and type of impact. For instance, GHG emissions from transport resulting from construction can be monetised using the same value as for occupational waste once converted to consistent metrics i.e. tonnes of carbon dioxide equivalent (tCO2e).

The physical flows are then summarised for each impact group and type, followed by any context dependent factors.

GHG emissions

Valuation

As with the case of carbon sequestration, the emissions from construction and occupation should be valued using the non-traded carbon price since they are outside the scope of the EU ETS.

Table 24 details the BEIS traded and non-traded carbon prices which are valued in terms of £ per tonne of carbon dioxide equivalent (tCO2e). Note that all studies in the literature review have used these values or their predecessor which was based on the social cost of carbon.

Table 24: Valuation - GHG emissions

Description	Source	Price year	2021 Value (£ / tCO2e)		
			Low	Central	High
Traded carbon value*	BEIS (2020a)	2018	4	21	37
Non-traded carbon value*	BEIS (2020a)	2018	**35**	**70**	**106**

** Note: both sets of prices rise over time to reflect the increasing difficulty in abating marginal emissions (i.e. once the low hanging fruit has already been picked).*

Physical flow

As detailed earlier, there are multiple pathways linking GHG emissions to the construction and occupation of housing developments. These pathways and the available evidence to quantify these are summarised in **Table 25**. These conversion values can be used unless specific local values are known.

Table 25: Physical flow – GHG emissions

Impact group	Impact type	Coverage
Construction	Aggregates	**Step 1: mass of aggregates per property** Masses of aggregates required per building are estimated in *Office of the Deputy Prime Minister (2005, p. 69)* at 45 tonnes per flat and 60 tonnes per house. Masses of housing construction waste are estimated in *Defra (2004, p. 3)*, ranging from 45-60 tonnes depending on the EcoHomes standard of the property. **Step 2: mass of GHG emissions per mass of aggregates** *BEIS (2020b, "Material Use")* provides estimates of the mass of GHG emissions (kgCO2e) per tonne of housing construction material. Values are disaggregated by type of material (e.g. aggregates, bricks, metal) as well as the source of the materials (primary material production, re-used, open-loop source or closed-loop source). No evidence identified on the stored carbon in building materials in the literature.
	Construction activity	No evidence identified on the greenhouse emissions from construction activity in the literature.
	Transport	**Step 1: distance travelled per property** No evidence identified on the distance required to transport construction materials and workers to and from the housing development in the literature. **Step 2: mass of air pollutant per distance travelled** Once the distance travelled has been quantified as well as the vehicle type, *BEIS (2020b, "Delivery Vehicles")* provides estimates the mass of GHG emissions (kgCO2e) per mile or km travelled for different vehicle types (vans and heavy goods vehicles (HGVs)), and fuel types (petrol, diesel, electric etc).
	Waste	**Step 1: Mass of construction waste per property** Masses of housing construction waste are estimated in *Office of the Deputy Prime Minister (2005, p. 76)*, ranging from 9-11.25 tonnes depending on the EcoHomes standard of the property. Masses of housing construction waste are estimated in *Defra (2004, p. 2)*, ranging from 9-11.25 tonnes depending on the EcoHomes standard of the property.

Impact group	Impact type	Coverage
		Step 2: Mass of GHG emissions per mass of construction waste *BEIS (2020b, "Waste Disposal")* provides estimates of the mass of GHG emissions (kgCO2e) per tonne of household construction waste. Values are disaggregated by type of waste (e.g. aggregates, bricks, metal) as well as the disposal method (Re-use, open-loop, closed-loop, combustion, composting, landfill, anaerobic digestion).
Occupation	Energy use	Out of scope
	Water consumption	**Step 1: GHG emissions from water consumption per property** *Artesia and eftec (2019, p.24)* applied total carbon emissions from water consumption at 2.63 kgCO2e per property per day (around 1 tonne CO2e/property/year) based on a PCC of approximately 138 litres/household/day. The report also calculated emissions from household water use as PCC falls (to 82l/property/day). Alternatively, GHG emissions from water consumption are provided in *BEIS (2020b)* which estimated that water supply generates 0.344 kgCO2e/m3 (344 kgCO2e/Ml) and treatment 0.708 kgCO2e/m3 (708 kgCO2e/Ml).
	Transport	**Step 1: Distance travelled per person** *Dft (2020c, p.2)* estimates the number miles travelled by car per person at 5,009 in 2019. **Step 2: Detailed breakdown of transport use** *Dft (2020b)* provides estimates of the proportion of cars, LGV & other vehicle kilometres using petrol, diesel or electricity in the UK for the years 2005-2050 (A1.3.9) along with forecast assumed vehicle fuel efficiency improvements to 2050 (A1.3.10) **Step 3: mass of GHG emissions per distance travelled** *BEIS (2020b, "Passenger Vehicles")* provides estimates the mass of GHG emissions (kgCO2e) per mile or km travelled for different modes of transport (car, motorbike, bus etc), vehicle type and size as well as fuel types (petrol, diesel, electric etc).
	Waste	**Step 1: Mass of household waste per property** Masses of household waste are estimated in *Office of the Deputy Prime Minister (2005, p. 79)*, ranging from 0.88-1.25 tonnes depending on the EcoHomes standard of the property. Masses of household waste are estimated in *Defra (2004, p. 4)*, ranging from 0.62-1.25 tonnes depending on the EcoHomes standard of the property and occupancy.

Impact group	Impact type	Coverage
		Updated values are available from *Defra (2018b, p. 33)* for which the England household is estimated at 0.41 tonnes per person in 2016. Based on the average household size in the UK in 2016 of 2.4 *(ONS, 2016)*, and assuming equal waste production per person, this equates to 0.98 tonnes per household. The household waste composition for England is estimated in *Defra (2019b, p.5)* which enables more accurate figures in BEIS (2020b) to be used. **Step 2: Mass of GHG emissions per mass of household waste** *BEIS (2020b, "Waste Disposal")* provides estimates the mass of GHG emissions (kgCO2e) per tonne of household waste. Values are disaggregated by type of household waste (e.g. refuse, electrical items, plastic) as well as the disposal method (Re-use, open-loop, closed-loop, combustion, composting, landfill, anaerobic digestion).

Context dependent factors

No evidence assessing context dependent factors has been identified in the literature relating to GHG emissions. Table **Table 26** presents where these may be relevant in in appraisals. These will be detailed in subsequent phases of work.

Table 26: Context dependent factors – GHG emissions

Factor	Construction	Occupation
Development size	Y	Y
Development location and condition	Y	Y
Intervention type	Y	Y
Housing type	Y	Y
Construction method	Y	Y
Standards and benchmarks	-	Y

Air pollution

Valuation

As with the case of air pollution removal, the emissions from construction and occupation of housing developments can be valued using the estimates provided in **Table 9** which are measured in terms of £ per tonne of the pollutants. Similarly, for PM2.5 and NOx, when the location of the housing development is known, values can be taken from **Table 11** which take into account the population density of the local population to the emissions.

Physical flow

As detailed previously, there are multiple pathways linking air pollution to the construction and occupation of housing developments. These pathways and the available evidence to quantify these are summarised in **Table 27.** These conversion values can be used unless local values specific to the housing development are known.

Table 27: Physical flow – air pollution

Impact group	Impact type	Coverage
Construction	Aggregates	**Step 1: mass of aggregates per property** Masses of aggregates required per building are estimated in *Office of the Deputy Prime Minister (2005, p. 69)* at 45 tonnes per flat and 60 tonnes per house. Masses of housing construction waste are estimated in *Defra (2004, p. 3)*, ranging from 45-60 tonnes depending on the EcoHomes standard of the property. **Step 2: mass of air pollutant emitted per mass of aggregates** No evidence identified on the mass of air pollution generated per mass of in the literature.
	Construction activity	No evidence identified on the air pollution generated from construction activity in the literature.
	Transport	**Step 1: distance travelled per property** To the knowledge of the authors, no evidence is available on the distance required to transport construction materials and workers to and from the housing development in the literature. **Step 2: mass of air pollutant per distance travelled** Once the distance travelled has been quantified as well as the vehicle type, *DfT (2020b)* provides estimates of the mass of air pollutant emissions (grams of PM10[14] and NOx) per km travelled for different modes of transport (car, LGV, HGV, bus, coach), vehicle type and size as well as fuel types (petrol, diesel). (A3.2)
	Waste	**Step 1: Mass of construction waste per property** Masses of housing construction waste are estimated in *Office of the Deputy Prime Minister (2005, p. 76)*, ranging from 9-11.25 tonnes depending on the EcoHomes standard of the property. Masses of housing construction waste are estimated in *Defra (2004, p. 2)*, ranging from 9-11.25 tonnes depending on the EcoHomes standard of the property. **Step 2: Mass of air pollutants emitted per mass of construction waste**

[14] The impacts from PM10 can be converted to PM2.5 using a conversion factor of 0.673 (DfT, 2020b, A3.2).

Impact group	Impact type	Coverage
		No evidence identified on the air pollution generated from the transport, treatment and disposal of construction waste in the literature.
Occupation	Energy use	No evidence identified on the air pollution generated from household energy use in the literature.
	Transport	**Step 1: Distance travelled per person** *DfT (2020c, p.2)* estimates the number miles travelled by car per person at 5,009 in 2019. **Step 2: Detailed breakdown of transport use** *DfT (2020b)* provides estimates of the proportion of cars, LGV & other vehicle kilometres using petrol, diesel or electricity in the UK for the years 2005-2050 (A1.3.9) along with forecast assumed vehicle fuel efficiency improvements to 2050 (A1.3.10). **Step 3: mass of air pollutant per distance travelled** *DfT (2020b)* provides estimates of the mass of air pollutant emissions (grams of PM10[15] and NOx) per km travelled for different modes of transport (car, LGV, HGV, bus, coach), vehicle type and size as well as fuel types (petrol, diesel). (A3.2)
	Waste	**Step 1: Mass of household waste per property** Masses of household waste are estimated in *Office of the Deputy Prime Minister (2005, p. 79)*, ranging from 0.88-1.25 tonnes depending on the EcoHomes standard of the property. Masses of household waste are estimated in *Defra (2004, p. 4)*, ranging from 0.62-1.25 tonnes depending on the EcoHomes standard of the property and occupancy. Updated values are available from *Defra (2018b, p. 33)* for which the England household is estimated at 0.41 tonnes per person in 2016. Based on the average household size in the UK in 2016 of 2.4 *(ONS, 2016)*, and assuming equal waste production per person, this equates to 0.98 tonnes per household. The household waste composition for England is estimated in *Defra (2019b, p.5)* which could allow for more accurate air pollutant emission factors to be used. **Step 2: Mass of air pollutants emitted per mass of household waste**

[15] The impacts from PM10 can be converted to PM2.5 using a conversion factor of 0.673 (DfT, 2020b, A3.2).

Impact group	Impact type	Coverage
		No evidence identified on the air pollution generated from the transport, treatment and disposal of household waste in the literature.

Context dependent factors

No evidence assessing context dependent factors has been identified in literature relating to air pollution. **Table 28** presents where these may be relevant in in appraisals. These will be detailed in subsequent phases of work.

Table 28: Context dependent factors – air pollution

Factor	Construction	Occupation
Development size	Y	Y
Development location and condition	Y	Y
Intervention type	Y	Y
Housing type	Y	Y
Construction method	Y	Y
Standards and benchmarks	-	Y

Noise

Noise pollution can arise from the temporary construction of housing developments as well as the permanent increase in road traffic. As identified by Defra (2014a), excessive noise can have the following detrimental effects on the local population:

- **Amenity** - the conscious displeasure of those exposed to the noise, both for sleep disturbance and general annoyance.
- **Health** - noise is associated with a range of effects on health heart attacks, strokes and dementia.
- **Productivity** - through distraction, fatigue and interrupting communication noise can have a negative impact on productivity and school attainment.
- **Environmental** - noise can have a notable impact on the natural environment, for example noise may alter bird breeding patterns, disturb wildlife and damage sensitive ecosystems.

It is estimated that the annual social cost of urban road noise in England is £7 to 10 billion, placing it at a similar magnitude to road accidents (Defra, 2014a). Moreover, noise pollution was identified as the second largest health risk in Western Europe in a report published by the World Health Organisation (WHO, 2011).

Valuation

The most recent Defra guidance on valuing noise pollution (Defra, 2014b) proposes two approaches to the valuation of noise based on the nature of the change:

- When the total noise impact is estimated to be below £50 million, marginal values can be used (see below).

- For cases when noise is expected to be a significant factor in decision making, detailed analysis should be undertaken based on a bespoke review of the latest available evidence.

Marginal damage costs for road travel are given in Defra (2014a) for changes in both the day and night time noise per household from 45 to 81 decibels, as summarised in **Table 29** and **Table 30** below). The values should be multiplied by the number of years and households to which they apply.

Table 29: Valuation – noise (daytime)

Change in noise metric by decibel (dBA) (daytime noise metric)		Total Road (including sleep disturbance) (£ per household per dB change – 2014 prices)
45.0	46.0	£11.28
46.0	47.0	£11.23
47.0	48.0	£11.31
…	…	
80.0	81.0	£195.03

Source: Defra (2014a, Table 1)

Table 30: Valuation – noise (night time)

Change in Lnight noise metric by decibel dB(A)		Road (£ per household per dB change – 2014 prices)
45.0	46.0	£29.20
46.0	47.0	£32.07
47.0	48.0	£34.94
…	…	
80.0	81.0	£86.62

Source: Defra (2014a, Table 2)

Note however that of the impacts from noise listed above, only amenity (sleep disturbance and annoyance) as well as the health impacts on heart attacks, strokes and dementia are valued. Since these are based on the value of quality-adjusted life-years (QALYs), these are welfare as opposed to exchange values.

It is also worth noting that these values are based on the probability of experiencing a negative impact from any of these impacts. DfT guidance on applying these values (DfT, 2017) states that not everyone will experience the same health impact at a given level of noise and so evidence-based probabilities are applied. The guidance therefore advises that these values can be used to value impacts for a population, but not for individuals. Nevertheless, these values are widely used in appraisal and are included in the Green Book (HM Treasury, 2020), DfT's WebTAG (DfT, 2020a, A3.2) as well as Defra's ENCA (Defra, 2020a).

As part of their guidance, Defra have produced a transport noise modelling tool (Defra, 2014c) which allows sensitivity to be applied to the "central scenario" values presented above. As explained in the "model guide" tab, the sensitivity tab allows the user to test the range of uncertainty for the inputs for which we have a quantifiable range. In particular:

- Value of a quality adjusted life year (QALY) using the Interdepartmental Group on the Value of Life and Health (IGVLH) of between £30,000 and £80,000 (with £60,000 as the central scenario).

- Quantifying the effects of sleep disturbance and annoyance using high, central and low disability weights (disability adjusted life years, or DALYs).

- Applying low, moderate and high sleep disturbance, and moderate and low annoyance response functions.

Physical flow

There are multiple pathways linking noise to the construction and occupation of housing developments. These pathways and the available evidence to quantify these are summarised in Table 31. These conversion values can be used unless local values specific to the housing development are known.

Table 31: Physical flow – noise

Group	Type	Description
Construction	Aggregates	No evidence identified on the noise pollution generated from the extraction and production of construction materials in the literature.
	Construction activity	Indicative values for noise levels associated with different construction activities are given in *HSE (2021)*. No standard values however are given for the duration of noise pollution or for assessing the baseline noise levels and so these would have to be estimated for each site. Note that while Defra have a noise modelling tool designed to calculate the marginal costs associated with increases in transport noise *(Defra, 2014a)*, no such tool is available for construction and so the guidance recommends contacting Defra directly[16].
	Transport	**Step 1: distance travelled per property** No evidence identified on the distance required to transport construction materials and workers to and from the housing development in the literature. **Step 2: noise impact per distance travelled** *DfT (2020b)* provides estimates of the noise impact of different modes of transport (cars, LGVs etc.) per km of road use for various location groupings (London, inner and outer conurbations, other urban and rural) (A5.4.2).
	Waste	No evidence identified on the noise pollution generated from the transport, treatment and disposal of construction waste in the literature.
Occupation	Transport	**Step 1: Distance travelled per occupant** *DfT (2020c, p.2)* estimates the number miles travelled by car per person at 5,009 in 2019. **Step 2: Detailed breakdown of transport use**

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		DfT (2020b) provides estimates of the proportion of cars, LGV & other vehicle kilometres using petrol, diesel or electricity in the UK for the years 2005-2050 (A1.3.9) along with forecast assumed vehicle fuel efficiency improvements to 2050 (A1.3.10). **Step 2: noise impact per distance travelled** *DfT (2020b)* provides estimates of the noise impact of different modes of transport (cars, LGVs etc.) per km of road use for various location groupings (London, inner and outer conurbations, other urban and rural) (A5.4.2).
	Waste	No evidence identified on the noise pollution generated from the transport, treatment and disposal of household waste in the literature.

Context dependent factors

No evidence assessing context dependent factors has been identified in literature relating to noise. **Table 32** presents where these may be relevant in in appraisals. These will be detailed in subsequent phases of work.

Table 32: Context dependent factors – air pollution

Factor	**Construction**	**Occupation**
Development size	Y	Y
Development location and condition	Y	Y
Intervention type	Y	Y
Housing type	Y	Y
Construction method	Y	Y
Standards and benchmarks	-	Y

Other impacts

No evidence was found on the following impacts from the construction or occupation of housing developments in the literature:

- Water quality.
- Landscape.
- Biodiversity.
- Heritage.
- Light pollution.

Summary of findings

This section summarises the coverage of available evidence and key gaps in the literature presented above as well as suggested indicative values to use in appraisal.

The following criteria have been used to assess the coverage of valuation and physical flow evidence in the literature:

Table 33: Valuation coverage criteria

Coverage rating	Definition
(green)	Widely accepted values available e.g. from published Government guidance
(amber)	Valuation evidence available however user input or further analysis is required (especially when the value is highly context dependent)
(red)	No evidence identified in the literature

Table 34: Physical flow coverage criteria

Coverage rating	Definition
(green)	Readily available evidence to determine physical flows
(amber)	Partial coverage of evidence to estimate physical flows, with further analysis required (especially when the impact is highly context dependent)
(red)	No evidence identified in the literature

Land take

Type of Impact	Impact	Valuation		Physical flow	
		Coverage	Suggested indicative values	Coverage	Suggested indicative values
Land use change	Carbon sequestration		Non-traded carbon price *(BEIS, 2020a)* - Table 7		National per hectare sequestration rates *(Defra, 2020a) -* Table 8
	Air pollution removal		Dependent on the air pollutant and spatial context a) National per tonne values: PM2.5, SO2 and NOx *(Defra, 2020b),* NO2, O3 *(Jones et al., 2017)* - Table 9 b) Habitat and spatially specific per hectare values for PM2.5, SO2, NO2 and O3 combined *(Jones et al., 2017)* – Table c) Spatially specific (local authority level) PM2.5 per hectare values *(eftec and CEH, 2019)* - Figure 7 d) Spatially specific PM2.5 and NOx per tonne values *(Defra, 2020b)* - Table 11		Dependent on the source of air pollution removal e) Habitats: national air pollution removal rates per hectare for PM2.5, NO2, SO2 and O3 *(Jones et al., 2017)* - Table 12 f) Green roofs: National air pollution removal rates per hectare for PM10, PM2.5, NO2, SO2 and O3 *(CIRIA, 2019)* - Table 13 g) Trees: National air pollution removal rates per tree for PM10, PM2.5, NO2, SO2 and O3 *(CIRIA, 2019)* - Table 14
	Recreation		Site specific values can be estimated using the ORVal tool *(University of Exeter, 2019b)* - Figure 8. If visit numbers are known, national per habitat values are given in *(Sen et al., 2014)* - Table 15		Site specific values can be estimated using the ORVal tool *(University of Exeter, 2019b)* - Figure 8
	Landscape		Dependent on landscape feature to be valued:		Bespoke analysis required

			h) Natural features such as street trees and sustainable drainage systems ponds *(CIRIA, 2019)* - Table 16. Risk of double counting other impacts (see above) i) Local parks and greenspace *(CIRIA, 2019)* - Table 17. Risk of double counting other impacts (see above) j) Additional values provided in ENCA *(Defra, 2020a, Services Databook - "Amenity")*		
	River flood regulation		National values per hectare for multiple habitats *(Defra, 2020a)* - Table 18		National flood storage volumes per hectare for multiple habitats *(Defra, 2020a)* - Table 19
	Food (crops & livestock)		National gross margin values per hectare for multiple agricultural products *(Nix, 2019)* - Table 20		National outputs per hectare for multiple agricultural products *(Nix, 2019)* - Table 21
	Timber		National per cubic metre value of £25.2/m^3 (2019 prices) *(Forest Research, 2019)*		National per hectare volume of 8.5 m^3/ha/year *(Forest Research, 2019; Forestry Commission, 2019)*
	Local temperature regulation		Bespoke modelling required based on extrapolations from *ONS (2019)*		Bespoke modelling required based on extrapolations from *ONS (2019)*
	Biodiversity		National per hectare values for multiple habitats *(Defra, 2020a)*		Proxy assessment through the Biodiversity Metric 2.0 *(Natural England, 2019)*
	Heritage		No evidence identified		No evidence identified

Construction

Type of Impact	Impact	Valuation		Physical flow	
		Coverage	**Suggested indicative values**	**Coverage**	**Suggested indicative values**
Aggregates	GHG emissions		Non-traded carbon price *(BEIS, 2020a)* - Table 24		Emission factors *(BEIS, 2020b)*
Construction activity	GHG emissions		Non-traded carbon price *(BEIS, 2020a)* - Table 24		No evidence identified
	Air pollution		Dependent on the air pollutant and spatial context k) National per tonne values: PM2.5, SO2 and NOx *(Defra, 2020b),* NO2, O3 *(Jones et al., 2017)* - Table l) Spatially specific PM2.5 and NOx per tonne values - Table		No evidence identified
	Noise		Noise damage costs available in *Defra (2014a)* however these are transport focused. Bespoke analysis required		Indicative construction noise values *(HSE, 2021)*. However, no standard values or tools available to estimate baseline noise nor the duration of impacts
Transport	GHG emissions		Non-traded carbon price *(BEIS, 2020a)* - Table 24		Transport emission factors *(BEIS, 2020b)*. However, no evidence identified to determine distances involved. Bespoke analysis required
	Air pollution		Air pollution damage costs *(Defra, 2020b)*		Transport air pollution (PM2.5 and NOx) factors *(DfT, 2020b)*. However, no evidence identified to determine distances involved. Bespoke analysis required
	Noise		Transport noise damage costs *(Defra, 2014a)*: m) Day time - Table 29		Transport noise factors *(DfT, 2020b)*. However, no evidence identified to

			n) Night-time - Table 30		determine distances involved. Bespoke analysis required
Waste	GHG emissions		Non-traded carbon price *(BEIS, 2020a)* - Table		Construction waster emission factors *(BEIS, 2020b)*. National average mass of construction waste per property *(Office of the Deputy Prime Minister, 2005; Defra, 2004)*
	Air pollution		Air pollution damage costs *(Defra, 2020b)*		No evidence identified
	Noise		Noise damage costs available in *Defra (2014a)* however these are transport focused. Bespoke analysis required		No evidence identified
	Landscape		No evidence identified		No evidence identified

Occupation

Type of Impact	Impact	Valuation		Physical flow	
		Coverage	Suggested indicative values	Coverage	Suggested indicative values
Energy use	Air pollution		Dependent on the air pollutant and spatial context o) National per tonne values: PM2.5, SO2 and NOx *(Defra, 2020b)*, NO2, O3 *(Jones et al., 2017)* - Table 9 p) Spatially specific PM2.5 and NOx per tonne values - Table 10		No evidence identified
	Light pollution		No evidence identified		No evidence identified
Water consumption	GHG emissions		Non-traded carbon price *(BEIS, 2020a)* - Table 24		Water use emission factors *(Artesia and eftec, 2019; BEIS, 2020b)*
	Landscape		No evidence identified		No evidence identified
	Biodiversity		No evidence identified		No evidence identified
	Water quality		No evidence identified		No evidence identified
Transport	GHG emissions		Non-traded carbon price *(BEIS, 2020a)* - Table 24		Transport emission factors *(BEIS, 2020b)*. National average household distances travelled *(Dft, 2020b; Dft, 2020c)*
	Air pollution		Dependent on the air pollutant and spatial context q) National per tonne values: PM2.5, SO2 and NOx *(Defra, 2020b)*, NO2, O3 *(Jones et al., 2017)* - Table 9 r) Spatially specific PM2.5 and NOx per tonne values - Table 10		Transport air pollution (PM2.5 and NOx) factors *(DfT, 2020b)*. National average household distances travelled *(Dft, 2020b; Dft, 2020c)*

	Noise		Transport noise damage costs *(Defra, 2014a)*: s) Day time - Table 29 t) Night-time - Table 30		Transport noise factors *(DfT, 2020b)*. National average household distances travelled *(Dft, 2020b; Dft, 2020c)*
	Landscape		No evidence identified		No evidence identified
	Biodiversity		No evidence identified		No evidence identified
	Heritage		No evidence identified		No evidence identified
Waste	GHG emissions		Non-traded carbon price *(BEIS, 2020a)* - Table 24		Construction waste emission factors *(BEIS, 2020b)*. National average mass of household waste per property *(Defra, 2018b; Defra, 2019b)*
	Air pollution		Dependent on the air pollutant and spatial context u) National per tonne values: PM2.5, SO2 and NOx *(Defra, 2020b),* NO2, O3 *(Jones et al., 2017)* - Table 9 v) Spatially specific PM2.5 and NOx per tonne values - Table 10		National average mass of household waste per property *(Defra, 2018b; Defra, 2019b)*. However, no air pollution factors identified
	Noise		Noise damage costs available in *Defra (2014a)* however these are transport focused. Bespoke analysis required		National average mass of household waste per property *(Defra, 2018b; Defra, 2019b)*. However, no noise pollution factors identified
	Landscape		No evidence identified		No evidence identified

Conclusions

This report has provided an overview of the conceptual basis for valuing environmental impacts along with a review of existing evidence and tools. This review has been framed around three broad categories of impact from housing developments:

- **Land take**: Permanent net changes to ecosystem service provision resulting from the land use change.
- **Construction**: One-off / temporary impacts from the production, use, transport and waste of materials used in the construction of housing.
- **Occupation**: On-going impacts of the occupants' energy use, water consumption, transport and waste for the duration of the properties' life.

Outputs from the review include the identification of evidence, values and tools that can be readily applied in appraisals (with appropriate care and critical thinking). Practical issues to their application are also discussed such as context dependent factors and when there is a risk of double counting of impacts. Areas where impacts cannot be reliably or robustly assessed at present, and overall gaps in the evidence base are also presented.

At this stage, focus has largely been on approaches for valuing impacts in abstract of an economic appraisal context (e.g. methodology, existing studies, tools). Issues such as attribution, additionality and establishing the net effect against a baseline position or counterfactual scenario are critical for robust appraisal practice, and robust application of the evidence identified here needs to account for these considerations. To help develop the understanding of the needs for applying environmental values in practical appraisals, the findings from the literature review will be applied to two case studies with differing scope and scale of impacts:

- Burgess Hill Northern Arc: a greenfield regeneration project in Mid Sussex District that aims to deliver 3,500 homes and a variety of educational, social, commercial, and environmental spaces.
- East Ketley: a brownfield development site in Telford that aims to deliver 415 homes, a local community centre and significant "natural" open space.

Through developing overarching logic models and theories of change for the three stages of development (see **Annex B**), these case studies will explore the issues mentioned above. The case studies will also be used to explore and highlight the following:

- The importance of spatial context in the scale and significance of environmental effects.
- Which impacts, at which development stages (land take, construction and occupation), are likely to have the greatest impact on the overall benefit cost ratio (BCR) of a project.
- Whether the inclusion of those benefits is a) feasible, given the internal resources that would be required to develop this information, and b) proportionate – given the likely impact on the overall BCR.

Drawing on the findings of the literature review and the case studies, the consultants will present recommendations for next steps in terms of how environmental benefits are considered in Homes England's project appraisal processes, and suggestions for subsequent research to address key gaps in the evidence base.

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Annex A: Detailed valuation methodologies

This annex details the four main groups of methodologies used in economic valuation:

- Market-based.
- Revealed preference.
- Stated preference.
- Subjective wellbeing.

Market based methods

Market-based methods use evidence from markets in which environmental goods and services are traded, markets in which they enter into the production functions for traded goods and services, or markets for substitutes or alternative resources.

Market prices can be used for traded goods, for example food. However, prices are not welfare-based values:

- It is necessary to correct for 'distortions' such as subsidies or taxes.
- Prices do not reveal the 'consumer surplus', the welfare gain to the consumer over and above the price paid.
- Prices include the resource cost (for example the cost of farm machinery, fuel and labour) that do not form part of value (this is often dealt with by reporting 'value added', i.e. price net of costs).
- Prices arise in markets by the interaction of demand and supply, and an environmental change that alters this balance – for example, changing supply – will usually cause price to change.
- A full analysis using markets therefore requires estimation of a demand curve and a supply curve, examining how values and costs change with quantity.
- In many cases, it may also be necessary to assess whether or not the exploitation of a resource is sustainable (and if not, there is an additional 'resource cost' associated with reducing natural capital stocks).

Production functions use statistical analysis to determine how changes in some ecosystem function affect production of another good or service which is a traded resource, or can be valued using another technique. The primary difficulty in this method is the availability of scientific knowledge and/or data, necessary to allow estimation of the production function.

Cost of illness methods are a particular class of production function where environmental services are linked to health measures, as part of estimating the health damage of pollution, or the health benefits of a clean environment. To give a monetary value, the health impacts need to be valued using additional methods such as costs of treatment avoided, and/or estimates of willingness to pay to avoid illness.

Replacement cost methods estimate a value based on the cost to replace an ecosystem function or service. Can be applied to entire ecosystems (for example, the cost of providing new habitat to compensate for habitat losses) or more often to replacing specific ecological functions with human-engineered alternatives (cost of alternatives).

A special case in which market values (and production functions) are used is the **resource rent method** which separates out the contribution of the ecosystem service from the other inputs – manufactured capital, human labour, energy etc. This calculates the "market exchange" value of an ecosystem service by taking the gross value of the final products and then deducting the cost of all other inputs (labour, produced capital and intermediate inputs). The residual can be considered the value of the ecosystem service (UN Statistic Division, in prep).

Revealed preference

Revealed preference methods analyse relationships between demand for some market goods and preferences for related non-market goods/services. These methods only work if changes in provision of the non-market good have an observable impact on the demand for a market good. Examples include:

- Where expenditure in the markets can substitute for the benefit gained from the non-market good (averting behaviour).
- Where non-market good or service is an attribute (or characteristics) of a market good or service (hedonic pricing; recreation demand models).
- Where non-market good or service is a complement to a market good or service (or vice versa) (travel cost; recreational demand models).

Averting behaviour involves estimating household 'production functions' that allow calculation of values for risks and disamenities via the expenditures households incur to avoid them. Examples include spending on water filters to compensate for poor quality water; or double glazing to reduce noise. Problems include for example joint impacts (e.g. double glazing will impact both noise and thermal comfort), 'lumpiness' in investments and transactions costs and imperfect information about risks, effectiveness of measures, and the endogeneity of risk perceptions.

Where non-market good or service is an attribute (or characteristics) of a market good or service. These are property and labour markets. **Hedonic property pricing method** estimates the premium people are willing to pay for higher levels of environmental goods (like nice view, peace & quiet, good air quality) or to avoid lower levels (e.g. living near a landfill). Sale/rental values of properties are modelled as a function of property 'attributes' including environmental quality (such as noise nuisance, air pollution, or proximity to desirable/undesirable features, such as an urban green space or landfill sites). The method only accounts for use values associated with occupation of the property and does not cover values to non-residents. The method assumes markets are perfectly functioning, though people may have poor knowledge regarding both the levels and the impacts of some attributes (e.g. air pollution), and housing markets generally have high transactions costs (taxes and moving costs) and may therefore respond slowly to changed conditions. **Hedonic wage method** uses a similar approach to value risks to health/life, via the wage premium for dangerous jobs or increases in occupational risk.

Where the non-market good or service is a complement to a market good or service (or vice versa). The key example is recreation and known as **travel cost method** which estimates what people spend in the travel market and the value of their time as a proxy for how much they enjoy the welfare benefits of recreation.

Stated preference

Stated preference methods are based on surveys which create simulated markets for respondents to express their preferences:

- **Contingent valuation** (CV) asks directly how much respondents are willing to pay to secure the change presented, or willing to accept compensation to avoid it, via open-ended questions or different forms of bidding formats.

- **Discrete choice experiments** (DCE) are based on respondents' choices for their preferred scenario among alternatives. Scenarios are described by different combinations of the goods and services in terms of their environmental as well as cost attributes, each taking different levels in each scenario. Information on the values that people assign to improvements in the different goods and services are indirectly inferred from the trade-offs that people are willing to make when choosing their preferred alternatives.

Both CV and DCE formats enable estimation of welfare values for the good or service as a whole; DCE also allows for the calculation of implicit prices of specific attributes. One advantage of stated preference (over revealed preference) methods is that they can elicit preferences for scenarios that are yet to occur, therefore providing ex-ante information on expected WTP to inform the design of future policies. Another is the ability to capture non-use values as well as use values. Responses in stated preference surveys may show high sensitivity to factors that should not matter (according to economic theory) and/or insensitivity to factors that should. Critics argue that hypothetical questions generate hypothetical, invalid responses. However, many decades of research have led to strategies to limit these potential biases through careful study design and testing.

Subjective wellbeing

Research in the relatively new area of Happiness Economics has led to the recent development of a valuation approach based on people's subjective wellbeing (SWB). The approach is referred to as Wellbeing Valuation (WV). The method estimates value by inferring the impact on an individual's SWB of the outcomes, goods or services they experience. Impact can then be converted into a monetary amount by estimating the equivalent amount of income they would be willing to pay to receive the proposed positive change in an outcome (or avoid a proposed negative change), which can be estimated by assessing the amount of income required to keep SWB constant. These methods are not yet widely used and continue to evolve, as the HM Treasury Green Book acknowledges[17].

The subjective wellbeing approach provides an alternative to the preferences-based perspective for valuation. In general terms it is based around measures of individual's self-reported life satisfaction, happiness, and/or psychological wellbeing. There are various approaches that measure aspects of subjective wellbeing. The ONS Annual Population Survey (APS) uses four questions as part of the Measuring National Wellbeing Programme[18].

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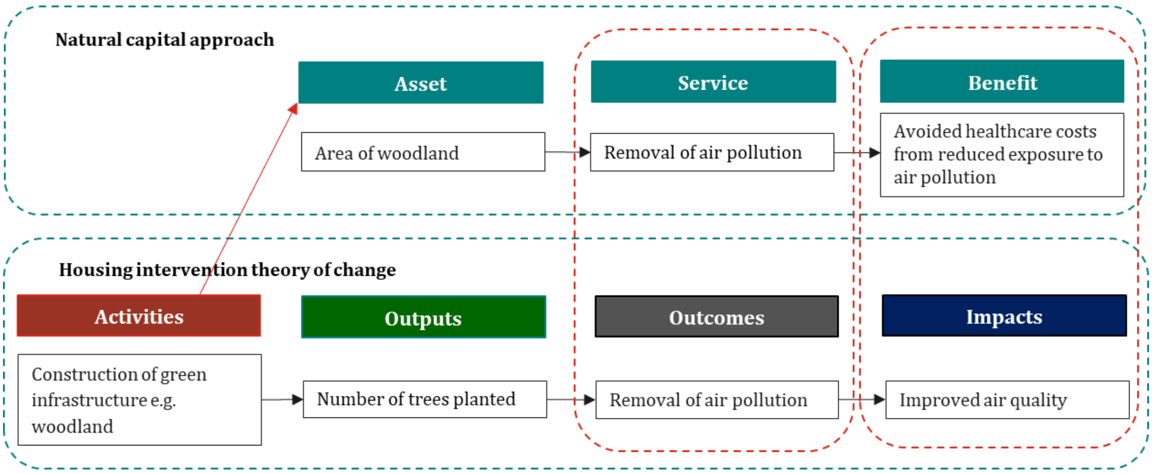
[17] "For use in shortlist appraisal it may be appropriate to use subjective wellbeing as the outcome variable for Social CEA in certain circumstances. It is recognised that the methodology continues to evolve19 and it may be particularly useful in certain policy areas, for example community cohesion, children and families. Where valuations are considered robust enough for inclusion in Social CBA, benefits or costs must not be double counted, which could occur if a benefit or cost arising from a policy were counted by different valuation methods"
[18] These are: (i) Overall, how satisfied are you with your life nowadays?; (ii) Overall, to what extent do you feel the things you do in your life are worthwhile?; (iii) Overall, how happy did you feel yesterday?; and (iv) Overall, how anxious did you feel yesterday?

Annex B: Overlaying natural capital logic chain on housing intervention theory of change

The logic models (housing intervention theory of change) developed for the case studies are framed in terms of activities > outputs > outcomes > impacts. This differs from the natural capital approach which considers asset > service > benefits relationships, in addition to an explicit focus on asset condition and dependencies. **Figure B.1** illustrates the points of overlap between the two approaches in the case of air pollution removal from woodlands. As can be seen, for land take impacts, the two approaches are compatible, with 'activities' affecting the asset quantity (area of woodland) and 'outputs' determining the service provided. In both approaches this results in the removal of air quality and the subsequent benefits to the local population from reduced exposure. For construction and occupation impacts, the natural capital approach is less applicable, with impacts based on activities as opposed to changes to asset quantity and condition.

Figure B.1: logic models (land take)



Performance Standards

Purpose of Document

- This research provides a methodology and a set of evidence that can be used to estimate the impacts of improved performance standards associated with the development of new housing.
- This research was completed following the completion of the literature review (above), which identified this as an area that required further research in order to be included within the appraisal guidance / ENHAT tool.
- The research considers five areas of performance that were identified in consultation with Homes England, which are: water use; surface water management or surface water flooding mitigation; climate change resilience; modern methods of construction; and energy use. For climate change resilience and modern methods of construction it was found that the existing evidence is very limited, and so these sections scope additional research that has subsequently been completed (see next two research reports included within this compendium).

Date Completed: June 2022

1. Introduction

This section presents:

- The background and future use for the environmental impacts appraisal guidance
- The evidence need for the appraisal guidance that is addressed by this report
- The research conducted under this workstream
- The report structure

This report provides a methodology and set of evidence to estimate the impacts of improved performance standards (IPS), with the intent of including those values within the 'Environmental Impacts of Housing Development' appraisal guidance. This report and its annexes are intended to be supplements to that appraisal guidance and the evidence referenced in this report is presented in the accompanying reference table, greenhouse gas (GHG) calculator and GHG results sheet.

Background And Future Use of the Impact of Improved Performance Standards Research

The IPS workstream is part of evidence gathering for the appraisal guidance that will be used to assess the environmental impacts from housing developments supported by Homes England. These appraisals will be a part of early-stage business case development and project evaluation at Homes England, and the overall guidance development is being completed in the following stages:

- **Stage 3: Draft appraisal guidance and scope empirical research** – this identified areas that required further research and produced a draft guidance.

- **Stage 4: Implement empirical research** – the current phase of work, including the Impact of Improved Performance Standards.

- **Stage 5: Produce final guidance –** concluding stage that will combine the Stage 3 and Stage 4 outputs into an appraisal guidance.

Research Aim

In Stage 3 of the project, the impacts of improved performance standards was identified as an area that required further research in order to be included within the appraisal guidance. The overall guidance is framed according to the following impact types:

- **Land take impacts:** Permanent net changes to ecosystem service provision resulting from the land use change.

- **Construction impacts:** One-off / temporary impacts from the production, use, transport and waste of materials used in the construction of housing.

- **Occupation impacts:** On-going impacts of the occupants' energy use, water consumption, transport and waste for the duration of the properties' life.

The IPS research will focus on five areas of performance, which were identified in consultation with Homes England:

1. **Water use** (occupation).

2. **Surface water management or surface water flooding mitigation** (land-take, construction, and occupation).

3. **Climate change resilience** (occupation).

4. **Modern methods of construction** (construction).

5. **Energy use** (update baseline and standards) (occupation).[19]

The purpose of the IPS research is to quantify the environmental impacts of design standards for these areas. These quantified environmental impacts will be valued in monetary terms for use in the appraisal and comparison of the environmental impacts of developments undertaken by Homes England.

Report Structure

The remainder of this technical report is structured as follows:

- Section 2 – Framework and method.
- Section 3 – Impacts of Energy Use Performance Standards.
- Section 4 – Impacts of Water Use Performance Standards.
- Section 5 – Impacts of Flood Risk Mitigation Performance Standards.
- Section 6 – Other Performance Areas.
- Section 7 – Discussion.
- Section 8 – Conclusions.

This report is also accompanied by the following annexes and documents:

- Annex A – Assumptions and estimates regarding SuDS implementations.
- The reference table (excel sheet) for water use and surface water management values.
- GHG Calculator.
- GHG Results Sheet.

[19] This workstream updates the greenhouse calculator tool developed for Homes England by SQW which measures the expected environmental impacts of building homes under differing energy use performance standards.

Framework and Approach

This section presents:

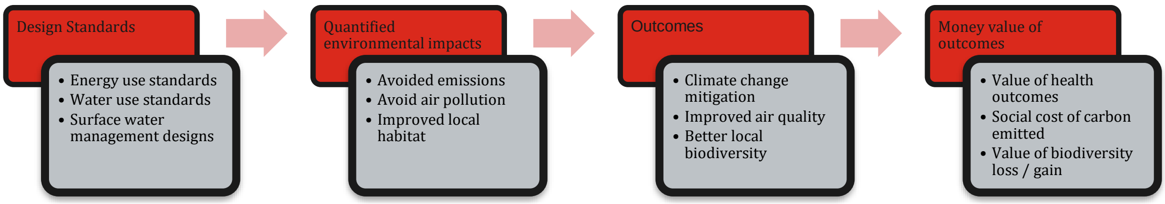
- The conceptual framework and logic chain used to identify impacts and benefits from improved performance standards
- The general methodology used to identify and quantify these impacts and their benefits

The main project task to provide evidence on the impacts of IPS are: (i) set out the conceptual framework for quantifying, valuing, and comparing the impacts of improved design standards; (ii) define a set of typologies for both homes and their accompanying performance standards; and (iii) conduct a literature review and expert consultation to create a reference table of quantified impacts and their values based on these typologies (where the current evidence is available).

Conceptual Framework – Linking Performance Standards to Outcomes

The conceptual framework is based around a logic chain that connects performance standards for homes to the quantified impacts of those standards, which can then be valued in money terms (see Figure 1).

Figure 1: Logic chain from design standards to money value of impacts (mitigation outcomes).



When considering the impact categories listed above (land take, construction, and occupation), there are two broad categories of positive outcomes that can be achieved due to an improved performance standard. There are:

- **Mitigation outcomes**: avoided negative environment impacts (such as avoided green-house gas emissions) or active improvements to environmental quality as part of a development (such as improving local-level biodiversity through habitat improvements).

- **Adaptation outcomes**: avoided negative impacts to the welfare of residents caused by changes in the environment, both immediately outside and inside the home.

This research focuses on mitigation outcomes for energy use, water use, and surface water management. An analysis of performance standards for climate change adaptation and modern methods of construction (MMC) should encompass both mitigation and adaptation – this will be addressed as part of the background and scoping research for these areas.

Performance Standards and Occupant Behaviour

The environmental outcome of a specific performance standard being used in a home will be dependent on the behaviour of that home's occupants. However, predicting occupant behaviour is complex, and this research does not need to attempt to estimate or quantify behaviour to provide estimates of impacts and benefits. Instead, for most standards, a 'fixtures' approach can be used which links usage rates and outcomes to designs of fixtures. This fixture method is already well quantified for many design areas[20]. Impacts and outcomes are then based on an average or expectation of occupant behaviour in homes with certain types of designs (fixtures).

'Fixture' approaches may not be appropriate for climate change adaption performance standards, as climate change adaption standards incorporate the risk and welfare changes due to changing conditions, such as more common heat waves. Therefore, behavioural adaptation – such as occupants installing air conditioning if their home is poorly insulated against heat – may need to be considered to effectively estimate the environmental and social impacts of a design or standard as these adaptations are likely to vary more widely for occupants based on their own preferences, tolerances, and individual circumstances. The implications of occupant behaviour are explored more thoroughly in section 7.

Typologies – Defining the Links Between Standards and Their Outcomes

A set of typologies are used for house types and performance standards for energy, water use and surface water management, which form the basis of the reference table for impacts and values. The housing typology is outlined below, and the performance standard typologies will be defined in their respective sections.

The home types used are based on the GHG calculator tool developed by SQW. It is intended to be typical of the kinds of housing units that would be developed on sites being brought forward by Homes England. The housing types are as follows:

- 2 bed terrace.
- 2 bed semi / end terrace.
- 3 bed terrace.
- 3 bed semi / end terrace.
- 3 bed detached.
- 3 bed townhouse (narrow fronted, mid terrace).
- 4 bed townhouse (narrow fronted, end of terrace).
- 4 bed detached.
- 5 bed detached.
- 1 bed flat.
- 2 bed flat.

[20] For example, see the Building Regulations Part G for expected water use due to types of fixtures.

- 2 bed semi-detached bungalow.

In this research, individual homes are the most basic unit for which the impact of a performance standard can be estimated. This approach is compatible with existing standards for water use and energy use, but for other performance standards, such as surface water flooding mitigation, the most basic unit for analysis will be the entire development due to the nature of the designs used in surface water management. Overall, the reference table and this report accommodates both per unit and total project analysis as appropriate.

Impacts of Energy Use Performance Standards

This section presents:

- An overview of current designs, methods, and building regulations for energy use
- The performance standards identified as useful reference points in early stage appraisals
- The evidence and literature used to develop the reference table to assess these performance standards

Background

The basis for assessing emissions (and their associated impact) in domestic housing is driven by Part L of the Building Regulations. In 2021, a Green House Gas (GHG) calculator tool was produced for use by Homes England in the appraisal process. This provided four different scenarios, as follows:

- **BASELINE:** Compliance with Approved Document Part L1a (2013).
    - This included a heating system based on the use of natural gas.

- **B1:** Meeting the anticipated emissions requirements of the UPDATE to Part L1a (2013) to Part L Volume 2022 (as understood in 2021).
    - This included a heating system based on natural gas but with the inclusion of renewables (photovoltaics).

- **B2:** Meeting the anticipated emissions requirements of the UPDATE to Part L1a (2013) to Part L Volume 2022 (as understood in 2021).
    - This included a heating system based on air source heat pumps.

- **C:** Achieving the requirements of the Future Homes Standard due to come into force in 2025 (as understood in 2021).
    - In this scenario, heat was supplied by heat pumps with additional renewable capacity in the form of photovoltaic panels.

These scenarios were applied to the housing typology for section 2 of this report.

The data from this analysis was compiled into the new GHG Calculator, which provided a 100 year emissions profile for each of the 4 scenarios, based on a proposed accommodation schedule defined by the user. Using data from HM Treasury (also found within the Green Book GHG Toolkit spreadsheet), the GHG Calculator mapped emissions over time, fully taking account of the gradual decarbonisation of the Grid. This data was then applied to the Green Book GHG Toolkit spreadsheet to value the carbon impact and establish the present value (PV)[21] of those emissions for the development option tested.

[21] The IAG spreadsheet tool (Green Book GHG Toolkit) uses the term Net Present Value (NPV). However, as this research is only looking one dimension of the total cost benefit analysis in this application, Present Value PV is more appropriate and will be used here.

Updated Performance Standards

In the period between the issue of the GHG Calculator in the spring of 2021, further clarifications and details have emerged in respect to Approved Document Part L Volume 1, which came into force on June 15th 2022. This has precipitated the need to update the GHG Calculator tool, and the four scenarios that can be assessed within it, as follows:

- **A1:** (baseline) Compliance with Approved Document Part L Volume 1 (2022).
  - This includes a heating system based on the use of natural gas with photovoltaic panels included.

- **A2:** Compliance with Approved Document Part L Volume 1 (2022).
  - This includes a heating system based on the use of air source heat pumps for the provision of space heating and hot water.

- **FHS:** Compliance with the expected emissions requirements of the Future Homes Standard.
  - This includes a heating system based on the use of air source heat pumps for the provision of space heating and hot water, plus photovoltaic panels.

- **OZC:** Operationally Zero Carbon.
  - A per the FHS scenario, but with additional PV to reduce calculated emissions to zero (an intentionally simplistic approach for appraisal processes, discussed in more detail in the Points to Note section below).

These four standards scenarios (and particularly the first three) are being used because they represent the vast majority of the scenarios that will be applicable for all development being brought forward post June 2022. A1 and A2 are most familiar to the development industry, and there is already a rapid transition away from A1 and towards A2, recognising the need to create buildings that do not need retrofitting away for natural gas heating.

Standard A1 has been retained following instruction from Homes England, acknowledging it is a useful baseline and that some developers are still applying this as their standard approach. Critically, using this standard as a baseline helps demonstrate the stark difference in lifetime emissions between fossil fuels and application of (electrically driven) low carbon technologies.

The house type mix and geometry remain as per the original GHG Calculator.

The Green Book GHG Toolkit, has also, in the intervening period, become defunct, and at time of writing there is no confirmed date for its renewal. It has been confirmed by BEIS that the GHG Toolkit should not be used for appraisal purposes; rather, it has published updated background data tables that can be taken by knowledgeable and experienced users in order to 'manually' calculate the PV associated with different emissions options.

In order to address a 'temporary fix' has been implemented in the GHG Calculator which draws data from the data tables published by BEIS in October 2021 and provides the required output PVs for energy use, emissions and air quality impacts from energy use. Unless and until a new Treasury/BEIS GHG Toolkit is provided, this Calculator will need regularly updating, on an annual basis as a minimum.

User Information & Methodology

In order to appraise the impacts of energy use, the user will need a copy of:

- The GHG Calculator v.3.0 170322 – this is an Excel workbook and there is detailed guidance within that workbook on how to use and extract the required data.

- The GHG Results Sheet – a simple Excel file used to record the different options appraised within the GHG Calculator.

The Calculator enables users to create different appraisal options, by inputting data regarding the proposed accommodation schedule and selecting performance standards for each house type built each year over the construction period. Using the data sources outlined below, it then calculates the anticipated energy demands, associated emissions and air quality impact of the OPTION and provides the associated PV.

Each Option being assessed should then be saved, and the PV data transferred into the Results Sheet to enable simple comparison of the different Options appraised.

Data Sources

There are a number of data sources which provide the basis of the GHG Calculator, as follows:

- Building Regulations compliant energy demand and carbon assessment data. This uses the SAP calculation engine and is predicated on house types.

- House types – these were agreed with Homes England in 2021 and are based on actual house types delivered by developers in the UK. The drawings and information underpinning them however are copyright protected and contain intellectual property belonging to the designer/developers who provided them. They will therefore not be made available to users of the Calculator.

- Green Book Supplementary Guidance: valuation of energy use and greenhouse gas emissions for appraisal[22]. This guidance included the data tables, and this data has been used within the Calculator to inform a range of outputs including value of carbon, emissions factors, air quality pricing, etc. This data has been brought into the Calculator in lieu of an up-to-date Toolkit available from HMG.

Points to Note

There are a number of points to note in respect of appraising the impacts of energy use from new development.

Firstly, the new Building Regulations regime came into force in June 2022. The base case within the Calculator is compliant with this standard. However, any planning application that is submitted / registered prior to June 15th 2022 will still be able to use the 2013 Regulations standards for any project with construction commencing to one year after that point (the Transition Period). It is unlikely that any scheme being appraised now will be submitted in outline by June 2022, but users should be aware of this point.

Linked to the above, from June 15th 2022 a new calculation methodology will be applied in Building Regulations with a new requirement in respect of Primary Energy use. It has not been possible to use this in developing the Calculator as

[22] https://www.gov.uk/government/publications/valuation-of-energy-use-and-greenhouse-gas-emissions-for-appraisal

it does not formally exist other than in ‘beta’ versions. It is unlikely that the energy demand calculations will vary significantly, but it is recommended that the 12 house types are reassessed under this new methodology (called ‘SAP10.2’) to ensure figures are fully up to date and as robust as possible in the summer.

HM Government may release a new Toolkit at some point in the future. At that point Homes England will need to decide whether to:

- continue using the Calculator in its current form, but just ensuring that newly released Green Book valuation data is updated annually within it.
- revert to using the new Toolkit, running 3 spreadsheets instead of 2 for the appraisal of Options.

The choice of discount factor has a significant impact on the PV, and advice must be sought accordingly as to the appropriate figure to use. The same figure is used across the entire period of appraisal, and is set at the default level of 3.5%, unless amended by the user.

All PV outputs will be negative, because new development will always result in additional energy use and emissions. Choosing higher performance standards brings the PV figure closer to zero. This is true with the exception of the scenario where all dwellings are assumed to be built to be operationally zero carbon from the outset. Because the data assumes very slightly more renewable energy is generated on the building than is needed, there is a positive impact in this case.

However, it should be noted generally that the final OZC option includes simplistic assumptions to enable the emissions figures to reach zero. This is achieved by increasing the assumed amount of photovoltaic on the building to meet this target. It should not be assumed that such a quantity of photovoltaic (which ranges from 3.5 to 7.25kW per dwelling) is achievable on a given house type – rather, it gives an indication of the challenge in meeting this requirement on site and will need design teams to think very carefully about how this standard will be met in practice through a combination of design and infrastructure solutions.

Impacts of Water Use Performance Standards

The methods for determining impact due to water use has been progressed since this research stream was conducted, specifically to include more detail on the reference case and changes in water use due to the movement of individuals. Please refer to the Environmental Impact of New Housing Development (eftec and SQW, 2023) and ENHAT (eftec and SQW, 2023) to see the updated method.

This section presents:

- An overview of current designs, methods, and building regulations for water use
- The performance standards identified as useful reference points in early stage appraisals
- The evidence and literature used to develop the reference table to assess these performance standards

Water use performance standards are laid out in the Building Regulations Part G. By those standards, the fittings used in a residence should result in average water use of less than 125 litres per person per day. This is to be achieved by a combination of maximum consumption rates for certain fittings with the home, such as toilets, shower heads, bath tub size, basin taps, sink taps, and washing appliances. Part G also gives an enhanced national standard of 110 litres per person per day, that can be required for planning permission in certain areas, which is determined by the local planning authorities.[23] Current average use is much higher, at 141 litres per person per day.[24]

Impacts of Water Use Standards

The report “Pathways to long-term PCC reduction” (2019, Water UK)[25] examines the costs and benefits of demand side measures for reducing water consumption. This includes changing building regulations for both overall water use performance, and concludes that individual fitting performance is an important step towards reducing overall residential water use in the UK. These reductions will be necessary, as long-term forecasts of water use imply increasing pressure on current water supply sources.

This increase in demand will increase the need for new water infrastructure and storage and potentially damage the environment – particularly sensitive surface and groundwater catchments – due to increased abstraction[26]. Natural England has advised[27] that new developments in some areas (such as Chichester, Crawley, and Horsham) must not lead to increased water abstraction (e.g. the development must be water neutral) as to not further strain local water supply and environmental systems. In addition to impacts from abstraction and infrastructure development, there are also carbon emissions from pumping and supplying water[28], as well as from treating wastewater.

The primary areas of impact from improved performance standards this research will address are:

- Delayed and/or avoided infrastructure investments.

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[23] According to the “Consultation on measures to reduce personal water use” (Defra, 2019), around 100 authorities have adopted this standard.
[24] Defra, “Consultation on measures to reduce personal water use”, 2019
[25] Artesia, eftec, “Pathways to long-term PCC reduction”, 2019
[26] https://www.gov.uk/government/publications/meeting-our-future-water-needs-a-national-framework-for-water-resources
[27] https://www.horsham.gov.uk/planning/water-neutrality-in-horsham-district
[28] Environment Agency, “Greenhouse gas emissions of water supply and demand management options”, 2008

- Environmental impacts from reduced abstraction, including diminished effects of drought and/or surface and ground water depletion.

- Reduced greenhouse gas emissions from reduced water use.

Available Evidence

Current evidence exists on all of these areas of impact. Each section below will address the relevant evidence for each impact area and how it is incorporated to the reference table.

Avoided Infrastructure Investments

One method to calculate the estimated benefit of avoided future infrastructure investment due to improved standards is to apply an average incremental cost of the most likely *avoided* infrastructure investment for a development. Following research carried out for the National Infrastructure Commission (NIC)[29], Artesia and eftec (2019) applied average incremental costs for new water abstraction or storage infrastructure ranges between £633 per megalitre for new surface water and £1729 per megalitre for new reservoirs in an economic assessment of pathways to long-term per capita consumption reduction[30].

In applying these values, the average incremental cost should be used – not the average incremental *social* cost, to avoid any double counting that may occur with benefits due to reduced abstraction.

Reduced Abstraction

The benefit of reduced abstraction can be interpreted as representing household preferences for water conservation and those associated benefits. The Artesia and eftec (2019) report applies a marginal social benefit of £0.36 per litre per household per day per year from reduced abstraction. The Environmental Agency "Groundwater Appraisal Guidance" (Sept 2018) recommends a social cost of abstraction at £1.21 per cubic meter for areas of serious water stress, and £0.48 for all other areas, which is the equivalent of £0.44 per litre per household per day per year for areas of serious water stress, and £0.18 per litre per household per day per year elsewhere. As these values are within the same factor of magnitude, the EA (2018) values have been presented in the reference table. Users of the reference table can then choose which value is more appropriate – areas NOT under stress being the suggested default choice.

Reduced GHG Emissions

The Artesia and eftec (2019) report applies GHG emissions for water delivery and treatment of 0.17 kg CO_2e per property per day for a usage rate of around 138 litres per person per day. These values are validated by the finding presented in the Water UK Annual emissions report 2021[31], which gives an average annual emissions per property of around 0.15 kg CO_2e. The energy use due to appliances and hot water are intentionally avoided here, as there will be overlaps and potential double counting of impacts with the energy use section of this report.

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[29] https://nic.org.uk/studies-reports/national-infrastructure-assessment/national-infrastructure-assessment-1/costs-of-water-resource-management/
[30] https://www.water.org.uk/wp-content/uploads/2019/12/Water-UK-Research-on-reducing-water-use.pdf
[31] https://www.water.org.uk/publication/annual-emissions-report-2021/

Water Use Performance Standards

The performance standards are as follows:

- A – minimum standard under part G, 125 litres per person per day.
- B – enhanced national standard, 110 litres per person per day (the current “optional” standard under part G).
- C – minimum viable standard (that ensures quality of user experience) for a mains only solution, based on efficient fixtures and fittings alone, typically 105 litre per person per day (Current policy 5.15 of the London Plan, for example).
- D – standard with rain or grey water recycling, around 85 litres per person per day.

User Information and Methodology

The reference table quantifies water use impacts from avoided infrastructure investments, avoided abstraction, and the GHG emissions for water delivery and water treatment. To use the reference table, the user should take the following steps:

1. Identify the standard that will be used for the units in a development.
2. Estimate the number of dwellings and the average occupancy for those units.
3. Apply the per person per year values from the “water use impacts” tab of the reference table. If uncertain of which specific value to use, the most likely values for each impact areas have been highlighted in light green.
4. The carbon values are given as kg CO_2e per person per year. These will need to be monetised using the Green Book guidance (see the section for energy use).
5. Finally, add the monetised impacts from each area together. This value is the estimated environmental cost of the development due to water use.
6. To quantify the benefit of using an improved standard (as an example standard C as opposed to standard A), the user should perform this exercise for both standards, and subtract the value for the more rigorous standard from the less rigorous standard. The difference will be the estimated environmental benefit of using the more rigorous water performance standard.

Other values are given in the water use impacts tab, to allow the appraiser to use more specific values if further specifics are known about the project (such as the level local water stress).

Points to Note

There are two main points to note in regards to water performance standards.

The first is in regard to water neutral developments. There are currently no examples of water neutral developments that do not use water offsets. While this may alleviate water stress in the particular area of the development, there will still be environmental costs to the water use of the development. Therefore, it can not be assumed that a water neutral development has no environmental impact from water use.

The second is that people's welfare can diminish with reduced water use. For example, if fixtures are installed in a home that have low flow rates – like showers with poor pressure – people will have a lower utility from the experience of that home. However, in the fixtures based approach taken here, no behavioural change is assumed to compensate, although this may be observed in actuality – such as households replacing shower heads or sink taps.

Box 4.1 below gives two example calculations using the values provided in the worksheet. While these values may seem minimal, it is important to note that some of the fixtures used to obtain the higher performance standard will also be relatively low cost and may also provide direct benefits, such as a reduced water bill for residents.

Box 4-1: Water Use Performance Standard Examples

Case 1 – 100 units, with an average occupancy of 2.55 residents per unit, using standard level A

255 ppl *125 litres / person / day * 365 days / year =
1.16 million litres of water / year

Infrastructure – 255* £29.07 = £7,413 /year
Abstraction – 255*£23.65 = £6,031 / year
Carbon emissions – 4855 kgCO2e/ year

Total estimated environmental cost =
£13,444 and 4855 kgCO2e/ year
£52.72 and 19 kgCO2e/person / year

Case 2 – 100 units with an average occupancy of 2.55 residents per unit, using standard level C

255 ppl *95 litres / person / day * 365 days / year =
0.98 million litres of water / year

Infrastructure– 255* £24.42 = £6,227 /year
Abstraction – 255*£19,87 = £5,066 / year
Carbon emissions – 4079 kgCO2e/ year

Total estimated environmental cost =
£11,233 and 4079 kgCO2e/ year
£44.05 and 16 kgCO2e/person / year

Impacts of Surface Water Management Performance Standards

The methods for determining impact due to blue-green infrastructure has been progressed since this research streams was conducted, and has been simplified to be better fit for purpose. Please refer to the Environmental Impact of New Housing Development (eftec and SQW, 2023) and ENHAT (eftec and SQW, 2023) to see the updated method.

This section presents:

- An overview of current designs, methods and building regulations for flood risk mitigation and surface water management
- A description and explanation of SuDS, its importance to surface water management in England, and its relationship to BGI
- The performance standards identified as useful reference points in early stage appraisals
- The evidence and literature used to develop the reference table to assess these performance standards

Introduction

Surface water management systems mitigate the risk of flooding from heavy and/or prolonged rain (surface water flooding)[32]. All new developments must be designed to ensure that drainage flow rates are high enough to deal with extreme rainfall. The Building Regulations Part H describes the requirements for rainwater drainage; in short, surface water management designs must be able to carry all rainwater away from the roof of structures, and then discharge all water from buildings and hardscaping and landscaping to some type of infiltration system, watercourse, or sewer where that water is dissipated or flows away.

Current guidance encourages all developments of 10 homes or more to utilise sustainable drainage systems (SuDS)[33], but the actual design requirements may vary by the size of the development and the planning district in question. SuDS are an alternative to traditional drainage solutions, which should improve environmental outcomes over traditional drainage systems that directly channel surface water through a network of channels, sewers, or pipes to nearby watercourses. SuDS are designed to mimic natural drainage systems through the use of infiltration, swales, and basins. The aim of SuDS is to mitigate surface water flood risk at the same level as a traditional system, while also improving water quality and increasing the amenity and biodiversity value of the local environment. Therefore, to measure the impacts of improved standards for surface water management designs, the task is to compare "traditional" drainage solutions against several improved categories that utilise SuDS.

[32] Other areas of flood risk such as fluvial flooding are generally dealt with through planning. Flood risk classification for river and coastal flooding range from zone 1 (low probability, less than 1 in 1000 annually) to zone 3b (the functional flood plain). It is inadvisable to build in zone 2, unless specific designs, such as raised structures, are used to mitigate against the flood risk. When building in zone 1 however, this type of flood risk can largely be ignored.
[33] https://www.legislation.gov.uk/ukpga/2010/29/enacted

SuDS systems are part of a large group of ‘green’ development features that can be referred to as blue green infrastructure (BGI)[34]. While SuDS generally refers to only the features specifically aimed at surface water management, BGI can refer to any blue or green portion of a development that serves functional purposes while providing environmental benefits. The environmental impacts of SuDS and BGI systems are typically interconnected however. Users should be mindful of potential for double counting benefits if also performing analysis of BGI on a site.

Measurements of the Impacts and Benefits of SuDS and Blue Green Infrastructure

There is substantial existing research estimating the impacts and benefits of using SuDS designs over traditional drainage systems. In the UK, the B£ST guidance developed by CIRIA[35] provides extensive summary research along with comprehensive tables of estimated impact and benefits values for SuDS and blue-green infrastructure. The benefit categories used in the B£ST guidance that are considered in this project are:

- Air Quality.
- Amenity.
- Property value (“asset performance”).
- Biodiversity and ecology.
- Building temperature.
- Carbon reduction and sequestration.
- Flooding.
- Health.
- Noise.
- Water Quality.
- Water Quantity.

As the purpose of this research is to inform early-stage appraisals, the above list of impact and benefit categories is fit for purpose. These categories typically capture most of the important benefit impacts of BGI.

A course assessment of these benefits can be performed using the B£ST tool with: (i) an estimated number of trees to be planted; (ii) new hectares of woodland to be added; (iii) the number of people that will benefit from new greenspace; (iv) the number of properties that will flood less frequently or less severely; (v) the area of land that will

[34] Blue green infrastructure is networks of environmental features and natural areas designed to deliver eco-systems services, which includes (but it not limited to) flood control.
[35] Horton, B., Digman, C.J., Ashley, R.M., and McMullan, J., (2019). B£ST Guidance – Guidance to assess the benefits of blue and green infrastructure using B£ST.

improve biodiversity; and, (vi) the length or area of watercourse / water body that will be improved. There is also an intermediate appraisal option provided in the B£ST guidance, which requires much more information to effectively conduct the appraisal. In situations where this information about a development is available it may be more appropriate for users to use the B£ST tools directly.

Table 1: Information requirements for the B£ST tool (intermediate assessment)

Benefit Category	Information required
Air Quality	Size/type of green components in scheme such as the number of trees and green roofs
Amenity	Number/type of homes/commercial properties and number of people impacted by scheme
Asset performance	Change in size/type of green and blue space due to scheme
Biodiversity and ecology	Change in size/type of green and blue space due to scheme
Building temperature	Area of green roof / number of trees
Carbon sequestration	Number and type of trees
Flooding	Number of buildings or people impacted by the scheme
Health	Number of homes and number of people impacted by scheme
Noise	Size/type of green components in scheme such as number of trees
Water quality	Current and projected water quality status and length/area of waterbody impacted
Water quantity	Volume of water infiltrating to groundwater, Number of properties, household size, water consumption rates

However, a streamlined process will have value for an early-stage appraisal, to understand the magnitude of the environmental benefits from pursuing an improved performance standard. The reference table takes the impact and benefit estimates and applies them directly to the set of typologies, allowing the practitioner to quickly and easily determine the change in impact due to changes in the type of standards used of surface water management. This requires less information, and while it is less precise many of the largest impact categories (such as amenity and air quality improvements) can still be estimated.

Surface Water Management Performance Standards

The demands and designs required to mitigate surface water flood risk depend on several site and development characteristics. This focus here is on the aspects of surface water management designs that are likely to affect environmental impacts and outcomes. For example, the use of SuDS over traditional drainage systems such as drains, holding tanks, and pumps. To make the assessment feasible during the early stages of the appraisal, the reference table uses the following dimensions to estimate impact and benefit values:

- Site size in hectares.
- Development density and average residents per dwelling.
- Region of the development.
- Approximate area of green space (both SuDS and non-SuDS) on the site, estimated in levels of 10%, 20%, or 30%.
- The approximate quality of that greenspace.
- The existence of watercourses or ponds on site (once completed).

These specific dimensions used correspond to the areas of impact (air quality, amenity, health, and recreation) that have the largest magnitude of benefits in monetary terms. Other design characteristics, such as green roofs, can also provide environmental quality benefits, but the magnitude of those benefits is observed to be relatively low in comparison to the benefits provided by access to ponds or increased amounts of greenspace.

The performance standards based on the criteria above are defined on a scale from A to R. The specific standards, and how they were determined are laid out in Annex A.

User Information and Methodology

The reference table quantifies the environmental improvements of BGI over traditional drainage systems. To do this, a set of assumptions are made for various levels of BGI implementation, and impacts estimated based on those assumptions (Annex A). To use the reference table an appraiser should follow these steps:

1. Determine the performance standard that will be used for the development based on the amount of BGI specific greenspace included in the design, the quality of that green space, and whether the site has a watercourse or waterbody involved in the drainage system design.
2. Input the region, site size, site density, and expected occupancy into the assumptions page. The appraiser should also verify the assumptions made about the design are appropriate, especially where they have information available.
3. Record the impacts and benefits of the drainage system design. The carbon values are given as kg CO_2e per person per year. These will need to be monetised using the BEIS guidance and rules for valuing greenhouse gas emissions.
4. Finally, add the monetised impacts to the carbon values. This value is the estimated environmental benefit of the development due to the drainage system used.
5. To quantify the benefit of using an improved standard (as an example standard C as opposed to the baseline), the user should perform this exercise for both standards and subtract the value for the less rigorous standard from the more rigorous standard. The difference will be the estimated environmental benefit of using the better drainage performance standard.

Points to Note

The purpose of the reference table and the performance standard categories are to provide broad estimates – in terms of order of magnitude – for the potential environmental benefit of using a SuDS system. This is in line with the overall use-case for the appraisal guidance, and therefore the estimate provided here are not intended to encompass all impact categories. The direction of a surface water management design is easiest to dictate at the inception of a project, and as such choosing a general performance standard to adhere to early in the project can yield greater public benefits, as those benefits will be understood and designed for.

Additionally, the way that the reference table is set up will allow the user to adjust some values if desired (such as the number of trees per hectare on a site). Generally, it is advised to use a different performance standard, but if some values of standards are deemed to be inappropriate for an analysis, then they may be adjusted to fit a proposed design.

Much of the estimated benefit value comes from green space – or park – users, homes with views of "green streets" or waterbodies due to the design, and are quality improvements – specifically PM-10 reductions from trees.

Many of the designs used for surface water management, such as improved planting, can lead to land value uplift – the increase in the value of land due to improvements. As such, there is the potential for the benefits estimated here to overlap elsewhere within the appraisal of non-environmental impacts. The values that are most likely to overlap with land value uplift are amenity values, as these types of values can be factored into home prices and property values. Users of these estimates should be aware of this potential double counting, and take care to avoid it in the appraisal process.

Box 1 below shows a side-by-side comparison of two similar examples, where one project uses higher quality greenspace than the other. Note that the benefit is over a case where the development has minimal BGI. The magnitude of these benefits is small on a per household basis. However, these benefits do not include land uplift values, which are calculated elsewhere within the appraisal process.

Box 1: Surface Water Management Performance Standard Examples

Case 1 – 100 total units on 2 hectares;
Average occupancy of 2.55 residents per unit;
Standard level J – 10% green space of standard quality and a watercourse on the site

Total benefit - £5,453 and 650 kg CO2e / year

Case 2 – 100 total units on 2 hectares;
Average occupancy of 2.55 residents per unit:
Standard level P – 10% green space of best quality, and a watercourse on the site

Total benefit - £13,591 and 1,352 kg CO2e / year

Modern Methods of Construction – Scoping

This section presents:

- Current evidence regarding the impacts of performance standards or improved designs for modern methods of construction
- A proposed method for evaluating the impact of modern methods of construction, and a suggested alternative approach

Modern Methods of Construction (MMC) refers to any construction process that uses off-site construction techniques or uses new technology or improved processes to fabricate buildings. There is a wide range of methods which are explored further in the following section, but generally MMCs should improve techniques to make construction better, faster, more efficient. Since MMC represents an improvement in process, and efficiency is a primary goal of MMC, it is expected that MMC will also improve the environmental outcomes of construction.

MMC Categories, Materials, and Impacts

MMC has been put into seven categories by MHCLG:

- Category 1 – Pre-Manufacturing – 3D primary structural systems.
- Category 2 – Pre-Manufacturing – 2D primary structural systems.
- Category 3 – Pre-Manufacturing – Non systemised structural components.
- Category 4 – Pre-Manufacturing – Additive Manufacturing.
- Category 5 – Pre-Manufacturing – Non-structural assemblies and sub-assemblies.
- Category 6 – Traditional building product led site labour reduction/productivity improvements.
- Category 7 – Site process led labour reduction/productivity improvements.

Further these categories of construction can apply to seven material genres[36]: (i) mass engineered timber; (ii) timber framed; (iii) light gauge steel framed; (iv) hot rolled fabricated steel; (v) hot rolled / light gauge steel combination; (vi) concrete and cement derived; and (vii) timber frame / concrete combination.

Finally, the impact areas of MMC are expected to be:

1. Change to onsite labour and disturbance.

[36] These are referred to as "genres" because they only typify the primary structural material and are not intended to be define anything beyond the primary structural construction material.

2. Change to offsite labour and disturbance.
3. Reduction in waste generated.
4. Improvements in amount or type of materials used.
5. Improved construction programme certainty.
6. Improved construction quality.

Several of these categories relate to environmental impact from construction and therefore an expected a link between implementing MMC and reducing those impacts.

Available Evidence

The available evidence has not yet strongly supported a link between MMC and improved environmental impacts. In many cases it has been difficult to identify and collect the relevant data, and in other case the primary area of concern for the research is something other than environmental impact. For example, in consultation with Atkins and Homes England on current work being undertaken, it is clear that understanding the efficiency and cost of construction for MMC versus traditional methods are the primary research goals, and environmental impacts from using MMCs is a secondary research aim.

Proposed Approach

Until further data and evidence is gathered, and additional research is published (such as the current research begin undertaken by Homes England with Atkins and UCL), it will be difficult to set out meaningful performance standards with assigned environmental impacts for MMC. Instead, an embodied carbon approach is recommended. Performance standards could be applied for the materials genres list above in combination with characteristics of the proposed development to incorporate an estimate of embodied carbon into the appraisal guidance. There is already existing guidance on performing embodied carbon calculations[37], but the calculations and information requirements are too detailed for early-stage appraisals.

The main opportunity is to develop an early-stage appraisal reference tool for embodied carbon values based on the materials being used for a development (i.e. wood framed, light gauge steel), the type of structures being constructed (i.e. detached homes, flats in 3-4 storey building), and other factors that would effect embodied carbon such as associated infrastructure (i.e. parking and access roads). The guidance and associated reference table would give the user an estimate of the magnitude of embodied carbon for different projects and allow comparisons between proposed development designs.

[37] https://www.istructe.org/IStructE/media/Public/TSE-Archive/2020/A-brief-guide-to-calculating-embodied-carbon.pdf

Climate Adaptation in Home Design

This section presents:

- Current evidence regarding the impacts of performance standards or improved designs for climate change mitigation in home design
- A proposed method for evaluating the impact of climate change adaptation

Design for climate adaptation aims to reduce the impact to human health and welfare from future changes to the climate and environmental conditions. Homes built today are intended to last for several decades, if not over a century, and therefore should be constructed with these future changes in mind. The following considers how some climate change risks will affect human health and welfare in the home, and how design or performance standards might help to mitigate those identified risks.

Areas of Impact

The Third UK Climate Change Risk Assessment (CCRA3) identifies several areas of risk due to changing climate, on a scale from "more action needed" to "sustain current action". Several of these risks are related to the health and the home and many, such as those from flooding, are already addressed elsewhere in the appraisal guidance. However, certain identified risks due to climate change are not addressed in other sections of the appraisal guidance and are directly related to building design. These are:

- risks to health and wellbeing from high temperatures.
- risks to building fabric.
- risks to health and wellbeing from changes in air quality.

"Design for Future Climate"[38] provides 3 categories of impacts that the changing climate will have on the building designs. These are:

- Designs affecting comfort and energy performance – warmer winters may reduce the need for heating, but this might be mitigated by increasing need for cooling during summer.
- Designs affecting construction – resistance to extreme conditions, detailing, and the behaviour of materials.
- Designs to manage water – both too much (flooding) and too little (shortages and soil movement).[39]

Combining these three areas of design for buildings with the areas of potential impact to people from climate change, a few more specific areas of design and performance standards would be central to evaluating the impacts and benefits of improved design. Those areas are:

[38] Bill Gething, "Design for future climate - Opportunities for adaptation in the built environment", 2010
[39] Note that this is already addressed via Building Regulations Part H.

- Design to improve ventilation, screening, and other natural cooling and heating in buildings.
- Design to increase a building's resistance to storms.
- Design to improve air quality in buildings during poor air quality events.

Available Evidence

Heatwaves and increased indoor temperatures have been linked to reductions in worker productivity.[40] While these changes in productivity are mostly linked to outdoor professions, an increase in home working combined with high indoor temperatures would also have productivity effects as high temperatures can make workers feel less energetic and reduce concentration.

Heatwaves and increasing temperatures have also been linked to higher rates of morbidity, with monetised annual health impacts in the billions of pounds.[41] Therefore, cooler indoor temperatures and greater resilience of homes to heat waves could provide significant benefits in terms of reduced health effects. Indoor air quality due to a range of pollutants is also linked to productivity and health outcomes.[42]

Finally, storm damage to buildings is expected to increase due to climate change. While there is little evidence that wind damage will increase in the UK in the coming decades, rain fall is expected to increase, especially in high rain events.[43] The flooding implications have already been addressed elsewhere, but buildings designs may need to also change to be able to address heavy and sustained rains.

Proposed Approach

To evaluate the potential impact of performance standards on the above areas of impact, three separate workstreams are proposed. These would:

- Evaluate and quantify the human health impacts of indoor temperature improvements from ventilation, screening, and other passive cooling designs for dwellings.
- Evaluate and quantify the impact of improved indoor air quality from better ventilation, building sealing, or active air filtration designs.
- Evaluate and quantify the avoided long-term costs of improving storm resilience for dwellings.

The end product of these workstreams would be a report and reference table similar to that produced for energy use, water use, and surface water mitigation standards in the previous sections of this report.

[40] http://eprints.lse.ac.uk/90474/4/Frankhauser_Upholding_labour_productivity.pdf
[41] https://www.ncbi.nlm.nih.gov/pmc/articles/PMC4454966/
[42] https://www.hsph.harvard.edu/news/press-releases/office-air-quality-may-affect-employees-cognition-productivity/
[43] https://www.metoffice.gov.uk/research/climate/understanding-climate/uk-and-global-extreme-events-wind-storms

Conclusions

This section presents:

- A recap of the information presented in this report
- Recommendations on how this information should be used in the appraisal guidance

This report outlines an approach to evaluating the environmental impacts of performance standards for energy use, water use, and surface water mitigation in residential building design. The approach and methods detailed are intended to be incorporated into the environmental impacts of housing development appraisal guidance, and to inform Homes England business case development and project appraisals.

This report also presents options for providing a similar approach for the impacts of standards relating to construction methods and materials and climate change resilience. These suggestions will be followed by project proposals at the request of Homes England.

Annex A: Assumptions regarding blue-green infrastructure levels

The typology of standards for surface water management performance standards presented in this report were developed to estimate environmental benefit values. These are presented the accompanying reference table, and their development required making several assumptions about the quality and scope of these improved performance standards. The assumptions made were informed by information taken from several case studies and previous Homes England projects and are displayed within the reference table so that users can easily identify which standard might be apply to the options being appraised based on proximity to these assumptions.

To obtain meaningful estimates on environmental impacts and benefits from the use of BGI, assumptions have been made along the following dimensions for each performance standard:

- Trees per hectare of development (small, medium, and large).
- Percentage of homes on “green” streets.
- Percentage of homes overlooking a pond or other body of water.
- Annual visitors to create greenspace, expressed as a percentage of the residents in the development.
- The amount of floodplain constructed or restored (as a percentage of the site).
- The amount of land improved for biodiversity (as a percentage of the site).

This set of assumptions provides a reasonably full picture of the potential benefits conferred by BGI, with minimal information requirements.

The values for these dimensions varied systematically as both the amount of BGI and the quality of BGI increase in the typologies. The inclusion of watercourses and ponds also has large implications for environmental amenity value and was included in the assumptions.

Case Studies

The following are case studies that were used to inform the assumptions made in the reference table.

Kings Crescent estate – Hackney

Kings Crescent estate is a 4.2 hectare estate regeneration project that will provide 767 dwellings in total. After consultation it was determined that SUDs could be used on the site, and the plan now includes raingardens, SUDS tree pits, and other SUDS features such as permeable surfaces. Based on planning documents, it is estimated that 2-5% of the site includes basins, swales, or raingardens, and that a small portion on homes are on green streets or alleyways. Due to the height and the density of the dwellings, it is estimated that around 10% of dwellings could be considered to have benefit from being on a green street. Per the typology, this site would be considered type “D” – there is a small area of greenspace or BGI, but the space that does exist is of good quality, and effort has been made to include trees and other greening features as a part of the site. Due to the density however, the site cannot obtain a “best” rating for the quality of the greenspace. As shown below in the photos, there are a few medium – small sized trees, a good area of raingardens and swales (when compared to the total hardscaped area). Some amount of biodiversity improvement is likely over a strictly hardscaped drainage systems, and the area is designed with play areas and benches to encourage public use.

Figure A-1: Kings Crescent estate SUDS implementation

Rectory Garden – Rain Park

While not part of a housing development project, the Rectory Garden rain park provides an illustration of improving the environmental quality of an area through SUDS implementation. Rain gardens and basins were used to improve drainage, and the planting and implementation is done in such a way as to improve biodiversity outcomes on the site. This is a best-case outcome for a SUDS design, with a high proportion of environmental improvements for the space used.

A high portion of the homes near the gardens would be considered to be on green streets, and there is also a large number of medium to large size trees on the site. Finally, a high percentage of the site was improved for biodiversity (roughly a third to half of the greenspace), and features were added to provide recreational amenity and encourage visitation to the park.

Figure A-2: Rectory Gardens Rain Park

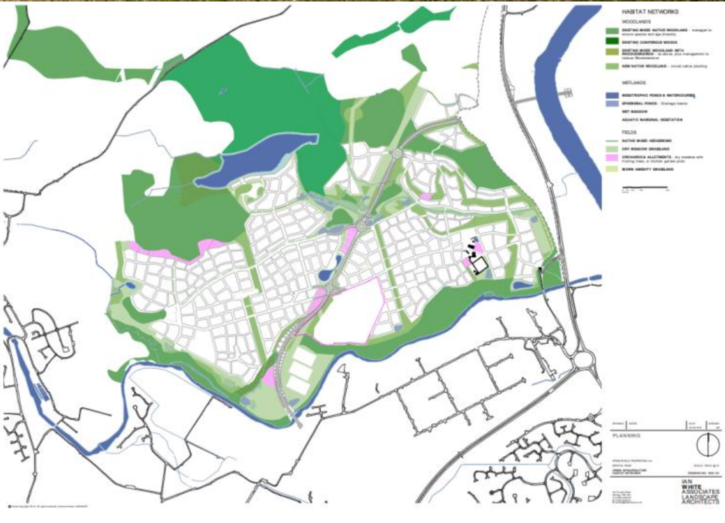
Bertha Park - Perth

Bertha Park in Perth is an example of a very large development of over 3,000 homes on a 333ha greenfield development. The landscaping plan for the development included providing green infrastructure in a “multi-functional landscape” to create habitats, visual amenity, drainage, and recreation. The development also includes a central lake with overflow areas that provide habitats to encourage biodiversity.

The project is an example of a project with a large portion of greenspace as a percentage of the total development, which is concentrated around the planned and existing watercourses. It is also an example of a project that utilizes the existing watercourses and waterbodies as a part of the surface water flooding mitigation planning.

Overall, based on the planning documents it is estimated that around 30% of the development is green space, and there is the existence of the watercourses and ponds. The quality of the greenspace however might be considered "better". There is some space provided for biodiversity and recreation, but there are some notable missing features, such as trees and a focus on green streets through-out the development.

Figure A-3: Bertha Park image and plan



Upton - Northampton

Managed by the Land Trust, Upton is a 5 hectare, 1000+ dwelling area that implemented SUDS (among other community changes) in 2016. The completed design includes a permanent pond, several rain gardens and basins, as well as street greening and some area for biodiversity. Overall, the area of greenspace is relatively low throughout the development but is well distributed and provides green streets for a large portion of the residents. There are very few trees included in the greenspace, but ponds and rain gardens are used throughout.

Figure A-4: Images of Upton SUDS implementation

Spencer's Park – Hemel, Hempstead

This development of 280 units is the first portion of a larger 600 unit scheme. Significant amounts of high quality green space are included in the BGI implementation. The project includes many trees, water features, as well as quality landscaping.

Figure A-4: Map and images of proposed Spencer's Park development

Defining the standards

The following are explanations of the standard definitions used in the SFM standards relating to BGI implementation. The definition for each level of performance standard is described in Table A-1 and in the following text.

Percentage of green space

Greenspace was capped at 30% of the total developed space, based on estimates of the maximum greenspace and BGI observed in the case studies above (for example, Spencer's Park). As these performance standards are for SuDS implementation with blue green infrastructure, a minimum level of 10% greenspace was used, as any value below this indicates that benefits from BGI would be minimal or very similar to the baseline scenario.

Quality of green space

The quality of the greenspace included in a development is described from “standard” to “best”. These levels are further defined in the workbook as follows:

- Standard: grass or general open green space with minimal planting and trees.
- Better: no more than 75% of the green space by canopy area is grass, and the rest is areas of plants, shrubs, and trees.
- Best: no more than 50% of the green space is grass, with extensive areas of plants and shrubs, as well trees (with some being large trees).

Again, these levels and their descriptions are based on observations and case studies. A high proportion of green space in development tends to be grass and lawn, with a few trees or plantings along the outside of open areas. As green space becomes more design, more trees and plants are added, until a “best” level where designs intentionally include native plants, large trees, and a great ratio of land with planting to grass.

Watercourses

The presence of watercourses has a large impact on the environmental benefit values of BGI and SuDS implementations. As such, the existence of year round watercourses or water bodies on a site is given its own category for evaluating surface water flooding mitigation.

Table A-1: BGI assumptions for each surface water flooding performance standard

Performance Standard				Trees (Number per hectare of development)			% of homes on "green" streets	% of homes overlooking a pond or body of water	Primary park visitors (visitors that visit this area most often) - as percentage of local residents	Floodplain built or restored (% of site)	Land improved for biodiversity (% of site)
Letter	Green %	Quality of Green	Watercourse?	Small	Med	Large					
BASE	0%	N/A	No	0	0	0	0.0%	0%	0%	0.0%	0.0%
A	10%	Standard	No	20	5	0	0.0%	0%	10%	0.0%	0.0%
B	20%	Standard	No	40	10	0	0.0%	0%	15%	0.0%	0.0%
C	30%	Standard	No	60	15	0	0.0%	0%	20%	0.0%	0.0%
D	10%	Better	No	40	10	1	10.0%	0%	20%	2.5%	2.5%
E	20%	Better	No	80	20	2	25.0%	0%	30%	5.0%	5.0%
F	30%	Better	No	120	30	3	50.0%	0%	40%	7.5%	7.5%
G	10%	Best	No	40	10	2	25.0%	0%	25%	2.5%	5.0%
H	20%	Best	No	80	20	4	50.0%	0%	50%	5.0%	10.0%
I	30%	Best	No	120	30	6	75.0%	0%	75%	7.5%	15.0%
J	10%	Standard	Yes	20	5	0	0.0%	25.0%	20%	2.5%	0.0%
K	20%	Standard	Yes	40	10	0	0.0%	25.0%	30%	5.0%	0.0%
L	30%	Standard	Yes	60	15	0	0.0%	25.0%	40%	7.5%	0.0%
M	10%	Better	Yes	40	10	1	10.0%	33.0%	30%	5.0%	2.5%
N	20%	Better	Yes	80	20	2	25.0%	33.0%	50%	10.0%	5.0%
O	30%	Better	Yes	120	30	3	50.0%	33.0%	70%	15.0%	7.5%
P	10%	Best	Yes	40	10	2	25.0%	50.0%	50%	5.0%	5.0%

Q	**20%**	**Best**	**Yes**	80	20	4	50.0%	50.0%	75%	10.0%	10.0%
R	**30%**	**Best**	**Yes**	120	30	6	75.0%	50.0%	100%	15.0%	15.0%

Assumptions on Impact Parameters

With the standards defined, several assumptions were made about the impact parameters that would accompany those definitions.

Trees – number and size

The number of trees varies from 20 small trees per hectare in the baseline scenario to up to 120 small, 30 medium, and 6 large trees per hectare of developed land for scenario. Most – if not all – developments, have some amount of public green infrastructure, such as street trees or planters. Therefore, it was determined that some number of trees should be included, and 20 small trees represents one tree every 20 meters along the perimeter of a hectare development. This is a reasonable spacing for "minimal" street trees.

At the other end, in the "best" quality scenario, street trees would line most or all streets in combination with bioswales and basin, be at close spacings, and be present in any greenspace used for SuDS as well. Many common trees have a "spread" of around 7-8 meters, and most building guidelines recommend that there is some clear space between trees to allow for visibility and maintenance. This then represents trees at a space of 10 meters – or 40 medium trees along the outside of a 1-hectare development at the high end.

Aside from street trees, green-space and non-street basins would also be planted under the "best" scenario. As seen in the Rectory Gardens example, this type of planting tends to be well spread out, so the maximum number of trees would be limited. Therefore, a value of 6 large trees – representing existing trees on the land before development that are retained – and a few newly planted trees are included alongside the street trees, diminishing with greenspace and greenspace quality.

Homes on Green Streets

Homes on green streets confer benefits to residents both by increasing local amenity and by improving home values. What qualifies as a green street is a subjective distinction, but in the study[44] the values used are based on street trees as an indication of green streets. While it is clear that there is value to residents for living on greener streets with more planting, the differentiation would be relative. Therefore, the reference table simply uses increased values with both quality and greenspace, to indicate more residents would feel they are living on a green street.

Homes Overlooking a Body of Water

Stated preference research by Bastien, Arthur, and Mcloughlin (2011)[45] shows that overlooking a body of water – in this case, a SuDS pond – confers and amenity benefit to residents. Other research, such as Gibbons, Mourato, and Mendes (2014)[46] find that homes prices are positively correlated with nearby water bodies, implying that these water bodies confer an amenity benefit to households. In the cases of standards A through I, this does not apply, as there are no waterbodies. For J though R, the question is how many homes would gain improved amenity from

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[44] https://www.academia.edu/3772933/Promoting_urban_greening_Valuing_the_development_of_green_infrastructureinvestments_in_the_urban_core_of_Manchester_UK

[45] https://onlinelibrary.wiley.com/doi/abs/10.1111/j.1747-6593.2011.00259.x

[46] http://eprints.lse.ac.uk/49375/1/__lse.ac.uk_storage_LIBRARY_Secondary_libfile_shared_repository_Content_Mourato%2C%20S_Mourato_amenity_%20value_English_Mourato_amenity_value_english_2014.pdf

waterbodies. This is the parameter that will most likely need adjustment by users, as it is difficult to predict when looking at previous case studies. Values of 25-50% have been used in the reference table, assuming that half of units face onto the water body in “best” scenarios.

This research uses the values produced via the stated preference methodology, as this method is more likely to only capture the amenity benefits of SuDS installations, and not the land value uplift associated with those SuDS installations. Hedonic pricing, which estimates benefit values directly through changes in housing prices, will include land uplift values, and therefore may conflict with other aspects of the appraisal process.

Visitors

The visitor estimate is used to capture some recreation and amenity value from the green space provided. Higher quality green space should see higher usages rates, but this is also heavily dependent on other access to nature and parks.

The reference table uses a percentage of the developments residents as an estimation metric for this category. At the low end, there are almost no visitors (1 in 10) and at the high-end there are lots (10 in 10). The upper estimates do not indicate that all of the development’s residents will use the space, rather that the quality of the green space attracts visitors from other sites. Note that to be considered a “visitor”, that person should visit this greenspace most frequently out of all the immediate options.

Floodplain Built or Restored and Land Improved for Biodiversity

These two criteria are closely related for most SuDS implementations, as floodplain and land improved for biodiversity often occupy the space. Generally, it has been assumed that no land is improved for biodiversity under standard implementation, and that half of the greenspace has been improved for biodiversity under the “best” performance standard.

Embodied Carbon

Purpose of Document

- This report provides evidence on the emissions associated with the delivery of new housing development. This report focuses on the embodied emissions associated with housing development; operational emissions (which form part of the Whole Life Cycle Analysis) are considered in other parts of the research stream.
- This research considers the impact that different design and specification decisions within the design/construction process have on the level of emissions. This includes considering the role of transport, supply chain processes, site location, waste management and demountability on the level of emissions.
- The report presents evidence relating to the current standards for housing development and provides detail on the embodied emissions associated with specific building types aligned to the current industry approaches and standards.
- A tool was produced alongside this report, which has subsequently been incorporated into the final appraisal guidance and ENHAT tool.

Date Completed: June 2022

Introduction

As we move to a decarbonised Grid and move away from fossil fuels as a heating source in new developments – gas boilers no longer being permitted from 2025 – embodied emissions will become the dominant form of emissions related to (new) buildings.

Calculating the impact of embodied – or more accurately Whole Life Cycle emissions – is therefore crucial in understanding the potential climate impact of new developments.

However, the process of doing so is complex and requires a comprehensive understanding of different design and specification decisions in the design/construction process. Issues such as transport, supply chain processes, site location, waste management, demountability, etc – all contribute to the emissions associated with development, in addition to those generated through operation and energy supply.

This stream of work has sought to:

- Undertake research to establish the current state of the art in respect of standards, guidance, approaches and implementation of embodied carbon analysis within the development process.
- Undertake detailed analysis on a specific house type to understand the impact of decision making in respect of three different standards for embodied emissions, and estimate the cost of these impacts.
- Create a simple Embodied Emissions Appraisal Tool in Excel to enable Homes England to easily and simply assess the carbon and financial impact of decisions in this space for new homes.
- Develop guidance for the use of the Tool (this document).

Operational emissions – which form a part of Whole Life Cycle analysis – have been dealt with under a separate stream of work, and an associated operational emissions tool created to assess their overall impact within the Homes England appraisal process.

General Methodology

This stream of work included the following individual work strands:

a. Background research review – this desktop exercise examined a wide range of background academic and industry papers, guidance and information to establish the current state of the art in respect of embodied emissions practice in the UK (and more widely).

b. Development of the assessment methodology – agreement with Homes England of the approach to the modelling of a specific building type aligned to the current industry approaches and standards. This included the range of embodied emissions modelling and associated cost analysis (estimated CAPEX impact).

c. Modelling was undertaken and results compiled as background evidence to support key conclusions – with the key output metric a cost/sq. metre (£/m^2) for different approaches to embodied carbon design.

d. The Embodied Carbon Calculator Tool (the 'Tool') was compiled using this evidence, the output of which has been reviewed by both the consultant team (Daedalus Environmental, SQW and eftec) and Homes England for usability and robustness, alongside this accompanying guidance.

The Tool includes a lifecycle valuation of emissions (over a 60-year period) alongside the estimated CAPEX associated with different design decisions to enable a more complete appraisal.

Key Research Findings

A comprehensive summary of the research phase of this Module has been produced and issued to Homes England.

The understanding of embodied / whole life cycle emissions within the construction process is – on an industry wide basis – highly variable and strategies for addressing it are implemented on an inconsistent basis.

This is the case despite sound and proper analysis being underpinned by comprehensive standards and frameworks for analysis agreed by professional bodies including RICS, RIBA, the IStructE, and others.

The issue, therefore, is not the 'academic' knowledge of what needs to be done and how, rather it is:

- The current absence of statutory frameworks to enforce it in relevant sector (WLC is not a current requirement of Building Regulations and it only appears as a requirement in a very limited number of planning frameworks, such as the London Plan).
- Development teams who – in the face of WLC being an option rather than a requirement – have not developed or invested in the required expertise to address the issue comprehensively.
- It is also likely to be the case that the traditional volume housing developers have long established supply chains and processes that do not facilitate a deviation towards lower embodied carbon materials or innovation in design that would help create a shift towards more sustainable, low carbon supply chains. There is much inertia and the supply chains, as a result, remain in their infancy.

Until embodied or WLC emissions are underpinned in development decision making, it is unlikely that this picture will change. Bringing embodied emissions into the Homes England decision making process is vital first step in bringing about change and ensuring that development partners take the issue seriously and invest in the expertise needed to make lasting change.

Supporting Evidence

Building Analysis

Approach

It was originally proposed that we try and establish the cost of reducing the level of embodied emissions (measured using the metric $kgCO_2e/m^2$) using information derived from the research phase of the development. This was to be based on a Baseline / Enhanced / Best Practice basis. Following the research phase, it became clear that the data was inconclusive and therefore not robust enough to use.

Moreover, there were a number of key practical considerations that such data would or could not take into account, including:

- the Homes England role and the timing of appraisal within the development process (which at Outline Business Case Stage would preclude any detailed building analysis).

- the very large variability in terms of transport impact (which precluded any confidence in transport related emissions unless specific to a given development scheme, location and identified supply chain).

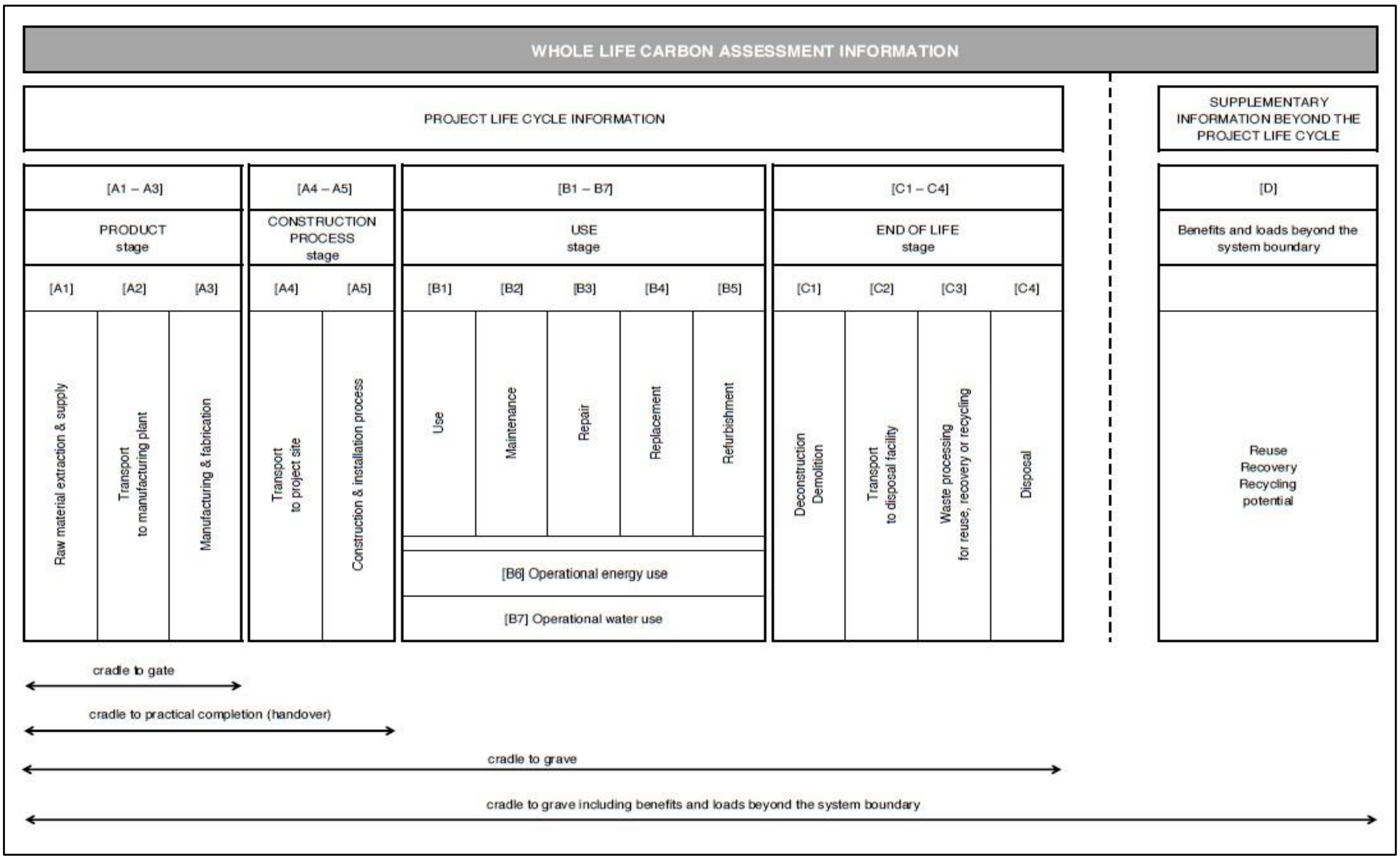
- the variability in terms of infrastructure requirements – foundations, groundworks, road layout etc – that are highly dependent on site conditions and location.

The consequence was that a $kgCO_2e/m^2$ approach would not be feasible at OBC stage. One further point to note is that some elements of infrastructure – specifically roads and their construction – have little flexibility in design where they are to be adopted by a local authority. In that respect there is little influence Homes England, or indeed a developer at a later stage, may have. In this area, it is unlikely that detailed research would add significant value to optioneering and option choice at OBC stage.

Further discussions were held with the Homes England team in respect of the emerging data being developed by the Future Homes Hub in this field. However, the deadline for the completion of this module required a different approach to be identified. Following a workshop with the Homes England team it was agreed that we would, for the purpose of this module, focus on those elements over which we could reasonably expect Homes England to have some level of influence, and where data was not solely reliant on location. Thus the focus has been on the building construction methodology and specification of materials.

The analysis of embodied emissions even on this basis is extremely resource intensive and costly, so budgetary constraints dictated we focused our attention on developing a simple £/m2 metric across three different construction scenarios, with a single property examined in detail. This was undertaken using the modular information for the assessment as per EN 15978 including typical system boundaries, implemented by RICS, as shown in the figure below:

Figure 1: RICS Whole Life Carbon Assessment for the Built Environment (2017) - life cycle stages



Over time, it will be necessary to expand this background evidence to include a range of different house types, but to prove the approach, and for project teams and those involved in business case preparation to understand the broad scale of the impact, this was agreed to be a reasonable starting point.

Embodied Carbon Scenarios

A three bedroom, semi-detached property was then modelled in detail to establish a detailed schedule of quantities of different materials across three embodied carbon scenarios, entitled:

- **Baseline** - standard construction associated with current house building expected to meet Part L requirements, including brick block construction, timber truss roof, standard forms of insulation, concrete strip foundations, etc.

- **Improved** - the key materials used in this scheme are timber for the framing of the external envelope of the building, and cellulose (a form of natural fibrous insulation material, derived from newspapers) as an insulation material.

- **Optimised** - the key materials used in this scheme are timber for the framing of the external envelope of the building and hempcrete (a form of natural fibrous insulation material, derived from hemp) as an insulation material.

For each of these scenarios, we identified a different materials strategy with consistent assumptions made for all building elements to ensure a like for like comparison of options, across:

- Demolition and excavation works.
- Substructure foundations.
- Superstructure framing.
- Superstructure floors.
- Superstructure roof.
- External walls.
- Internal walls.
- Finishes.
- Window and doors.
- Building services.
- Construction site emissions.

Details of each material schedule can be found in the Annex.

The use of natural materials such as cellulose presents an opportunity to store carbon for an extended period as at End of Life the material can be reused/recycled to form new insulation panels.

The use of natural materials also presents an opportunity to store carbon for an extended period – for example hempcrete can be crushed and reused for the development of new blocks/hemp-lime mixture at the end-of-life scenario. This continues to retain the captured carbon from the environment and serves as a carbon store.

Cost modelling

General

The schedule of quantities for the three scenarios was then costed by Gardiner Theobald, and the results compiled into the subsequently developed Excel Tool. The data is therefore in-built into that sheet – establishing a broad metric of £/m2 that is then applied across buildings of different sizes to give an indication of different cost impacts for developments of different sizes.

Regional Differences

To take account of regional variations in CAPEX costs within the Tool, multiplication factors, for the different regions in England, based on BCIS data (November 2022) have been built in, as follows:

Table 1: BCIS Location Factors (BCIS November 2022)

Location Factors	
North East	91
North West	100
Yorkshire & Humber	92
East Midlands	104
West Midlands	96
East of England	99
London	123
South East	110
South West	103

Thus, for example, based on BCIS regional data, CAPEX costs in the Tool have been reduced by 9% for the North East, and increased by 23% for projects in London.

Cost Confidence

The costs for the different approaches to embodied carbon are based on the house type tested. There is clearly going to be some considerable variation depending on the final layout, and the Tool therefore includes three different sets of cost data for each scenario tested, using suggested confidence intervals on cost from Gardiner Theobald, leading to a range in the CAPEX results (LOW – CENTRAL – HIGH). In this respect the LOW and HIGH CAPEX costs are +/- 25% from the CENTRAL figure.

Over time, and as more background data becomes available, it is strongly recommended that the existing data in the Tool is updated to reflect this and strengthen assumptions around cost confidence.

Valuing Carbon

As with the Operational Emissions Tool developed in 2021, the Embodied Carbon Tool also assesses the value of carbon to society. Supplementary Guidance to HM Treasury's Green Book[47] publishes data in respect of the value of emissions on a diminishing basis over the next 60 years. This approach has been integrated into the Tool to enable the user to attribute a value to carbon (specifically using the published CENTRAL SERIES) in the analysis and to value the carbon impact and establish a Net Present Value.

Opting to use the Improved or Optimised approach to materials specification will come at an increased capital cost, but have longer term carbon benefits. The Tool enables comparison of these two data sets when undertaking the required appraisal.

The Embodied Carbon Calculation Tool (CCA Tool)

The CCA Tool is provided in Excel format. This will enable straightforward updates over time, and currently enables appraisal for dwellings built up to 2035. Step by step instructions on how to use the tool are provided within the Tool

[47] https://www.gov.uk/government/publications/valuation-of-energy-use-and-greenhouse-gas-emissions-for-appraisal

itself on the first tab, 'Guidance Notes'. The Tool is simple to use and requires only a limited number of numerical inputs or drop down selections to establish the financial impact of embodied carbon design decisions.
The second tab – 'Input and Summary Sheet' – is the only tab which the user can input project related data and is the same tab where the required appraisal results can be found. The remaining tabs are locked to prevent unauthorised changes to the underlying datasets.

Different appraisal scenarios/options can then be copied to and saved in the Embodied Carbon Tool Results Sheet to enable comparison of scenario / option performance.

Points to Note & Limitations

Embodied carbon or WLC impact assessment is not yet a consistent field of study and implementation. We would argue that whilst a robust framework for assessment exists based on international and nationally adopted standards, it remains non-mandatory and therefore the wider skill sets in the industry do not yet exist for widespread implementation, especially at different (smaller) scales of development.

Done properly, it is a complex and time consuming exercise, and requires verification of the assumptions and underlying data (particularly from the supply chain) to be meaningful. There are, too, a significant number of variables for any development that need to be comprehensively understood, and which simply cannot be accounted for in a relatively simple appraisal tool.

Of particular note are the implications of development location and incumbent supply chains. However, what this Tool does do is begin to bring the issue of embodied emissions to the fore in the decision making process at a key stage in the decision-making process when options are being developed and appraised and key cost-benefit trade-offs established. Ongoing research and gathering of relevant data over time will enhance the robustness of the approach.

There are a small number of limitations which the user should be aware of in using the Tool, as follows:

- Regional variations
  Transport costs and impacts from the construction phases of new development will be driven by each site's location and we have not been able to control for them in this analysis. As a result, transport costs and impacts are excluded from this version of the Tool. Arguably Homes England will have little control over the ongoing emissions related to transport and given the role of the Tool in framing and appraising options related to Homes England's intervention, this unlikely to be a differentiating factor at Outline Business Case stage.

- Alterations and Retrofitting
  We have made no assumptions in respect of future extensions or physical amendments to buildings over time.

- Beyond End of Life
  Within the RICS framework for WLC analysis, Stage D or beyond end of life impacts have not been included – there is currently no robust data available in this regard.

- Costs

Costs associated with these measures will need regular review and updates and are based on a single house type. Whilst an allowance has been made for regional variations in CAPEX using the BCIS Location Factors, we would strongly recommend that the costs are reviewed on an annual basis as a minimum to take account of highly variable market price trends.

- Conflict with Other Streams
  Buildings with low embodied emissions are not created in isolation from other climate and carbon impact decision making requirements, such as operational emissions and climate adaptation outcomes, for which different appraisal Tools and guidance modules exist. However, the User needs to be aware that decisions in respect of one outcome can affect these other outcomes. A key trade-off to note is in terms of thermal mass of the building, for example. Improved climate adaptive capacity of internal spaces is achieved by increased thermal mass of the building structure. However, a greater building mass means more material within the building. Those materials are very likely to come with an increased embodied carbon impact, especially if that mass is achieved with cheaper materials like concrete and blockwork. With that in mind, a balanced set of priorities for any given project is essential, and a team appointed by the developer (or Homes England depending on the stage of the process) who are capable of calculating the costs and benefits of different design approaches and construction specifications.

Annex – Materials Schedules

Baseline

RICS category	Resource
1.1.1.Standard foundations	Medium density concrete block - 215mm Thick
1.1.1.Standard foundations	Ready-mix concrete, GEN 3 (16/20 MPa), 25% Cement replacement with blast furnace slag (GGBS)
1.1.3.Lowest floor construction	Waterproofing membrane, 1.5 mm Thick
1.1.3.Lowest floor construction	Ready-mix concrete, GEN 3 (16/20 MPa), with Portland Limestone Cement (14% Limestone)
1.1.3.Lowest floor construction	Ready-mix concrete, C30/37, 10% (typical) recycled binders in cement (300 kg/m3)
1.1.3.Lowest floor construction	Sand, compacted dry density, 1682 kg/m3
1.1.3.Lowest floor construction	Precast concrete T-Beam, 33.4 kg/m (British Precast)
2.1. Frame	Steel hot rolled S275
2.2.1.Floors	Gypsum plasterboard, 12.5 mm thick e.g. Gyproc WallBoard
2.2.1.Floors	Plywood, 22mm thick, 620 kg/m3
2.2.1.Floors	OSB I-Joists, per linear meter, 150 x 50 e.g. James Jones and Sons
2.3.Roofs	PVC based synthetic waterproofing roof sheet, 1.5 mm, e.g. Sikaplan S / Trocal S
2.3.Roofs	Gypsum plasterboard, 12.5 mm thick e.g. Gyproc WallBoard
2.3.Roofs	Plywood, 22mm thick, 620 kg/m3
2.3.Roofs	PIR insulation boards, 100mm thick , L = 0.022 W/mK, R = 3 m2K/W
2.3.Roofs	Timber, Softwood
2.3.Roofs	Brick tiles, e.g. Quinn
2.4.1.Stair and ramp structures	Solid wood flooring, with hard wax oil e.g. Moelven Wood
2.5. External Walls	Gypsum plasterboard, 12.5 mm thick e.g. Gyproc WallBoard
2.5. External Walls	Gypsum plasterboard, 12.5 mm thick, e.g. Wallboard (Knauf UK)
2.5. External Walls	PIR insulation boards, 100mm thick , L = 0.022 W/mK, R = 3 m2K/W
2.5. External Walls	Autoclaved aerated concrete blocks, e.g. Aircrete (BPCF)
2.5. External Walls	Autoclaved aerated concrete blocks, e.g. Aircrete (BPCF)
2.5. External Walls	PIR insulation boards, 100mm thick , L = 0.022 W/mK, R = 3 m2K/W
2.5. External Walls	Red brick, average production, UK
2.5. External Walls	Hot-dip galvanised steel profiles
2.5. External Walls	Hot-dip galvanised steel profiles
2.6.1.External Windows	Double-glazed PVC frame window
2.6.2.External doors	Double-glazed PVC frame door
2.7.1.Walls and Partitions	Gypsum finish plaster
2.7.1.Walls and Partitions	Autoclaved aerated concrete blocks, e.g. Aircrete (BPCF)
2.7.1.Walls and Partitions	Gypsum plasterboard, 12.5 mm thick, e.g. Wallboard (Knauf UK)
2.7.1.Walls and Partitions	Plywood, 22mm thick, 620 kg/m3
2.7.1.Walls and Partitions	Timber, Softwood
2.8.Internal doors	Laminated veneer lumber (LVL), internal doors
5.4.3.Hot water distribution	Electric boiler, standard residential
5.4.Water installations	Drinking water supply piping network
5.4.Water installations	Sewage water drainage piping network
5.6.Space heating and Airconditioning	Heat distribution system pipework
5.8.Electrical installations	Electricity cabling
5.Services	Air source heat pump, standard residential
8.2.1.Roads, paths and pavings	Granular fill/ sub-base
Site Works	

Improved

RICS category	Resource
1.1.1.Standard foundations	Medium density concrete block - 215mm Thick
1.1.1.Standard foundations	Ready-mix concrete, GEN 3 (16/20 MPa), 25% Cement replacement with blast furnace slag (GGBS)
1.1.3.Lowest floor construction	Waterproofing membrane, 1.5 mm Thick
1.1.3.Lowest floor construction	Plywood, 22mm thick, 620 kg/m3
1.1.3.Lowest floor construction	PIR insulation boards, 100mm thick , L = 0.022 W/mK, R = 3 m2K/W
1.1.3.Lowest floor construction	EPS insulation, 0.033 W/mK
1.1.3.Lowest floor construction	Timber, Softwood
2.2.1.Floors	Gypsum plasterboard, 12.5 mm thick e.g. Gyproc WallBoard
2.2.1.Floors	Plywood, 22mm thick, 620 kg/m3
2.2.1.Floors	OSB I-Joists, per linear meter, 150 x 50 e.g. James Jones and Sons
2.3.Roofs	PVC based synthetic waterproofing roof sheet, 1.5 mm, e.g. Sikaplan S / Trocal S
2.3.Roofs	Gypsum finish plaster
2.3.Roofs	Gypsum plasterboard, 12.5 mm thick e.g. Gyproc WallBoard
2.3.Roofs	Plywood, 22mm thick, 620 kg/m3
2.3.Roofs	Cellulose insulation, blown, L = 0.039 W/mK, R = 2.56 m2K/W
2.3.Roofs	Timber, Softwood
2.3.Roofs	Brick tiles, e.g. Quinn
2.4.1.Stair and ramp structures	Solid wood flooring, with hard wax oil e.g. Moelven Wood
2.5.1.External enclosing walls above ground level	PVC based synthetic waterproofing roof sheet, 1.5 mm, e.g. Sikaplan S / Trocal S
2.5.1.External enclosing walls above ground level	Gypsum plasterboard, 12.5 mm thick e.g. Gyproc WallBoard
2.5.1.External enclosing walls above ground level	Single skin wall from bricks, including mortar, with Mortar 1:3 cement:sand mix
2.5.1.External enclosing walls above ground level	Hot-dip galvanised steel profiles
2.5.1.External enclosing walls above ground level	Cellulose insulation, blown, L = 0.039 W/mK, R = 2.56 m2K/W
2.5.1.External enclosing walls above ground level	Treated wooden cladding
2.5.1.External enclosing walls above ground level	Timber, Softwood
2.6.Windows and external doors	Laminated veneer lumber (LVL), external door
2.6.Windows and external doors	Double-glazed PVC frame window
2.7.1.Walls and Partitions	Gypsum finish plaster
2.7.1.Walls and Partitions	Gypsum plasterboard, 12.5 mm thick e.g. Gyproc WallBoard
2.7.1.Walls and Partitions	Gypsum plasterboard, 12.5 mm thick e.g. Gyproc WallBoard
2.7.1.Walls and Partitions	Timber, Softwood
2.8.Internal doors	Laminated veneer lumber (LVL), internal doors
5.4.Water installations	Drinking water supply piping network
5.4.Water installations	Sewage water drainage piping network
5.6.Space heating and Airconditioning	Electric boiler, standard residential
5.6.Space heating and Airconditioning	Heat distribution system pipework
5.8.Electrical installations	Electricity cabling
5.Services	Air source heat pump, standard residential
8.2.1.Roads, paths and pavings	Granular fill/ sub-base
Site Works	

Optimised

RICS category	Resource
1.1.1.Standard foundations	Medium density concrete block - 215mm Thick
1.1.1.Standard foundations	Ready-mix concrete, GEN 3 (16/20 MPa), 25% Cement replacement with blast furnace slag (GGBS)
1.1.3.Lowest floor construction	Waterproofing membrane, 1.5 mm Thick
1.1.3.Lowest floor construction	Plywood, 22mm thick, 620 kg/m3
1.1.3.Lowest floor construction	Hemp masonry unit with lime based binder (hempcrete)
1.1.3.Lowest floor construction	Timber, Softwood
2.2.1.Floors	Gypsum plasterboard, 12.5 mm thick e.g. Gyproc WallBoard
2.2.1.Floors	Plywood, 22mm thick, 620 kg/m3
2.2.1.Floors	OSB I-Joists, per linear meter, 150 x 50 e.g. James Jones and Sons
2.3.Roofs	PVC based synthetic waterproofing roof sheet, 1.5 mm, e.g. Sikaplan S / Trocal S
2.3.Roofs	Gypsum plasterboard, 12.5 mm thick e.g. Gyproc WallBoard
2.3.Roofs	Plywood, 22mm thick, 620 kg/m3
2.3.Roofs	Natural clay lime plaster e.g. Clime (Armourcoat)
2.3.Roofs	Hemp masonry unit with lime based binder (hempcrete)
2.3.Roofs	Timber, Softwood
2.3.Roofs	Natural stone roof slates
2.4.1.Stair and ramp structures	Solid wood flooring, with hard wax oil e.g. Moelven Wood
2.5.1.External enclosing walls above ground level	PVC based synthetic waterproofing roof sheet, 1.5 mm, e.g. Sikaplan S / Trocal S
2.5.1.External enclosing walls above ground level	Gypsum plasterboard, 12.5 mm thick e.g. Gyproc WallBoard
2.5.1.External enclosing walls above ground level	Hot-dip galvanised steel profiles
2.5.1.External enclosing walls above ground level	Hemp masonry unit with lime based binder (hempcrete)
2.5.1.External enclosing walls above ground level	Treated wooden cladding
2.5.1.External enclosing walls above ground level	Timber, Softwood
2.6.2.External doors	Laminated veneer lumber (LVL), 9% moisture content, 510 kg/m3 (Stora Enso)
2.6.Windows and external doors	Double glazing windows with wooden frame
2.7.1.Walls and Partitions	Gypsum plasterboard, 12.5 mm thick e.g. Gyproc WallBoard
2.7.1.Walls and Partitions	Gypsum plasterboard, 12.5 mm thick e.g. Gyproc WallBoard
2.7.1.Walls and Partitions	Natural clay lime plaster e.g. Clime (Armourcoat)
2.7.1.Walls and Partitions	Timber, Softwood
2.8.Internal doors	Laminated veneer lumber (LVL), internal doors
5.4.3.Hot water distribution	Electric boiler, standard residential
5.4.Water installations	Drinking water supply piping network
5.4.Water installations	Sewage water drainage piping network
5.6.Space heating and Airconditioning	Heat distribution system pipework
5.8.Electrical installations	Electricity cabling
5.Services	Air source heat pump, standard residential
8.2.1.Roads, paths and pavings	Granular fill/ sub-base
Site Works	

Climate Change Adaptation

Purpose of Document

- Designing for climate adaptation – i.e. the impacts that are expected to occur as a result of a changing climate, irrespective of any attempts to mitigate emissions into the atmosphere – helps to reduce the impact to human health and welfare from future changes to the climate and environmental conditions.
- This research identifies the benefits and costs associated with adapting housing now to cope with the expected future climate and environmental conditions.
- A tool was produced alongside this report, which has subsequently been incorporated into the final appraisal guidance and ENHAT tool.

Date Completed: December 2022

Introduction

Designing for climate adaptation – i.e. the impacts that are expected to occur as a result of a changing climate, irrespective of any attempts to mitigate emissions into the atmosphere – helps to reduce the impact to human health and welfare from future changes to the climate and environmental conditions.

Adaptation issues are very complex and also come with some level of uncertainty, depending on the building typology, geographical location and external factors (e.g. microclimate, urban/rural, and so forth). Key adaptation issues are, however, already addressed – 'as standard' – within the design and development process.

An example is flood risk and surface water drainage, whereby there are already robust assessment and design processes in place to ensure that new development does not increase flood risk, even in the more severe events resulting from climate change in coming decades. An allowance for increased storm flows – typically at 40% as a result of climate change – are included in flood calculations and mitigation measures are included in masterplans to manage them, such as storage basins, balancing ponds, swales, etc. The cost impact of doing so is therefore included in a standard development appraisal. These flood related aspects are therefore not included in this module, although a separate module has been prepared covering the biodiversity benefits of different levels of Sustainable Urban Drainage Scheme (SUDS) provision.

Rather, this module focuses on another key risk associated with climate adaptation which a. needs urgent consideration and b. is measurable from an impact and cost perspective: overheating and internal comfort. A warmer climate, coupled with increasingly airtight and efficient buildings, will increase overheating risk within homes. Addressing this now in the evaluation process will help ensure long term habitability of buildings, make them more affordable to run, and therefore help sustain value.

To this end a CCA Evaluation Tool has been developed to help users understand the cost impact of making design and specification decisions which address these issues, and which accompanies this Guidance.

General Methodology

In order to reach the final output of the CCA Evaluation, the following steps were undertaken.

- Background research review – this desktop exercise examined a wide range of background academic and industry papers, guidance and information to establish the current state of the art in respect of climate adaptation practice in the UK (and more widely).

- Development of the assessment methodology – a draft approach to the modelling of buildings in future climate scenarios, aligned to the current industry approaches and standards, was agreed with Homes England. This included the range of technical building modelling and cost analysis (covering both CAPEX and OPEX elements).

- Modelling was undertaken and results compiled as background evidence to support key conclusions regarding the extent of measures needed for buildings to remain habitable in 2050 (and beyond).

- The CCA Calculator was compiled using this evidence, the output of which has been reviewed by both the consultant team (Daedalus Environmental, SQW and eftec) and Homes England for usability and robustness, alongside this accompanying guidance.

Key Research Findings

The adoption of climate adapted approaches to design and construction are non-mandatory in the UK, unless specified within the local planning framework. One example of a lead locality in this regard is the London Plan which has stringent adaptation requirements.

Recent changes to Part L of the Building Regulations requires a greater focus on overheating, albeit the assessment methodology is very rudimentary, and is not predicated on future climate change.

IEMA has produced more comprehensive guidance on adaptation for developments going through the EIA process, but adaptation issues are not often – or are only now being – scoped into that process.

Adaptation is a broad area of study affecting multiple different specialisms across engineering, architecture, geotechnical and flood risk, and more. Flood risk and surface water drainage is already comprehensively addressed – but of increased interest is the internal performance of spaces in the future. Will buildings remain usable / habitable in 30 or 60 years' time? Understanding the cost / benefit of implementing measures **now**, versus having to retrofit them later is now a key consideration. The Design for Future Climate programme broke new ground in providing a framework for assessment of new development and their outputs are still available online – but not widely adopted.

Importantly, development professionals must assess and understand the risks and solutions from the outset of a development project – and therefore the CCA Tool provided with this module is a vital first step in bringing adaptation measures actively into the process.

Background Evidence

Building and Typology Analysis

Approach

The assessment of overheating risk as a result of climate change in buildings can be undertaken on a rudimentary basis using the current Part L Building Regulations approach. However, this was deemed insufficiently robust, with more comprehensive analysis possible using Design Simulation Modelling, or DSM. DSM software enables an in-depth dive into the performance of dwellings across many different metrics on a simulated basis.

The criteria/standards and framework for assessing the buildings is defined by CIBSE Guide TM59: Design Methodology for the Assessment of Overheating Risk in Homes (CIBSE, June 2017). When using the CIBSE model for homes which are predominantly naturally ventilated, compliance is based on passing both of the following two criteria:

- (a) For living rooms, kitchens and bedrooms: the number of hours during which ΔT is greater than or equal to one degree (K) during the period May to September inclusive shall not be more than 3 percent of occupied hours (CIBSE TM52 Criterion 1: Hours of exceedance).

- b) For bedrooms only: to guarantee comfort during the sleeping hours the operative temperature in the bedroom from 10 pm to 7 am shall not exceed 26°C for more than 1% of annual hours. (Note: 1% of the annual hours between 22:00 and 07:00 for bedrooms is 32 hours, so 33 or more hours above 26 °C will be recorded as a fail). The third criterion sets an absolute maximum daily temperature for a room, beyond which the level of overheating is unacceptable.
-

(CIBSE, 2017)

[ΔT is defined as the difference between the actual operative temperature in the room at any time and the limiting maximum acceptable temperature, rounded to the nearest whole degree].

For the purposes of this research we used IES Virtual Environment, although other software providers are available with similar capability. These simulations need three primary inputs:

- Details of the physical characteristics of the building to be modelled.
- A location and orientation.
- A 'weather file' – essentially details of the climate variables over a given year within which the building is modelled.

The weather files used for the DSM were provided by the University of Exeter's Prometheus project, which itself generated probabilistic weather data based on different confidence intervals using Climate Impact Programme data from 2008 (UKCP08). Whilst 2008 data could be considered out of date, in practice the review of this data in 2018 found the 2008 predictions to be robust and valid – and in any event the weather file data has not been updated since that point.

Further details in respect of the Prometheus data can be found here: PROMETHEUS - University of Exeter
It was originally proposed by the project team that we assess these buildings on the basis of a 2080 weather file, but following consultation with the Homes England team we agreed to use a 2050 High Emissions data set with a 90% confidence interval.

The 'high emissions' versions of the data are now deemed most accurate given the lack of progress in emissions reduction globally, and of course provide a robust reasonable worst case scenario for the purposes of this module. In addition, the impact of these measures beyond c.2080 was deemed too far in the future to have a meaningful impact on the financial evaluation approach given likely discount rates within any analysis and in the resulting CCA Tool which is described later.

Outputs

There are, in reality, an almost infinite number of variables that could be assessed, however – and in agreement with Homes England, a fixed set of DSM tests were subsequently undertaken that sought to provide a reasonable balance between:

- Likely building characteristics.
- The level of detail needed for an evaluation process at pre-development stage.

- The budget available for this module of the guidance.

This schedule of testing is provided in the table below:

Table 1: Property testing under DSM

Property Testing Schedule					
Scope	**Locations (4)**	Cambridge	Exeter	Manchester	Newcastle
	House types (4)	2 Bedroom Flat	2 Bedroom Mid Terrace	3 Bedroom Semi Detached	4 Bedroom Detached
Data Choice	**Year**	2050	Dynamic simulation modelling requires use of hourly .epw files. No such files have been created from the UKCP18 probabilistic data sets, UKCP09 files used. This choice of data, however, is robust/conservative enough for the purpose at hand.		
	Emissions Scenario	High			
	Confidence Interval	90%			
Scenarios	**Test 1**	Baseline	Standard building specification		
	Test 2	Intermediate	Building integrated design solutions including some external design interventions		
	Test 3	Enhanced	As above plus further external design interventions and M&E solutions		
Total Tests / Datasets		**48**			

Four regional locations, four house types, one weather file (for each location) and three scenarios to test resulted in a total of 48 datasets as underpinning evidence for the calculation tool.

In each test, therefore, we examined the benefit of an increasing number of mitigation / design measures to reduce overheating impact to a level that would be deemed acceptable under TM59, across three scenarios: Baseline (no measures), Intermediate (some measures which enabled some limited compliance, but fell short of providing mechanical cooling / air conditioning) and Enhanced (a full set of measures which, in every case, ensured compliance).

These measures have been costed across the four house types from a capital expenditure (CAPEX) perspective, and a set of operational expenditure (OPEX) assumptions have been developed, covering periodic maintenance and replacement over a 60 year period following completion. More detail on this can be found in the Cost Impact Assumptions section below.

Assumptions

The house types used for this analysis are standard homes of a type that would be typically found on residential sites across the UK. These types, however, have been provided by the team undertaking the analysis and cannot be shared as they are subject to copyright. The nature / 'look-and-feel' of the properties was discussed with Homes England who agreed their use as the basis of the analysis.
The list of assumptions in the DSM is too great to list here – there are several hundred within DSM models in practice – from construction details, to thermal performance of building elements, to occupancy, levels of thermal mass, use of the building, efficiency of M&E systems, etc. However, some of the key broader assumptions are that:

- In each case it was assumed the main living spaces of the homes faced south and were therefore most at risk.
- Residents used the passive measures proposed for the properties, such as external shutters, in a sensible way that optimised overheating mitigation (i.e. closed them for relevant periods of the day).
- Residents were capable of understanding and using the heating – and cooling – systems efficiently.
- The baseline heating system is an air source heat pump – reflecting the imminent move away from fossil fuels by 2025.

In terms of measures themselves:

- Baseline – no specific measures included, which represents the 'do nothing' scenario and the cost baseline against which the other two scenarios were assessed.
- Intermediate – reduce thermal emissivity of glazing (reducing the g-value of the glass from 0.6 to 0.4), purge ventilation fan system, external shutters to windows on orientations most impacted by solar gain – typically between east, south and west.
- Enhanced – as per the Intermediate option but with the addition of reverse cycle cooling capability – in practice an upgrade to the heat pump system that would provide some limited cooling in those spaces identified as having high overheating risk, including bedrooms and living spaces mostly 50W of cooling capacity and in some cases 100W).

Cost Impact

Approach

In CAPEX terms, a schedule of costs associated with the design measures under the three scenarios was compiled by Gardiner Theobald for the four different house types. The OPEX costs have been developed jointly by Daedalus and GT. Both sets of data are built into the CCA Calculation Tool.

Each house type has been given a base build cost, with each additional measure costed separately, enabling us to calculate a percentage uplift in build cost to achieve a specific CCA performance standard. The base build cost for the flat assumes NIA net to gross ratio of 75%.

From an OPEX perspective, a host of additional assumptions have been made to take account of running, maintenance and replacement costs. The replacement and maintenance costs are not translated into percentage rates that can be applied to a floor area – because they sit outside the initial construction cost model and envelope, and are assumed to be met by the householder. OPEX costs are therefore applied depending on the number of bedrooms within the property.

The key OPEX assumptions include:

Table 2: Operational expenditure assumptions

Consideration	Performance Level		
	Baseline	Intermediate	Enhanced
OPEX period	60 years		
Inflation	Excluded		
Retrofit assumptions	Year 15 to Intermediate Level; Year 30 to Enhanced Level; 30% cost increase over and above installation on initial construction	Year 30 to Enhanced Level	None required
Purge ventilation maintenance	Maintenance costs incurred at 5 year intervals, systems replaced at 15 year intervals		
Purge ventilation running costs	Negligible and excluded		
Glazing replacement	15 year intervals (costs are performance uplift costs only, not the whole glazing unit)		
Reverse cycle cooling installation and replacement	Installation costs are for uplift in unit specification to provide the cooling capability only, not the whole cost of the heat pump unit which is assumed as a baseline, fossil fuel free, heating system. Units assumed replaced every 15 years, with annual maintenance		
Reverse cycle cooling costs	120 days per annum at average of 1kW of cooling capability for 8 hours per day, whenever capability is available.		
Shutter installation	Installed to bedrooms only		
Shutter maintenance and replacement	Maintenance costs included at 15% of installation cost every 10 years, replaced every 30 years		

Regional Differences

To take account of regional variations in CAPEX costs within the Tool, multiplication factors, for the different regions in England, based on BCIS data (November 2022) have been built in, as follows:

Table 3: BCIS Location Factors (BCIS November 2022)

Location Factors	
North East	91
North West	100
Yorkshire & Humber	92
East Midlands	104
West Midlands	96
East of England	99
London	123
South East	110
South West	103

Thus, CAPEX costs have been reduced by 9% for the North East, and increased by 23% for projects in London, for example, within the Tool. OPEX costs are not affected by the BCIS figures, as they will be incurred by the property owner and not the developer.

Cost Confidence

The costs for CCA measures are based on a small number of 4 house types tested – and are therefore illustrative for a 2 bed flat, 2 bed house, 3 bed house and 4 bed house respectively. There is clearly going to be variation depending on the final layout, and the CCA Tool therefore includes three different sets of cost data for each scenario tested, using suggested confidence intervals on cost, leading to a range in the CAPEX and OPEX results (LOW – CENTRAL – HIGH).

In this respect the LOW and HIGH CAPEX costs are +/- 25% from the CENTRAL figure. The LOW AND HIGH OPEX costs are also +/-25% from the CENTRAL figure. The potential variability in OPEX is to take account of the fact that the approach of different householders in the long term could be very different – from usage of systems (e.g. cooling) to replacement of measures (e.g. external shutters) to frequency within which the systems in place are serviced/maintained.

Output

The cost data is included in tabs within the CCA Tool. Over time, this cost data will need to be reviewed annually both in terms of upfront CAPEX cost of measures and OPEX costs, and in terms of the latter to reflect energy price rises over time.

The Climate Change Adaptation Calculation Tool (CCA Tool)

The CCA Tool is provided in Excel format. This will enable straightforward updates over time, and currently enables evaluation for everything built up to 2035. Step by step instructions on how to use the tool are provided within the Tool itself on the first tab, 'Guidance Notes'. The Tool is simple to use and requires only a limited number of numerical inputs or drop down selections to establish the financial impact of climate change adaptation design decisions.

The second tab – 'Input and Summary Sheet' – is the only tab which the user can input project related data, and is the same tab where the required evaluation information can be found. The remaining tabs are locked to prevent unauthorised changes to the underlying datasets.

Different evaluation scenarios can then be saved in the CCA Tool Results Sheet – which saves the user from having to save multiple versions of the main tool, if required.

For the purposes of economic appraisal, the CAPEX costs will need to be incorporated into development appraisals for the options which will in turn (depending on the form of Homes England's intervention) have a bearing on the financial costs and economic costs of the appraisal.

The Net Present Value (NPV) of the OPEX costs will be included in the economic appraisal as a disbenefit because these will be borne by users over time.

Points to Note & Limitations

The likely future impacts of climate change are already well understood, but the underlying research has shown that whilst there is plenty of activity in the climate adaptation 'space', there is only limited implementation of relevant design thinking and mitigation measures in practice when it comes to the built environment.

The inclusion of climate adaptation in the Homes England evaluation framework – whilst at this stage limited to the issue of overheating and comfort – is important as it provides impetus to a growing body of expertise in this sector.

There are a handful of limitations which the user should be aware of in evaluating the overheating impact and in using the Tool, as follows:

User impact

We cannot legislate for the end user of the properties, i.e. residents. Ongoing operational costs of homes are HIGHLY variable, and whilst the underlying DSM results are comprehensive and robust, in practice we would anticipate considerable variability in how people use their home (see the related point in the retrofitting section below), how much energy they use, whether they need spaces cooling and under what conditions. This is exacerbated by the fact that people feel comfortable in very different environmental conditions, for example as a result of age of the occupier. The Tool does not attempt to allow for multiple 'user types'.

Regional variations

We have assessed homes in four different regions of the UK, explained in the Methodology section above. In practice, the CCA impact related to overheating will be affected on a much more granular scale. The Prometheus team can develop data down to the 5km square level, for example. The local impacts of climate change will be highly variable – and it is strongly recommended that a. climate adaptation is fully addressed in the design process and that b. a more local assessment of impact using the DSM methodology is undertaken for each home by the appointed developer or development team.

Retrofitting

We have had to make a number of assumptions about how and when people will maintain or replace the adaptation features installed on their homes. As above different residents will behave in very different ways and the operational cost variability will be significant in practice.

Climate data

Climate impact data is becoming increasingly robust, but it remains – particularly in the case of the Prometheus data sets – probabilistic in nature and the confidence intervals associated with it means there is no guarantee that a home will perform in a particular way in a particular year. What this data does do is provide the most robust / detailed approach to building analysis currently available, and gives confidence that these measures will have an impact over time.

Costs

Costs associated with these measures will need regular review and updates and are based on four specific house types. Whilst an allowance has been made for regional variations using the BCIS Location Factors, we would strongly recommend that the costs are reviewed on an annual basis as a minimum to take account of highly variable market price trends.

Other Climate Adaptation Issues

This Guidance and Tool covers the risk of overheating and comfort in internal spaces. Other standards are already widely used within the development sector, particularly in relation to flood risk. Over time, further consideration of issues including (for example)…

- structural risk (for example through drying out of underlying soils – which is a very locationally specific issue).
- construction detailing and risk of water ingress from increased storm flows.
- insurance costs and insurability generally.
- long term impact on house prices / house values.

…could also be considered within the evaluation process.

Conflict with Other Streams

Adapted buildings are not created in isolation from other climate and carbon impact decision making requirements, such as operational and embodied emissions, for which different evaluation Tools exist in this guidance. However, the User needs to be aware that decisions in respect of one impact can affect the other. A key one to note is in terms of thermal mass of the building, for example. Improved climate adaptive capacity of internal spaces is achieved by increased thermal mass of the building structure. However, a greater building mass means more material within the building. Those materials are very likely to come with an increased embodied carbon impact, especially if that mass is achieved with cheaper materials like concrete and blockwork. With that in mind a balanced set of priorities for any given project is essential, and a team appointed by the developer (or Homes England depending on the stage of the process) who are capable of calculating the costs and benefits of different design and construction specification approaches.

Population Adjustment

Purpose of Document

- It was identified that the robustness of the appraisal guidance would be weak in the absence of a better understanding of the demographics of new housing developments, particularly for the application of per person benefits / disbenefit values in order to be able to calculate the environmental impacts associated with housing schemes.
- This research provides population adjustment values to be used in appraising the impact of new housing development. These values have been incorporated into the appraisal guidance and ENHAT tool, so are automatically incorporated into the calculations undertaken.

Date Completed: March 2023

Introduction

Homes England have appointed SQW and eftec to develop a methodology and evidence base to appraise the environmental impacts of new housing developments. It is the first attempt to assess the environmental impacts of housing for economic appraisal purposes and is considered to be an ongoing area of research with emerging evidence and research likely to further enhance the appraisal of environmental impacts of housing in the future.

Following a review of the existing research, it was identified that the robustness of the appraisal guidance would be weak in the absence of a better understanding of the demographics of new housing developments, particularly for the application of per person benefit / disbenefit values in being able to calculate the environmental impacts of housing schemes. It was expected that the demographics of new housing developments would vary due to a number of different factors, especially in areas of high housing demand.

SQW was appointed by Homes England to undertake further research on the relationship between new housing developments and household/population characteristics with a view to providing a reference table of population adjustment factors which could be used by appraisers when applying per person impacts in business cases.

To complete this research, various data sources have been considered, to form a better understanding of the relationship between population and housing growth across different geographies using a standard typology of house types.

This report sets out the methodology and outputs of the research, and it continues as follows:

- Chapter 2 provides more detail on the background to the relationship between population growth and housing delivery and existing research/methodologies.
- Chapter 3 provides an overview on the methodology selected and data sources used.
- Chapter 4 provides the results and an overview of the metrics to be used in appraisal guidance (with metrics for individual local authorities provided in Annex A).
- Chapter 5 provides concluding remarks.

This report contains two annexes; Annex A provides the values for each local authority to be used in appraisals, and Annex B provides detail on an alternative econometric-based approach undertaken by SQW, which was discounted given the complexity of the assumptions required.

Relationship between Population & Housing Growth

The relationship between housing delivery and population growth is complex, with numerous factors influencing the scale of population growth that results from a new home being delivered.

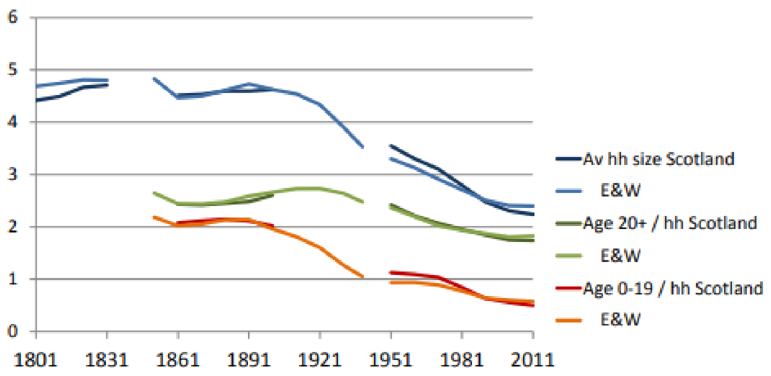
Trends in Relationship between Population Growth & Housing

Over the last two centuries, England has experienced a decline in average household size, falling from over four persons per household right up until the 1920s to an average of 2.4 persons per household at the 2021 Census. Analysis from the London School of Economics[48] found that this largely reflects two key trends within demographic data:

- People starting families later and having fewer children when they do – the UK's fertility rate has fallen from a peak of 2.85 children in 1965 to 1.8 children per mother in 2019.

- The effects of this declining fertility rate on average household size have, more recently, been dampened by the fact that more children live with their parents for longer, with around half of 23-year-olds currently living with their parents[49]. This partly reflects challenges around the availability and affordability of housing for young people, with average house prices in England currently being 9.1 times the average annual full-time wage (compared to 3.5 times in 1997).

Figure 1: Historic Average Household Size and Adults per Household, 1801-2011

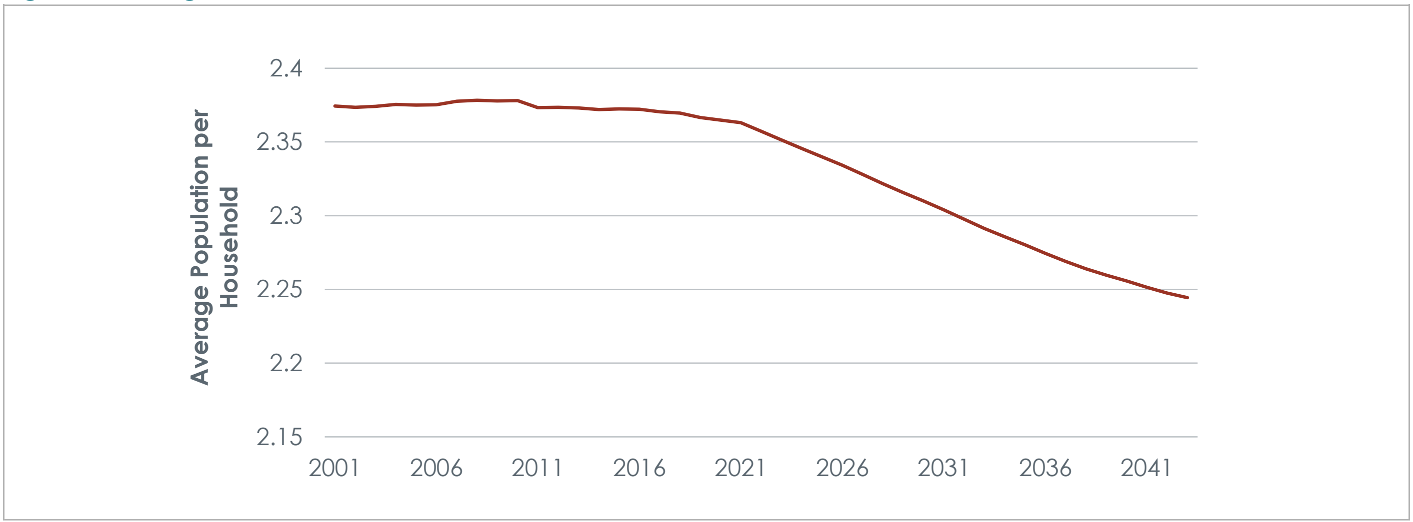


Source: Explaining Changes in Household Size, Simpson & Berrington; available at: https://www.lse.ac.uk/international-development/Assets/Documents/bsps/events/Explaining-changes-in-family-size.pdf

The falling trend in average household size is projected to continue, as demonstrated by ONS Household Projections (2018-based), which show that the average household size is expected to decline from 2.36 in 2021 to 2.24 in 2041.

[48] https://www.lse.ac.uk/international-development/Assets/Documents/bsps/events/Explaining-changes-in-family-size.pdf
[49] Labour Force Survey, ONS, 2021

Figure 2: Average Household Size, 2001-41



Source: Household projections for England, ONS, 2020

Existing Methodologies for Calculating Population Growth relative to New Housing

Consultations with relevant teams from Homes England, ONS and DLUHC suggest that there is no 'approved' method for calculating the average occupancy of new homes. Informally, many use a typical 2.4 persons per additional dwelling metric, but no further research has been undertaken in relation to this. The 2.4 metric is the national average household size calculated using Census 2021 data (and previously Census 2011 data), and this has been adopted by other government institutions, including Natural England[50] in formal guidance.

Guidance from Natural England is one of the few sources of insight on this subject which has been developed in the context of nutrient neutrality regulations that have been applied to 32 local authorities (largely across the south of England). These regulations aim to ensure that new developments don't add to the nutrient loads within the local river catchment area, and therefore it has become important to understand the potential occupancy of new housing to understand potential nutrient impacts.

Natural England currently recommends using the average occupancy rate of 2.4 persons per household as calculated by the Office for National Statistics (ONS). Natural England have indicated that whilst they will only support an occupancy rate of 2.4, an occupancy rate specific to a local authority area can be used if sufficient evidence exists to support this figure. The approach set out in the Natural England guidance assumes that all residential development that creates additional housing stock will lead to either inward migration and/or internal population growth within an authority area. If local authorities are able to provide sufficient evidence that their occupancy levels are different from the Natural England approach, then an alternative occupancy rate can be applied. A number of local authorities who are impacted by nutrient neutrality regulations have done their own research on the net increase in population that comes from housing development. A summary of these studies is provided in the table below. The alternative approach in many cases has involved the application of Census 2011 average household size data to a finer grained housing typology, rather than applying the blanket average of 2.4.

[50] Nutrient Neutrality Generic Methodology, February 2022, https://www.push.gov.uk/wp-content/uploads/2022/04/Natural-England-Nutrient-Neutral-Generic-Methodology-March-2022.pdf

Table 1: Alternative Average Household Size Approaches

Local Authority	Average Household Size Identified	Methodology
Ashford[51]	House: 2.4 Flat: 1.75	Applies Census 2011 occupancy data
Cornwall[52]	House: 2.4 Flat: 1.65	Not stated
Dorset[53]	House: 2.42 Flat: 1.65	Applies Census 2011 occupancy data
Folkestone & Hythe[54]	2.18	Not stated
Herefordshire[55]	2.3	Applies Census 2011 occupancy data
Mendip / Sedgemoor / Somerset West & Taunton / South Somerset[56]	House: 2.4 Flat: 1.65	Applies Census 2011 occupancy data
New Forest[57]	Studio/1-bed: 1.4 2-bed: 2.1; 3-bed: 3.0 4+ bed: 3.75	Not stated
Southampton[58]	1 bed: 1.41; 2 bed: 2.13 3 bed: 2.74; 4 bed: 3.43 5+ bed: 4.09	Applies Census 2011 occupancy data.

Source: SQW research

Aside from the guidance provided by Natural England, there is no other official guidance available on this topic, reinforcing the need for additional research.

Methodology & Data Sources

SQW has sought to develop a bespoke approach for Homes England in order to better understand the net additional population growth that arises from new housing development. Several different approaches have been considered:

- ***Approach 1***: Using Valuation Office Agency (VOA) data on housing completions and Census data on average occupancy to estimate what population growth might have been expected to occur within a local authority, and comparing this to actual population growth (measured through Annual Population Survey), to understand how actual occupancy differs from expected occupancy levels.

- ***Approach 2***: Developing an econometric-based approach for analysis; in this case using panel vector autoregression model using population and housing data, allowing a test of the responsiveness of population

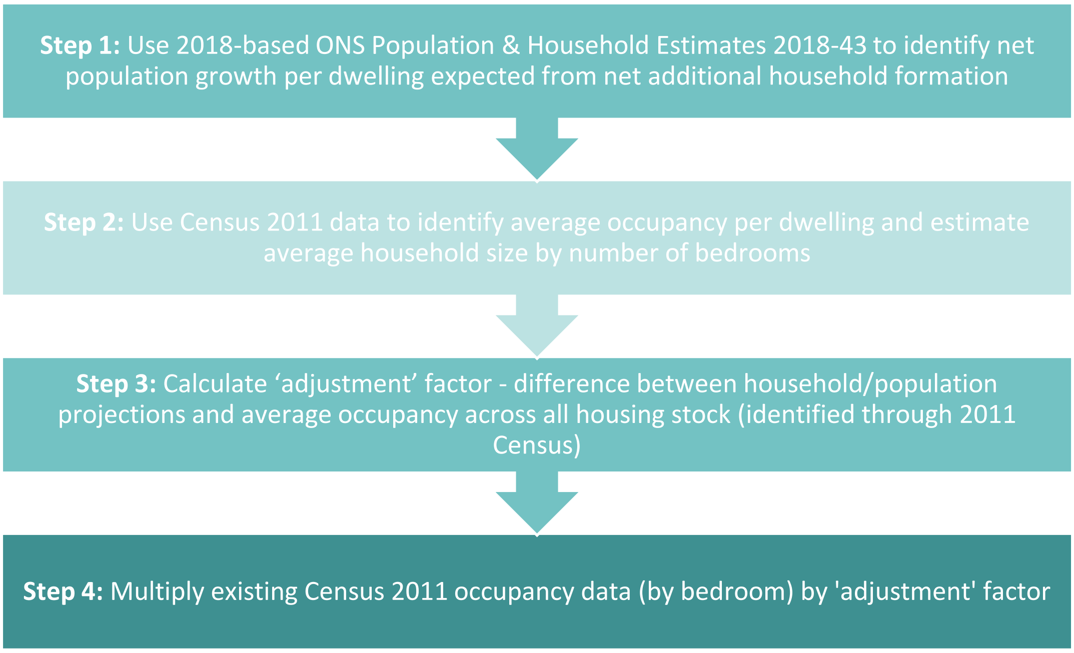
[51] Information page to help developers submitting nutrient calculations & mitigation for developments affected by nutrient neutrality (ashford.gov.uk)
[52] Nutrient neutrality in Cornwall - Cornwall Council
[53] Appendix 2 - Nitrogen Reduction in Poole Harbour Supplementary Planning Guidance.pdf (dorsetcouncil.gov.uk)
[54] EB_02.95_FHDC_Habitats_Regulations_Assessment_Addendum_-_Nutrient_Neutrality__07.12.2020.pdf (folkestone-hythe.gov.uk)
[55] https://www.herefordshire.gov.uk/nutrient-management/nutrient-management-guidance-developers/3
[56] https://www.somersetwestandtaunton.gov.uk/planning/phosphates-on-the-somerset-levels-and-moors/
[57] Nutrient neutral development - New Forest District Council
[58] https://www.southampton.gov.uk/media/plzdayzf/occupancy-rate-calculator-180722.xlsx

to a ‘shock’ in the growth rate of housing, therefore allowing an understanding of how population responds to the development of new housing. *A summary of the methodology applied is provided in Annex B.*

- ***Approach 3***: Using official household and population projection data prepared by the Office for National Statistics (ONS) to calculate the expected future occupancy rate of housing, comparing this to Census occupancy rates of housing (by bedroom size) and therefore allowing an estimation of net population growth arising from housing development (of different sizes/scales).

Having developed models for each of these approaches and tested their outputs, ***Approach 3*** was confirmed as the most reliable approach to calculating future occupancy rates by household, with the further advantage of relying upon long-established ONS projections for population and households. Using this approach also enables us to distinguish between total population data and household population, therefore removing population data relating to communal establishments[59] (which are less likely to be supported by Homes England).

Figure 3: Overview of Methodology



Data Sources

In developing the methodological approach to this research, we have sought to draw upon a range of data sources. The data below presents some of the methodological assumptions that underpin these data sources.

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[59] Types of Communal Establishments include: hospitals, care homes, prisons, defence bases, boarding schools and student halls of residence. In 2021, this accounted for 1,042,000 residents in England and Wales (1.7% of the total population).

Table 2: Data Sources & Methodologies

Data	Insight	Methodology
ONS 2018-based household projections	Data on population and household projections	1) Compiled by ONS using a two-stage process: a) Stage 1 analyses the latest sets of mid-year population estimates and sub-national population projections, and applies an adjustment to remove those living in communal establishments. b) Stage 2 calculates household headship rates to show the proportion of people in a demographic group who were the household reference person. These rates are then projected forward, to produce a projected number of households. 2) These projections only consider population based in households and not those in communal establishments. This data source has been selected, as it is consistent with the types of developments supported by Homes England.
ONS Census Data (2011 & 2021)	Average occupancy (by bedroom size)	3) Data collected during the 2011 and 2021 Census provides a more detailed perspective on demographic data relating to households and occupancy rates. 4) ***NOTE***: Census 2021 multi-variate data has not yet been released, so Census 2011 data has been used as appropriate.

The following tables provide an overview of the results from the approach described in Chapter 3. This chapter presents England data for context, but the **expectation is that local authority-level data is used for appraisal purposes**. This data is provided in Annex A.

Data in Table 3 shows the population and household data from the 2011 and 2021 Census. This shows total population for England (for those living in households only, and not communal establishments) and the number of households. By dividing the population by the number of households this indicates that the average number of persons per household is 2.4 persons nationally in both 2011 and 2021.

Table 3: Population & Household Data for England

Data Source	Indicator	Data for England
Census 2011	Population (in households)	52,059,931
	Number of households	22,063,368
	Average occupancy of each household	2.4
Census 2021	Population (in households)	55,504,302
	Number of households	23,436,086
	Average occupancy of each household	2.4

Source: Census 2011 & Census 2021, ONS

Multi-variate data from the 2011 Census provides insight on the number of people living in a household and the number of bedrooms within this household. This allows for an average occupancy to be calculated by different bedroom sizes, presented in Table 4.

Table 4: Average Occupancy by Bedroom Size, 2011

Number of Bedrooms in Household	Average Occupancy of Household
1 bedroom	1.4
2 bedroom	1.9
3 bedroom	2.6
4 bedroom	3.1
5+ bedroom	3.5

Source: SQW from Census 2011, ONS

To factor in how occupancy rates are expected to change into the future, household and population projection data has been examined. ONS 2018-based household and population projections have been used (the latest projections available at the time of writing) and the full length of projections have been used (2018-43) given that the appraisal period for housing development is up to 60 years for major developments[60]. Table shows the data for England, and the expected net increase in population expected between 2018 and 2043 per additional household.

An adjustment factor has then been calculated, which compares the difference between the 2011 Census occupancy rate (2.4) relative to the 2018-based household and population projections (1.5), which results in an adjustment factor for new housing from 2018 to 2043 of 0.6 for England.

Table 5: Expected Population and Household Growth, 2018-43

Indicator	Year	Data for England
Household Projections	2018	23,204,246
	2043	26,953,266
	Change 2018-43	3,749,020
Population Projections (for households)	2018	54,986,435
	2043	60,494,193
	Change 2018-43	5,507,758
Net Increase in Population per additional household	2018-43	1.5
Adjustment Factor (relative to 2011 Census data)		**0.6**

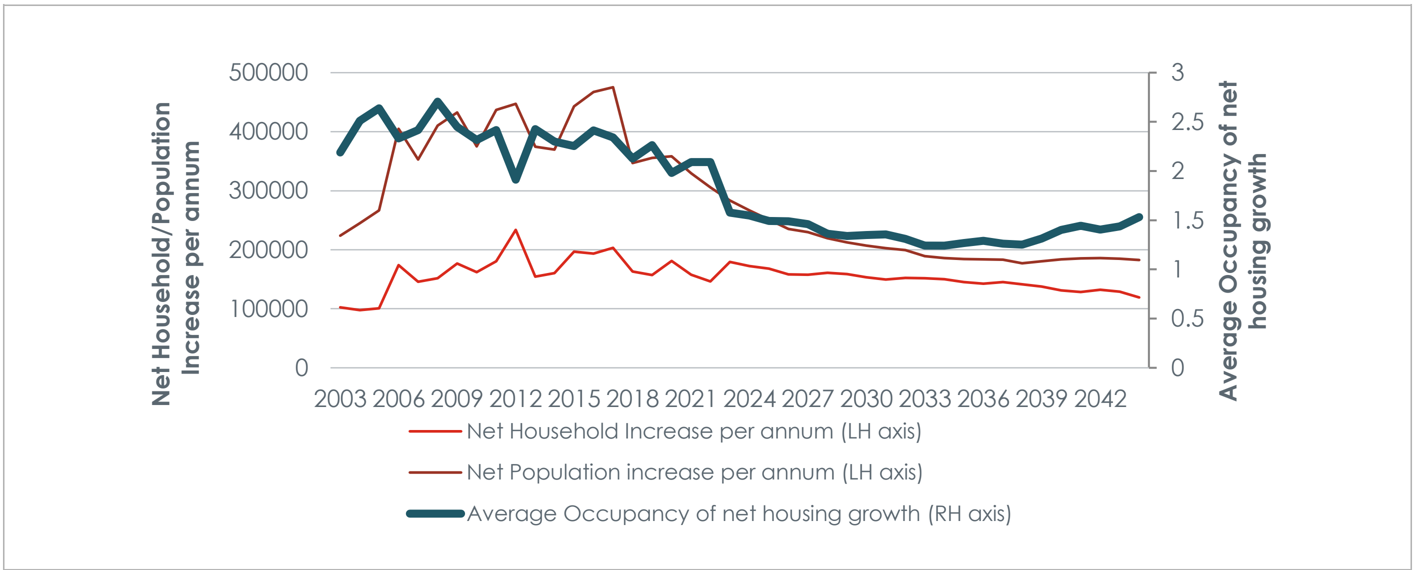
Source: 2018-based Household Projections for England, ONS, 2020

As might be expected, there is substantial sub-national variation behind the England-wide average. As Homes England will be supporting activity on specific sites this research is particularly interested in the net increase in population *per local authority* that comes from the delivery of new housing. Given the statistical variation of the results (when analysis was undertaken at local authority level), and some unreliability of household and population projections at local authority level, results from regional data has been used to calculate individual local authority adjustment factors and subsequent analysis.

[60] The DCLG Appraisal Guide, DCLG, 2016

Examining the net increase in both the overall population and number of households using 2018-based household and population projections shows that the net increase in population (resulting from the formation of one additional household) tends to fall in a range between 1 and 2 persons between 2018 and 2043, averaging out at 1.5 over the period (as per Table 5).

Figure 3: Actual/Expected net increase in population/households in England and resulting average occupancy of net additional households, 2001-43



Source: 2018-based Household Projections for England, ONS, 2020

The adjustment factor (calculated in Table 5) has been applied to the average occupancy by bedroom size as identified through the 2011 Census data (Table 4). This results in the adjusted occupancy rate suitable for use in appraisals. Table 6 illustrates the approach at England level. This also shows the housing typologies that have been developed for the ENHAT model. Look-up tables showing the adjustment factors by house type and local authority district are found in Annex A.

Table 6: Adjusted Occupancy Rates for England

Number of Bedrooms	Homes England Housing Typologies	Census 2011 Average Occupancy	Adjustment Factor	Adjusted Occupancy Rate
1 bedroom	• 1 bed flat	1.4	0.6	0.8
2 bedroom	• 2 bed flat • 2 bed semi-detached bungalow • 2 bed terrace • 2 bed semi / end terrace	1.9		1.2
3 bedroom	• 3 bed terrace • 3 bed semi / end terrace • 3 bed detached • 3 bed townhouse (narrow fronted, mid terrace) flat	2.6		1.6
4 bedroom	• 4 bed townhouse (narrow fronted, end of terrace) • 4 bed detached	3.1		1.9
5+ bedroom	• 5 bed detached	3.5		2.2

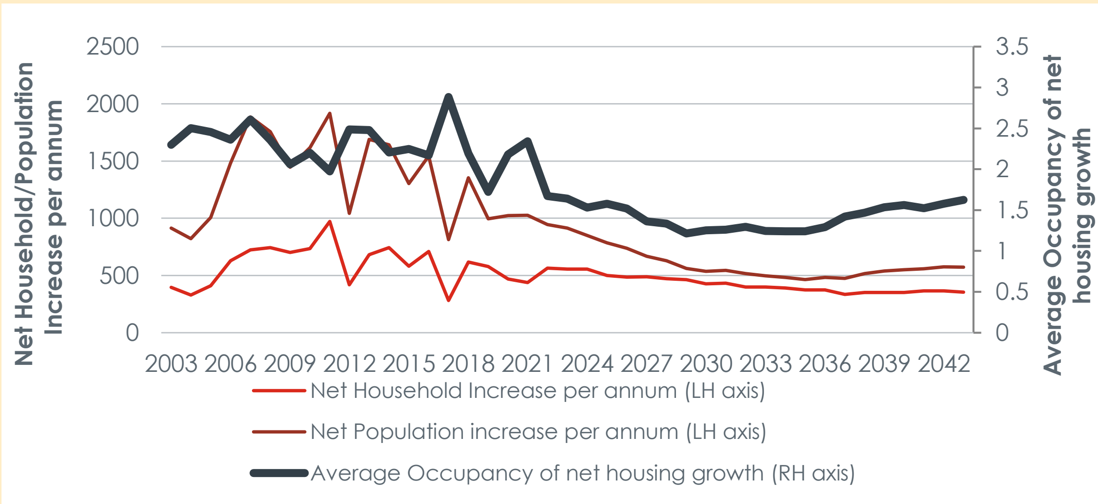
Source: SQW analysis of 2018-based Household Projections for England, ONS, 2020 & Census 2011, ONS data

Case Study – Mid-Sussex

To demonstrate the application of these metrics in the appraisal tool, the example of Mid-Sussex local authority has been used. Mid-Sussex is expected to experience a similar demographic change to the national one, with average occupancy of homes expected to decline over the next two decades.

Figure 4 shows the actual and expected net increase in population and households between 2001 and 2041 based on data from 2018-based household projections for England. Based on the net increase in population and households, an average occupancy of the net additional housing stock in a particular year has been calculated; this is shown by the thicker blue line in Figure 4.

Figure 4: Actual/Expected net increase in population/households in Mid-Sussex and resulting average occupancy of net additional households, 2001-41



Source: 2018-based Household Projections for England, ONS, 2020

To calculate the net additional population from a new home, the same methodology has been used as described above. This has resulted in the following values for occupancy rate and the adjustment factor required to calculate net population growth from an additional home.

Table 7: Adjusted Occupancy Rates for Mid-Sussex

Number of Bedrooms	Census 2011 Average Occupancy	Adjustment Factor	Adjusted Occupancy Rate
1 bedroom	1.3		0.7
2 bedroom	1.9		1.2
3 bedroom	2.5	0.6	1.4
4 bedroom	2.9		1.6
5+ bedroom	3.4		1.9

Source: SQW analysis of 2018-based Household Projections for England, ONS, 2020 & Census 2011, ONS datau

Conclusions

In analysing a range of different demographic and housing-related statistics, this research has identified an approach to calculating the net population growth that is expected to occur following housing delivery in each local authority, based on expected demographic trends put forward in the 2018-based population and household estimates. This provides values that can be used by appraisers to calculate per person environmental impacts associated with new housing development.

Given demographic trends nationally, as reported in Chapter 2, it is expected that the net additional population growth arising from new housing will be below the average occupancy rate of housing (across the existing stock). This reflects a lowering occupancy rate nationally; a trend that has occurred since the 1920s.

The results from the research show that for England as a whole:

- For each net additional 1-bedroom property built a net population increase of 0.8 persons is expected.
- For each net additional 2-bedroom property built a net population increase of 1.2 persons is expected.
- For each net additional 3-bedroom property built a net population increase of 1.6 persons is expected.
- For each net additional 4-bedroom property built a net population increase of 1.9 persons is expected.
- For each net additional 5+-bedroom property built a net population increase of 2.2 persons is expected.

A full breakdown of results for each local authority is provided in Annex A.

Updates Required

Given ongoing data releases, and particularly given the ongoing cycle of Census 2021 data releases, there will be a need for updates to the data that underpins the occupancy rates that have been calculated for each local authority. A spreadsheet has been provided to Homes England to allow for updates to be undertaken.

At the time of writing, SQW is aware of the following data releases that require the model to be updated:

- Housing occupancy (by bedroom size) needs to be updated when Census 2021 multi-variate data is released by ONS (expected Spring 2023).
- When 2020-based population and household projections are released by ONS (release date TBC), population and household projections will need to be updated.

Annex A: Average household size values for use in appraisal

This annex provides the average household size values for use in appraisals by local authority area, and number of bedrooms. This data has been incorporated into the ENHAT model, with local authority data automatically selected and applied based on site location.

Code	Local Authority	1-bed	2-bed	3-bed	4-bed	5-bed
E06000001	Hartlepool	0.5	0.7	1.0	1.2	1.3
E06000002	Middlesbrough	0.5	0.7	1.0	1.2	1.3
E06000003	Redcar and Cleveland	0.5	0.7	1.0	1.2	1.3
E06000004	Stockton-on-Tees	0.5	0.7	1.0	1.2	1.3
E06000005	Darlington	0.5	0.7	1.0	1.2	1.3
E06000006	Halton	0.8	1.1	1.6	1.9	2.2
E06000007	Warrington	0.8	1.1	1.6	1.9	2.2
E06000008	Blackburn with Darwen	0.8	1.1	1.6	1.9	2.2
E06000009	Blackpool	0.8	1.1	1.6	1.9	2.2
E06000010	Kingston upon Hull, City of	0.8	1.1	1.5	1.8	2.1
E06000011	East Riding of Yorkshire	0.8	1.1	1.5	1.8	2.1
E06000012	North East Lincolnshire	0.8	1.1	1.5	1.8	2.1
E06000013	North Lincolnshire	0.8	1.1	1.5	1.8	2.1
E06000014	York	0.8	1.1	1.5	1.8	2.1
E06000015	Derby	0.9	1.3	1.8	2.1	2.4
E06000016	Leicester	0.9	1.3	1.8	2.1	2.4
E06000017	Rutland	0.9	1.3	1.8	2.1	2.4
E06000018	Nottingham	0.9	1.3	1.8	2.1	2.4
E06000019	Herefordshire, County of	1.0	1.4	1.9	2.3	2.6
E06000020	Telford and Wrekin	1.0	1.4	1.9	2.3	2.6
E06000021	Stoke-on-Trent	1.0	1.4	1.9	2.3	2.6
E06000022	Bath and North East Somerset	0.9	1.3	1.7	2.0	2.3
E06000023	Bristol, City of	0.9	1.3	1.7	2.0	2.3
E06000024	North Somerset	0.9	1.3	1.7	2.0	2.3
E06000025	South Gloucestershire	0.9	1.3	1.7	2.0	2.3

E06000026	Plymouth	0.9	1.3	1.7	2.0	2.3
E06000027	Torbay	0.9	1.3	1.7	2.0	2.3
E06000030	Swindon	0.9	1.3	1.7	2.0	2.3
E06000031	Peterborough	0.8	1.2	1.6	1.8	2.1
E06000032	Luton	0.8	1.2	1.6	1.8	2.1
E06000033	Southend-on-Sea	0.8	1.2	1.6	1.8	2.1
E06000034	Thurrock	0.8	1.2	1.6	1.8	2.1
E06000035	Medway	0.7	1.1	1.4	1.6	1.9
E06000036	Bracknell Forest	0.7	1.1	1.4	1.6	1.9
E06000037	West Berkshire	0.7	1.1	1.4	1.6	1.9
E06000038	Reading	0.7	1.1	1.4	1.6	1.9
E06000039	Slough	0.7	1.1	1.4	1.6	1.9
E06000040	Windsor and Maidenhead	0.7	1.1	1.4	1.6	1.9
E06000041	Wokingham	0.7	1.1	1.4	1.6	1.9
E06000042	Milton Keynes	0.7	1.1	1.4	1.6	1.9
E06000043	Brighton and Hove	0.7	1.1	1.4	1.6	1.9
E06000044	Portsmouth	0.7	1.1	1.4	1.6	1.9
E06000045	Southampton	0.7	1.1	1.4	1.6	1.9
E06000046	Isle of Wight	0.7	1.1	1.4	1.6	1.9
E06000047	County Durham	0.5	0.7	1.0	1.2	1.3
E06000049	Cheshire East	0.8	1.1	1.6	1.9	2.2
E06000050	Cheshire West and Chester	0.8	1.1	1.6	1.9	2.2
E06000051	Shropshire	1.0	1.4	1.9	2.3	2.6
E06000052	Cornwall	0.9	1.3	1.7	2.0	2.3
E06000053	Isles of Scilly	0.9	1.3	1.7	2.0	2.3
E06000054	Wiltshire	0.9	1.3	1.7	2.0	2.3
E06000055	Bedford	0.8	1.2	1.6	1.8	2.1
E06000056	Central Bedfordshire	0.8	1.2	1.6	1.8	2.1
E06000057	Northumberland	0.5	0.7	1.0	1.2	1.3
E06000058	Bournemouth, Christchurch and Poole	0.9	1.3	1.7	2.0	2.3
E06000059	Dorset	0.9	1.3	1.7	2.0	2.3
E06000060	Buckinghamshire	0.7	1.1	1.4	1.6	1.9

E06000061	North Northamptonshire	0.9	1.3	1.8	2.1	2.4
E06000062	West Northamptonshire	0.9	1.3	1.8	2.1	2.4
E07000008	Cambridge	0.8	1.2	1.6	1.8	2.1
E07000009	East Cambridgeshire	0.8	1.2	1.6	1.8	2.1
E07000010	Fenland	0.8	1.2	1.6	1.8	2.1
E07000011	Huntingdonshire	0.8	1.2	1.6	1.8	2.1
E07000012	South Cambridgeshire	0.8	1.2	1.6	1.8	2.1
E07000026	Allerdale	0.8	1.1	1.6	1.9	2.2
E07000027	Barrow-in-Furness	0.8	1.1	1.6	1.9	2.2
E07000028	Carlisle	0.8	1.1	1.6	1.9	2.2
E07000029	Copeland	0.8	1.1	1.6	1.9	2.2
E07000030	Eden	0.8	1.1	1.6	1.9	2.2
E07000031	South Lakeland	0.8	1.1	1.6	1.9	2.2
E07000032	Amber Valley	0.9	1.3	1.8	2.1	2.4
E07000033	Bolsover	0.9	1.3	1.8	2.1	2.4
E07000034	Chesterfield	0.9	1.3	1.8	2.1	2.4
E07000035	Derbyshire Dales	0.9	1.3	1.8	2.1	2.4
E07000036	Erewash	0.9	1.3	1.8	2.1	2.4
E07000037	High Peak	0.9	1.3	1.8	2.1	2.4
E07000038	North East Derbyshire	0.9	1.3	1.8	2.1	2.4
E07000039	South Derbyshire	0.9	1.3	1.8	2.1	2.4
E07000040	East Devon	0.9	1.3	1.7	2.0	2.3
E07000041	Exeter	0.9	1.3	1.7	2.0	2.3
E07000042	Mid Devon	0.9	1.3	1.7	2.0	2.3
E07000043	North Devon	0.9	1.3	1.7	2.0	2.3
E07000044	South Hams	0.9	1.3	1.7	2.0	2.3
E07000045	Teignbridge	0.9	1.3	1.7	2.0	2.3
E07000046	Torridge	0.9	1.3	1.7	2.0	2.3
E07000047	West Devon	0.9	1.3	1.7	2.0	2.3
E07000061	Eastbourne	0.7	1.1	1.4	1.6	1.9
E07000062	Hastings	0.7	1.1	1.4	1.6	1.9
E07000063	Lewes	0.7	1.1	1.4	1.6	1.9
E07000064	Rother	0.7	1.1	1.4	1.6	1.9

E07000065	Wealden	0.7	1.1	1.4	1.6	1.9
E07000066	Basildon	0.8	1.2	1.6	1.8	2.1
E07000067	Braintree	0.8	1.2	1.6	1.8	2.1
E07000068	Brentwood	0.8	1.2	1.6	1.8	2.1
E07000069	Castle Point	0.8	1.2	1.6	1.8	2.1
E07000070	Chelmsford	0.8	1.2	1.6	1.8	2.1
E07000071	Colchester	0.8	1.2	1.6	1.8	2.1
E07000072	Epping Forest	0.8	1.2	1.6	1.8	2.1
E07000073	Harlow	0.8	1.2	1.6	1.8	2.1
E07000074	Maldon	0.8	1.2	1.6	1.8	2.1
E07000075	Rochford	0.8	1.2	1.6	1.8	2.1
E07000076	Tendring	0.8	1.2	1.6	1.8	2.1
E07000077	Uttlesford	0.8	1.2	1.6	1.8	2.1
E07000078	Cheltenham	0.9	1.3	1.7	2.0	2.3
E07000079	Cotswold	0.9	1.3	1.7	2.0	2.3
E07000080	Forest of Dean	0.9	1.3	1.7	2.0	2.3
E07000081	Gloucester	0.9	1.3	1.7	2.0	2.3
E07000082	Stroud	0.9	1.3	1.7	2.0	2.3
E07000083	Tewkesbury	0.9	1.3	1.7	2.0	2.3
E07000084	Basingstoke and Deane	0.7	1.1	1.4	1.6	1.9
E07000085	East Hampshire	0.7	1.1	1.4	1.6	1.9
E07000086	Eastleigh	0.7	1.1	1.4	1.6	1.9
E07000087	Fareham	0.7	1.1	1.4	1.6	1.9
E07000088	Gosport	0.7	1.1	1.4	1.6	1.9
E07000089	Hart	0.7	1.1	1.4	1.6	1.9
E07000090	Havant	0.7	1.1	1.4	1.6	1.9
E07000091	New Forest	0.7	1.1	1.4	1.6	1.9
E07000092	Rushmoor	0.7	1.1	1.4	1.6	1.9
E07000093	Test Valley	0.7	1.1	1.4	1.6	1.9
E07000094	Winchester	0.7	1.1	1.4	1.6	1.9
E07000095	Broxbourne	0.8	1.2	1.6	1.8	2.1
E07000096	Dacorum	0.8	1.2	1.6	1.8	2.1
E07000098	Hertsmere	0.8	1.2	1.6	1.8	2.1

E07000099	North Hertfordshire	0.8	1.2	1.6	1.8	2.1
E07000102	Three Rivers	0.8	1.2	1.6	1.8	2.1
E07000103	Watford	0.8	1.2	1.6	1.8	2.1
E07000105	Ashford	0.7	1.1	1.4	1.6	1.9
E07000106	Canterbury	0.7	1.1	1.4	1.6	1.9
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E07000108	Dover	0.7	1.1	1.4	1.6	1.9
E07000109	Gravesham	0.7	1.1	1.4	1.6	1.9
E07000110	Maidstone	0.7	1.1	1.4	1.6	1.9
E07000111	Sevenoaks	0.7	1.1	1.4	1.6	1.9
E07000112	Folkestone and Hythe	0.7	1.1	1.4	1.6	1.9
E07000113	Swale	0.7	1.1	1.4	1.6	1.9
E07000114	Thanet	0.7	1.1	1.4	1.6	1.9
E07000115	Tonbridge and Malling	0.7	1.1	1.4	1.6	1.9
E07000116	Tunbridge Wells	0.7	1.1	1.4	1.6	1.9
E07000117	Burnley	0.8	1.1	1.6	1.9	2.2
E07000118	Chorley	0.8	1.1	1.6	1.9	2.2
E07000119	Fylde	0.8	1.1	1.6	1.9	2.2
E07000120	Hyndburn	0.8	1.1	1.6	1.9	2.2
E07000121	Lancaster	0.8	1.1	1.6	1.9	2.2
E07000122	Pendle	0.8	1.1	1.6	1.9	2.2
E07000123	Preston	0.8	1.1	1.6	1.9	2.2
E07000124	Ribble Valley	0.8	1.1	1.6	1.9	2.2
E07000125	Rossendale	0.8	1.1	1.6	1.9	2.2
E07000126	South Ribble	0.8	1.1	1.6	1.9	2.2
E07000127	West Lancashire	0.8	1.1	1.6	1.9	2.2
E07000128	Wyre	0.8	1.1	1.6	1.9	2.2
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E07000130	Charnwood	0.9	1.3	1.8	2.1	2.4
E07000131	Harborough	0.9	1.3	1.8	2.1	2.4
E07000132	Hinckley and Bosworth	0.9	1.3	1.8	2.1	2.4
E07000133	Melton	0.9	1.3	1.8	2.1	2.4
E07000134	North West Leicestershire	0.9	1.3	1.8	2.1	2.4

E07000135	Oadby and Wigston	0.9	1.3	1.8	2.1	2.4
E07000136	Boston	0.9	1.3	1.8	2.1	2.4
E07000137	East Lindsey	0.9	1.3	1.8	2.1	2.4
E07000138	Lincoln	0.9	1.3	1.8	2.1	2.4
E07000139	North Kesteven	0.9	1.3	1.8	2.1	2.4
E07000140	South Holland	0.9	1.3	1.8	2.1	2.4
E07000141	South Kesteven	0.9	1.3	1.8	2.1	2.4
E07000142	West Lindsey	0.9	1.3	1.8	2.1	2.4
E07000143	Breckland	0.8	1.2	1.6	1.8	2.1
E07000144	Broadland	0.8	1.2	1.6	1.8	2.1
E07000145	Great Yarmouth	0.8	1.2	1.6	1.8	2.1
E07000146	King's Lynn and West Norfolk	0.8	1.2	1.6	1.8	2.1
E07000147	North Norfolk	0.8	1.2	1.6	1.8	2.1
E07000148	Norwich	0.8	1.2	1.6	1.8	2.1
E07000149	South Norfolk	0.8	1.2	1.6	1.8	2.1
E07000163	Craven	0.8	1.1	1.5	1.8	2.1
E07000164	Hambleton	0.8	1.1	1.5	1.8	2.1
E07000165	Harrogate	0.8	1.1	1.5	1.8	2.1
E07000166	Richmondshire	0.8	1.1	1.5	1.8	2.1
E07000167	Ryedale	0.8	1.1	1.5	1.8	2.1
E07000168	Scarborough	0.8	1.1	1.5	1.8	2.1
E07000169	Selby	0.8	1.1	1.5	1.8	2.1
E07000170	Ashfield	0.9	1.3	1.8	2.1	2.4
E07000171	Bassetlaw	0.9	1.3	1.8	2.1	2.4
E07000172	Broxtowe	0.9	1.3	1.8	2.1	2.4
E07000173	Gedling	0.9	1.3	1.8	2.1	2.4
E07000174	Mansfield	0.9	1.3	1.8	2.1	2.4
E07000175	Newark and Sherwood	0.9	1.3	1.8	2.1	2.4
E07000176	Rushcliffe	0.9	1.3	1.8	2.1	2.4
E07000177	Cherwell	0.7	1.1	1.4	1.6	1.9
E07000178	Oxford	0.7	1.1	1.4	1.6	1.9
E07000179	South Oxfordshire	0.7	1.1	1.4	1.6	1.9
E07000180	Vale of White Horse	0.7	1.1	1.4	1.6	1.9

E07000181	West Oxfordshire	0.7	1.1	1.4	1.6	1.9
E07000187	Mendip	0.9	1.3	1.7	2.0	2.3
E07000188	Sedgemoor	0.9	1.3	1.7	2.0	2.3
E07000189	South Somerset	0.9	1.3	1.7	2.0	2.3
E07000192	Cannock Chase	1.0	1.4	1.9	2.3	2.6
E07000193	East Staffordshire	1.0	1.4	1.9	2.3	2.6
E07000194	Lichfield	1.0	1.4	1.9	2.3	2.6
E07000195	Newcastle-under-Lyme	1.0	1.4	1.9	2.3	2.6
E07000196	South Staffordshire	1.0	1.4	1.9	2.3	2.6
E07000197	Stafford	1.0	1.4	1.9	2.3	2.6
E07000198	Staffordshire Moorlands	1.0	1.4	1.9	2.3	2.6
E07000199	Tamworth	1.0	1.4	1.9	2.3	2.6
E07000200	Babergh	0.8	1.2	1.6	1.8	2.1
E07000202	Ipswich	0.8	1.2	1.6	1.8	2.1
E07000203	Mid Suffolk	0.8	1.2	1.6	1.8	2.1
E07000207	Elmbridge	0.7	1.1	1.4	1.6	1.9
E07000208	Epsom and Ewell	0.7	1.1	1.4	1.6	1.9
E07000209	Guildford	0.7	1.1	1.4	1.6	1.9
E07000210	Mole Valley	0.7	1.1	1.4	1.6	1.9
E07000211	Reigate and Banstead	0.7	1.1	1.4	1.6	1.9
E07000212	Runnymede	0.7	1.1	1.4	1.6	1.9
E07000213	Spelthorne	0.7	1.1	1.4	1.6	1.9
E07000214	Surrey Heath	0.7	1.1	1.4	1.6	1.9
E07000215	Tandridge	0.7	1.1	1.4	1.6	1.9
E07000216	Waverley	0.7	1.1	1.4	1.6	1.9
E07000217	Woking	0.7	1.1	1.4	1.6	1.9
E07000218	North Warwickshire	1.0	1.4	1.9	2.3	2.6
E07000219	Nuneaton and Bedworth	1.0	1.4	1.9	2.3	2.6
E07000220	Rugby	1.0	1.4	1.9	2.3	2.6
E07000221	Stratford-on-Avon	1.0	1.4	1.9	2.3	2.6
E07000222	Warwick	1.0	1.4	1.9	2.3	2.6
E07000223	Adur	0.7	1.1	1.4	1.6	1.9
E07000224	Arun	0.7	1.1	1.4	1.6	1.9

E07000225	Chichester	0.7	1.1	1.4	1.6	1.9
E07000226	Crawley	0.7	1.1	1.4	1.6	1.9
E07000227	Horsham	0.7	1.1	1.4	1.6	1.9
E07000228	Mid Sussex	0.7	1.1	1.4	1.6	1.9
E07000229	Worthing	0.7	1.1	1.4	1.6	1.9
E07000234	Bromsgrove	1.0	1.4	1.9	2.3	2.6
E07000235	Malvern Hills	1.0	1.4	1.9	2.3	2.6
E07000236	Redditch	1.0	1.4	1.9	2.3	2.6
E07000237	Worcester	1.0	1.4	1.9	2.3	2.6
E07000238	Wychavon	1.0	1.4	1.9	2.3	2.6
E07000239	Wyre Forest	1.0	1.4	1.9	2.3	2.6
E07000240	St Albans	0.8	1.2	1.6	1.8	2.1
E07000241	Welwyn Hatfield	0.8	1.2	1.6	1.8	2.1
E07000242	East Hertfordshire	0.8	1.2	1.6	1.8	2.1
E07000243	Stevenage	0.8	1.2	1.6	1.8	2.1
E07000244	East Suffolk	0.8	1.2	1.6	1.8	2.1
E07000245	West Suffolk	0.8	1.2	1.6	1.8	2.1
E07000246	Somerset West and Taunton	0.9	1.3	1.7	2.0	2.3
E08000001	Bolton	0.9	1.3	1.7	2.0	2.3
E08000002	Bury	0.9	1.3	1.7	2.0	2.3
E08000003	Manchester	0.8	1.1	1.6	1.9	2.2
E08000004	Oldham	0.8	1.1	1.6	1.9	2.2
E08000005	Rochdale	0.8	1.1	1.6	1.9	2.2
E08000006	Salford	0.8	1.1	1.6	1.9	2.2
E08000007	Stockport	0.8	1.1	1.6	1.9	2.2
E08000008	Tameside	0.8	1.1	1.6	1.9	2.2
E08000009	Trafford	0.8	1.1	1.6	1.9	2.2
E08000010	Wigan	0.8	1.1	1.6	1.9	2.2
E08000011	Knowsley	0.8	1.1	1.6	1.9	2.2
E08000012	Liverpool	0.8	1.1	1.6	1.9	2.2
E08000013	St. Helens	0.8	1.1	1.6	1.9	2.2
E08000014	Sefton	0.8	1.1	1.6	1.9	2.2
E08000015	Wirral	0.8	1.1	1.6	1.9	2.2

E08000016	Barnsley	0.8	1.1	1.6	1.9	2.2
E08000017	Doncaster	0.8	1.1	1.6	1.9	2.2
E08000018	Rotherham	0.8	1.1	1.5	1.8	2.1
E08000019	Sheffield	0.8	1.1	1.5	1.8	2.1
E08000021	Newcastle upon Tyne	0.8	1.1	1.5	1.8	2.1
E08000022	North Tyneside	0.8	1.1	1.5	1.8	2.1
E08000023	South Tyneside	0.5	0.7	1.0	1.2	1.3
E08000024	Sunderland	0.5	0.7	1.0	1.2	1.3
E08000025	Birmingham	0.5	0.7	1.0	1.2	1.3
E08000026	Coventry	0.5	0.7	1.0	1.2	1.3
E08000027	Dudley	1.0	1.4	1.9	2.3	2.6
E08000028	Sandwell	1.0	1.4	1.9	2.3	2.6
E08000029	Solihull	1.0	1.4	1.9	2.3	2.6
E08000030	Walsall	1.0	1.4	1.9	2.3	2.6
E08000031	Wolverhampton	1.0	1.4	1.9	2.3	2.6
E08000032	Bradford	1.0	1.4	1.9	2.3	2.6
E08000033	Calderdale	1.0	1.4	1.9	2.3	2.6
E08000034	Kirklees	0.8	1.1	1.5	1.8	2.1
E08000035	Leeds	0.8	1.1	1.5	1.8	2.1
E08000036	Wakefield	0.8	1.1	1.5	1.8	2.1
E08000037	Gateshead	0.8	1.1	1.5	1.8	2.1

Annex B: Alternative approach to estimating the expected number of occupants per new dwelling

In carrying out this assignment we developed an alternative approach to producing a set of predictions for the expected number of occupants per new dwelling at the Local Authority level. This approach was based on a formal statistical model of the relationship between population and housing stock. In this annex we provide a headline description of this statistical model, summarise the results and offer a brief discussion on the shortcomings of using approaches underpinned by historical data.

The model

After considering several alternative statistical approaches we concluded that a **panel vector autoregression model** would be best suited for this analysis. In such a model, population and housing are allowed to mutually affect each other – the population in an area can react to an increase (or decrease) in local housing supply while the housing stock can adjust to changes in population.

From a 'mechanical' point of view **the model consists of two equations**:

- The first equation describes the relationship between population growth, its past values and past values of housing growth.

- The second equation represents the opposite side of the relationship, it describes the relationship between housing growth, its past values and past values of population growth.[61]

Both equations were estimated simultaneously using the generalised method of moments and analysed by:

- Conducting statistical tests to determine which of the two variables 'causes' which (or whether the causality flows both ways).[62]

- Examining impulse responses – i.e. how one of the variables react to a change (a 'shock') in another variable.

The analysis was carried out in Stata using the pvar suite of commands developed by Abrigo and Love (2016).[63]

The analysis relied on Local Authority level ONS population estimates[64] and DLUHC data on net additional dwellings.[65] These annual data covered the period from 2005 to 2020. The time period was selected to be as short as possible to capture more recent and relevant trends while allowing the model to satisfy robustness tests.[66]

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[61] The use of past values is the 'autoregression' part of the model's name/type. The two equations explaining two variables (population and housing growth) are the 'vector' part of it.
[62] Within the context of this model we operated with the concept of Granger (1969) causality. Variable X is said to Granger-cause variable Y if past values of X improve the prediction for the current and future values of Y relative to the predictions of Y based solely on its own past.
[63] Abrigo, M.R. and Love, I., 2016. Estimation of panel vector autoregression in Stata. *The Stata Journal*, *16*(3), pp.778-804.
[64] Obtained through nomis
[65] Available through ONS
[66] These tests involved checking: a) the time-series properties of the data (stationarity); b) validity of past values of variables as 'instruments' to overcome the Nickell (1981) bias; c) model's 'stability' i.e. that variables in the model respond to 'shocks' within a limited amount of time (finite propagation).

Local Authorities were grouped into five broad geographical regions – the North (North East, North West, Yorkshire and the Humber); Midlands (East and West) and South West; East of England, London and South East – which were analysed separately. This is the 'panel' part of the model's type – the model considers groups of Local Authorities rather than each one individually and assumes that the underlying relationship between population and housing is the same for all Local Authorities within each of the groups. Carrying out the estimations separately for each Local Authority was not feasible due to the relatively small number of observations per area, we would not have enough statistical power to capture the relationship.

Four out of five regional models (the North was the exception) included one- and two-year lags in their specifications. In other words, population and housing growth were explained by their values from up to two years ago. The decision on the number of lags was data-driven and determined according to the selection criteria described in Andrews and Lu (2001).[67] The model for the North included only one lag to satisfy our robustness tests.

Approach to estimating the expected number of occupants

In order to arrive to the estimate for the number of people that can be expected to occupy a new dwelling we analysed the responses of population growth to a one standard deviation 'shock' in the growth rate of housing in each of the modelled regions. In other words, we 'simulated' additional housing being delivered and traced the response of the population.

The data suggested that following a higher than usual increase in housing supply, population growth remains above its pre-shock level for three years. This likely reflects the delays that may be associated with the way the housing market functions as we as 'cluster' development effects where an area gets developed and remains on a high growth trajectory for several years. **We therefore analysed the cumulative effects over three years.[68]**

Using the most recent available data, for each Local Authority the cumulative changes in the growth rates of population and housing predicted by the model (which were expressed in percentages) were converted into the 'level' changes expressed in terms of the number of dwellings and people. Then **a ratio of the expected increase in population to the expected increase in the number of dwellings was calculated, giving us the estimate for the average number of occupants per new dwelling in each Local Authority**.

Results

Table summarises the results of our analysis – the Local Authority level results were aggregated to the level of Regions of England.[69] For comparison, the table also presents the average number of people per existing dwelling which was calculated as a simple ratio of population to existing housing stock (and averaged over the 2005 – 2020 period).

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[67] Andrews, D.W. and Lu, B., 2001. Consistent model and moment selection procedures for GMM estimation with application to dynamic panel data models. *Journal of econometrics*, *101*(1), pp.123-164.

[68] In our analysis population was allowed to react to a shock in housing supply in the same year (as people can move into dwellings that become available). However, housing stock could only react to a population shock with a delay of at least one year (as it takes time for housing to be developed). Without these additional constraints it would not be possible to capture any contemporaneous effects, i.e. there would be a delay in response of both variables. These assumptions were also supported by the direction of Granger causality observed in the data, with population tending to Granger-cause housing. When both were causing each other the effect of population growth on housing was stronger than the other way around.

[69] The Local Authority level results are available on request.

Table A: Estimated average number of occupants per new dwelling

Region	Average number of occupants per new dwelling	st. deviation	min	max	Average number of people per existing dwelling
East of England	**2.01**	0.12	1.62	2.32	2.29
East Midlands	**1.97**	0.09	1.76	2.21	2.27
London	**3.07**	0.37	1.93	3.70	2.46
North East	**1.12**	0.04	1.07	1.21	2.14
North West	**1.14**	0.07	0.98	1.29	2.18
South East	**2.89**	0.15	2.51	3.33	2.31
South West	**1.86**	0.13	1.37	2.05	2.15
West Midlands	**1.98**	0.10	1.83	2.27	2.28
Yorkshire and The Humber	**1.15**	0.07	0.95	1.31	2.19

Source: SQW

As expected, the results show a clear North-South divide. The distribution of the estimates is less compressed than the current average number of occupants per dwelling and is arguably too wide to be directly applied for the purposes of sustainability calculations.

Reflections

The main strength of this statistical approach is that it does not impose any ex-ante assumptions on the direction of causality between population in housing and allows for a dynamic interplay between the two, capturing the complexity of the relationship. However, this method is underpinned by historical data and trends. The model picks up the substantially lower population growth in the North and high population growth in London compared to the rest of the country (Table B) which drive the large variation in the produced estimates.

Table B: Average annual population and housing growth by region, 2005 - 2020[70]

	Average population growth	Average growth in housing stock
East of England	0.76%	0.83%
East Midlands	0.76%	0.86%
London	1.10%	0.99%
North East	0.25%	0.61%
North West	0.36%	0.59%
South East	0.72%	0.83%
South West	0.68%	0.91%

[70] Calculated as a difference in the logarithms of housing stock and population between two consecutive years, which is an approximation.

	Average population growth	Average growth in housing stock
West Midlands	0.58%	0.77%
Yorkshire and The Humber	0.51%	0.65%

Source: SQW

In our opinion, this model provides a useful insight into differences between Local Authorities and reflects the trends in 'attractiveness' of regions. However, since it puts a large weight on historical trends and does not reflect the current or future policy landscape (including the Levelling Up agenda) **we do not consider it to be appropriate to directly apply these results for the purposes of sustainability calculations** (or any other calculations involving predicted occupancy rates). However, in the future, the results could be used alongside other methods (including the one outlined in the main body of the report) to 'sense check' or improve the predictions by, for example, comparing the relative 'rankings' of Local Authorities.