# A pragmatic framework for local operationalisation of national-level biodiversity impact mitigation commitments

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**Abstract**

Countries around the world are attempting to navigate complex trade-offs between biodiversity and other land use objectives such as infrastructure expansion, with many adopting "net outcomes" policies that aim to ensure economic development leaves biodiversity better off than before. The implementation of net outcomes policies often occurs on a project-by-project basis, which can lead to implementation missing opportunities for integrated thinking that delivers across multiple objectives. Here, we present a new practical framework for delivering a biodiversity mitigation strategy that achieves multiple societal objectives whilst being applicable at the scale of an individual project. We apply the framework to the case study of a major development in Oxfordshire subject to Biodiversity Net Gain legislation. We first calculate the requirement for off-site biodiversity offsetting, given the realistic limits in scope of on-site biodiversity impact mitigation. Three offsetting strategies are co-created with local stakeholders, which all meet the required biodiversity gains, but differ with regards to social equity and the bundle of ecosystem services delivered. Making these contrasting project characteristics transparent and comparable empowers local stakeholders to choose the offset strategy that meets their local preferences across these often-competing priorities, whilst helping contribute to overarching strategic development goals.

## 1. Introduction

Commitments made by 196 countries under the Kunming-Montreal Global Biodiversity Framework (KMGBF) of the Convention on Biological Diversity require countries to act together to "halt and reverse biodiversity loss by 2030" towards a world in 2050 where nature and humanity are thriving (Convention on Biological Diversity 2022). Target 1 of this Framework requires that all areas are under "participatory, integrated and biodiversity-inclusive spatial planning..." by 2030, and Target 14 requires "the full integration of biodiversity into policies, regulations, planning and development processes". This is critically important because with finite land area, trade-offs between land uses are inevitable. Trade-offs between national and global commitments to nature recovery and investments in infrastructure development are particularly likely (Spaiser et al. 2017; zu Ermgassen et al. 2022). For example, there are substantial investments in infrastructure already in the pipeline, such that 70% of the infrastructure envisaged to be on this planet by 2050 is yet to be built (UNEP & IEA 2017). However, opportunities do exist for aligning nature recovery actions with infrastructure development (Kiesecker et al. 2010).

A "net outcomes" approach to ensuring that overall biodiversity is not depleted as a result of developments is gaining traction worldwide (Bull et al. 2020). This recognises that in many countries, infrastructure expansion is necessary to enhance human wellbeing (Haberl et al. 2019), but that in order to fulfil national and international obligations to halt and reverse biodiversity loss, new developments must have an overall positive impact on biodiversity. This can be done in two ways: i) accommodating nature and even enhancing it within the footprint of developments, with appropriate design; ii) investing in nature recovery in areas which are not scheduled for infrastructure development, to compensate for losses incurred elsewhere.

Operationalising a net outcomes approach to the mitigation of biodiversity losses (either towards no net loss of biodiversity, or a net gain) requires a framework to structure actions. At the project level, the use of a so-called "mitigation hierarchy" for direct biodiversity impacts within the footprint of a development is mandated in many jurisdictions (zu Ermgassen et al. 2019). This requires developers first to take preventative measures (avoid impacts on biodiversity to the extent feasible, then reduce them), followed by compensatory measures (restoring impacted biodiversity, and then offsetting any residual impact through action elsewhere), towards a target of no net loss or net gain of biodiversity (Baker et al. 2019). Much attention has focussed on establishing scientific principles for the final offsetting step (Moilanen and Kotiaho 2018), with much less attention on avoidance of impact in the first place (Phalan et al. 2018). In addition, monitoring for ongoing compliance with promised biodiversity enhancements is generally lacking (zu Ermgassen et al. 2021). Together these issues tend to incentivise over-promising of biodiversity gains and underestimation of losses, a focus on the cheapest options for mitigation in the short term (Clare et al. 2011), and a focus on the compensatory rather than preventative steps of the mitigation hierarchy (Phalan et al. 2018).

Governments, industry bodies and NGOs provide guidance and best practice principles for mitigating the impacts of development on biodiversity at the project level (e.g. Baker et al. 2019). However, in order for mitigation of biodiversity impacts to be fully integrated into national-level planning as required by Targets 1 and 14 of the KMGBF, there is a need to include biodiversity considerations in public procurement and decision-making across all departments of government, bringing biodiversity in alongside factors such as economic growth, health, food security, poverty reduction, and the provision of housing and education. One particularly salient consideration is the balancing of the costs and benefits of economic developments for local residents, against the national-level costs and benefits that economic development can bring. At the local level, access to the benefits from biodiversity can be critical to human wellbeing (Diaz et al. 2018; Jones et al. 2019). Developments that bring national-level benefits (such as power generation, or transport infrastructure) may limit access to these local benefits. If biodiversity losses are compensated for via offsets, these offsets can themselves exacerbate local alienation from nature (Kalliolevo et al. 2021), for example if they involve restricting public access to natural areas. Hence good practice guidelines have been developed for ensuring that local people are no worse off, and preferably better off, as a result of a development and associated biodiversity offsets (Bull et al. 2018).

England is an interesting and topical case study as to how these complex interrelationships between biodiversity and development are playing out at national and local levels. There is a raft of new policy around land use in England prompted by Brexit, including the 2021 Environment Act that mandates a minimum 10% Biodiversity Net Gain (BNG) for new developments. The same act also required local councils to develop and deliver Local Nature Recovery Strategies (LNRSs). In 2024, the new government committed to building 1.5 million new houses over the next 5 years and relaxing planning restrictions in order to allow this to happen (HM Government 2024). Commitments have also been made to ensure that communities are able to access nature, particularly lower-income and nature-deprived neighbourhoods (Defra 2023a). In order to support the Biodiversity Net Gain policy, several years of iterative modifications and consultations have resulted in the development of a metric to calculate losses and gains in biodiversity as a result of land conversion for housing or other infrastructure (the Defra Statutory Biodiversity Metric; Defra 2023b). This metric is now being considered for use by several other countries around the world (Duffus et al. in press).

Despite the guidance available, an issue remains as to how to operationalise national-level policy aspirations at the scale of individual projects, within a broad and complex policy context. Such decisions tend to be made on a case-by-case basis, based upon proposals put forward by the developer and scrutinised by a Local Planning Authority. Similar problems have been identified in other countries, such as France (Bigard et al. 2020). In this paper, we explore how off-site offsetting to fulfil a Biodiversity Net Gain requirement could be implemented, using a large housing development as a case study. In so doing, we highlight the challenges of real-world project-scale decision-making, and suggest an operationalisable framework to support the delivery of Biodiversity Net Gain at the project level, in line with national-level policy commitments.

## 2. Methods

Our framework first requires a biodiversity target to be expressed in policy, and a metric for calculating whether that target has been reached. The biodiversity outcomes of the development under consideration must at a minimum meet that target. However, ensuring best value for the public purse requires that a range of scenarios with different configurations of biodiversity actions to deliver against this target are considered. The configuration chosen should be the one that maximises the cost-effective delivery of other benefits important to public policy. These could include the provision of ecosystem services such as flood control or carbon storage, or the fulfilment of public preferences for new or enhanced natural spaces (Figure 1).

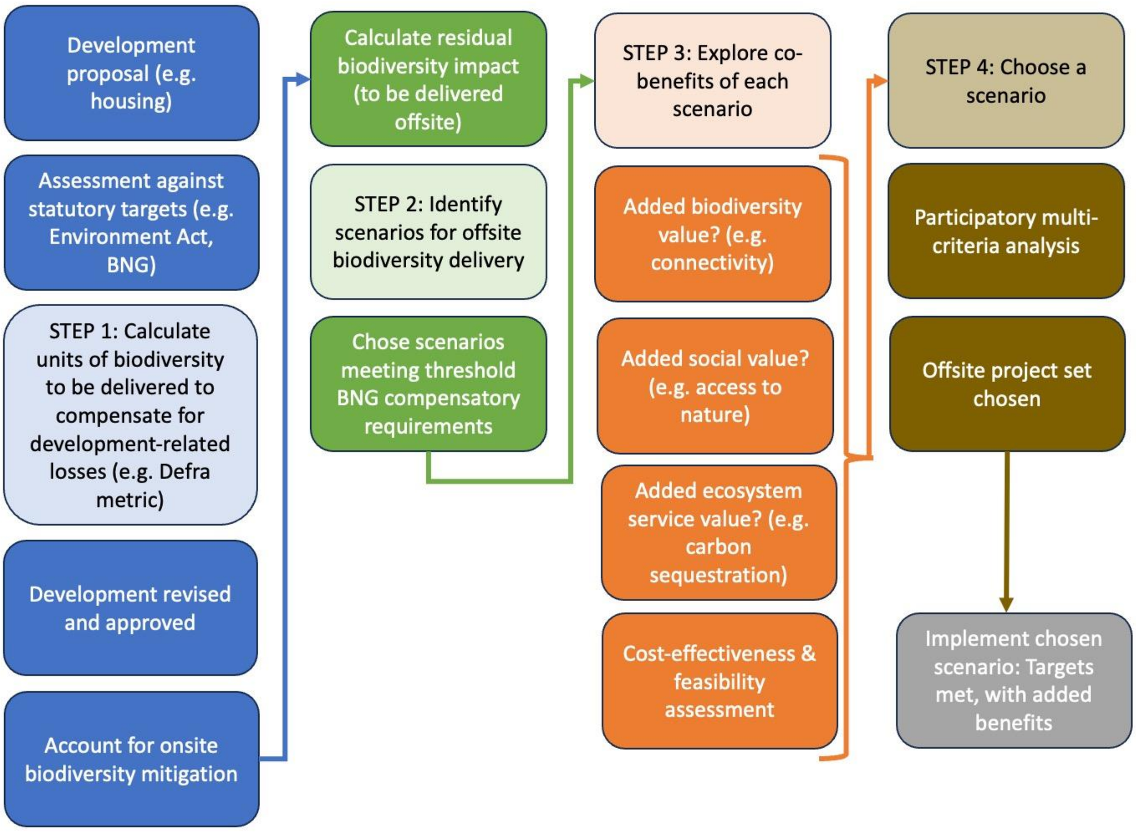



**Figure 1. Stylised example of the framework for choosing an appropriate scenario for delivering off-site biodiversity compensation for a development project, showing the steps which we illustrate in our case study.**

England has a number of biodiversity targets enshrined in the Environment Act, including halting the decline in species abundance by 2030 and reversing it by 2042. Regarding the biodiversity impact of new development, the key target is a Biodiversity Net Gain of 10% for all new developments in England, as measured using the Defra Statutory Biodiversity Metric (henceforward "Defra Metric"). We chose to use this target and metric for our case study.

The Defra Metric is a spreadsheet-based approach that enables the user to calculate the number of “biodiversity units” at a site. The developer first calculates the number of units to be retained and the number to be lost when an area is converted from its current land use to developed land (assumed to be zero biodiversity units). This calculation is based on habitat area in hectares (or length in kilometres for linear features) multiplied by scores representing habitat condition (its relative quality) and distinctiveness (a proxy for the habitat’s conservation value in an English context), with a multiplier representing strategic significance (location with respect to areas designated as of importance for nature). They then propose compensation for the lost units plus a ten percent increase, either elsewhere within the development footprint (“on-site”) or in another location (“off-site”). These proposed gains are calculated in the same way as losses, with the addition of risk multipliers to represent feasibility of creation and time lags, with a further spatial penalty for off-site locations that are far away.

We searched for a suitable case study site for demonstrating how our framework could be operationalised. We chose a large housing development outside Oxford (c.1500 houses) which is currently being delivered. At the time of this study, the developer had publicly submitted its outline plans for Biodiversity Net Gain, together with the detailed metric calculations underpinning these plans. The development involves converting agricultural land to housing and other public amenities, with new habitats for nature. The development sits partially within the Nature Recovery Network for Berkshire, Buckinghamshire and Oxfordshire (Smith et al. 2022), which will influence the spatial conservation priorities for the counties' LNRS. It also lies adjacent to an existing Site of Special Scientific Interest (SSSI: a site formally designated as having high biodiversity value and afforded partial legal protection). The proposed development borders an area of existing housing with high levels of social deprivation, where we have carried out research focussed on local relationships with nature, residents' perceptions of the potential impact of new housing on access to nature, and the acceptability of trade-offs in offset design and delivery (Butler et al. in review). We do not identify the development as the aim here is to provide a case study for our framework, rather than to critique a particular housing development. Although we did engage with the developer directly, and improvements were made to the developer's biodiversity gain plan as a result, all the data we use for this analysis are based on their original planning proposal, which is in the public domain.

***Step 1: Calculate units of biodiversity to be delivered***

This initial step involves determination of the amount of offsetting required as a result of the impact of the development, as the last step of the mitigation hierarchy, in order to comply with BNG requirements. In our case study, the housing configuration and associated biodiversity enhancement plans had already been decided upon by the developer, so we could not explore scenarios for the delivery of biodiversity through a mix of on-site and off-site actions. This development, like the vast majority of developments deemed BNG-compliant in the English planning system to date (zu Ermgassen et al. 2021), had calculated that it could achieve all its Biodiversity Net Gain requirements through habitat enhancement and creation on-site rather than resorting to off-site offsetting. However, our analysis of the submitted Biodiversity Net Gain plans for on-site habitat enhancement and creation identified 145.8 units of biodiversity gain which were promised but highly unlikely to be ecologically feasible and realistically deliverable within the development footprint, resulting in an 18% net loss of biodiversity units, rather than the required 10% gain (Supplementary Material 1). Many ecologically sensitive habitats, such as lowland meadows, require delicate and prescriptive management regimes (Rothero et al. 2016) and frequently cannot be delivered on-site due to anthropogenic pressures such as disturbance. Furthermore, this disturbance also limits the condition which habitats can attain. Therefore, in cases where developers are promising to deliver such habitats, there is a serious risk that they may not be achieved (Rampling et al. 2024). A more realistic approach would be to turn to the off-site BNG market for the delivery of good quality, ecologically sensitive habitats.

We therefore explored scenarios in which the 145.8 additional units could be delivered off-site in order to reach the developer's BNG target. We used Defra Metric Version 3.1 to carry out this analysis, rather than the most up-to-date Statutory Biodiversity Metric because this was the version submitted by the developer in their initial plans, however changes between these iterations of the metric are minor. In future implementations of this framework for other projects, opportunities to explore different scenarios for biodiversity delivery in a mixture of on-site and off-site actions should ideally be available *a priori*, rather than needing to identify units for scenario analysis *post-hoc*.

***Step 2: Identify scenarios for biodiversity delivery***

To provide a realistic example of how to operationalise our framework, we explored three scenarios of potential actions to deliver Biodiversity Net Gain, which differed in their focus in ways which reflect some of the most pressing priorities for local councils, residents, and nature conservation organisations. These scenarios were developed in consultation with the local Wildlife Trust (Berkshire, Buckinghamshire and Oxfordshire Wildlife Trust, or BBOWT), and by drawing insights from research carried out with local residents directly affected by the development to understand their priorities for nature (Butler et al. in review). The scenarios were also informed by previous research on the optimal design of Biodiversity Net Gain strategies for nature and people (e.g. Faccioli et al. 2024, Simpson et al. 2022, Mancini et al. 2024, Sullivan and Hannis 2015), and by our knowledge of the ecological, social and institutional context of the local area in which we were working.

The two key dimensions which were prioritised to different degrees in our scenarios were: i) public access to green space and ii) additional biodiversity value, in terms of strategic benefits for conservation not represented in the Defra Metric's calculation (Table 2). Both of these dimensions are explicitly named as objectives of BNG policy (NAO 2024), so another way in which our research is valuable is in highlighting potential trade-offs between the different existing policy objectives associated with BNG.

The three scenarios we developed for allocating biodiversity units to off-site offsets were therefore: i) A scenario which prioritises local access to nature for the existing residents most affected by the new development; ii) A scenario that maximises the additional biodiversity value of the off-site land parcels; and iii) A scenario which balances public access and biodiversity value. Each of these scenarios involved identifying particular parcels of land which would be used for biodiversity offsets, and calculating the gain which would be realistically achievable through transitions from their current habitat type to a future more biodiversity-rich habitat type.

The locations and future habitat types of parcels were selected based on criteria for each scenario that represent the defined priorities above. These generalised criteria can be applied across the country for parcel selection, by following the methodology detailed below (Table 1). A general assumptive criterion is that higher levels of public access lead to lower condition and lower distinctiveness habitats as a result of disturbance and trampling.

**Table 1. Habitat parcel selection criteria.**

| | **Scenario 1: Local values** | **Scenario 2: Biodiversity values** | **Scenario 3: Balanced values** |
|---|---|---|---|

| | | | |
|---|---|---|---|
| Location criteria | Closest possible proximity to existing dwellings pre-development that will lose access to greenspace, and closest possible proximity to public thoroughfares. | Falls within statutory or draft LNRS (or other Nature Recovery Network that will be used to inform the LNRS); attempt to select parcels adjacent to existing designated sites within the county. | Selection of parcels to take public pressure away from and buffer the nearest existing designated sites that are likely to be impacted by the development, but also to provide access for new and existing dwellings. |
| Location criteria methods | GIS distance calculation with respect to residential dwellings on satellite layer and open access layer. | Access the statutory or draft LNRS (or Nature Recovery Network) for the region; identify existing designated sites, such as SSSIs, NNRs, LNRs, and LWSs. | Identify the closest existing designated sites using GIS distance calculation and select parcels nearby. |
| Future habitat type criteria | Habitats that can withstand high public pressure, and are aligned with local residents' priorities, based on a case study consultation in Oxfordshire (Butler et al. in review): sites with a diversity of habitats; restoring habitat lost as a result of the development; habitats that are typical of the character of the landscape. | Habitat types that are priorities for the county; habitat types that are most beneficial for connecting and buffering existing designated sites; habitat types and conditions that are indicative of lower public pressure. | Habitat types that can buffer existing designated sites; habitat types that can withstand public pressure. |
| Future habitat type criteria methods | No high distinctiveness habitats; at least 3 Defra Metric broad habitat types; baseline habitats from planning applications that are lost post-development; use historical landcover maps e.g.: UKCEH | At least ⅓ of the future habitat area is a Priority Habitat for the county; if parcels lie adjacent to existing designated sites, such as SSSIs and LWSs, attempt to match the broad habitat type; medium or above distinctiveness | No very high distinctiveness habitats; no good condition habitats; if parcels lie adjacent to existing designated sites, such as SSSIs and LWSs, attempt to match the broad habitat type. |

| | | | |
|---|---|---|---|
| | Landcover Maps (UKCEH 2024) to identify previous habitat types in the locations; identify most common habitat types in the county. | habitats. | |
| Operationalisation in this case study | A mixture of low-medium distinctiveness habitats: broadleaved and mixed woodland, modified and other neutral grassland, ponds, and mixed scrub, replacing current arable fields surrounding existing residential dwellings, with existing public footpaths crossing them. | A selection of medium-very high distinctiveness habitats: broadleaved woodland, other neutral grassland, and lowland meadows (Priority Habitat), replacing current arable fields, which sit within the Nature Recovery Network and are all adjacent to existing SSSIs. | A set of low-high distinctiveness habitats of poor-moderate condition: broadleaved and mixed deciduous woodland (Priority Habitat), and modified and other neutral grassland, replacing current arable fields which are within walking distance of new and existing dwellings, and lie close to an existing SSSI, which a proposed broadleaved woodland parcel would buffer. |

Following habitat parcel selection, we then added and subtracted parcels until the target number of biodiversity units was reached. This also aligns with recommended practice for exploring the options for delivering best value projects (HM Treasury 2022), and with general practice in industry, in which developers will only consider a limited range of sites based on practicalities such as land ownership.

We assumed that all parcels of land identified could in principle be acquired for use as offsets (i.e., through sale or lease from current landowners). We only considered area habitats (no hedgerows or rivers) and only those currently used as cropland, with the entire field as the discrete parcel. This was because cropland has a low baseline biodiversity value within the Defra Metric, maximising biodiversity enhancement opportunities per hectare, and because this is the land type most usually acquired for housing development and associated biodiversity offsets (zu Ermgassen et al. 2021; Rampling et al. 2024). Fields were acquired in rough order of the potential additional biodiversity units achievable per hectare until the threshold of 145.8 units was reached and exceeded. All land was assumed to be acquired at the same time as the development. For the full calculations for each scenario, see Supplementary Material 2.

We iterated options until we reached three configurations that fulfilled the priorities of the three scenarios, while also delivering at least the 145.8 units of biodiversity required for legal compliance with the 10% Biodiversity Net Gain associated with the development. We then sense-checked these configurations with colleagues from the local Wildlife Trust with substantial experience in Biodiversity Net Gain and land allocation for conservation (BBOWT). We discussed which habitats are typical of the types of area that a conservation NGO would propose as a biodiversity offset under ideal conditions. This includes the principle that poor condition habitats are unlikely to be prioritised by a conservation NGO; further, the organisation is likely to look for areas which can add value by, for example, connecting two conservation areas or extending an existing conservation area.

***Step 3: Explore the co-benefits delivered by each scenario***

In this step, we compared the three scenarios against key dimensions of co-benefits which could be defensibly quantified (Table 2).

**Table 2. Dimensions against which scenarios are compared, starting with basic descriptive elements, then additional biodiversity benefits beyond those expressed in the metric units, then the economic and social values, and finally carbon sequestration as an example of an ecosystem service.**

| Dimension (unit) | Description | Source/method |
|---|---|---|
| *Descriptive elements* | | |
| Total number of biodiversity units delivered | Needs to be >145.8 units but as close as possible | Defra Metric 3.1 calculation; See Supplementary Material 2 |
| Additional area of non-urban habitat under management (ha) | Total area covered by the offset; relates to the cost of land purchase/lease as well as representing the area of habitat that contributes to overall greenspace | GIS calculation |
| Mean distance from current housing to offset site (m) | Calculated from Local Community Centre to centre of each parcel | GIS calculation; See Supplementary Material 2&3 |
| *Additional biodiversity benefits* | | |
| Proportion of habitat created which is within Nature Recovery Network (%) | Measure of the broader strategic significance of the biodiversity units | GIS calculation |
| Proportion of area contributing to Priority Habitats (%) | Measure of potential broader contribution to nature conservation | GIS calculation |
| Restoration potential (unit change per ha without multipliers) | Excluding feasibility, time-lag and strategic significance multipliers, to give a raw estimate of the level of biodiversity enhancement that could be obtained | Defra Metric 3.1 calculation; See Supplementary Material 2 |
| *Economic and social values* | | |

| | | |
|---|---|---|
| Total cost of delivery of biodiversity units (£) | Taken from the statutory credit prices provided by Defra, without the spatial risk multiplier (SRM) (x2) to give an indication of the typical cost of specific types of habitat creation. | Defra guidance (https://www.gov.uk/guidance/statutory-biodiversity-credit-prices); See Supplementary Material 2 |
| Utility to local residents (modelled coefficient) | Modelled coefficient for utility based on expressed values for distance from the development site, public access and biodiversity value. | Butler et al. (in review); See Supplementary Material 4 |
| *Ecosystem service* | | |
| Additional carbon storage generated (MgC/ha) | Vegetation and soil carbon stock mean value | Mean estimates for both aboveground and belowground biomass for different habitat types extracted from Cantarello et al. (2011) |

## 3. Results

### 3.1 Scenarios

Our three scenarios for biodiversity delivery all met the criteria for Biodiversity Net Gain but with very different spatial configurations and additional outcomes for people and nature (Figure 2). See Supplementary Material 2 for full detail regarding the habitats within each scenario.

***Scenario 1: Maximise value to local residents***

This scenario is informed by local public opinion and accessibility above all (Table 1). The locations of the biodiversity offsets are determined by selecting fields which are highly accessible (i.e., within walking distance and close to footpaths) for local people living in existing dwellings who will lose access to greenspace from the new development (Figure 2a). The habitat types chosen for the biodiversity uplift are influenced by what people living in this place feel is important, based on local consultation (Butler et al. in review): diversity in habitats; restoring what used to be there; and producing natural areas which feel within the character of the landscape. The potential additional value for biodiversity is low, however, owing to high levels of access preventing high conservation value habitats from forming. This means that a greater area is required to achieve Biodiversity Net Gain. Due to their positioning, these new areas do not lie within the Nature Recovery Network, and have low connectivity value for nature. The habitat created is also relatively fragmented, with small pieces woven into the urban area.

***Scenario 2: Maximise biodiversity value***

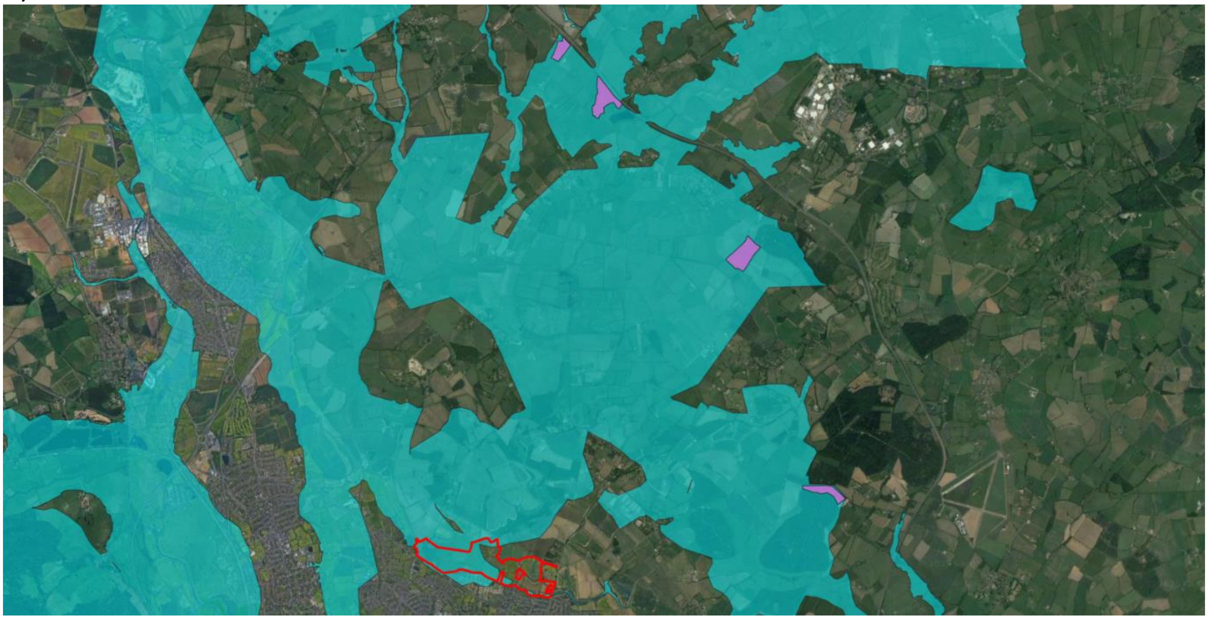
These offsets are of the type that would be identified by actors such as conservation NGOs as good candidates for habitat banking, based on maximising the per hectare biodiversity value of the sites (Table 1). As distance to people's place of residence is not a consideration, sites are prioritised solely for additional biodiversity potential on top of the BNG requirement (Figure 2b). Habitat types are determined by priorities for the county and extending areas within existing designated sites. Each of the four sites included in the offset set is within the Nature Recovery Network, thereby contributing to strategic priorities for biodiversity recovery at the landscape scale. The sites are largely inaccessible to the public, preventing damaging levels of access impacting the restoration of sensitive habitats. They either connect existing nationally or locally designated conservation areas or buffer such areas against potential human disturbance or encroachment. For example, parcel 2.1 (Supplementary Material 2) connects two fragments of nationally important SSSI woodland. Since site management is carried out by conservation NGOs and there is no access to the site, there is a strong chance of high conservation value habitats being achieved, in good condition, giving greater restoration potential per hectare.

***Scenario 3: Balance access and biodiversity values***

The offsets in this configuration are generally accessible for people but also benefit the wider landscape and biodiversity (Table 1). The locations of the offsets are determined by the proximity to nearby existing protected sites that are likely to be impacted by the development, and the location of existing developer-owned land (thereby reducing the cost to the developer). In this case, the development site lies adjacent to a predominantly wooded nature reserve (and Site of Special Scientific Interest), thus the offsets are nearby or adjacent to the development (Figure 2c). The aim is to divert the public to the newly created habitat, and so buffer the SSSI by mitigating potential development-induced increases in public pressure. The sites are accessible to the new community within the development, but are harder to access for the original residents who have had green space compromised by the new development. The majority of the area feeds into the Nature Recovery Network, and has high connective value for biodiversity. Habitat types to be created have been selected to extend the SSSI habitats and connect to similar habitats previously isolated by arable fields, for example joining up the wooded SSSI to nearby woodland fragments. However, high levels of public access will prevent high conservation value habitat in good condition from establishing.

a)

b)



c)

**Figure 2. Habitat configurations for delivering Biodiversity Net Gain under three different scenarios. a) Maximise value to local residents; b) Maximise biodiversity value; c) Balance access and biodiversity based on developer priorities. The pink blocks represent the habitats created, and the red line designates the boundary of the proposed development, next to an area of existing housing. For b) the blocked blue area is the Nature Recovery Network. Note the difference in spatial scale for b). The hatched green area in c) is the Site of Special Scientific Interest. See Supplementary Material 2 for details on habitat type and condition.**

### 3.2 Performance against assessment criteria

The scenarios perform quite differently against the assessment criteria (Table 3). In all cases, realistic configurations could be found that produced a biodiversity uplift of the required level (close to 145.8 units, using the Defra Metric). The amount of land required to achieve this was very different between the biodiversity-focussed scenario (scenario 2) and the other two; this is because, in the biodiversity-focussed scenario, options are available which score highly on habitat distinctiveness and condition if the requirements for local implementation and public accessibility are loosened. If the amount of biodiversity uplift per hectare is high, then the number of hectares required to reach the target is lower. This has knock-on effects on the cost of land purchase, making scenario 2 overall cheaper than the locally-focussed and balanced scenarios.

Prioritising local residents' values for offsets (scenario 1) lowers the potential additional biodiversity value of the habitats, since they are not strategically allocated for landscape-scale conservation and generally lie outside of the Nature Recovery Network. The overall gain in social utility from this scenario, calculated from a Discrete Choice Experiment aimed at the general Oxfordshire population (Butler et al. in review), is only slightly higher than the least-preferred scenario (scenario 2: biodiversity). This is because, in the latter, the longer distance and lack of access were balanced by local attitudes towards a potential increase in biodiversity, which residents valued highly relative to other attributes. The balanced scenario (scenario 3) gave substantially more utility in this simple analysis, because despite the reduction in access compared to local values, the relative increase in biodiversity value more-than-compensated for this. However, it is important to note that the nuances of site placements and residents' values for particular areas are not well represented in Choice Experiments.

**Table 3. Performance of the three scenarios against a range of dimensions for decision-making (listed in Table 2). The best-case values are in bold, and worst-case in italics, in each case. The proportional difference between the scenarios (listed in order of scenario 1, 2, 3) is calculated with 1 representing the lowest value in each case, in order to highlight the magnitude of the differences between scenarios for each dimension of analysis.**

| **Dimension** | **Scenario 1: Local values** | **Scenario 2: Biodiversity values** | **Scenario 3: Balanced values** | **Proportional difference between scenarios** |
|---|---|---|---|---|
| Total biodiversity units delivered (Defra Metric) | 148.35 | 145.99 | 147.02 | - |
| Additional area of nonurban habitat under management (ha) | **91.7** | *55.7* | 66.9 | 1.65 : 1 : 1.2 |
| Mean distance from local residents (m) | **1537** | *8215* | 1950 | 1 : 4.34 : 1.27 |
| % of habitat creation within the Nature Recovery Network | *7.2* | **100** | 95.9 | 1 : 12.89 : 12.32 |
| % area contributing to Priority Habitats | *0.0* | **46.1** | 17.2 | 1 : 46.1 : 17.2 |
| Restoration potential (unit change per ha without multipliers) | *2.05* | **10.80** | 3.09 | 1 : 4.27 : 1.51 |
| Unit delivery price (£) | £6,942,360 | **£6,789,120** | *£7,311,920* | 1.02 : 1 : 1.08 |
| Utility to local residents, (modelled coefficient) | 0.0108 | *-0.0118* | **0.140** | 1.92 : 1 : 12.86 |
| Additional carbon storage generated (vegetation and soil carbon stock mean (MgC/ha)) | 8599 | *4800* | **10391** | 1.79 : 1 : 2.16 |

The specifics of a given development are important in determining various outcomes. In particular, acquisition and ongoing management costs depend upon a range of factors beyond just the size and type of the land parcel, such as who currently owns the site and whether they would prefer to sell to the developer or a land manager (such as a conservation NGO), or to manage the land themselves. In this case, the land parcels identified in scenarios 1 and 2 are in private ownership, while those in scenario 3 are already owned by the developer so implementing biodiversity enhancements on these would be an opportunity cost rather than a land purchase cost. This scenario, therefore, might be expected to be the one most likely to be chosen, although the land parcels identified in scenario 2 were identified by BBOWT as potentially feasible to purchase, so this could also represent an option. The least likely to be implemented is scenario 1, where substantial land purchases would be required in a peri-urban area.

Finally, there is a lot of policy interest in the potential added value of biodiversity offsets for ecosystem service provision, such that the UK National Ecosystem Assessment (http://uknea.unep-wcmc.org/Resources/tabid/82/Default.aspx) discusses the need for Environmental Net Gain rather than Biodiversity Net Gain. Ecosystem services that could come into an evaluation of which scenario to choose might include flood risk mitigation, carbon sequestration, or cultural and recreational value (represented by access to green space, in our case). In our analysis we focussed on carbon sequestration potential, because this is one of the more robustly quantifiable ecosystem services. Two of the scenarios have a large component of woodland creation, in order to enhance biodiversity values and provide landscape connectivity; this also sequesters more carbon. The local values scenario has less sequestration potential because its mix of newly created habitats includes mixed woodland habitat preferred by stakeholders, whilst the balanced values scenario creates deciduous woodland only, which sequesters more carbon.

## 4 Discussion

The societal value of biodiversity can be inferred from policy commitments made by governments (such as Biodiversity Net Gain, or halting and reversing declines in species population abundance). The question, however, is how best to move from a societally-agreed biodiversity commitment to project-level operationalisation, such that biodiversity targets are met in a cost-effective way which also accounts for other societal values of nature, including accessibility and provision of ecosystem services. One approach would be to focus simply on the cost of delivery, and choose the cheapest set of biodiversity enhancements that meet a BNG target. This could be seen as tempting both for developers, and for local authorities seeking to maximise the delivery of other policy priorities such as affordable homes or transport infrastructure that developers might otherwise provide as part of their requirement to provide social value outcomes (in the UK, these are specified under a section 106 planning consent agreement).

However, two things mitigate against this as the best approach. Firstly, the values that local residents have for biodiversity are complex, place-based and deep-rooted (Diaz et al. 2018, Griffiths et al. 2020). Cost-efficiency plus a Section 106 agreement are unlikely to replace these values, particularly as values for nature are intertwined with the need for procedural and recognition equity through full participation in the planning process (Brennan and Sanchez 2012). Secondly, all biodiversity metrics are inadequate at representing the full suite of biodiversity, and the Defra Metric is no exception. For example, it is habitat-based and appears not to capture species richness or abundance well (Duffus et al. in press, Marshall et al. 2024). Therefore, the units calculated using the Defra Metric (or any other method for quantifying gains and losses in biodiversity) will always need to be supplemented with more nuanced and case-specific considerations that encompass a wider conceptualisation of biodiversity, if the intention of the policy (that biodiversity should, overall, be in a better state post-development than pre-development) is to be achieved in practice.

The framework which we have developed and trialled here strikes a balance between pragmatism and rigour, and could be useful as a way to expose and weigh up the social, economic and ecological outcomes of a range of scenarios for delivering BNG in an explicitly spatial manner. As a robust method that is relatively straightforward to implement, it would allow Local Planning Authorities, developers, or other interested parties to explore the implications of different configurations of biodiversity offsets on a range of dimensions.

In line with our research aim, we chose to trial a locally-informed, iterative method for choosing sites. However, even given the constraints of the configuration of the Oxfordshire landscape, a very large number of scenarios for allocation of particular land parcels to biodiversity offsets could be envisaged. One option for cutting through this complexity would be to use a Systematic Conservation Planning tool such as Marxan to produce solutions in a quantitative optimisation process (Smith et al. 2022). This, however, misses the nuance of local priorities and circumstances.

Our approach to weighing up the strengths and weaknesses of the different scenarios could be replaced with a more formal multi-criteria decision analysis (e.g. Esmail & Geneletti 2018, Andonegi et al. 2021), a Discrete Choice Experiment (e.g. Faccioli et al. 2024), or a full monetary valuation if desired (e.g. Wam et al. 2016). However, in many cases, the value of the framework we describe for developers or local planning authorities is likely to lie simply in the explicit laying out of the outcomes of a set of potential scenarios with regard to the different priorities that they are trying to trade off, as a foundation for deliberation.

In our case study, each of the three options (focussed on local access, additional biodiversity gains, or a balance) were beneficial on some of the ecological and social dimensions but not all. Broadly, as would be expected, the scenario focussed on meeting local needs produced large natural areas close to homes - large, because the areas were likely to be of lower biodiversity value and so more land was needed to fulfil the BNG requirements. On the other hand, areas selected for high biodiversity value required less land and gave high levels of biodiversity enhancement on a range of criteria beyond the basic BNG requirements, including contributions to Priority Habitats and the Nature Recovery Network. The total management costs did not vary strongly between these scenarios, indicating a larger cost per hectare for the biodiversity-focussed scenario.

In contradistinction to the findings of Mancini et al. (2024), who analysed the "bang for buck" of BNG offsets on agricultural land at the national level, we found that a scenario aiming to balance both ecological and social criteria at the local level performed relatively well. Mancini et al. (2024)'s modelling suggested that local offsets (as incentivised by current BNG policy) are severely suboptimal on both social and biodiversity criteria. This difference is attributable to our ability, when faced with the specifics of a particular local situation, to find sites which can feasibly supply reasonable levels of both social and biodiversity benefit.

Importantly, although our analysis emphasised the differences between pathways to achieving off-site biodiversity gain, in fact delivering natural areas valued by local residents and areas of high-quality biodiversity is not mutually exclusive. A potential approach to achieving both would be to deliver a proportion of the required off-site BNG units through a "local values" pathway and a proportion through a "biodiversity values" pathway. This could allow for the creation of locally accessible greenspace in addition to what is provided by on-site BNG, whilst also feeding finance into ambitious nature recovery projects with higher restoration potential.

Currently, it appears that the vast majority of biodiversity units under BNG are likely to be delivered on-site by developers (zu Ermgassen et al. 2021). This is facilitated by the ease with which the Defra Metric can be used to generate enough on-site biodiversity units despite the conversion of a substantial proportion of the area into the chosen infrastructure. However, our case study demonstrates that these calculations need to be reality-checked to ensure that they are actually deliverable; in this case we found a substantial proportion of the promised on-site biodiversity units were not deliverable (Supplementary Material 1). In the context of a housing project such as we have analysed, a high level of human pressure is likely, and promised biodiversity maintenance actions require ongoing investment of resources. Once the developer has handed over the site to users, there is little incentive to continue to provide the care required for Biodiversity Net Gain (e.g. maintenance of freshwater ecosystems, maturing woodlands and wildflower areas), or for other familiar mitigation and enhancement measures frequently required as part of the legally-binding commitments for planning permission (e.g. maintenance of reptile hibernacula and bat boxes). Our finding of a net loss of 18% in biodiversity units after inspecting the ecological feasibility is significant, and if occurring more widely, could lead to net gains on paper that are not translated to the real world. A recent study found that a large proportion of the non-BNG mitigation actions promised at the time of planning consent had not been delivered (Chapman et al. 2024), and research suggests BNG is likely to suffer from similar non-compliance levels due to a lack of ground-truthing and enforcement mechanisms, especially where the local planning authority is under-resourced (Rampling et al. 2024; Wentworth 2024). Potentially, if a framework such as the one proposed here was widely available and used, this could encourage Local Planning Authorities to ask more of developers. This could include contributing to off-site nature recovery and to meeting wildlife priorities for existing local residents, as well as raising their ambition regarding actions for biodiversity on-site. There may then be more of a market for offsets that are strategically positioned to maximise biodiversity value; if these were provided and managed by conservation NGOs they would have a better chance of delivering for nature than developer-managed sites.

Participatory processes are particularly important for local residents to feel that developments and associated offsets are responding to their needs and priorities (Brennan and Sanchez 2012). Studies such as Faccioli et al. (2024) show that there are strong overlaps between what people value and what is needed for biodiversity enhancement, as well as divergences. But setting these processes within an inclusive, strategic spatial planning framework is vital to ensure that project-level decisions genuinely contribute to landscape-scale nature recovery, and to sustainable development under Targets 1 and 14 of the Global Biodiversity Framework. Such a planning framework would enable other priorities which aren’t considered here - such as food production - to be included in decision-making, as well as minimising leakage of biodiversity impacts outside of the immediate project area. Importantly, in order to minimise trade-offs and find synergies, it is important to have clarity on which of the Government's many priorities should be targets or constraints, and which are dynamically optimisable. For example, if ambitious targets for house-building, nature recovery, food production and renewable energy infrastructure all must be met in the same space, without any flexibility, it is highly unlikely that an optimal solution will exist, let alone a set of potential scenarios to select between (zu Ermgassen et al. 2022). Therefore, a viable pathway towards sustainable development will also require broader systemic re-examination of how best to provide for human needs, and of opportunities to reduce the planetary impacts of infrastructure, beyond its immediate footprint.

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**Author contribution statement**

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**Supplementary Material 1: Discrepancy table.**

The difference in units between the on-site habitat creation/enhancement proposed by the developer and the habitat creation/enhancement deemed likely to occur given current conditions and expert knowledge of habitat creation feasibility (for example, based on expected levels of public pressure, expected achievable and enforceable management, existing neighbouring habitats, and site fertility scores).

| **Impossible/ infeasible within development footprint** | **Likely baseline habitat (the parcels are aggregated so cannot be matched up)** | **Creation/ enhancement** | **Promised parcel as labelled by developer** | **UKHab that the developer is promising** | **Developer's promised units** | **Proposed habitat by us (more likely)** | **Proposed units by us** | **Difference in developer's and our units** | **Reasoning for lack of feasibility and the disagreement in habitats** |
|---|---|---|---|---|---|---|---|---|---|
| Infeasible | Cropland | Creation | Long grass/ tussock mix | Moderate ONG | 124.72 | Poor ONG | 69.39 | 55.33 | Creation of moderate ONG from cropland is difficult for three broad reasons here: (1) establishment of an ONG that matches the UKHab description with indicator species is difficult from cropland with high chemical input and enrichment. High fertility will prevent ONG indicator species from establishing even with seeding. No baseline parcels tested were below 10mg/kg P.<br>(2) Ongoing management to maintain moderate ONG is difficult and time-consuming with correct cut timings, which haven't been explicitly mentioned in the Biodiversity Enhancement and Management Plan (BEMP).<br>(3) These previous two reasons are exacerbated by the on-site nature of the parcels – easy access in a highly populated area within the development suggests moderate ONG will be hard to maintain – as it will suffer from trampling and pollution/enrichment. Bare ground, sub-optimal species, and damage all contribute to lower condition score. |

| | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| Infeasible | Cropland | Creation | Wildflower grass mixes | Good ONG | 83.61 | Poor ONG | 37.06 | 46.55 | See above, except this time even harder to achieve good condition ONG from scratch. |
| Impossible | Cropland | Creation | Amenity grassland within residential areas | Poor MG | 20.84 | Un-vegetated garden | 0 | 20.84 | MG is being promised here within residential areas. No gardens (vegetated or otherwise) are included in the metric at all, so it has to be assumed that their summed area comes under "amenity grassland within residential areas". In the BEMP, no indication was given whether the developer would introduce an agreement that gardens were to be managed by residents in a particular way, therefore the highest that can be promised here is un-vegetated garden as there is no agreement residents will not remove grass. |
| Infeasible | Cropland | Creation | Amenity grassland | Moderate MG | 0.24 | Poor MG | 0.14 | 0.1 | Amenity grassland (as described by the developer) can be used for any recreation e.g. football pitch. So we cannot be certain that this habitat will achieve even 2+ floral species per metre squared. 6+ floral species are necessary for moderate condition MG. |
| Infeasible | Cropland | Creation | Native wet woodland | Moderate wet woodland | 13.85 | Poor wet woodland | 9.89 | 3.96 | Creation of moderate wet woodland from scratch (cropland) will be very difficult here within the target time to completion. Woodland condition scoring depends on criteria such as: presence of veteran trees (new creation = no ancient trees and there was no indication in the BEMP to create rotholes etc. for artificial veteran tree establishment), lack of enrichment and disturbance (influenced massively by previous chemical input plus easily accessible greenspace and damage), presence of deadwood (which was not mentioned in the BEMP until we influenced it), presence of several storeys and age classes of trees, presence of ancient woodland indicators or even NVC communities (unlikely given the timeframe of creation), lack of invasive species (which are present in the surrounding residential areas already). |

| | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| Infeasible | Cropland | Creation | Native woodland | Moderate other woodland; broadleaved | 28.13 | Poor other woodland; broadleaved | 20.08 | 8.05 | Same as above. We would argue only poor woodland creation is possible from cropland here. |
| Impossible | Cropland | Creation | Ornamental planting | Poor mixed scrub | 0.27 | Introduced shrub | 0.14 | 0.13 | Mixed scrub as a habitat type is reserved for self-established mostly native species, potentially with some wild-growing invasives, not for ornamental hedges and plants. There is a category for this in the metric: introduced shrub. |
| Impossible | Moderate traditional orchard | Enhancement | 7 | Moderate -> good traditional orchard | 3.41 | Moderate -> moderate traditional orchard | 0 | 3.41 | To move from moderate to good condition traditional orchard, there needs to be ancient or veteran trees created, which seems unlikely if there currently aren't. Furthermore, you must achieve many of these criteria: ground flora must be 9+ species per metre squared, at least 95% of trees are free from damage, less than 10% of ground cover is sub-optimal species e.g. white clover, nettles etc. These all seem infeasible in a residential orchard in the middle of a development. |
| Infeasible | Poor other woodland; broadleaved | Enhancement | 16 | Poor -> moderate other woodland; broadleaved | 7.41 | Poor -> poor other woodland; broadleaved | 0 | 7.41 | Enhancement from poor to moderate other woodland; broadleaved requires prescriptive management of which there was no detail e.g. preventing enrichment in a residential area with previous high chemical input, leaving deadwood if fallen, creating new veteran trees, seeding NVC communities, restricting disease, removing invasive plant species. This all seems unlikely in an accessible residential area that is close to houses. |
| TOTAL | | | | | | | | 145.78 | |

**Supplementary Material 2: Biodiversity Metric 3.1 calculations, satellite maps, and individual attributes for each parcel.**

Scenario 1: Local Values +148.35 units, average distance to Local Community Centre = 1537m, 0% area Priority Habitat

| Baseline Habitat | # | Area (ha) | Habitat created | Estimated cost per unit for habitat creation | Habitat distinctiveness | Habitat condition | Strategic significance | Spatial risk category | Units delivered | Unit change | Unit change * cost per unit | Distance of centroid to Local Community Centre (m) |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Cropland | 1.1 | 15.4 | Other neutral grassland | £42,000 | Medium | Poor | Low | Compensation inside LPA boundary or NCA of impact site | 57.36 | 26.56 | £1,115,520 | 710.64 |
| Cropland | 1.2 | 27.0 | Other woodland; mixed | £48,000 | Medium | Poor | Low | Compensation inside LPA boundary or NCA of impact site | 90.38 | 36.38 | £1,746,240 | 1053.47 |
| Cropland | 1.3 | 4.1 | Other neutral grassland | £42,000 | Medium | Poor | Low | Compensation inside LPA boundary or NCA of impact site | 15.27 | 7.07 | £296,940 | 1383.39 |
| Cropland | 1.4 | 2.5 | Modified grassland | £42,000 | Low | Good | Low | Compensation inside LPA boundary or NCA of impact site | 11.69 | 6.69 | £280,980 | 1444.46 |
| Cropland | 1.5 | 2.0 | Ponds (non-priority habitat) | £125,000 | Medium | Poor | Low | Compensation inside LPA boundary or NCA of impact site | 7.72 | 3.72 | £465,000 | 1113.37 |
| Cropland | 1.6 | 9.6 | Modified grassland | £42,000 | Low | Moderate | Low | Compensation inside LPA | 33.30 | 14.1 | £592,200 | 1344.77 |

| | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | | | | boundary or NCA of impact site | | | | |
| Cropland | 1.7 | 12.4 | Mixed scrub | £42,000 | Medium | Poor | Low | Compensation inside LPA boundary or NCA of impact site | 47.86 | 23.06 | £968,520 | 1380.92 |
| Cropland | 1.8 | 7.6 | Other woodland; broadleaved | £48,000 | Medium | Poor | Low | Compensation inside LPA boundary or NCA of impact site | 25.44 | 10.24 | £491,520 | 1580.84 |
| Cropland | 1.9 | 5.1 | Other woodland; mixed | £48,000 | Medium | Poor | High | Compensation inside LPA boundary or NCA of impact site | 19.63 | 9.43 | £452,640 | 2553.96 |
| Cropland | 1.10 | 6.0 | Other woodland; mixed | £48,000 | Medium | Poor | High | Compensation inside LPA boundary or NCA of impact site | 23.10 | 11.1 | £532,800 | 2804.82 |

Units at baseline: 183.40

Units post-development with no multipliers: 371.80

Difference with no multipliers: +188.40

Scenario 1: Local Values

Scenario 2: Biodiversity Values +145.99 units, average distance to Local Community Centre = 8215m, 46.1% area Priority Habitat

| Baseline Habitat | # | Area (ha) | Habitat created | Estimated cost per unit for habitat creation | Habitat distinctiveness | Habitat condition | Strategic significance | Spatial risk category | Units delivered | Unit change | Unit change * cost per unit | Distance of centroid to Local Community Centre (m) |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Cropland | 2.1 | 10.6 | Other woodland; broadleaved | £48,000 | Medium | Moderate | High | Compensation inside LPA boundary or NCA of impact site | 57.15 | 35.95 | £1,725,600 | 5793.89 |
| Cropland | 2.2 | 19.4 | Other neutral grassland | £42,000 | Medium | Moderate | High | Compensation outside LPA or NCA of impact site, but in neighbouring LPA or NCA | 112.02 | 73.22 | £3,075,240 | 7488.65 |
| Cropland | 2.3 | 18.0 | Lowland meadows | £54,000* | V. High | Moderate | High | Compensation outside LPA or NCA of impact site, but in neighbouring LPA or NCA | 57.40 | 21.4 | £1,155,600 | 9369.41 |
| Cropland | 2.4 | 7.7 | Lowland meadows | £54,000* | V. High | Good | High | Compensation outside LPA or NCA of impact site, but in neighbouring LPA or NCA | 30.82 | 15.42 | £832,680 | 10209.16 |

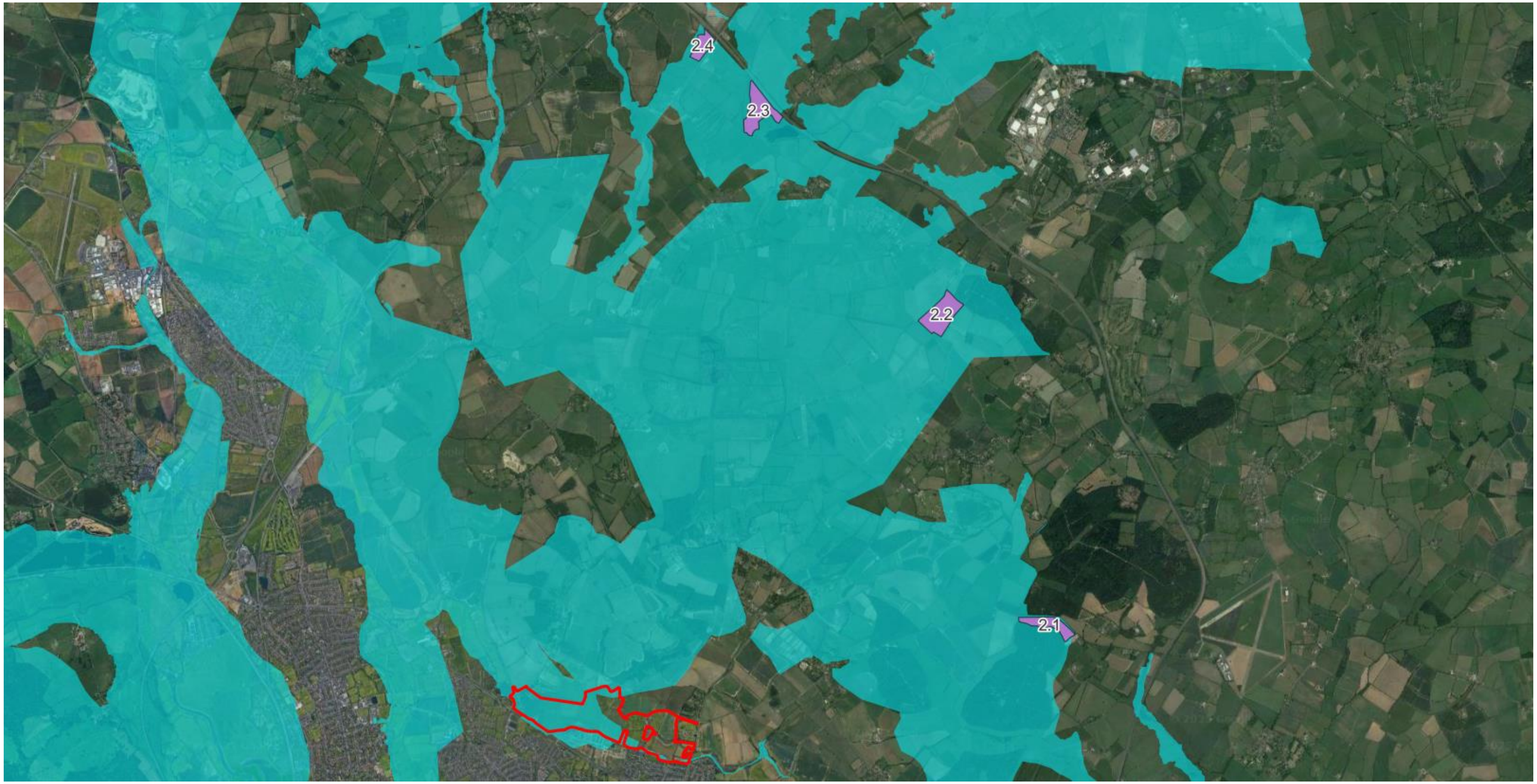
Units at baseline: 111.40

Units post-development with no multipliers: 712.80

Difference with no multipliers: +601.40

** Lowland Meadow is a very high distinctiveness habitat (not included in statutory credit prices), so the cost per unit for this habitat type is estimated from the statutory credit price trajectory moving from medium to high distinctiveness grasslands i.e. medium distinctiveness grassland credit price = £42,000; high distinctiveness grassland credit price = £48,000; difference = £6,000.*

Scenario 2: Biodiversity Values



Scenario 3: Balanced Values +147.02 units, average distance to Local Community Centre = 1950m, 17.2% area Priority Habitat

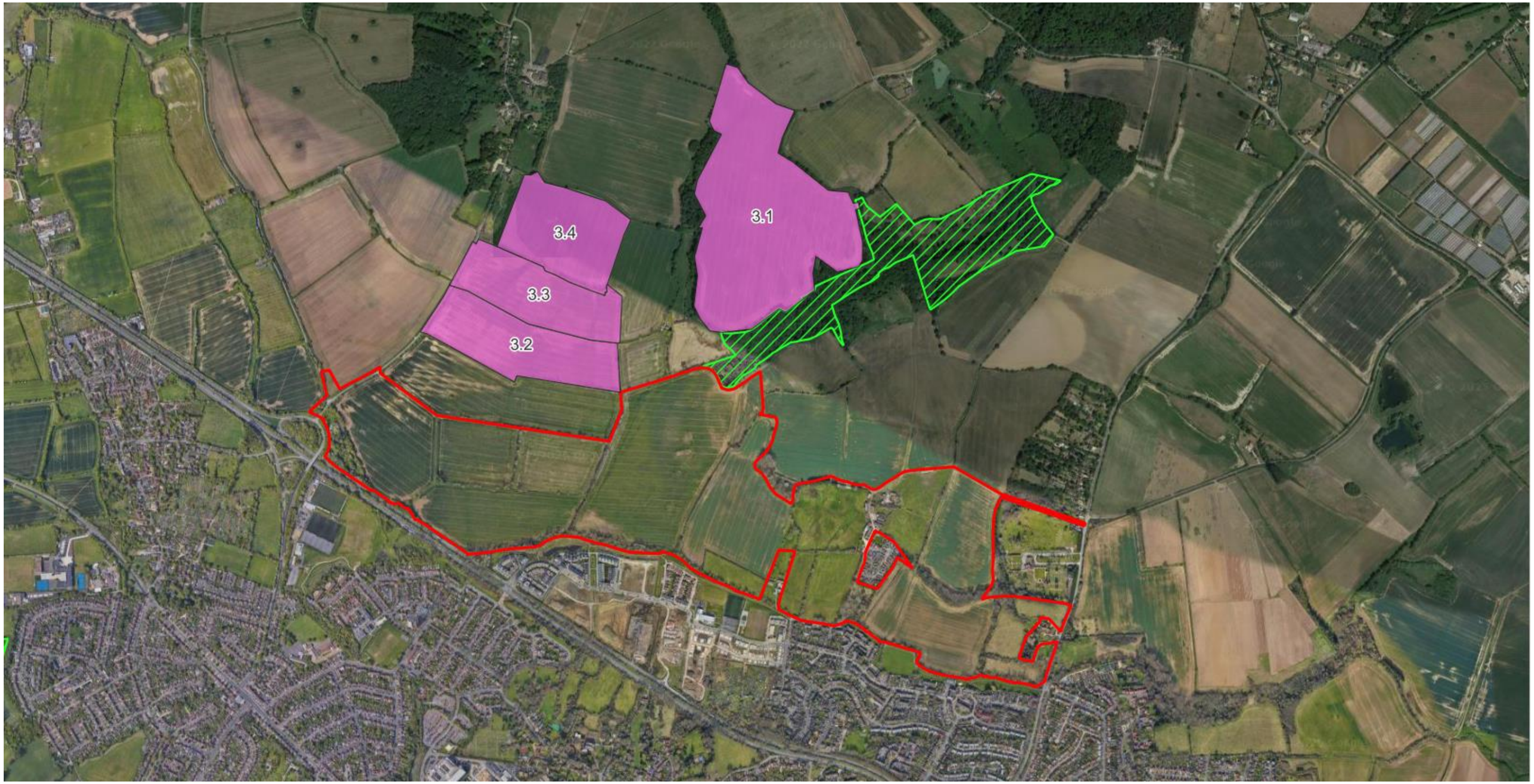
| Baseline Habitat | # | Area (ha) | Habitat created | Estimated cost per unit for habitat creation | Habitat distinctiveness | Habitat condition | Strategic significance | Spatial risk category | Units delivered | Unit change | Unit change * cost per unit | Distance of centroid to Local Community Centre (m) |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Cropland | 3.1 | 32.3 | Other woodland; broadleaved | £48,000 | Medium | Poor | High | Compensation inside LPA boundary or NCA of impact site | 124.34 | 59.74 | £2,867,520 | 1781.89 |
| Cropland | 3.2 | 12.4 | Other neutral grassland | £42,000 | Medium | Moderate | High | Compensation inside LPA boundary or NCA of impact site | 95.47 | 70.67 | £2,968,140 | 1929.07 |
| Cropland | 3.3 | 10.7 | Modified grassland | £42,000 | Low | Moderate | High | Compensation inside LPA boundary or NCA of impact site | 42.68 | 21.28 | £893,760 | 1997.31 |
| Cropland | 3.4 | 11.5 | Lowland mixed deciduous woodland | £125,000 | High | Poor | High | Compensation inside LPA boundary or NCA of impact site | 18.34 | -4.66 | £582,500 | 2090.96 |

Units at baseline: 133.80

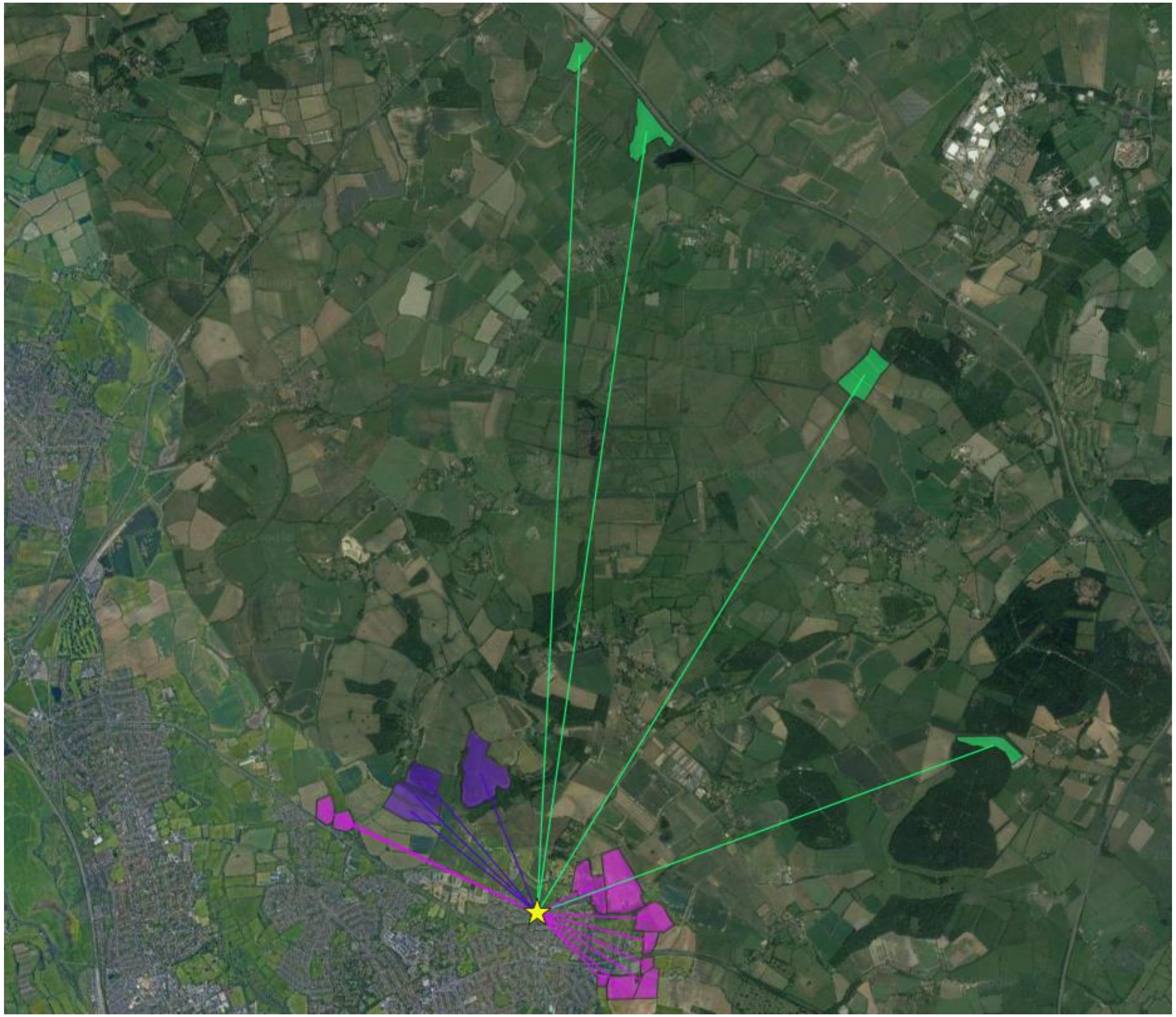
Units post-development with no multipliers: 340.20

Difference with no multipliers: +206.40

Scenario 3: Balanced Values



**Supplementary Material 3: Distances of each habitat creation parcel to Local Community Centre.**



**Supplementary Material 4: Computation of dimension 'utility to local residents'.**

To calculate the utility scores for each scenario a linear utility function, parameterised by the results of a Multinomial Logit Model (MNL), was used to populate a matrix of scenarios based on combinations of choice attributes in R (RStudio, 2020). Utility in this context, in line with Random Utility Theory (Czajkowski & Hanley 2012; McFadden, 1974, 1980), assumes a utilitarian-welfarist epistemology, reflecting an individual's subjective judgement of welfare provided by sets of non-market goods. Using the results of a separate study (Butler et al. in review) the MNL modelled the preferences of 396 regional residents for Biodiversity Net Gain offset outcomes associated with local housing development. The original choice experiment was of an unlabelled, symmetric design and consisted of five qualitative attributes which represents material outcomes of the development-offset process that could be retro-fitted to the scenarios outlined in this paper. These included outcomes related to proportion of the BNG that was delivered off-site (i.e., outside and away from the boundaries of the new development site); the distance of the offset site from the original site of impact (which was within 5km, 20km or 50km of any given respondent's home); the level of species richness produced by the biodiversity net gain offset in its final form; the presence/absence of public access at the offset site (presence/absence of footpaths); and the provision of affordable housing within the new development.

The linear utility function is the default or standard specification within the choice experiment and analysis literature (Sennhauser, 2010) as opposed to non-linear specifications (such as step-wise or quadratic) and assumes that the marginal utility associated with the substitution of one attribute for another is constant. Goodness of fit testing and comparison (i.e., Akaike information criterion; Bayesian information criterion; and McFadden adjusted $R^2$) indicated that a linear form was superior. The linear specification for the choice model estimated can be seen as a linear additive function expressed as $U_{ij} = \beta X_j S_i + \varepsilon_{ij}$ where ($U$) denotes the utility value derived by an individual ( *i* ) in alternative ( *j* ), which is dependent on the observable characteristics of that outcome ($\beta$) and the systematic element ($X$) of the alternative *j* and the socio-economic characteristics of the individual ($S_i$), in addition to a random error element ($\varepsilon$) that varies over alternatives and individuals.

For the purposes of demonstration, utility scores were computed for attribute combinations that broadly correspond to our scenarios. A simple linear utility function containing only the coefficients and systematic element was considered sufficient for the purposes of this abstract exercise, while error term is implicitly accounted for in the probabilistic framework of the MNL. We are also satisfied with mean effect, or *expected utility,* rather than its variability across the population and therefore excluded $S_i$. This can be expressed in the equation ($U = \beta 0 + \beta 1 \cdot a1 + \beta 2 \cdot a2 + \beta 3 \cdot a3$ ….). β0 denotes the coefficient of the constant which can be ignored here given it does not vary across alternatives, while the rest (i.e., β1; β2…) denote coefficient values for each attribute to be multiplied by the severity, or level, of that attribute (i.e., *a1, a2…)*.

The MNL estimates for each attribute included in the original analysis were (standard errors are in parentheses):

| ***Offsite %*** | | ***Distance*** | ***Public access*** | ***Species Richness*** | ***Affordable Housing %*** |
|---|---|---|---|---|---|
| **.118** | **[*.03*]** | **-.13** | **.679** | **.459** | **.263** |
| | | **[*.03*]** | **[*.05*]** | **[*.04*]** | **[*.03*]** |

Therefore, the basic utility function used to calculate scores is:

$$U = .118 \cdot Offsite - .13 \cdot Distance + .679 \cdot \textit{Public access} + .459 \cdot \textit{Species richness} + .263 \cdot \textit{Affordable housing}$$

For the purposes of this demonstration, we assume that each variable can take one of three levels, effectively Low (or zero), Medium, or High, which we describe below as Levels 1, 2, or 3. As the formula is linear and additive, while the theoretical scenarios constructed do not incorporate trade-offs that might associated with the provision of affordable housing, it is assumed for each scenario that the level for the affordable housing is constant, being fixed at the reference level of 10% (i.e., level 1), which reflects the minimum counselled by the UK government's National Planning Policy Framework. This would therefore not necessitate any additional investment or economic opportunity cost from the standing of stakeholders involved. The proportion of the offset that is delivered off-site (i.e., offsite %) is also held constant at 50% (i.e., level 2) for the purposes of this analysis (although in reality the units are not divided equally in this fashion). This is to reflect the fact that this value does not vary between options, given that every offset is necessitated by the same deficit and delivery of units in order to achieve the additional 10% target.

The application of the linear function to compute utility for each scenario was performed in R by first generating a matrix of utility scores for every possible combination of attribute level while allowing for increments of 0.5 (except for affordable housing which was fixed at level 1; and offsite % which was fixed at level 2). Access was coded binarily from 0 (= no public access) to 1 (= public access). Therefore, coefficients reflect the difference in utility relative to the reference category. This means that for this exercise we are not able to say whether absolute utility is negative or positive.

In this case, as the relationships are linear, each level additional to the reference level results in a proportionate gain in utility. For example: Species richness at level 1 (= *b * 1* = 0.458); at level 2 (= *b* * 2 = 0.918); at level 3 (= *b* * 3 = 1.377).

To enable useful comparison the utility scores for our three scenarios within this hypothetical space of possible options and the distribution of values, we normalised scores using 0 as a mid-point so that scores fell between -1 and 1 following min-max normalisation routine $(i.e., Normalised\ U = \frac{U - \text{Min}\ U}{Max\ U - Min\ U}\ x\ 2 - 1$The *maximum utility* identified = 2.426 , while the *minimum utility* = 0.568, relative to the reference point of 10% affordable housing, 10access.

**Scenario 1 (Local values)**

This encapsulates the principle of nearby net-gain for local people, maximising for closeness and accessibility, but incurring a trade-off whereby it supposed that the level of biodiversity (here conceived as species richness) that can be realistically supported under these circumstances is penalised. The *distance* of the net-gain site from the site of development is assumed to be minimal, therefore *a2* = 1; *public access* is assumed to be present at the net-gain site, therefore *a3* = 1; while the level of *species richness* supported by the net-gain site is assumed to be minimal, therefore *a4* = 1.

The computation for this scenario ($_{s1}$) is as follows:

**Varied attribute levels**: Distance = 1; Access = 1; Species richness = 1

$U_{s1}$ = (0.118*2) - (0.13*1); + (0.679*1) + (0.459*1) + (0.263*1)

$U_{s1}$ = 0.236 – 0.13 + 0.679 + 0.459 +0.263 = 1.507

$U_{s1}$ = 1.5073 (*SE* = 0.079)

$$Normalised\ U_{s1} = \frac{1.507 - .568}{2.426 - .568}\ x\ 2 - 1 = .01$$

$$Normalised\ U_{s1} = .0108$$

**Scenario 2 (Biodiversity values)**

This reflects a biodiversity banking approach, maximising for biodiversity outcomes, at the cost of public access and closeness. The *distance* of the net-gain site from the site of development is assumed to be maximal, therefore *a2* = 3; *public access* is assumed to be non-existent at the net-gain site, therefore *a3* = 0; while the level of *species richness* supported by the net-gain site is assumed to be high, therefore *a4* = 3.

The computation for this scenario ($_{s2}$) is as follows:

**Varied attribute levels**: Distance = 3; Access = 0; Species richness = 3

$U_{s2}$ = (0.118*2) - (0.13*3) + (0.679*0) + (0.459*3) + (0.263*1)

$U_{s2}$ = 0.236 - 0.39 + 1.377 + .263 = 1.486

$U_{s2}$ = 1.486 (*SE* = 0.169)

$$Normalised\ U_{s2} = \frac{1.486 - .568}{2.426 - .568}\ x\ 2 - 1 = -0\ .11$$

$$Normalised\ U_{s2} = -0.0118$$

**Scenario 3 (Balanced values)**

This conveys a developer-led approach and therefore tries to incorporate the observed trends to date while providing a useful alternative for comparison. This is characterised by local off-site provision convenient for the developer rather than the local community, balanced access, and moderate biodiversity outcomes due to the public having some access. The *distance* of the net-gain site from the site of development is assumed to be minimal, therefore $a2$ = 1; *public access* is assumed to be moderate but restricted at the net-gain site, therefore $a3$ = 2; and the level of *species richness* supported by the net-gain site is also assumed to be moderate, therefore $a4$ = 2.

The computation for this scenario ($_{s3}$) is as follows:

**Varied attribute levels**: Distance = 1; Access = 0.5; Species richness = 2

$U_{s3}$ = (0.118*2) - (0.13*1) + (.679*0.5) + (.459*2) + (0.263*1)

$U_{s3}$ = 0.236 – 0.13 + 0.34 + 0.918 + 0.263 = 1.627

$U_{s3}$ = 1.627 (*SE* = 0.107)

$$Normalised\ U_{s2} == \frac{1.627 - .568}{2.426 - .568}\ x\ 2 - 1 = 1.627$$

$$Normalised\ U_{s2} = 0.140$$