Journal of Environmental Management 299 (2021) 113622

Contents lists available at ScienceDirect

Journal of Environmental Management

journal homepage: www.elsevier.com/locate/jenvman

Metrics for environmental compensation: A comparative analysis of Swedish municipalities

Tore Söderqvist [a], Scott Cole [b], Frida Franzén [c], Linus Hasselström [d], Thomas H. Beery [e], Fredrik Bengtsson [f], Helena Björn [g], Elsie Kjeller [h], Erik Lindblom [i], Anna Mellin [i], Johanna Wiberg [j], K. Ingemar Jönsson [h,*]

[a] *Anthesis Enveco AB, Barnhusgatan 4, SE-111 23 Stockholm, Sweden*
[b] *EnviroEconomics Sweden Consultancy, Grantäppevägen 3, SE-461 58 Trollhättan, Sweden*
[c] *Tyréns AB, Peter Myndes Backe 16, SE-118 86 Stockholm, Sweden*
[d] *Department of Sustainable Development, Environmental Science and Engineering, KTH Royal Institute of Technology, SE-100 44 Stockholm, Sweden*
[e] *Department of Mathematics and Science Education, Kristianstad University, SE-291 88 Kristianstad, Sweden*
[f] *Department of City Planning, Helsingborg Municipality, SE-251 89 Helsingborg, Sweden*
[g] *Section of Planning, Lomma Municipality, Hamngatan 3, SE-234 81 Lomma, Sweden*
[h] *Department of Environmental Science and Bioscience, Kristianstad University, SE-291 88 Kristianstad, Sweden*
[i] *IVL Swedish Environmental Research Institute, Box 21060, SE-100 31 Stockholm, Sweden*
[j] *Ecogain AB, Västra Norrlandsgatan 10 D, SE-903 27 Umeå, Sweden*

ARTICLE INFO

Keywords:
No net loss
Net gain
Biodiversity offset
Mitigation hierarchy
Balancing principle
Spatial planning

ABSTRACT

Environmental compensation (EC) aims at addressing environmental losses due to development projects and involves a need to compare development losses with compensation gains using relevant metrics. A conceptual procedure for computing no net loss is formulated and used as a point of departure for a comparative analysis of metrics used by five Swedish municipalities as a part of their EC implementation in the spatial planning context of detailed development plans. While Swedish law does not require EC in this context, these municipalities have still decided to introduce EC requirements for development projects that occur on municipality-owned land and to promote voluntary EC among private actors in development projects on private land. There is substantial variation across the municipalities studied with respect to both metrics and attributes subject to measurement, but there are also similarities: The attributes considered when assessing the need for EC in conjunction with development are not only about nature per se, but also about recreational opportunities and other types ecosystem services; semi-quantitative metrics such as scores are common while quantitative or monetary metrics are rare; and metrics are rarely applied to assess compensatory gains, focusing instead on losses from development. Streamlining across municipalities might be warranted for increasing predictability and transparency for developers and citizens, but it also introduces considerable challenges such as a need for developing consistent guidelines for semi-quantitative metrics, and to handle substitutability issues if metrics are not only applied on individual attributes but also on groups of attributes. The broad scope of attributes used by the municipalities is in line with an international tendency to broaden EC to include not only biodiversity aspects but also ecosystem services. Moreover, the EC systems applied by the municipalities are of particular importance for highlighting the crucial role of environmental management for maintaining and enhancing biodiversity and ecosystem services not only in areas having formal protection status but also in the everyday landscape. The municipalities' experience and strengths and weaknesses associated with their EC systems are therefore relevant also in an international perspective.

* Corresponding author.
E-mail address: ingemar.jonsson@hkr.se (K.I. Jönsson).

https://doi.org/10.1016/j.jenvman.2021.113622
Received 15 March 2021; Received in revised form 16 June 2021; Accepted 23 August 2021
Available online 31 August 2021

1. Introduction

Environmental compensation (EC), often called biodiversity offsetting, aims at addressing environmental losses due to development projects. The increasing pressures on biodiversity and nature's capacity to supply ecosystem services to humans necessitate action (COM, 2020; IPBES, 2019), and EC is one tool available for reversing the trend. For example, the EU Biodiversity strategy for 2020 (Action 7 in COM, 2011) acknowledged that EC has a role to play in achieving no net loss (NNL) of biodiversity and ecosystem services, and the updated strategy for 2030 (COM, 2020) suggests a net-gain principle. Thus, EC has a broad scope, covering not only biodiversity as such but also the various economic, social and cultural aspects associated with ecosystem services (BBOP, 2012a; Calvet et al., 2015; COM, 2011; Jacob et al., 2016; Lipton et al., 2018).

EC is typically viewed as a conservation measure to be applied as the last step of a mitigation hierarchy, where negative environmental impact of development projects should first be avoided (if possible); unavoidable impacts are to be minimized or restored, and finally any residual loss ("the debit") is compensated for. Compensation gains can occur in terms of creating or enhancing environmental resources ("the credit"), either at the development site ("on-site EC") or elsewhere ("off-site EC") (Arlidge et al., 2018; BBOP, 2012b; Maron et al., 2012; Moilanen and Laitila, 2016). NNL is achieved if the gain accomplished by an EC project is at least equivalent to the residual loss caused by the development (BBOP, 2012b; COM, 2014).

The broad scope of EC and the urgency to ensure credits at least as large as debits suggests an intricate question: How to measure losses and gains to be able to assess whether an EC project results in NNL, net gain or net loss? One purpose of this paper is to review how this challenge has been approached in EC initiatives among Swedish municipalities and identify similar and distinguishing features with respect to metrics *sensu* Dickie et al. (2013), i.e., a set of measurements enabling comparisons between losses and gains.

The problem of matching loss with gain is integral to EC practice. Three main types of equivalency methods can be distinguished, each using one or several semi-quantitative (e.g., scores), quantitative and/or monetary metrics, while also accounting for the value of time (Cole, 2013; Lipton et al., 2018): (1) habitat equivalency analysis (HEA), where habitat quality and/or habitat quantity is used as a metric; (2) resource equivalency analysis (REA), where environmental resource-specific metrics are used instead of habitat metrics, e.g., biomass of fish or the quantity of a specific species, and (3) value equivalency analysis (VEA), which goes beyond the biophysical equivalency considered by HEA and REA by expressing losses and gains in terms of how they affect human wellbeing. VEA typically applies valuation methods developed in environmental economics for measuring human wellbeing change in a monetary metric, see, e.g., Freeman et al. (2014) on such methods. Application of these methods in both the EU and US has historically produced a substantial variety of metrics, and publications addressing this topic continue to increase, see examples in Lipton et al. (2018) and Wende et al. (2018a). For biodiversity, relatively good availability of data on landscape or habitat patterns is likely to explain a prevalence of metrics based on habitat attributes and area, but such metrics might not capture essential aspects such as ecological and species population processes (Marshall et al., 2020). Additional challenges associated with metrics arise because EC applications are, not uncontroversially (Jacob et al., 2016; Persson, 2013), expanding in scope from biodiversity to a range of different ecosystem services (Sonter et al., 2020) and in different ecological, political, economic, social and cultural contexts (Carreras Gamarra et al., 2018). These challenges include how changes in the provision of ecosystem services should be measured for adequately reflect the impact on human wellbeing, taking into account also fairness with respect to current and future generations (Agarwala et al., 2014; Costanza, 2020; Dasgupta, 2021). In addition, widening the EC scope to ecosystem services might result in less attention to nature's non-instrumental values, whose safeguarding is demanded, not least in an EC context (Cole et al., 2021; Edvardsson Björnberg, 2020).

This situation suggests a considerable need to review experience of various metrics in different contexts. This paper contributes to building such knowledge by comparing EC systems applied by municipalities (local authorities) in Sweden. To the best of our knowledge, this has not been done before in the structured and detailed way applied in this paper. A more general and descriptive summary of municipal EC systems was included in a recent Swedish government inquiry, which had the broader purpose of reviewing the Swedish EC context and experience as a whole and suggest measures that could improve EC practice (SOU, 2017). The Swedish Environmental Code includes provisions for EC in the case of development projects expected to have substantial environmental impacts; see Persson et al. (2015) for a review of the use of EC in the case of major infrastructure projects. There are Swedish national governmental EC guidelines for such development projects, not recommending any specific metrics, but acknowledging the considerable challenges of quantifying loss and gain and suggesting that semi-quantitative metrics are in some cases a necessary option (Swedish EPA, 2016).

However, the Swedish Environmental Code's EC provisions rarely apply for locally-permitted projects such as residential, commercial/retail, and/or business development, including associated local infrastructure such as roads. While such projects may not involve environmental impacts major enough to require approval via the Swedish Environmental Code, projects of this kind can still be environmentally harmful from a local perspective, especially when viewed from the cumulative effect of many projects (Conway et al., 2013). This puts municipalities' spatial planning through detailed development plans (DDPs, Swedish: *detaljplaner*) into spotlight, because DDPs are a key instrument for regulating development on a local scale. Pursuant to the Swedish Planning and Building Act, DDPs empower Sweden's 290 municipalities to regulate land and water use and oversee the built environment, including the use and design of public spaces (Boverket, 2018). However, the Swedish Planning and Building Act is not fully applicable for introducing EC requirements (via, e.g., DDPs), although such provisions were suggested by the recent government inquiry (SOU, 2017). Nevertheless, some Swedish municipalities encourage the use of EC for development projects on privately owned land through voluntary agreements with developers, and have introduced their own EC requirements for development projects occurring on municipality-owned land. In total, Swedish municipalities own about 2% of the Swedish land area (Statistics Sweden, 2019a), but this proportion varies substantially across individual municipalities, and municipality-owned land tends to be often appropriate for new development (Caesar, 2016). For example, 97% of Swedish municipalities recently reported that they own land suitable for housing (Boverket, 2020).

The use of EC in Swedish municipalities dates back to the late 1990s when pioneering attempts were made to introduce "the balancing principle" into spatial planning in some municipalities in the southernmost part of Sweden (Rundcrantz and Skärbäck, 2003; Skärbäck, 1997). The principle was inspired by the German EC system and is similar to the mitigation hierarchy mentioned above, but it makes a distinction between on-site EC (Swedish: *utjämna*) and, as a secondary option, off-site EC (Swedish: *ersätta*), where a site can be defined as the area covered by a DDP (Skärbäck, 1997). Therefore some Swedish municipalities can be expected to possess important EC experience in the case of environmental impact that might not be regulated through the Swedish Environmental Code but still might have considerable ecological, economic, social and cultural impact locally. For example, the everyday landscape in terms of green spaces such as parks, groves and woods within or close to dwelling areas might not have any formal nature protection status, but might still be of considerable importance for both biodiversity and people's wellbeing (Parris et al., 2018; Shanahan et al., 2016). What types of impacts have municipalities been most concerned about when applying their EC systems? What metrics have been applied for those impacts and how is an objective such as NNL assessed? Are there differences and similarities in the metrics across municipalities?

This paper aims at answering these questions by reviewing the EC systems of a sample of Swedish municipalities. We first developed a general conceptual structure for characterizing types of impact and associated metrics that allowed us to compare these aspects across municipalities. This conceptual structure, which also defines NNL in a mathematically succinct way, is presented in Section 2.1. The data collection including the selection of municipalities are described in Section 2.2. Section 3 contains the results of the review and comparison, which are then discussed in Section 4, followed by conclusions in Section 5.

2. Method and materials

2.1. A conceptual structure for comparing EC systems

We have developed a conceptual three-step procedure detailing how metrics are applied to assess and compare losses and gains, to evaluate the NNL criterion. The procedure is presented by using a hypothetical and simple example of a site to be developed, where all steps are summarized mathematically in a more general format. The procedure is purposely stylized for enabling a structured comparison across municipalities; some relevant and real-world complications are mentioned after the third step. The procedure is subsequently applied in Section 3 for the selected municipalities (described in Section 2.2).

2.1.1. Step 1: Identify relevant attributes of the development site

The point of departure for this step is a gross list of attributes of a development site that are to be considered for compensation if they are partly or completely lost due to development. The first step entails identifying which attributes in such a gross list are present at the site.

For the sake of simplicity, assume a gross list consisting of the following three attributes: Recreational use (denoted by z_1), meadow biotope (z_2) and forest biotope (z_3). Assume also that only the first two attributes are present at the site, which means that these two constitute a net list of attributes for the site.

General formulation of Step 1:

- The set $Z_{gross} = \{z \mid z$ is all attributes considered for compensation$\}$ is a gross list of attributes.
- $Z_{net} = \{z_1, \ldots, z_i, \ldots, z_n\}$ is a net list of the n attributes present at the site, where $Z_{net} \subsetneqq Z_{gross}$.

2.1.2. Step 2: Assess the loss in the attributes due to development

This step includes applying a set of metrics that defines a loss in each attribute. A loss is a change, meaning that a baseline, such as the pre-development situation, is generally needed for assessing the degree of severity of the loss. For example, the consequences of a 1-ha loss in a biotope might differ depending on whether the biotope's initial extent was 10, 100 or 1000 ha.

Assume that for recreational use, a semi-quantitative metric is applied by a point scale that can take the values of 1, 2 or 3 (p_1). For meadow biotope, the number of hectares (p_2) is applied. The pre-development values for the two attributes, denoted by subindex *pre-dev*, are $p_{1,pre\text{-}dev}$ and $p_{2,pre\text{-}dev}$, respectively. Assume that the pre-development values are $p_{1,pre\text{-}dev} = 3$ points for recreational use and $p_{2,pre\text{-}dev} = 10$ ha for the meadow biotope. The metrics are subsequently applied for assessing the post-development value (if no compensation is carried out), denoted by subindex *post-dev*. Assume that $p_{1,post\text{-}dev} = 1$ point and $p_{2,post\text{-}dev} = 4$ ha.

The loss is defined as the difference between the pre-development value and the post-development value for each of the attributes. For recreational use, this means that the development implies a reduction from 3 points to 1 point, i.e., the loss is 2 points. The meadow biotope is reduced from 10 ha to 4 ha, i.e., the loss is 6 ha. Denoting the loss for the two attributes by l_1 and l_2, this means that $l_1 = 3 - 1 = 2$ points and $l_2 = 10 - 4 = 6$ ha.

General formulation of Step 2:

- The set $P = \{p_1, \ldots, p_i, \ldots, p_n\}$ is a list of metrics associated with each of the n attributes in Z_{net}.
- $[p_{1,pre\text{-}dev} \cdots p_{i,pre\text{-}dev} \cdots p_{n,pre\text{-}dev}]$ is a $1 \times n$ matrix $\boldsymbol{P}_{pre\text{-}dev}$ with pre-development values of the attributes.
- $[p_{1,post\text{-}dev} \cdots p_{i,post\text{-}dev} \cdots p_{n,post\text{-}dev}]$ is a $1 \times n$ matrix $\boldsymbol{P}_{post\text{-}dev}$ with post-development values of the attributes.
- $[l_1 \ldots l_i \ldots l_n]$ is a $1 \times n$ matrix $\boldsymbol{L}$ with losses in attributes, where $\boldsymbol{L} = \boldsymbol{P}_{pre\text{-}dev} - \boldsymbol{P}_{post\text{-}dev}$.

2.1.3. Step 3: Assess the gain and the net gain in the attributes due to compensation

The extent of the losses in the attributes found in Step 2 can be used to inform the extent and scale of a compensation project for achieving gains. The gain implied by the compensation project is defined as the difference between the post-compensation value and the pre-compensation value; this gain is for each of the attributes, where the metrics in P are again applied. Note again the need for a baseline, here termed as the pre-compensation value, measured at the site where compensation takes place. This value is equal to the post-development value if compensation is to be performed on-site, but if compensation is to be performed at a different location than the development site (off-site EC), the baseline at that site will determine the pre-compensation value.

For the two attributes in the example, assume that a compensation project entails an increase in recreational use amounting to $3 - 1 = 2$ points and an increase in meadow biotope of $121 - 114 = 7$ ha. This implies a net gain of $2 - 2 = 0$ points for recreational use and $7 - 6 = 1$ ha for meadow biotope. Denoting the gain by g_1 and g_2, this can be expressed as $g_1 = p_{1,post\text{-}comp} - p_{1,pre\text{-}comp} = 3 - 1 = 2$ points and $g_2 = p_{2,post\text{-}comp} - p_{2,pre\text{-}comp} = 121 - 114 = 7$ ha (indicating off-site EC since $p_{2,pre\text{-}comp}$ is not equal to $p_{2,post\text{-}dev}$). The net gain v_1 for recreational use amounts to $g_1 - l_1 = 0$ and the net gain v_2 for meadow biotope amounts to $g_2 - l_2 = 1$. This compensation project would thus give a no net loss because $v_i \geq 0$ for both z_1 and z_2.

General formulation of Step 3:

- $[p_{1,pre\text{-}comp} \cdots p_{i,pre\text{-}comp} \cdots p_{n,pre\text{-}comp}]$ is a $1 \times n$ matrix $\boldsymbol{P}_{pre\text{-}comp}$ with pre-compensation values of the attributes.
- $[p_{1,post\text{-}comp} \cdots p_{i,post\text{-}comp} \cdots p_{n,post\text{-}comp}]$ is a $1 \times n$ matrix $\boldsymbol{P}_{post\text{-}comp}$ with post-compensation values of the attributes.
- $[g_1 \ldots g_i \ldots g_n]$ is a $1 \times n$ matrix $\boldsymbol{G}$ with gains in the attributes, where $\boldsymbol{G} = \boldsymbol{P}_{post\text{-}comp} - \boldsymbol{P}_{pre\text{-}comp}$.
- The net gains $[v_1 \ldots v_i \ldots v_n]$ is a $1 \times n$ matrix $\boldsymbol{V}$, where $\boldsymbol{V} = \boldsymbol{G} - \boldsymbol{L}$.
- No net loss (NNL) is defined as the situation where $v_i \geq 0 \; \forall \, i = 1, \ldots, n$.

2.1.4. Some observations regarding the steps

As will be evident from Section 3, this stylized three-step procedure will inevitably meet many complications in a real-world setting. One such complication is that the compensation project may have other consequences beyond mitigating the development project's specific impacts. For example, assume that the only identified impact of a development project is a reduction of a wetland biotope, which might be compensated by converting an off-site lawn to a wetland. However, the lawn might have a social function as a meeting place that can be affected by the conversion. This complication illustrates the importance of a comprehensive damage assessment that considers all relevant attributes when assessing the impacts of the development project and the compensation project, respectively.

An additional example of a complication is whether some substitutability among attributes should be allowed or not. This could mean that a net loss in one attribute is allowed to be compensated for by a sufficiently large net gain in another attribute. In practice, accepting such trade-offs could be manifested by aggregating individual attributes into groups of attributes and assess losses and gains at a group level. This approach suggests a need for applying metrics that allow aggregation, e.g., a monetary metric or a rule for how points given for individual attributes can be transformed to points for a group of attributes. Monetization of losses and gains of attributes suggests substitutability and also the possibility to assess NNL at aggregated levels, including at a total level for all attributes. However, aggregation might be controversial; for example, an aggregation through averaging might imply that a substantial loss in one individual attribute (which might be of importance for a specific group in society) is masked by small losses in the other attributes included in the aggregation. See, e.g., BBOP (2012b) for aggregated vs. disaggregated metrics.

A third example is the complications in defining baselines. For example, a gain in an attribute might be overestimated if a generally declining trend in that attribute is not taken into account at the compensatory site; alternatively, a loss may be underestimated if the damage site is undergoing an environmental improvement. See, e.g., Bull et al. (2014), Darbi and Tausch (2010), Maron et al. (2015, 2018) and Peterson et al. (2018) on static and dynamic debiting and crediting baselines.

As a final example, several compensation possibilities might have been identified that fulfill an objective such as the NNL criterion, which implies a need for criteria that are of help for the final selection of the compensation project. Several selection criteria have been suggested, see, e.g., Lipton and LeJeune (2018), UN (2003), US OPA (1990). One example is cost-effectiveness, i.e., selecting the compensation project that fulfills an objective to the lowest possible costs.

2.2. Municipality data on EC metrics

Municipalities included in the analysis were selected based on three criteria: (i) the existence of an established and written routine for applying EC in the DDP process, (ii) that the municipality had applied the routine long enough to have experience from multiple cases of compensation, and (iii) that this routine included semi-quantitative, quantitative and/or monetary metrics. The five Swedish municipalities included in this analysis (Göteborg, Halmstad, Helsingborg, Lomma, and Svedala) fulfill these criteria. Note that the focus on EC in the DDP process does not preclude that the municipalities also apply aspects of EC in other types of spatial planning, e.g., in municipal comprehensive plans. However, DDPs are a legally binding spatial planning instrument, while municipal comprehensive plans provide guidance and legal support but are not legally binding (Balfors et al., 2018). The data used for the analysis were obtained from the following written documentation, in a few cases complemented with personal communication with municipality officials for clarifications: Göteborg Municipality (2018, 2019), Halmstad Municipality (2016), Helsingborg Municipality (2014), Lomma Municipality (undated-a,b,c,d) and Svedala Municipality (2019; Ekologigruppen, 2018). This documentation represents general guidelines for how EC is to be applied in the municipalities; potential exceptions from these guidelines in specific DDPs have not been studied. A few basic facts about the municipalities are found in Table 1. Fig. 1 shows where in Sweden the municipalities are situated.

3. Results

In this section, the results for the municipalities are presented for each of the steps identified in Section 2.1.

3.1. Step 1: Identify relevant attributes of the development site

The municipalities' gross lists of attributes (Z_{gross}) are found as Supplementary Material (Table A1-5) and are summarized in Table 2. Those gross lists are used for identifying attributes present at a particular site, i.e., for defining a net list of attributes (Z_{net}). The number of attributes is considerable, ranging from 11 (Helsingborg) to 64 (Halmstad) and they include a substantial variety of environmental and human use aspects. All municipalities include attributes about the presence of habitats and more specific environmental resources (particularly more aspects of biodiversity such as species abundance) and numerous attributes about recreational and other human use of the environment. In principle, this suggests a need for metrics that are not limited to the equivalency method of HEA but also include metrics associated with REA and VEA.

All five municipalities apply some sorting of individual attributes into groups. The municipality having the largest number of attributes (Halmstad) applies a grouping at two levels, where 13 groups of attributes are in turn grouped into three groups. In two cases (Göteborg and Lomma), the grouping corresponds closely to the Millennium Ecosystem Assessment ecosystem services categorization (MEA, 2005) that are commonly used in Sweden (Swedish EPA, 2017): Supporting, provisioning, regulating and cultural services. The group labelling applied in the other municipalities are somewhat different, but still include attributes from all four ecosystem services categories. In Halmstad, the ecosystem services group is restricted to provisioning and regulating services. Recreational use constitutes a separate group in both Halmstad and Helsingborg, while in Lomma, Göteborg and Svedala recreation is contained within cultural ecosystem services. Thus, the categorization and labelling of ecosystem services within the metric systems differ somewhat, but attributes from all ecosystem services categories are included in all systems. The reasons why different municipalities have arrived at different groupings and categorization of ecosystem services are unclear, but since grouping of attributes might suggest substitutability (cf. Section 2.1), this has implications in later steps.

3.2. Step 2: Assess the loss in the attributes due to development

This step entails introducing semi-quantitative, quantitative and/or monetary metrics and is thus decisive for how net gains can be assessed in Step 3. Semi-quantitative metrics may be expressed either numerically (e.g., 1–5) or verbally (e.g., high-medium-low). It should be emphasized that the five municipalities also require, implicitly or explicitly, an impact judgment expressed in qualitative terms (free text format). However, while judgments expressed in such a format might be important and informative, they are not included in this comparative analysis because they do not allow systematic computation of losses, gains and net gains.

The metrics used by the five municipalities for assessing the pre-development values $\boldsymbol{P}_{pre\text{-}dev}$, post-development values $\boldsymbol{P}_{post\text{-}dev}$, and

Table 1
Basic facts about the municipalities included in the study. Corresponding figures for Sweden as a whole are also included. Sources: Statistics Sweden (2018, 2019a, 2019b, 2019c).

	Göteborg	Halmstad	Helsingborg	Lomma	Svedala	Sweden
Number of residents (Dec. 31, 2018)	571,868	101,268	145,415	24,763	21,576	10,230,185
Land area (km^2)	448	1014	344	55	218	407,311
Population density (residents per km^2 of land area)	1268	100	423	442	99	25
Percentage of total land area owned by either the municipality, municipal housing company or the county council	54	9	16	14	9	2

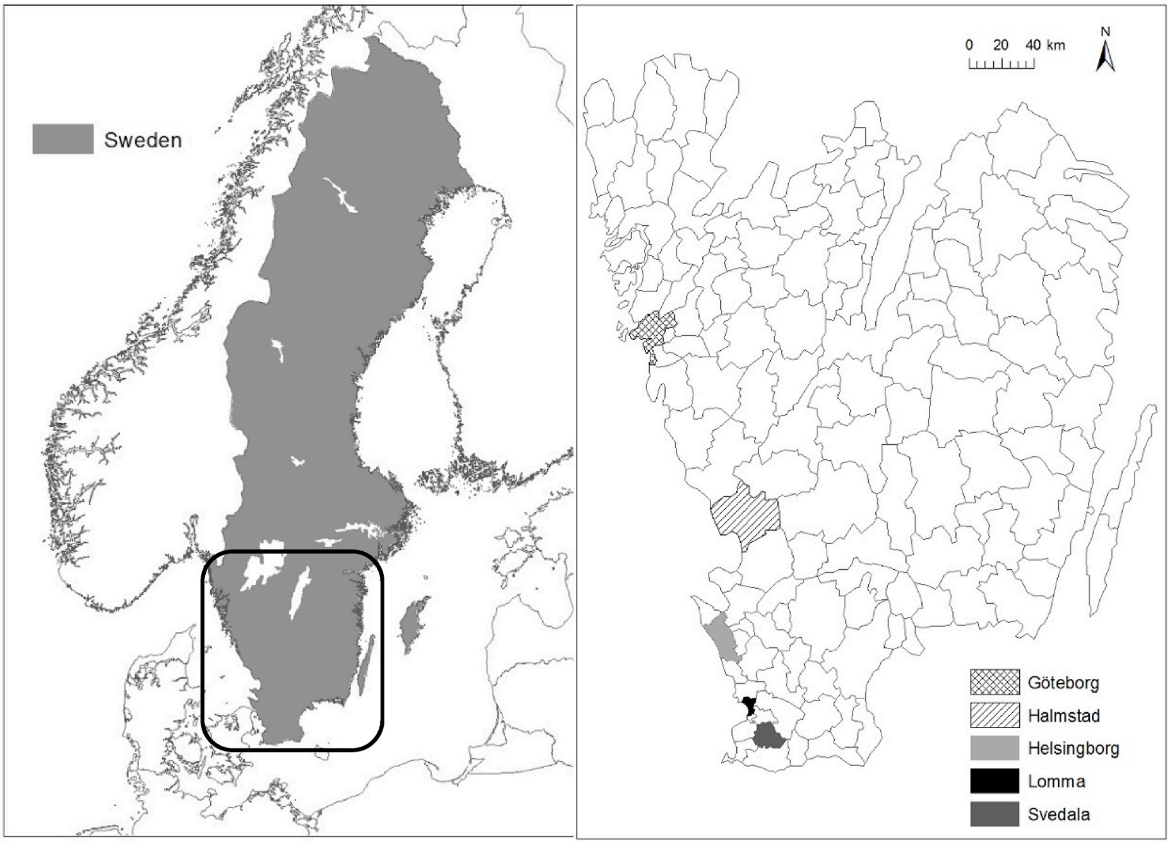

Fig. 1. The geographical location of the municipalities included in the study in the southern part of Sweden.

Table 2
Characteristics of the municipalities' gross lists of attributes (Z_{gross}).

	Number of attributes in Z_{gross}	Grouping of attributes (number of attributes given in parentheses)
Göteborg	43	4 groups: Cultural (23), supporting (11), provisioning (2) and regulating (7) ecosystem services
Halmstad	64	13 groups which in turn are aggregated into 3 "main areas": The main area *recreation* contains play (5), sports (8), exercise (3), nature based outdoor recreation (6), nature experience and social values (11); the main area *ecology* contains threatened species (5), valuable habitats (6), other green values (4); the main area *ecosystem services* contains climate (4), water (6), air (1), food (1), protection (4)
Helsingborg	11	2 groups: Recreational (7) and ecological (4) values
Lomma	24 (+4 overarching functions)	4 groups: Ecological values (2), provisioning (6), regulating (9) and cultural (7) ecosystem services
Svedala	13	2 groups: Nature values (9) and cultural and recreational values (4)

Sources: Göteborg Municipality (2019), Halmstad Municipality (2016), Helsingborg Municipality (2014), Lomma Municipality (undated-b), Svedala Municipality (2019).

losses (***L***) are found in Table 3. For most municipalities, the focus is on assessing the magnitude of loss associated with development. Not all of them assess $\boldsymbol{P}_{pre\text{-}dev}$ explicitly, which implies an unclear baseline and might therefore make it more difficult to assess the severity of the loss (cf. Step 2 in Section 2.1). Also, $\boldsymbol{P}_{post\text{-}dev}$ is not explicitly assessed by most municipalities.

The loss assessment is made at an individual attribute level in Göteborg, Halmstad, Helsingborg and Lomma, at a group level in Halmstad, Helsingborg, Lomma and Svedala, and at a total level (i.e., all attributes taken together) in Helsingborg, see Table 3. In Halmstad, Helsingborg and Lomma, this means that individual attribute losses are translated into group losses. This could be achieved with mathematical translations, for example, the group loss is computed as the average or maximum loss of the group's attributes; however, the group level assessment is instead made as an overall professional judgment. It could also be noted that Helsingborg and Lomma allow the semi-quantitative metric to express potential *gains* in attributes because of development; in Lomma this is allowed at the group level as well. In Svedala, the loss assessment is made only at group level, but on the other hand it is made for each natural area and cultural area identified within the development site, which still implies a loss assessment at a rather high geographical resolution. Although both this loss assessment and the assessment of $\boldsymbol{P}_{pre\text{-}dev}$ is made by using a three-step semi-quantitative scale, the loss assessment is made as an overall professional judgment that does not necessarily reveal the value of $\boldsymbol{P}_{post\text{-}dev}$ at group level.

As indicated in Table 3, the loss assessment in Göteborg and Helsingborg requires some additional explanations. In Göteborg, the pre-development value (a score of 1, 2 or 4) is multiplied by the loss score (1, 2 or 3) for each attribute. A product greater than or equal to 4 is interpreted as a need for compensation. While this is a general rule, it is acknowledged that exceptions may arise if there is a large loss in many small values.

In Helsingborg, a matrix relating the semi-quantitative loss assessments at the two group levels of recreational values and ecological values is used for defining an impact factor ranging from 0.2 to 3.0. The maximum value of the impact factor is defined from a combination of large negative losses for both recreational values and ecological values. This impact factor is multiplied by the area (in m^2) affected negatively

Table 3
Metrics applied for assessing pre-development values of attributes, post-development values of attributes and loss in attributes. Note: "No" means that there is no formalized and mandatory procedure described, but some metrics might still be included *ad hoc* as part of a qualitative (free text) assessment.

Metric	Göteborg[a]	Halmstad[b]	Helsingborg[c]	Lomma[d]	Svedala[e]
Assessment of the pre-development values ($\boldsymbol{P}_{pre\text{-}dev}$)					
Semi-quantitative	Yes, at attribute level (in case of negative impact): 1 = small value 2 = moderate value 4 = large value	No	No	No	Yes, at attribute level (besides use values) and group level: 1 = Some 2 = (Neither some nor high) 3 = High
Quantitative	Not explicitly as a part of the assessment	Not explicitly as a part of the assessment	Not explicitly as a part of the assessment	Yes, examples are given in the assessment guideline	Yes, examples are given in the assessment guideline
Monetary	No	No	No	No	No
Assessment of the post-development values ($\boldsymbol{P}_{post\text{-}dev}$)					
Semi-quantitative	No	No	No	No	Partly
Quantitative	Not explicitly as a part of the assessment	Not explicitly as a part of the assessment	Not explicitly as a part of the assessment	Yes, implicitly through the loss assessment	Not explicitly as a part of the assessment
Monetary	No	No	No	No	No
Assessment of the loss ($\boldsymbol{L}$)					
At attribute level					
Semi-quantitative	Yes: 1 = small loss 2 = moderate loss 3 = large loss And multiplication with $\boldsymbol{P}_{pre\text{-}dev}$, see text	No	Yes: • Small neg/pos • Moderate neg/pos • Large neg/pos • Uncertain neg/pos	Yes: • Small neg/pos • Moderate neg/pos • Large neg/pos • Uncertain neg/pos	No
Quantitative	Not explicitly as a part of the assessment	Not explicitly as a part of the assessment	Not explicitly as a part of the assessment	Yes, examples are given in the assessment guideline	Not explicitly as a part of the assessment
Monetary	No	No	No	No	No
At group level (i.e., metrics for the groups within attributes are sorted, see Table 2[f])					
Semi-quantitative	No	Yes: • Green = No loss • Yellow = Moderate loss • Red = Large loss	Yes: • Small neg • Moderate neg • Large neg	Yes: • Small neg/pos • Moderate neg/pos • Large neg/pos	Yes: • Green = No loss • Yellow = Negative impact • Red = Substantial damage
Quantitative	No	Not explicitly as a part of the assessment	Not explicitly as a part of the assessment	Yes, examples are given in the assessment guideline	Not explicitly as a part of the assessment
Monetary	No	No	No	No	No
At total level (i.e., metrics for all attributes taken together)					
Semi-quantitative	No	No	Yes, as a part of the monetary calculation, see text.	No	No
Quantitative	No	No	Yes, as a part of the monetary calculation, see text	No	No
Monetary	No	No	Yes, see text	No	No

[a] Source: Göteborg Municipality (2019).
[b] Source: Halmstad Municipality (2016).
[c] Source: Helsingborg Municipality (2014).
[d] Source: Lomma Municipality (undated-b, undated-c).
[e] Source: Svedala Municipality (2019).
[f] For Halmstad, the "main areas" in Table 2 are not included here because they are not subject to separate assessment.

by development and also by a monetary area value per m^2, normally ranging from SEK 150 to 900 per m^2. A low monetary value is applied for areas previously designated for development and a high value is applied for areas that currently lack sufficient green space or in areas previously designated as nature. The calculated product in SEK (impact factor × area × area value) is called "the balancing value" (Swedish: *balanseringsvärdet*) and can be interpreted as the value of $\boldsymbol{L}$ on a total level for a specific site.

As is evident from Table 3, semi-quantitative metrics dominate among the municipalities, which implies that Step 2 is for most municipalities not employed for building a basis for a quantitative HEA, REA or VEA. The only monetary metric used by the municipalities is "the balancing value" in Helsingborg, suggesting a VEA approach. However, the monetization is not explicitly linked to human wellbeing and is not followed up by a corresponding assessment of gain, see Step 3.

3.3. Step 3: Assess the gain and the net gain in the attributes due to compensation

This step is about computing the gain ($\boldsymbol{G} = \boldsymbol{P}_{post\text{-}comp} - \boldsymbol{P}_{pre\text{-}comp}$) of potential compensation alternatives and comparing them to the loss ($\boldsymbol{L}$) assessed in the previous step in order to find out the net gains ($\boldsymbol{V} = \boldsymbol{G} - \boldsymbol{L}$). Göteborg and Helsingborg do not apply any explicit procedure for assessment in this step, see Table 4. However, they indicate general principles for finding appropriate compensation measures. In the case of Göteborg, "*the scale of the compensation measure must reflect the loss in the damaged function*" (Göteborg Municipality, 2018, p. 9) and "*the compensation measure must to the greatest extent possible re-create corresponding functions and values that have been lost due to development*" (Göteborg Municipality, 2018, p. 11). For Helsingborg, it is indicated that suitable compensation measures are to be based on "*what values are lost or influenced*" (Helsingborg Municipality, 2014, p. 4). These principles indicate a strive for minimizing net loss or even reach a net gain, but they are not accompanied with an application of metrics that allow a calculation of this fulfillment.

In the case of Lomma, quantitative metrics are applied that can be used for ensuring that "*the compensation is to correspond to at least the value which is lost due to development*" (Lomma Municipality, undated-d, p. 10), and also identify offset ratios greater than 1:1, which the municipality views as being needed in many cases because of, for example,

Table 4
Metrics applied for assessing pre-compensation values of attributes, post-compensation values of attributes, and gain and net gain in attributes. Note: "No" means that there is no formalized and mandatory procedure described, but some metrics might still be included *ad hoc* as part of a qualitative (free text) assessment.

Metric	Göteborg[a]	Halmstad[b]	Helsingborg[c]	Lomma[d]	Svedala[e]
Assessment of the pre-compensation values ($P_{pre\text{-}comp}$)					
Semi-quantitative	No	No	No	No	No
Quantitative	No	No	No	Yes, examples are given in the assessment guideline	No
Monetary	No	No	No	No	No
Assessment of the post-compensation values ($P_{post\text{-}comp}$)					
Semi-quantitative	No	No	No	No	No
Quantitative	No	No	No	Yes, implicitly through the gain assessment	No
Monetary	No	No	No	No	No
Assessment of the gain (G)					
Semi-quantitative	No	No	No	No	Partly
Quantitative	No	No	No	Yes, examples are given in the assessment guideline	No
Monetary	No	No	No	No	No
Assessment of the net gain (V)[f]					
Semi-quantitative	No	Yes, at group level: • Green = No net loss • Yellow = Moderate net loss • Red = Large net loss	No	No	Yes, at group level: • Green = No net loss • Yellow = Net loss • Red = Substantial net loss
Quantitative	No	No	No	Yes, examples are given in the assessment guideline	No
Monetary	No	No	No	No	No

[a] Source: Göteborg Municipality (2019).
[b] Source: Halmstad Municipality (2016).
[c] Source: Helsingborg Municipality (2014).
[d] Source: Lomma Municipality (undated-b, undated-c).
[e] Source: Svedala Municipality (2019).
[f] For Halmstad, the "main areas" in Table 2 are not included here because they are not subject to separate assessment.

uncertainties in the development of values over time (*ibid.*). The use of quantitative metrics for both losses and gains implies an opportunity to carry out a full quantitative equivalency analysis. However, while examples of quantitative metrics are given, metrics are not determined for all attributes, which might still imply that the comparisons of losses to gains are delimited to a subset of attributes.

Halmstad and Svedala assess net gains at group level by using a similar semi-quantitative metric as was used in Step 2 for assessing the loss at group level, see Table 4. Both municipalities indicate a strive for as much "green lights" (i.e., no net loss) as possible. Thus, this represents a kind of full equivalency analysis but made in a semi-quantitative way on a group level. The assessment of net gains is done directly without any explicit comparison of pre-compensation and post-compensation values.

As general guidance for the final selection of compensation project, all five municipalities follow the balancing principle (see Section 1), but some of them elaborate it further in various ways. Göteborg, Halmstad and Helsingborg introduce proximity not only with respect to location but also to attributes and time as a criterion, stating that the compensation is to be "*close in function, site and time and have at least the same value that is lost*" (Göteborg Municipality, 2019, p. 11), "*the closer in time, space and value, the better*" (Halmstad Municipality, 2016, p. 7) and "*close in time and location whenever this is judged to be appropriate*" (Helsingborg Municipality, 2014, p. 4). In Helsingborg, proximity concerning location is stated to be of particular importance for recreational values, but "*for ecological values, another location might in some cases provide a higher value*" (Helsingborg Municipality, 2014, p. 4). Lomma notes that compensation of one type of loss with the same type is a primary option, which should be abandoned only if precluded by, for example, physical site conditions. Also, compensation measures should aim at multifunctionality by, as one example, making sure that measures reducing flooding risks also are beneficial for recreation and biodiversity (Lomma Municipality, undated-d). In the case of Göteborg, it is stated that an overall professional judgment of the reasonableness of the compensation project is also to be made (Göteborg Municipality, 2019) and that an "*economic cost-benefit balancing*" (Göteborg Municipality, 2018, p. 13) is a tool for such a judgment, which might open up for other considerations than no net loss to be taken into account.

3.4. Summary of key findings

The findings from our comparative analysis can be summarized as follows:

- There are similarities but also substantial differences across the municipalities' gross lists of attributes relevant to consider in an EC context. Similarities include that the attributes are not only about nature per se, but also about nature's support to humans, e.g., recreational aspects. The ecosystem service concept is used by all five municipalities, but in slightly different ways, and attributes belonging to all four ecosystem service categories of MEA (2005) are included in all municipalities. The number of relevant attributes varies substantially, from 11 in the case of Helsingborg to 64 in the case of Halmstad.
- All municipalities employ some way of sorting individual attributes into groups, e.g., that specific regulating ecosystem services such as local climate regulation and noise reduction are included in the group of "regulating ecosystem services". All municipalities except Göteborg also use a metric for the group level, and one municipality (Helsingborg) use a metric also for a total level, i.e., for all attributes taken together.
- All municipalities apply semi-quantitative metrics. Quantitative metrics are rarer, and only one municipality (Helsingborg) makes use of a monetary metric.
- All municipalities apply metrics for loss (L), but there is less focus on measuring gain (G) and net gain (V), which restricts the possibility to carry out a full equivalency analysis. Also, benchmarking, i.e., assessing pre-development values ($P_{pre\text{-}dev}$) and pre-compensation values ($P_{pre\text{-}comp}$), is not applied by all municipalities.
- All municipalities refer to the balancing principle, which entails that any residual loss after avoidance and minimization should in the first place be compensated on-site, with compensation off-site as a secondary option.

4. Discussion

The findings of this study raise a number of different issues related to metrics used in EC systems. It is evident that the municipalities' use of metrics is not streamlined. While there are similarities such as using the ecosystem service concept for identifying and sorting attributes and predominantly applying semi-quantitative metrics, there are also differences in terms of the number of attributes and how metrics are applied at attribute, group and total levels. This variety is not surprising because there are no national guidelines for gross lists of attributes and associated metrics (see also below), no EC requirements in the Swedish Planning and Building Act, and also because each municipality has made its own autonomous decision to introduce an EC system. In the following we discuss our results from some important perspectives related to the choice of EC systems and related metrics.

4.1. The use of different metrics

One important issue in applying EC is the use of semi-quantitative, quantitative or monetary metrics. The EC guidelines of the Swedish EPA (2016) do not recommend any specific metrics but state that there is a general need for quantitative metrics that capture the impact on relevant aspects including qualities, and that the same metric should be used for measuring both loss and gain. Quantitative metrics are often viewed as desirable because they help ensure comparability across different areas and different evaluators (Carreras Gamarra et al., 2018). However, semi-quantitative metrics dominate in the municipalities' EC systems, and this might be because the municipalities have included attributes that are difficult to define with precision and therefore not straightforward to quantify. For example, the gross lists of attributes include many ecosystem services that are tied to people's experience of nature, e.g., rest (Göteborg), forest feeling (Halmstad), peacefulness (Helsingborg), aesthetics (Lomma), and training and education (Svedala). The wide range of ecosystem services included in the gross lists also highlights that the scope of the municipalities' EC systems goes beyond cases of areas and species with formal protection status and considers the importance of the everyday landscape for people's wellbeing.

Semi-quantitative metrics are indeed an option often being used for complex ecosystem services (Rayment et al., 2014), and the EC guidelines of the Swedish EPA (2016) acknowledge that such metrics could be a reasonable option, but also that it implies a need for transparency in terms of the judgments made. An evaluator's choice of a score or a ranking might indeed lack transparency if there are no or vague guidelines for when a particular score or ranking is to be chosen, e.g., no precise definitions of conditions for when to set a score equal to 1 or a score equal to 2. Such a lack of precise guidelines is the case for many of the municipalities' semi-quantitative metrics; an important exception is the relatively detailed guidelines used in Svedala for selecting scores when assessing pre-development values of attributes (Ekologigruppen, 2018). Although a lack of precise guidelines does not mean that the choice of a particular score is not well-motivated, and a written motivation might always exist, it could still introduce an element of subjectivity, unpredictability and opacity in the EC systems.

4.2. Grouping of attributes

Most municipalities make assessments of *groups* of attributes. However, their documents are typically not precise about how to make assessments of groups from assessments of the individual attributes included in the groups. The tendency to make groups might be due to the fact that the municipalities' gross lists of attributes are long and reflect the multifunctional and complex nature of the everyday landscape. One way to help to make this complexity manageable is to sort attributes into groups and apply metrics for these groups. However, grouping of attributes might open up for trade-offs across attributes included in a group, and this might mask net losses for individual attributes, especially if metrics are only applied for groups, not for individual attributes (cf. Rayment et al., 2014). For example, Halmstad employs a metric for assessing loss (and net gain) at group level, but not at attribute level. Grouping should be accompanied by considerations about what is acceptable substitutability across attributes. For example, within a group of "recreation", could a negative impact on a picnic site be traded off against a positive impact on a running trail? Such a substitutability might be controversial, especially since equity aspects should also be considered (cf. Principle 7 in BBOP, 2012a); certain groups in society may prefer picnic sites whereas other groups in society prefer running trails, see also below on distributional issues. Grouping of attributes should thus be used with caution and clarity, e.g., by specifying conditions for when a loss in an individual attribute might be considerable enough to have a veto against being traded off against a gain in another individual attribute. Such conditions also help to clarify what would qualify as "in-kind" and "out-of-kind" compensation, taking into account what flexibility is viewed as acceptable (Bull et al., 2015).

4.3. Assessment of losses but not gains

In our analysis we found that metrics are primarily applied for assessing losses rather than for assessing gains. Not assessing gains precludes a full equivalency analysis (neither HEA, REA nor VEA). From a practical perspective, a focus on assessing losses might be understandable because a loss assessment requires efforts and might be prioritized just because it happens before assessing potential compensation alternatives. Also, gains are typically more uncertain and more difficult to assess, particularly for EC systems involving ecosystem services whose values are dependent on public preferences (Moilanen and Kotiaho, 2018). However, even metrics conveying uncertain values (about both losses and gains) can be highly useful because they help signaling knowledge gaps and provide an incentive for following up compensation results, i.e., to evaluate whether the actual compensation project reached the expected outcome. Also, the finding that benchmarking (assessment of pre-development and pre-compensation values) is not always used suggests a room for improvements in the municipalities' metrics. As emphasized by Maron et al. (2015, 2018), both applying a "debiting baseline" and a "crediting baseline" is important, because the consequences of changes (e.g., a loss or gain in a recreational area) are generally dependent on the status and evolvements of stocks (e.g., the total size of the recreational area).

4.4. A broader view on metrics in EC systems

The issues we have raised above are relevant to take into account in further development of the municipal EC systems. We believe that the EC systems and their metrics to an important extent so far reflect a willingness to create an initial structure in the mode of operation with respect to EC, and a willingness to facilitate dialogue about compensation across various actors, not least between the many municipality officials and departments that need to co-operate in an EC system (e.g., spatial planners, land development officials and environmental officials). More detailed specifications of attributes and development of associated metrics could be natural next steps to take. Such steps should also consider a fundamental issue in applying metrics: To what extent do metrics convey information on how different groups in society are affected by losses and gains? The metrics applied by the municipalities implicitly approach this issue to some extent by including a wide range of ecosystem services that provide support to wellbeing among local residents (e.g., recreational opportunities nearby) as well as to non-local populations (e.g., food production and nutrient uptake). However, not even local residents can be considered a homogenous group but represent various stakeholder groups that can be affected by losses and gains in unfair ways, cf. the picnic site example mentioned above. It would therefore be desirable if metrics could approach equity issues more explicitly. One potential approach is to draw on procedures in cost-benefit analysis for analyzing how benefits and costs are distributed among various groups in society (Johansson and Kriström, 2018): For example, net values of benefits minus costs can be calculated for affected groups to find out whether a weighted sum of these values is positive, where weights are assigned to the different groups according to distributional concerns (see OECD, 2018 on practical procedures). Similar considerations could be introduced when assessing losses and gains in an EC setting. While this adds complexity, it would also strengthen the EC application by necessitating identification of stakeholder groups; see, e.g., Reed et al. (2009) on methods for such identification and Griffiths et al. (2018) on the associated challenge of finding an appropriate level of aggregation for losses and gains from an equity perspective. Moreover, it would also stimulate discussions about how an equitable outcome can be defined, which is inevitably dependent on normative judgments in society regarding environmental justice.

4.5. *Streamlining of metrics in municipalities' EC systems?*

Would a streamlining of the municipalities' metrics be a desirable development? This question comes to a head in case the Swedish government would accept the recently proposed changes in the Swedish Planning and Building Act about allowing municipalities to apply requirements for EC in detailed development plans (SOU, 2017). Making EC a more powerful legal instrument for municipalities would involve a need for being clear towards developers about what EC requirements involve; compliance with the rule of law implies that legal provisions have to be well-defined, predictable, implementable and evaluable. These are important arguments for a streamlining involving an increased use of quantitative or monetary metrics, which is likely to increase predictability and to simplify evaluations of EC results within and across municipalities. At the same time, semi-quantitative metrics might be the only available option for some of the attributes that municipalities include as relevant for EC, and streamlining would for such metrics include stricter and consistent guidelines for scorings and rankings. However, there are arguments for streamlining also in a voluntary EC system. It would imply an increased transparency for citizens and developers and avoid unnecessary and duplicative effort; standardization of EC systems is likely to be one factor that stimulates cost-effectiveness in EC (Defra, 2019). However, streamlining is a challenge; a considerable variety of metrics are present even in a country like Germany, where there is more than 30 years of legally regulated EC practice (Wende et al., 2018b).[1] The local context, including variability in public preferences, stakeholder groups and environmental and social conditions, and municipalities' evident willingness to consider numerous ecosystem services, implies a degree of complexity suggesting that a streamlining should not be imposed in a top-down fashion. Instead, streamlining should be developed as a collaborative effort involving municipalities as well as state agencies, and be supported by further research on metrics, not least on attributes for which no established quantitative or monetary metrics exist, and ways to consider equity issues. However, national coordination and enforcement might be needed for a streamlining process to be realized. Perhaps a first step towards a streamlined metrics system could be to create a common system for attribute grouping, e.g., based on ecosystem services categories and a set of common generic attributes that may be complemented with additional attributes if needed to adapt to the local municipal context. Such a first step is likely to be facilitated by the existence of well-established frameworks for defining and categorizing ecosystem services, e.g., the international framework CICES (Haines-Young and Potschin-Young, 2018) upon which the Swedish EPA (2017) has built a list and classification of ecosystem services relevant in a Swedish context.

[1] The Impact Mitigation Regulation was introduced in 1976 under the German Federal Nature Conservation Act.

5. Conclusions

Based on a general conceptual structure for a comparative analysis of EC metrics, we analyzed the metrics used by five Swedish municipalities for assessing losses in terms of environmental damage implied by a development project and gains implied by a compensation project. The conceptual structure's three-step procedure enables mathematical formulations of what need to be measured for finding out whether compensation fulfils objectives such as NNL, and therefore what metrics to look for in the municipalities' EC systems, as well as facilitating a broader understanding and discourse around losses, gains and objectives such as NNL and their possible conflict with the practical world. The structure, the results from the municipality cases, and the issues brought up in the discussion show that the aggregation level chosen for NNL operationalization can be a key dilemma. Whether to treat loss and gain as one variable, or to group attributes, or to treat each attribute separately, is an open question. There are typically many attributes involved, probably because one important purpose of the municipalities' EC systems is to care for the everyday landscape. It may therefore be difficult to achieve NNL across all attributes, or to measure all attributes separately. Hence, attributes could be weighed together into sub-groups, representing different aspects of value. This raises concerns regarding trade-offs between attributes, further development of metrics and streamlining initiatives would call for more knowledge and scrutinizing regarding substitutability. Here, the interaction between compensation projects and broader regional and local environmental objectives and processes, such as green infrastructure planning, could be of particular importance, by highlighting attributes that should be given priority. A question that follows from this is how to best group attributes. For example, are all "recreation" or "biodiversity" attributes best put in separate groups, or are they better combined with entirely different attributes which may represent other types of similarities and trade-off possibilities? Answering such types of questions is likely to require a multidisciplinary approach, taking into account public preferences for various ecosystem services, environmental justice considerations, practical concerns and the system-ecological context.

Credit author statement

Conceptualization, T.S., K.I.J; methodology, T.S.; investigation, T.S.; writing—original draft preparation, T.S., S.C., F.F., L.H., K.I.J; writing—review and editing, T.S., S.C., F.F., L.H., K.I.J, T.H.B., F.B., H.B., E.K., E.L., A.M., J.W.; funding acquisition, K.I.J.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Acknowledgements

This work was part of the MuniComp project (*Environmental compensation as a policy instrument – a municipal perspective*) supported by the Swedish Environmental Protection Agency [grant number NV-06231-16]. We thank the reference group of the MuniComp project and two anonymous referees for valuable feedback, and the Skåne Association of Local Authorities for their communication role within the project, including organization of municipality workshops.

Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.jenvman.2021.113622.

References

Agarwala, M., Atkinson, G., Fry, B.P., Homewood, K., Mourato, S., Rowcliffe, J.M., Wallace, G., Milner-Gulland, E.J., 2014. Assessing the relationship between human well-being and ecosystem services: a review of frameworks. Conserv. Soc. 12, 437–449. https://doi.org/10.4103/0972-4923.155592.

Arlidge, W.N.S., Bull, J.W., Addison, P.F.E., Burgass, M.J., Gianuca, D., Gorham, T.M., Jacob, C., Shumway, N., Sinclair, S.P., Watson, J.E.M., Wilcox, C., Milner-Gulland, E. J., 2018. A global mitigation hierarchy for nature conservation. Bioscience 68 (5), 336–347. https://doi.org/10.1093/biosci/biy029.

Balfors, B., Wallström, J., Lundberg, K., Söderqvist, T., Hörnberg, C., Högström, J., 2018. Strategic environmental assessment in Swedish municipal planning: trends and challenges. Environ. Impact Assess. Rev. 73, 152–163. https://doi.org/10.1016/j.eiar.2018.07.003.

BBOP, 2012a. Standard on Biodiversity Offsets. Business and Biodiversity Offsets Programme. BBOP), Washington, DC. https://www.forest-trends.org/wp-content/uploads/imported/BBOP_Standard_on_Biodiversity_Offsets_1_Feb_2013.pdf. (Accessed 23 March 2019).

BBOP, 2012b. Resource Paper: No Net Loss and Loss-Gain Calculations in Biodiversity Offsets. Business and Biodiversity Offsets Programme, Washington, DC. https://www.forest-trends.org/publications/resource-paper-no-net-loss-and-loss-gain-calculations-in-biodiversity-offsets/. (Accessed 12 March 2021).

Boverket, 2018. Planning Process. The Swedish National Board of Housing, Building and Planning. Karlskrona. In: https://www.boverket.se/en/start/building-in-sweden/swedish-market/laws-and-regulations/planning-process/. (Accessed 27 January 2021).

Boverket, 2020. Mark – ett kommunalt verktyg för bostadsförsörjningen. The Swedish National Board of Housing, Building and Planning, Karlskrona. https://www.boverket.se/sv/samhallsplanering/bostadsmarknad/bostadsforsorjning/kommunernas-verktyg/mark. (Accessed 10 February 2021).

Bull, J.W., Gordon, A., Law, E., Suttle, K.B., Milner-Gulland, E.J., 2014. Importance of baseline specification in evaluating conservation interventions and achieving no net loss of biodiversity. Conserv. Biol. 28, 799–809. https://doi.org/10.1111/cobi.12243.

Bull, J.W., Hardy, M.J., Moilanen, A., Gordon, A., 2015. Categories of flexibility in biodiversity offsetting, and their implications for conservation. Biol. Conserv. 192, 522–532. https://doi.org/10.1016/j.biocon.2015.08.003.

Caesar, C., 2016. Municipal Landownership and Housing in Sweden. PhD thesis. Department of Real Estate and Construction Management, KTH Royal Institute of Technology, Stockholm.

Calvet, C., Napoléone, C., Salles, J.-M., 2015. The biodiversity offsetting dilemma: between economic rationales and ecological dynamics. Sustainability 7, 7357–7378. https://doi.org/10.3390/su7067357.

Carreras Gamarra, M.J., Lassoie, J.P., Milder, J., 2018. Accounting for no net loss: a critical assessment of biodiversity offsetting metrics and methods. J. Environ. Manag. 220, 36–43. https://doi.org/10.1016/j.jenvman.2018.05.008.

Cole, S.G., 2013. Equity over efficiency: a problem of credibility in scaling resource-based compensation. J. Environ. Econ. Policy 2, 93–117. https://doi.org/10.1080/21606544.2013.764616.

Cole, S., Moksnes, P.-O., Söderqvist, T., Wikström, S.A., Sundblad, G., Hasselström, L., Bergström, U., Kraufvelin, P., Bergström, L., 2021. Environmental compensation for biodiversity and ecosystem services: a flexible framework that addresses human wellbeing. Ecosyst. Serv. 50, 101319. https://doi.org/10.1016/j.ecoser.2021.101319.

COM, 2011. Communication from the Commission to the European Parliament, the Council, the Economic and Social Committee and the Committee of the Regions. Our Life Insurance, Our Natural Capital: an EU Biodiversity Strategy to 2020. European Commission,, 3.5.2011, COM(2011) 244 final. EUR-Lex document 52011DC0244. European Commission, Brussels. https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=celex%3A52011DC0244. (Accessed 2 July 2019).

COM, 2014. Halting Biodiversity Loss – the EU No Net Loss Initiative. Press release 6 June 2014, European Commission, Brussels. https://ec.europa.eu/commission/presscorner/detail/en/IP_14_645. (Accessed 10 August 2020).

COM, 2020. EU Biodiversity Strategy for 2030: Bringing Nature Back to Our Lives. European Commission, 20.5.2020 COM(2020) 380 Final. EUR-Lex document 52020DC0380. European Commission, Brussels.

Conway, M., Rayment, M., White, A., Berman, S., 2013. Exploring Potential Demand for and Supply of Habitat Banking in the EU and Appropriate Design Elements for a Habitat Banking Scheme. Report for the DG Environment, European Commission. ICF-GHK and BIO Intelligence Service, London. https://ec.europa.eu/environment/enveco/taxation/pdf/Habitat_banking_Report.pdf. (Accessed 11 March 2021).

Costanza, R., 2020. Valuing natural capital and ecosystem services toward the goals of efficiency, fairness, and sustainability. Ecosyst. Serv. 43, 101096. https://doi.org/10.1016/j.ecoser.2020.101096.

Darbi, M., Tausch, C., 2010. Loss-gain calculations in German impact mitigation regulation. In: Business and Biodiversity Offset Program (BBOP) Assurance and Guidelines Working Group Meeting. Cambridge, UK, 16–18 March 2010. https://www.forest-trends.org/wp-content/uploads/imported/loss-gain-calculations-in-german-imr_md_100324-pdf.pdf. (Accessed 5 July 2019).

Dasgupta, P., 2021. The Economics of Biodiversity: the Dasgupta Review. HM Treasury, London.

Defra, 2019. Biodiversity Net Gain and Local Nature Recovery Strategies – Impact Assessment. RPC-4277(1)-DEFRA-EA. Department for Environment, Food and Rural Affairs, London, 15 October 2019. https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/839610/net-gain-ia.pdf.

Dickie, I., Mesquite, S., Morandeau, D., Stoeckel, M.-E., Weaver, J., Wende, W., 2013. Glossary Working Group on No Net Loss and Their Services. DG Environment, European Commission, Brussels. http://ec.europa.eu/environment/nature/biodiversity/nnl/pdf/NNL_Glossary.pdf. (Accessed 4 July 2019).

Edvardsson Björnberg, K., 2020. What, if anything, is wrong with offsetting nature? Theoria 86, 749–768. https://doi.org/10.1111/theo.12287.

Ekologigruppen, 2018. Ekosystemtjänster i Svedala, Bara och Klågerup. Bilaga 1, Metodbeskrivning för värdering av ekosystemtjänster. Rapport beställd av Svedala kommun. Slutversion 2018-06-27. Report for Svedala Municipality by Ekologigruppen AB, Stockholm.

Freeman III, A.M., Herriges, J.A., Kling, C.L., 2014. The Measurement of Environmental and Resource Values: Theory and Methods, third ed. RFF Press, New York.

Göteborg Municipality, 2018. Kompensationsåtgärder för ekosystemtjänster i plan- och exploateringsprojekt i Göteborgs stad. Rapport, 2018-03-20. Göteborgs stad. https://goteborg.se/wps/wcm/connect/d356b19a-4e4d-4d0f-918a-77a8d20414e4/Kompensations%C3%A5tg%C3%A4rder+f%C3%B6r+ekosystemtj%C3%A4nster+i+plan-+och+exploateringsprojekt+i+G%C3%B6teborgs+Stad.pdf?MOD=AJPERES. (Accessed 16 May 2019).

Göteborg Municipality, 2019. Bedömning av behov av kompensationsåtgärder: Ekosystemtjänster inklusive rekreation och biologisk mångfald. Checklista, 2019-03-06. Göteborgs stad. https://goteborg.se/wps/wcm/connect/d4555ffb-b16d-422c-80e8-80becdd6576e/Checklista+f%C3%B6r+kompensations%C3%A5tg%C3%A4rder+-+ekosystemtj%C3%A4nster.pdf?MOD=AJPERES. (Accessed 16 May 2019).

Griffiths, V.F., Bull, J.W., Baker, J., Milner-Gulland, E.J., 2018. No net loss for people and biodiversity. Conserv. Biol. 33, 76–87. https://doi.org/10.1111/cobi.13184.

Haines-Young, R., Potschin-Young, M.B., 2018. Revision of the common international classification for ecosystem services (CICES V5.1): a policy brief. One Ecosyst. 3, e27108 https://doi.org/10.3897/oneeco.3.e27108.

Halmstad Municipality, 2016. Kompensationsåtgärder. Del 1, bakgrund & underlag till behovsbedömning, och del 2, behovsbedömning – checklista. Halmstads kommun, 2016-10-12.

Helsingborg Municipality, 2014. Balanseringsprincipen Helsingborg. Mall antagen av Plangruppen 2014. Helsingborgs stad.

IPBES, 2019. In: Brondizio, E.S., Settele, J., Díaz, S., Ngo, H.T. (Eds.), Global Assessment Report on Biodiversity and Ecosystem Services of the Intergovernmental Science-Policy Platform on Biodiversity and Ecosystem Services. IPBES secretariat, Bonn, Germany. https://ipbes.net/global-assessment. (Accessed 10 August 2020).

Jacob, C., Vaissiere, A.-C., Bas, A., Calvet, C., 2016. Investigating the inclusion of ecosystem services in biodiversity offsetting. Ecosyst. Serv. 21, 92–102. https://doi.org/10.1016/j.ecoser.2016.07.010.

Johansson, P.-O., Kriström, B., 2018. Cost-Benefit Analysis. Cambridge University Press, Cambridge, UK. https://doi.org/10.1017/9781108660624.

Lipton, J., LeJeune, K., 2018. Step 3 : determining and quantifying remediation benefits. In: Lipton, J., Özdemiroğlu, E., Chapman, D., Peers, J. (Eds.), Equivalency Methods for Environmental Liability: Assessing Damage and Compensation Under the European Environmental Liability Directive. Springer, Dordrecht, pp. 89–111.

Lipton, J., Özdemiroğlu, E., LeJeune, K., Peers, J., 2018. Resource equivalency methods in the European union: a 'toolkit' for calculating environmental liability. In: Lipton, J., Özdemiroğlu, E., Chapman, D., Peers, J. (Eds.), Equivalency Methods for Environmental Liability: Assessing Damage and Compensation Under the European Environmental Liability Directive. Springer, Dordrecht, pp. 21–42.

Lomma Municipality, undated-a. U03. Miljövärdesbedömning. Arbetsmaterial, Lomma Kommun. Document Received on 21 December 2018 from Lomma Municipality.

Lomma Municipality, undated-b. Underlag till Miljövärdesbedömning För Biologisk Mångfald Och Övriga Ekosystemtjänster. Arbetsmaterial, Lomma Kommun. Document Received on 21 December 2018 from Lomma Municipality.

Lomma Municipality, undated-c. U04. Miljövärdesbedömning Inklusive Kompensationsutredning. Arbetsmaterial, Lomma Kommun. Document Received on 21 December 2018 from Lomma Municipality.

Lomma Municipality, undated-d. Handbok I Miljökompensation. Utkast, Lomma Kommun. Document Received on 18 September 2020 from Lomma Municipality.

Maron, M., Hobbs, R.J., Moilanen, A., Matthews, J.W., Christie, K., Gardner, T.A., Keith, D.A., Lindenmayer, D.B., McAlpine, C., 2012. Faustian bargains? Restoration realities in the context of biodiversity offset policies. Biol. Conserv. 155, 141–148. https://doi.org/10.1016/j.biocon.2012.06.003.

Maron, M., Bull, J.W., Evans, M.C., Gordon, A., 2015. Locking in loss: baselines of decline in Australian biodiversity offset policies. Biol. Conserv. 192, 504–512. https://doi.org/10.1016/j.biocon.2015.05.017.

Maron, M., Brownlie, S., Bull, J.W., Evans, M.C., von Hase, A., Quétier, F., Watson, J.E.M., Gordon, A., 2018. The many meanings of no net loss in environmental policy. Nat. Sustain. 1, 19–27. https://doi.org/10.1038/s41893-017-0007-7.

Marshall, E., Wintle, B.A., Southwell, D., Kujala, H., 2020. What are we measuring? A review of metrics used to describe biodiversity in offsets exchanges. Biol. Conserv. 241, 108250. https://doi.org/10.1016/j.biocon.2019.108250.

MEA, 2005. Millennium Ecosystem Assessment. Ecosystems and Human Wellbeing - Synthesis. Island Press, Washington, DC. http://www.millenniumassessment.org/documents/document.356.aspx.pdf. (Accessed 12 March 2021).

Moilanen, A., Kotiaho, J.S., 2018. Fifteen operationally important decisions in the planning of biodiversity offsets. Biol. Conserv. 227, 112–120. https://doi.org/10.1016/j.biocon.2018.09.002.

Moilanen, A., Laitila, J., 2016. Indirect leakage leads to a failure of avoided loss biodiversity offsetting. J. Appl. Ecol. 53, 106–111. https://doi.org/10.1111/1365-2664.12565.

OECD, 2018. Cost-Benefit Analysis and the Environment: Further Developments and Policy Use. OECD Publishing, Paris. https://doi.org/10.1787/9789264085169-en.

Parris, K., Amati, M., Bekessy, S., Dagenais, D., Fryd, O., Hahs, A., Hes, D., Imberger, S., Livesley, S.J., Marshall, A., Rhodes, J., Threlfall, C.G., Tingley, R., van der Ree, R., Walsh, C., Wilkerson, M., Williams, N.S.G., 2018. The seven lamps of planning for biodiversity in the city. Cities 83, 54–83. https://doi.org/10.1016/j.cities.2018.06.007.

Persson, J., 2013. Perceptions of environmental compensation in different scientific fields. Int. J. Environ. Stud. 70 (4), 611–628. https://doi.org/10.1080/00207233.2013.835526.

Persson, J., Larsson, A., Villarroya, A., 2015. Compensation in Swedish infrastructure projects and suggestions on policy improvements. Nat. Conserv. 11, 113–127. https://doi.org/10.3897/natureconservation.11.4367.

Peterson, I., Maron, M., Moilanen, A., Bekessy, S., Gordon, A., 2018. A quantitative framework for evaluating the impact of biodiversity offset policies. Biol. Conserv. 224 https://doi.org/10.1016/j.biocon.2018.05.005, 169–169.

Rayment, M., Haines, R., McNeil, D., Conway, M., Tucker, G., Underwood, E., 2014. Study on Specific Design Elements of Biodiversity Offsets: Biodiversity Metrics & Mechanisms for Securing Long Term Conservation Benefits. Final Report for EU DG Environment ENV.B.2/ETU/2013/0060r, ICF Consulting Services Limited, London. https://ec.europa.eu/environment/nature/biodiversity/nnl/pdf/Biodiversity%20offsets%20metrics%20and%20mechanisms.pdf. (Accessed 19 April 2020).

Reed, M.S., Graves, A., Dandy, N., Posthumus, H., Hubacek, K., Morris, J., Prell, C., Quinn, C.H., Stringer, L.C., 2009. Who's in and why? A typology of stakeholder analysis methods for natural resource management. J. Environ. Manag. 90, 1933–1949. https://doi.org/10.1016/j.jenvman.2009.01.001.

Rundcrantz, K., Skärbäck, E., 2003. Environmental compensation in planning: a review of five different countries with major emphasis on the German system. Eur. Environ. 13, 204–226. https://doi.org/10.1002/eet.324.

Shanahan, D.F., Bush, R., Gaston, K.J., Lin, B.B., Dean, J., Barber, E., Fuller, R.A., Moore, M., 2016. Health benefits from nature experiences depend on dose. Sci. Rep. 6, 28551. https://doi.org/10.1038/srep28551.

Skärbäck, E., 1997. Balanserad samhällsbyggnad. Stad och land 147. SLU, Alnarp, Movium. Swedish University of Agricultural Sciences, Alnarp.

Sonter, L.J., Gordon, A., Archibald, C., Simmonds, J.S., Ward, M., Metzger, J.P., Rhodes, J.R., Maron, M., 2020. Offsetting impacts of development on biodiversity and ecosystem services. Ambio 49, 892–902. https://doi.org/10.1007/s13280-019-01245-3.

SOU, 2017. Ekologisk kompensation: Åtgärder för att motverka nettoförluster av biologisk mångfald och ekosystemtjänster, samtidigt som behovet av markexploatering tillgodoses. SOU 2017:34. Statens offentliga utredningar, Stockholm. http://www.sou.gov.se/wp-content/uploads/2017/04/SOU-2017_34_webb.pdf. (Accessed 12 March 2021).

Statistics Sweden, 2018. Markareal i hektar efter region, ägarkategori och vart 5:e år, publicerad 2018-09-20. Statistiska Centralbyrån, Örebro, Sweden. http://www.statistikdatabasen.scb.se/pxweb/sv/ssd/START_MI_MI0803_MI0803D/MarkagandeRegionAgar/. (Accessed 21 February 2020).

Statistics Sweden, 2019a. Markanvändningen i Sverige, Sjunde Utgåvan. Statistiska Centralbyrån, Örebro, Sweden.

Statistics Sweden, 2019b. Folkmängd i riket, län och kommuner 31 december 2018 och befolkningsändringar 2018. Statistiska Centralbyrån, Örebro, Sweden. https://www.scb.se/hitta-statistik/statistik-efter-amne/befolkning/befolkningens-sammansattning/befolkningsstatistik/pong/tabell-och-diagram/helarsstatistik–kommun-lan-och-riket/folkmangd-i-riket-lan-och-kommuner-sista-december-och-befolkningsforandringar/. (Accessed 24 September 2019).

Statistics Sweden, 2019c. Kommunarealer den 1 januari 2019, publicerad 2019-02-21. Statistiska Centralbyrån, Örebro, Sweden. http://www.scb.se/MI0802. (Accessed 24 September 2019).

Svedala Municipality, 2019. 2.0 Handbok för kompensationsåtgärder inför detaljplaneläggning. Dnr 2019-000318, 2019-04-30. Beslutades i Kommunfullmäktige 2011-12-12 och har sedan reviderats 2019-04-30. Svedala kommun.

Swedish EPA, 2016. Ekologisk kompensation: En vägledning om kompensation vid förlust av naturvärden. Handbok 2016:1, utgåva 1. Swedish Environmental Protection Agency, Stockholm (In Swedish with summary in English.). https://www.naturvardsverket.se/Documents/publikationer6400/978-91-620-0179-7.pdf?pid=17257. (Accessed 12 March 2021).

Swedish EPA, 2017. Ekosystemtjänstförteckning med inventering av dataunderlag: En kartläggning av ekosystemtjänster och grön infrastruktur. Report 6797. Swedish Environmental Protection Agency, Stockholm (In Swedish with summary in English.). https://www.naturvardsverket.se/Documents/publikationer6400/978-91-620-6797-7.pdf?pid=21706. (Accessed 12 March 2021).

UN, 2003. Report and Recommendations Made by the Panel of Commissioners 606 Concerning the Third Instalment of "F4" Claims. UN Doc. United Nations, New York. S/AC.26/2003/31. Paragraph 48. https://uncc.ch/sites/default/files/attachments/documents/r2005-10.pdf. (Accessed 12 March 2021).

US OPA (Oil Pollution Act), 1990. See Code of federal regulations (CFR), subchapter E: oil 615 pollution Act regulations. Section Part 990.10 introduction. CFR 990.54(a)(1). https://darrp.noaa.gov/sites/default/files/OPA_CFR-1999-title15-vol3-part990.pdf. (Accessed 14 August 2020).

Wende, W., Tucker, G.M., Quétier, F., Rayment, M., Darbi, M. (Eds.), 2018a. Biodiversity Offsets: European Perspectives on No Net Loss of Biodiversity and Ecosystem Services. Springer International Publishing AG, Cham, Switzerland. https://doi.org/10.1007/978-3-319-72581-9.

Wende, W., Albrecht, J., Darbi, M., Herbert, M., May, A., Schumacher, J., Szaramowicz, M., 2018b. Germany. In: Wende, W., Tucker, G.M., Quétier, F., Rayment, M., Darbi, M. (Eds.), Biodiversity Offsets: European Perspectives on No Net Loss of Biodiversity and Ecosystem Services. Springer International Publishing AG, Cham, Switzerland, pp. 123–156.