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Subnational Nature Offset Markets: Balancing National and Local Public Goods

Cathrine Hagem

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Abstract

Environmental restoration as a compensatory mechanism for the development of previously undisturbed land can play a significant role in fulfilling nature conservation objectives. Numerous local authorities have adopted spatial planning frameworks that incorporate nature targets, such as "no net loss" (NNL) often operationalized through net area or net biodiversity principles (i.e., area neutrality, or no net loss in biodiversity).

This study employs a simplified analytical economic model to evaluate the welfare implications of both local offset schemes and coordinated offset strategies across adjacent regions, accounting for ecosystem services that benefit the local community. We show that a standalone offset market generally fails to achieve the first-best outcome as an offset market designed to ensure NNL in developed land will typically diverge from the welfare-optimal level of net development. However, an advantage of the offset market is that restoration can be achieved without any public transfers.

Interregional cooperation in achieving NNL targets can improve overall welfare compared to isolated regional strategies. If the target is set to NNL, the offset market ensures that this target is achieved in a cost-effective manner as marginal cost of restoration equals marginal profit from development. However, an offset markets targeting net gain or net loss result in inefficient levels of both development and restoration. Furthermore, we suggest that implementing a permit system based on environmental value metrics rather than strict area-based neutrality (ambient permits), may mitigate some of the inefficiencies inherent in area neutrality frameworks.

Keywords: Environmental restoration, Nature degradation, Offset markets, Public goods, Biodiversity targets, Ambient permits.

JEL classification: D47, D61, Q26, Q51, Q57,Q58

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Address: Cathrine Hagem, Statistics Norway, Research department. E-mail: cah@ssb.no

Sammendrag

Miljørestaurering som kompensasjon for utbygging av urørt natur kan spille en viktig rolle i å nå mål for naturvern. Mange kommuner har målsettinger om begrensinger i nedbygging av natur, som for eksempel prinsippet om «ingen netto tap» (NNL). Dette betyr at utbygging skal kompenseres slik at det ikke blir mindre natur totalt.

I denne artikkelen bruker en forenklet økonomisk modell for å vurdere hvordan ulike kompensasjonsordninger påvirker samfunnets velferd. Vi ser både på lokale ordninger og samarbeid mellom naboregioner, og tar hensyn til naturverdier som kommer lokalsamfunnet til gode.

Resultatene viser at krav om ingen nettotap av natur ofte ikke gir den beste løsningen for samfunnet. Men det kan være en fordel at kompensasjonsordninger kan skje uten offentlige tilskudd.

Samarbeid mellom regioner gir bedre resultater enn om hver region jobber alene. Hvis målet er «ingen netto tap», kan et kompensasjonsmarked oppnå dette på en kostnadseffektiv måte – fordi kostnaden ved restaurering balanseres mot gevinsten ved utbygging. Derimot, hvis markedet sikter mot netto gevinst eller netto tap, blir både utbygging og restaurering ineffektiv.

Til slutt foreslår studien at man heller bør bruke et system med verdibaserte tillatelser – som tar hensyn til naturverdier – fremfor å bare måle areal. Dette kan redusere noen av svakhetene ved arealbaserte løsninger.

1. Introduction.

Economic growth often results in the loss of natural land, as increased demand for infrastructure—such as renewable energy installations, residential and vacation housing, and transportation networks—leads to the development of previously unspoiled areas (natural land). This expansion reduces the availability of natural land and diminishes associated ecosystem services. Restoration of previously degraded land can partially compensate for these adverse impacts. The practice of trading ecological losses in one location for gains in another, known as offsetting, is increasingly used to mitigate the environmental consequences of development (Droste, 2022). Offsetting is typically considered the final step in the mitigation hierarchy: avoid, minimize, remediate, and finally, offset (Arlidge et al., 2018). The Kunming-Montreal Global Biodiversity Framework sets targets for both conservation and restoration of nature.[1] In adopting the Framework, all Parties committed to setting national targets to implement it. The United Kingdom launched a compliance-based biodiversity offset market in 2024.[2]

There are also several local initiatives for environmental compensation to achieve no net loss (NNL) of nature, see Söderqvist et al. (2021), ESPON (2024) and Sponagel et al., (2022).[3] In the paper we consider the potential for an offset market within regional administrative units that have designated authority to regulate land use change within their respective borders. In many European countries the designated authority is the local governments, such as the municipalities (Gradinaru et al. 2023). We analyse how the design of a municipal (or regional) offset scheme affects social welfare, when not only national, but also the local benefits from restoration are considered.

We differentiate between ecosystem services that primarily benefit the local population—such as recreational opportunities and amenity values—and those that provide broader environmental benefits to the entire nation, including biodiversity conservation and wilderness preservation. This framework, also adopted by Grimsrud et al. (2024) and Greaker et al. (2024), suggests that the value of preserved or restored natural areas consists of two distinct components: a national value that

[1] https://www.cbd.int/gbf/introduction

[2] https://defraenvironment.blog.gov.uk/2024/11/06/setting-the-standard-for-biodiversity-markets-in-the-uk/ . See also Mancini et al. (2024)

[3] According to the SABIMA (a Norwegian NGO working to preserve biodiversity), more than 80 municipalities in Norway has area neutrality targets or are in the process of setting such targets. https://www.sabima.no/et-arealnoytralt-norge/. The terms "area neutrality" and "biodiversity no net loss" are used interchangeably.

remains constant regardless of location, and a location-specific value that reflects the added benefits to nearby residents

The aim of offsetting can be NNL, net gain or only offset a share of the degraded land. The aims can be achieved cost-effectively by proper design of taxes on development and subsidies on restoration projects. The targets can also be met without public financing, through offset markets (Kangas and Ollikainen, 2019; Simpson et al., 2021a; Hanley and Simpson, 2025). If an offsetting scheme is designed as a tradable permit market, supply of permits may come from private entities restoring previously developed land, and where land developers must purchase permits corresponding to their development of land in other areas (see inter alia Wissel and Wätzold, 2010; Needham et al., 2019). Offset markets may also be combined with other market-based instruments such as ecological taxes (Greaker et al., 2024).

Offset markets for nature present greater challenges than those for greenhouse gas emissions, as deterioration of nature in one area is not easily comparable to restoration of nature values in another area. There is a large literature on how degradedand restored habitats or ecosystems may differ in important dimension and criticism of the performance and benefits of nature offsets (see, inter alia, Drechsler and Wätzold, 2009; Quétier and Lavorel, 2011; Hrabanski, 2015; zu Ermgassen et al., 2020). Simpson et al. (2021b) simulate how changes in the ecological metric and geographic scale affect the performance of the offset market. See also, e.g., Carreras Gamarra et al. (2018) and Droste et al. (2022) for a discussion on how the choice of metrics that are used to assess biodiversity is crucial for the performance of offset markets.

Söderqvist et al. (2021) refers to three main types of equivalence methods for matching loss with gain: habitat equivalence analysis (habitat quantity and quality, HEA), resource equivalence methods (biomass or quantity of species, REA) and value equivalence analysis (VEA). The first two methods measures losses and gains in biophysical terms, see, e.g., Desvousges et al. (2018) and Baker et al., (2020). The latter expresses losses and gains in terms of how they affect human wellbeing and typically applies valuation methods developed in environmental economics for measuring changes in welfare in monetary terms, see, e.g., Champ et al. (2017).

We consider cases where it is possible to assign a monetary metric to both national value and local value of loss of nature, although we are aware that this can be controversial, see for instance Muradian and Gómez-Baggethun (2021). However, there are several studies on valuation of local recreational services, see e.g., Hermes et al. (2018), Mayer and Woltering (2018) and Skrydstrup et al. (2022). Furthermore, the monetary accounts of the UN's System of Environmental Accounting (SEEA-

EA) suggest methods for assigning monetary estimates on ecosystem degradation and enhancement.[4] Furthermore, if a country has established a national cap on the net loss of pristine land, the national cost associated with each municipality's net development aligns with the marginal cost of meeting that target—assuming a cost-efficient allocation of forgone development and restoration efforts across the country.

Although there is a large literature on nature offsets from the ecological perspective concerning assessment of ecological equivalency, there are few contributions from the economic literature. Some exceptions are Simpson et al. (2021a, 2021b) which model an offset market in an integrated ecological-economic model and explore, inter alia, how an increase in the target level of net gain affects the supply of restoration projects. There are also some papers discussing what can be learned from the economic literature on tradable pollution permit markets, see, e.g., Needham et al (2019) and Hanley and Simpson (2025), but these papers do not provide a formal analysis of offset permit market design. Although there is a lack of analysis of permit markets for offsets, tradeable permits have been extensively analysed in the economic literature on pollution control, both for local pollutants and global pollutants (greenhouse gas emissions). See, e.g., Montgomery (1972), Atkinson and Tietenberg (1982), Hagem and Westskog (1998) and Narassimhan et al., (2018).

This paper contributes to the literature by addressing a gap in the economic analysis of nature offset markets by employing standard economic theory to analyse how regional offset targets affect social welfare, and how an offset permit market can be designed when not only ecological equivalence is accounted for, but also the local values of cultural ecosystem services. One important implication of the development of land is the loss of recreational benefits to local communities. The recreational benefits of an area are dependent inter alia on the access possibility (distance from potential users) and numbers of users (or potential users) of the areas for recreational purposes. See e.g., Hermes et al. (2018), Mayer and Woltering (2018) and Skrydstrup et al. (2022) for assessment of recreational values. A distance decay function for disamenity cost of land development has been applied in, e.g., Lehmann et al. (2023), Ruhnau et al., (2024) and Grimsrud et al. (2024). See also Glenk et al. (2020) for a review of spatial dimension of stated preference valuation in environmental economics.

Furthermore, we analyse the implications of cooperation across adjacent regions. Both national values of restoration and the local recreational services can be regarded as public goods, meaning that they can be enjoyed without reducing their availability to others. However, access possibilities

[4] https://seea.un.org/ecosystem-accounting

and travel costs imply that the recreational values are dependent on the localisation of the land areas degraded or restored. This has important implications for the social benefit of joint offset markets and the optimal design. We employ a parsimonious analytical economic model including the cost of restoration, the profit from development and the inhabitants' valuation of net development (in monetary terms). We believe that this economic analysis of offset markets is a novel and useful contribution to the literature on offset markets. Our model provides clear insights into the welfare implications and potential inefficiencies of different offset market designs—insights that have not been previously demonstrated in the existing literature.

Implications of the design of offset schemes in the presence of local values is one of the main contributions of the paper. To focus on that topic, we simplify the analysis by assuming that developed land and potentially restored land are biophysically equivalent (per square kilometres, km^2) and thus exclude the discussion on relevant metrics for ecosystem equivalence. Although, we recognize that the problem of matching loss with gains in biophysical terms is a very important problem in offset market designs. This will be further discussed in the concluding remarks.

Cross-municipal offset trading can reduce aggregate costs by leveraging regional differences in restoration costs and development benefits. Furthermore, the more people who have easy access to the restored area, the higher the value of the restored area. In the present paper we suggest that offsets can be weighed according to the number of people having access to the area and their distance to the recreational areas by implementing a so-called ambient permit system (Atkinson and Tietenberg, 1982).

The economic model is presented in the next section. In the subsequent sections we derive the optimality conditions for offset policies given constraint on net development and cooperation across regions. We derive the following results:

From a welfare economics perspective NNL commitments at the regional level are generally suboptimal. The marginal cost of nature restoration tends to diverge from the marginal economic benefit of degradation under rigid NNL constraints. Moreover, even in the presence of a national NNL target, enforcing region-specific NNL outcomes is rarely efficient, due to the spatial heterogeneity in both the costs of restoration and the benefits derived from development of land.

An offset permit market can be introduced to achieve any chosen offset percentage (more, less or equal to 100 per cent). An offset market is revenue neutral for the regulator, but implies an inefficient combination of developments and offset, as marginal benefits of development differ from marginal cost of offsets when offset targets deviate from 100 per cent. Marginal benefit of development equals the offset percentage multiplied by the offset permit price, whereas marginal cost of producing offsets equals the offset price.

We show that total welfare can be improved by cooperation across adjacent municipalities due to mutual benefits from nature (public goods), and differences in environmental evaluation, cost of restoration and or benefits of land development.

We distinguish between area neutrality and environmental value neutrality. The first measures loss and gains in biophysical units (area developed), whereas the latter set a local economic value on the recreational value of land lost and gained, where the value can be depending on the number of people having easy access to the (recreational) areas. Area neutrality will in general not give a welfare optimizing outcome in the municipalities, although the national environmental values are provided cost-effectively across the cooperating municipalities.

Achieving environmental value neutrality can be pursued through fiscal instruments such as taxes and subsidies, or alternatively via an offset market utilizing ambient offset permits. However, this approach does not guarantee area neutrality. Consequently, a trade-off emerges between area neutrality and environmental value neutrality, particularly in contexts where local amenity values are significant—even when the biophysical characteristics of restored and developed sites are equivalent.

Our theoretical results are illustrated through a numerical example.

2. Municipal spatial planning in the presence of an environmental value of nature.

We begin by examining the welfare-maximizing spatial planning policy within a municipality, concerning both the extent of land development and the restoration of previously developed land. As outlined in the introduction, we assume that land suitable for development and developed land with potential for restoration are biophysically equivalent. Accordingly, both are considered to hold equal national value within the framework of biodiversity conservation policies.

Economic benefits of land development can be measured through market prices on the goods and services produced on the land (renewable energy production, construction of houses and cottages, etc.) less of the production cost. Let $B(e)$ be the net economic benefit of development of *e* km^2. Because the most profitable plots are developed first, the marginal benefit per additional km^2 decreases with *e*: $B'(e) > 0, B''(e) < 0$.

The restoration cost can be calculated using market prices for input factors of production, including the opportunity cost of land. We assume previously developed land can be restored to a quality equal to natural land. Let $C(x)$ denote the total cost of restoring *x* km^2 in the municipality. Because suitable restoration areas are limited, the cost of restoration per additional km^2 increases with the restored volume: $C'(x) > 0, C''(x) > 0$.

Restoration can be provided by the developers themselves or by other agents. Throughout the paper we assume rational agents and competitive markets, such that the market responses to policy instruments can be expressed by a representative agent for developers and a representative agent for the producers of restoration.

We assume that the municipal regulators incorporate the national value (*N*) of natural land in their welfare function.[5] This value concerns the valuation of national biodiversity conservation and is independent of the geographical location for development and restoration if the requirement for biophysically equivalent is satisfied. In addition, one important cultural ecosystem service of natural land is the recreational and amenity benefits to local communities. Let a denote the municipality's populations joint monetary environmental valuation of net loss of developed land per km^2 (value of

[5] This could be achieved by a financial transfer from the national regulator per unit net preserved land.

net gain per km[2]). It is reasonable to assume that this value is increasing in the number of inhabitants having access to the recreational area. We assume linear valuation.[6] For municipalities internalizing the national welfare of net natural land per km[2] (*N*), the welfare of land regulation (*W*) can be expressed as:

(1) $$W(e,x) = B(e) - C(x) + (N+a)(x-e),$$

where *N*+*a* is the marginal environmental value of land restored/land developed.

Maximizing welfare with respect to *x* and *e* gives the following first order conditions:

(2) $$B'(e) = C'(x) = N + a$$

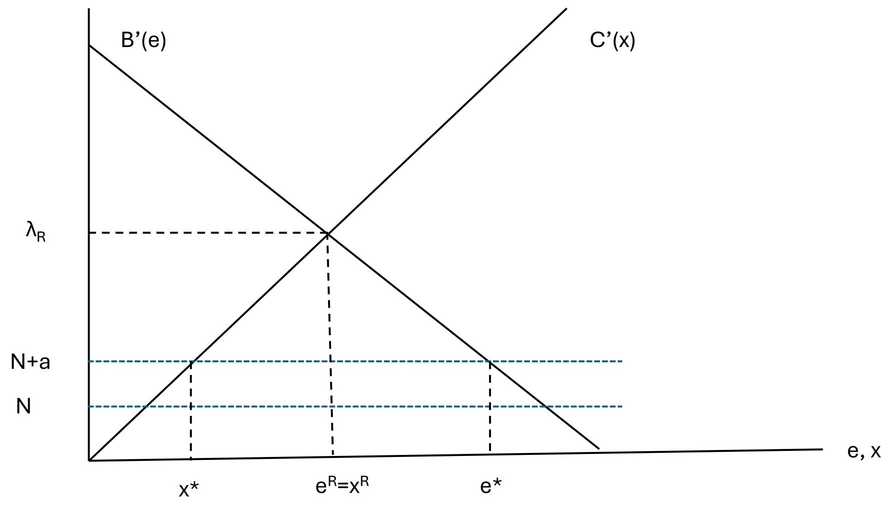
Let e^* and x^* be the solution to (2).

The net development of land equals $e^* - x^*$, and welfare equals:

(3) $$W^* = B(e^*) - C(x^*) + (N+a)(x^* - e^*)$$

The net optimal development (*e*-*x*) can be positive, negative, or zero. If it happens to be zero, the optimal welfare policy implies NNL. Figure 1. illustrate an optimal solution where the optimal net development is positive, which implies that $e^* > x^*$.

Figure 1 An optimal solution



[6] In the numerical illustration, see section 4, we draw on nature valuation estimates from Iversen et al. (2024), who find that the value per unit of developed land remains relatively stable regardless of the total area developed.

Proposition 1. *When monetary values can be assigned to land development and land restoration, the welfare-optimal level of net development is characterized by the condition that the marginal profit of development and the marginal cost of restoration equal the marginal environmental cost of net development.*

2.1. Policy instruments for optimality

The welfare optimum can be achieved by a combination of taxes and subsidies. Let *t* denote the tax per unit developed, and *s* the subsidy per unit restored. The developer's optimizing problem is given by

(4) $$Max \quad B(e) - te \quad w.r.t. \quad e$$

The restoration agent's optimizing problem is given by

(5) $$Max \quad sx - C(x) \quad w.r.t. \quad x$$

This gives the following first order conditions

(6) $$B'(e) = t$$

(7) $$C'(x) = s$$

First best is achieved by setting the subsidy and the tax equal to the valuation of net loss (*a*).[7]

(8) $$s^* = t^* = N + a$$

The regulator's net revenue (R) would be:

(9) $$R^* = p^*(e^* - x^*) > 0 \; for \; e^* > x^* \; and \; R^* < 0 \; for \; e^* < x^*$$

It can politically be problematic to implement ecological taxes and subsidies, especially on municipality levels. Furthermore, assigning monetary values to development of land can be challenging, and may not even be considered desirable by policy makers (see discussion in the introduction). This may be one of the reasons why regions aim for NNL without seeking for the optimal net development. In the next section we derive the optimality conditions, given a constraint of NNL.

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[7] The first best outcome can also be achieved by a combination of taxes/subsidies and an offset market, see Greaker et al. (2024).

2.2. No net loss constraint

Maximizing welfare, given NNL of nature (development of unspoiled land must equal restoration), can be expressed as:

(10)
$$
\begin{aligned}
&Max\, W(e,x) = B(e) - C(x) + (N+a)(x-e) \quad w.r.t \;\; x,e \\
&s.t. \quad x = e
\end{aligned}
$$

This gives the following first order conditions:

(11)
$$B'(e) = C'(x) = (N+a) + \lambda_{NNL}$$

Where λ_{NNL} is the shadow cost of the NNL constraint. Let e^R and x^R denote the outcome of this constrained optimization. The outcome of this policy is depicted in Figure 1, For tax and subsidy equal to $\lambda_R = (N+a) + \lambda_{NNL}$, the agents will implement this level of development and restoration. Setting the right level of the tax/subsidy demands information on profit function for land development, *B(e)*, and cost of restoration, *C(x)*, but does not require an economic value of preserved nature. Although the net revenue for regulator will be zero, a tax and subsidy system involve public financial transfers. Demanding compensation for development in terms of financing offsets (purchasing offsets) can be easier to implement, as this does not involve public financial transfers. Furthermore, the regulator does not need information on the cost of restoration and economic gain of development as the market will ensure that the target for NNL (or net gain) is achieved.

Below we consider the case of an offset market which is revenue neutral for the regulator.

2.3. Revenue neutral offset market

The regulator can aim to have all development offset by restoration, or the market can be designed to overcompensate (undercompensate) such that there will be a net gain (loss) in natural land. Consider an offset market, where the developers must purchase offsets corresponding to a share β of the developed land. Providers of offset can sell the offset on the market. For β =1, the market will ensure NNL (e=x), whereas for β >1 (β <1), there will be a net gain (loss) in natural land (measured in km^2 undeveloped/restored land). The developer's optimizing problem is given by

(12)
$$Max \quad B(e) - p\beta e\,,$$

Where *p* is the market price of offsets. The restoration agent's optimizing problem is given by:

(13)
$$Max \quad px - C(x)$$

The first order conditions give developments as functions of $\beta \cdot p$, and restorations as functions of p:

$$B'(e) = \beta \cdot p \Rightarrow$$
(14) $$e(\beta \cdot p)$$
$$C'(x) = p \Rightarrow$$
$$x(p)$$

The offset market equilibrium condition is:

(15) $$\beta \cdot e(\beta \cdot p) = x(p),$$

Let e^o, x^o and p^o be the solution to (14) and (15).

For $\beta = 1$, $x^O = e^O$, see (15), and the NNL target will be achieved cost-effectively, $B'(e^O) = C'(x^O)$. However, this will only give a first best solution for the special case where NNL actually is the welfare optimizing net development target, that is $B'(e^O) = C'(x^O) = a + N$, see (2).

Furthermore, we see that $B'(e^O) \neq C'(x^O)$ for $\beta \neq 1$, and a NNL target will not be achieved. For $\beta > 1$, the marginal benefit of development is larger than marginal cost of restoration ($B'(e^O) > C'(x^O)$). Given our assumption that the value of environmental benefit of restoration equals the value of the environmental loss of development per km^2, there is room for net welfare improvement by increasing both e and x with an equal amount, as this will improve the net economic benefit without increasing the net environmental value loss. For $\beta < 1$, the marginal benefit of development is lower than marginal cost of restoration, and there is room for welfare improvement by decreasing both *e* and *x* with an equal amount as this will increase net economic benefit without decreasing the net environmental value. Note, we cannot in general tell whether $\beta \neq 1$ leads to a higher or lower level of restoration than $\beta = 1$, see appendix A.[8]

This leads to the following propositions:

Proposition 2. *A standalone offset market generally fails to achieve the first-best outcome as an offset market designed to ensure NNL in developed land will typically diverge from the welfare-optimal level of net development. An advantage of the offset market is that restoration can be achieved without any public transfers.*

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[8] Simpson et al. (2021) show that a net gain target, compared with a no net loss target can lead to both higher and lower equilibrium offset price, and restoration efforts. However, they do not discuss the inefficiencies of offset markets.

Note that e^o and x^o could alternatively by achieved by a developer tax of βp^o and a restoration subsidy equal to p^o, and this would also lead to zero net public transfers.

Proposition 3. *If the target is set to no net loss ($\beta = 1$), the offset market ensures this goal is met cost-effectively, as the marginal cost of restoration equals the marginal benefit from development. In contrast, offset markets aiming for net gain (β>1) or net loss (β<1) leads to inefficient levels of both development and restoration when the environmental losses from development can be fully compensated through nature restoration.*

The fact that a NNL target generally differ from an optimal target is especially relevant when we consider municipal policies. As a follow up of the Kunming-Montreal global biodiversity framework, nations may set national targets for nature preservation. However, cost of restoration and benefit from land development may differ substantially across municipalities within a country. Hence, for each municipality to set a target for net loss is not cost-effective policy for achieving the national target. Cooperation across municipalities for achieving a national NNL target may substantially reduce the total cost when the cost of restoration and benefits of development differs across municipalities. In the next section we discuss the implication of cooperation among adjacent municipalities when also the local environmental goods are accounted for.

We start by deriving how cooperating would imply that it is welfare improving to set a higher joint target for net restoration, than in the unilateral policies. Thereafter we compare two different NNL targets, *Area neutrality* and *Environmental value neutrality*.

3. Municipal cooperation

We start by deriving how cooperating would imply that it is welfare improving to set a higher joint target for net restoration, than in the unilateral policies. Thereafter we compare two different NNL targets, *Area neutrality* and *Environmental value neutrality*.

3.1. Two municipalities (heterogeneous). Joint optimality

Increased loss of unspoiled nature may affect the recreational value for more people than the inhabitants of the municipality where the land is developed. Inhabitants of adjacent municipalities may also benefit from the use of recreational areas in the neighbouring municipality, without reducing the recreational value for the others (public goods). In the following, we consider two adjacent municipalities (denoted with subscript 1 and 2) and the potential gain from cooperation.[9]

It is reasonable to assume a distance decay in disamenities following from the development of unspoiled land. In the present paper we simplify by dividing the affected household in two. The household within the municipality borders and the household in the adjacent municipality. Although household in adjacent municipality is less affected, it is reasonable to assume that the development of land (restoration of land) in one municipality has an external negative (positive) welfare impact on inhabitants of the adjacent municipality

Let γ denote the distance decay parameter expressing the adjustment in environmental valuation in one of the municipalities of net increase in nature (per km^2) in the other municipality due to the distance (and travel possibilities) between the two municipalities. The distance decay parameter is between zero and one, o., indicating that net development in a neighboring municipality is detrimental to a given municipality, but less so than development within its own borders—and vice versa.

The net local environmental benefit per unit net increase in unspoiled nature in municipality *i* thus equals $(a_i + \gamma a_j)(x_i - e_i), i = 1,2, \ i \neq j$.

[9] National benefits can be internalized by taxes on net loss of unspoiled nature.

The maximization of joint welfare is given by:

(16) $$\begin{aligned}&Max \quad B_1(e_1)-C_1(x_1)+(N+a_1+\gamma a_2)(x_1-e_1)\\&+B_2(e_2)-C_2(x_2)+(N+a_2+\gamma a_1)(x_2-e_2)\end{aligned}$$

First order conditions are:

(17) $$\begin{aligned}B_1'(e_1)&=C_1'(x_1)=N+a_1+\gamma a_2\\B_2'(e_2)&=C_2'(x_2)=N+a_2+\gamma a_1\end{aligned}$$

We see by comparing (17) with (2), that maximizing joint welfare implies less development and more restoration than with unilateral optimization (for γ >0).

The optimal solution can be achieved by a combination of taxes and subsidies (as discussed in section (2), with:

(18) $$\begin{aligned}t_1&=s_1=N+a_1+\gamma a_2\\t_2&=s_2=N+a_2+\gamma a_1\end{aligned}$$

In joint welfare optimum, the optimal taxes and subsidies should differ across municipalities as the benefit of restoration differ across municipalities.

Proposition 4. *In the presence of local public environmental goods, cooperation on environmental restoration and development across municipalities results in lower net development in welfare optimum, compared with unilateral optimization. In case of heterogeneity in valuation of the local public goods across municipalities, optimal taxes and subsidies should vary across municipalities.*

By internalizing the external effects of net development, the joint welfare under cooperation will exceed the sum of unilateral welfare maximization. By cooperation, both municipalities face an additional cost as they develop less and restore more than they would under a unilateral policy. They gain by getting access to a larger recreational area in the neighbouring municipality compared to the unilateral solution. The sum of this can be negative for one of the municipalities (and positive for the other). For instance, a municipality with a small valuation of recreational area, for instance due to a relatively small population, neighbouring a municipality with a large population and easy access to the recreational area of the adjacent municipality, would prefer to have a larger net development than the optimal solution (*17*). However, since the total gain exceeds the sum of the unilateral solutions; the outcome can be implemented through side payments.

In the remaining of this paper, we focus on the binding no net loss target as this is a widely set target for local spatial policies (see discussion in in the introduction). We consider two types of no net loss targets: NNL of undeveloped land (area neutrality) and NNL of the environmental value of undeveloped land.

3.2. Municipal cooperation on NNL of undeveloped land (area neutrality)

Consider the case where two adjacent municipalities cooperate on no net loss of nature, measured in km^2 net development. The constrained joint maximization problem is given by

$$
\begin{aligned}
(19) \qquad & Max \quad B_1(e_1) - C_1(x_1) + (N + a_1 + \gamma a_2)(x_1 - e_1) \\
& + B_2(e_2) - C_2(x_2) + (N + a_2 + \gamma a_1)(x_2 - e_2) \\
& s.t. \quad e_1 + e_2 = x_1 + x_2
\end{aligned}
$$

The optimal solution is given by

$$
\begin{aligned}
(20) \qquad & B_1'(e_1) = C_1'(x_1) = N + a_1 + \gamma a_2 + \lambda_A \\
& B_2'(e_2) = C_2'(x_2) = N + a_2 + \gamma a_1 + \lambda_A
\end{aligned},
$$

where λ_A is the shadow value of the binding area neutrality constraint.

Compared to a situation without the area neutrality constraint (and λ_A >0), the development of new land is lower, and the restoration is higher.

Let the outcome of the variables of this optimisation problem be denoted by supscript *OA.* The constrained optimal solution can be achieved by a combination of taxes and subsidies (as discussed in section (2.1), with:

$$
\begin{aligned}
(21) \qquad & t_1^{OA} = s_1^{OA} = N + a_1 + \gamma a_2 + \lambda_A \\
& t_2^{OA} = s_2^{OA} = N + a_2 + \gamma a_1 + \lambda_A
\end{aligned}
$$

The solution is depicted in Figure 2, where $A_i \equiv N + a_i + \gamma a_j + \lambda_A \quad i = 1,2, \; i \neq j$.

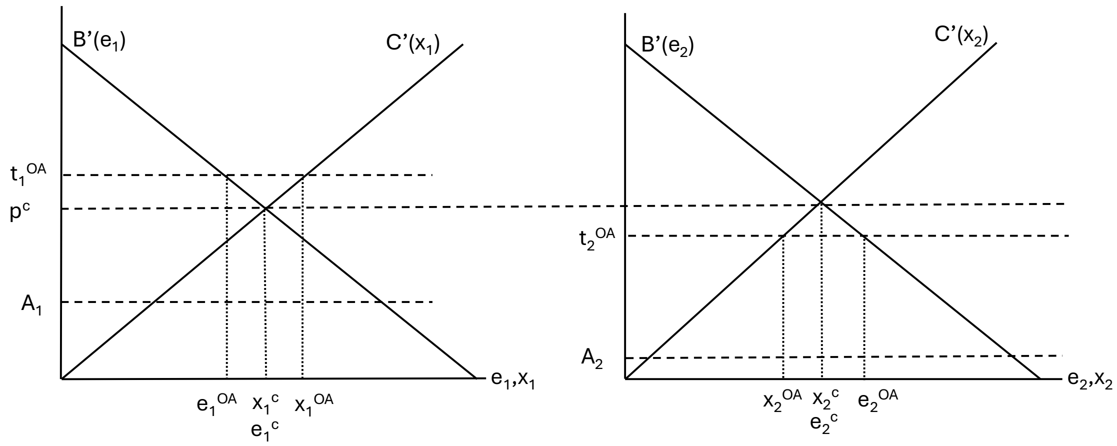
Proposition 5. *Under the constrained joint welfare optimum (binding NNL constraint), optimal taxes and subsidies differ across municipalities whenever local environmental values vary.*

We see that the difference in taxes and subsidies across municipalities equals the first best, see eq. (18), but the level is higher due to the NNL constraint.

The NNL constraint ensures that the sum of net development over both municipalities equal zero. However, one of the municipalities may have a positive net development, which is offset by a corresponding positive net restoration in the other municipalities. Cooperation across municipalities implies that the municipalities can take advantage of the differences in marginal cost of restoration, marginal profit from land development and marginal local environmental costs across municipalities to minimize the cost of the NNL target. In Figure 2, $A_1 \neq A_2$, but the marginal benefit of development and the marginal cost of restoration is assumed to be identical across the municipalities. In Figure 3, $A_1 = A_2$, but the marginal cost of restoration differs across municipalities.

One municipality can be more profitable for development (and restoration) than the other. The larger benefits from development, the larger restoration costs, and the smaller environmental cost, the more likely that the municipality has a positive net development in equilibrium (in the constrained optimum), and vice versa.

Figure 2 Municipality cooperation on area neutrality. Heterogeneity in environmental values



3.3. Offset markets. Area neutrality

Consider an offset market, where the developers must purchase offsets corresponding to developed land, and the developers can sell offsets corresponding to the restored land. This correspond to the system described in section 2.3, where betta equals 1, and there are two instead of only one municipality participating in the market. Let *p* denote the price of offsets in the market.

The agents' first order conditions are given by

(22) $$B_1'(e_1) = B_2'(e_2) = C_1'(x_1) = C_2'(x_2) = p$$

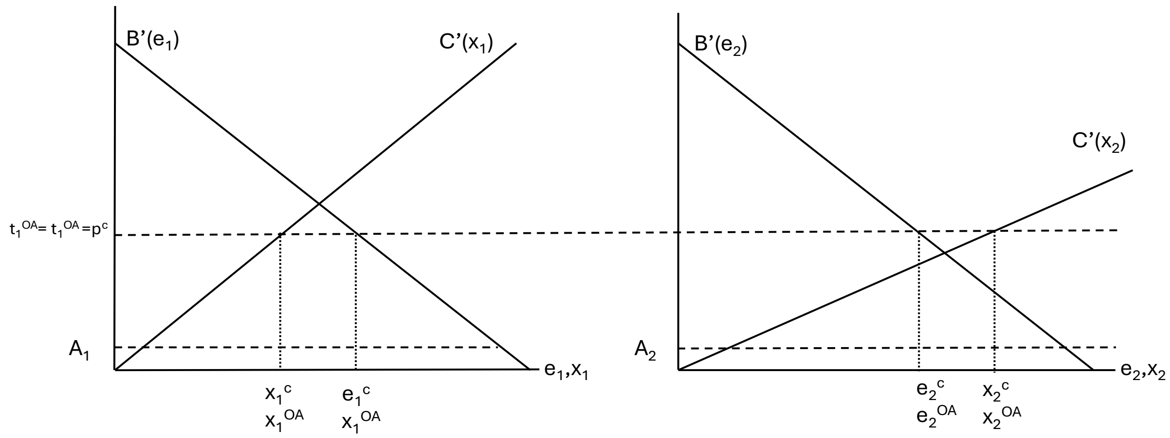
The first order conditions give developments and restorations as functions of the price in a common market of offsets, with the following equilibrium condition.

(23) $$e_1(p) + e_2(p) = x_1(p) + x_2(p)$$

Hence, the market price of offsets ensures that area neutrality is achieved. Let the outcome of the variables of this optimisation problem, characterized by (22) and (23), be denoted by supscript *c.* See Figure 3.

Proposition 6. *The offset market ensures that the distribution of net development across municipalities is cost minimizing. Furthermore, the system can be implemented without the need for monetary estimates of national and municipal environmental values.*

Figure 3 **Municipality cooperation on area neutrality. Heterogeneity in restoration costs**



However, this system does not take into account the heterogeneity in local environmental values across municipalities. As can be seen by comparing (22) with (20), the area neutral offset market will only achieve the optimal distribution of *net development* across municipalities in the special case where marginal environmental cost is equal in both municipalities (see Figure 2 and Figure 3). Hence, offset markets based on area developed only will not in general ensure a (constrained) optimal distribution of development and restoration across municipalities.

Proposition 7. *An offset market with NNL measured as area neutrality leads to a suboptimal distribution of development and restoration across municipalities compared to a system of differentiated taxes and subsidies when municipalities differ in local valuation of nature***.**

In the next section, we look at a design of an offset scheme where the differences in environmental valuation of net development across municipalities is accounted for.

To account for the diversity in local environmental impact of net development, the target of the cooperation across municipalities can be not net loss in the total environmental values (national values plus local environmental value of nature, *no net environmental degradation)* rather than NNL in developed areas. We show how this solution can be achieved by an ambient permit offset system.

3.4. Municipal cooperation on no net environmental degradation.

The municipalities can make an agreement on no net joint loss in the total environmental values. This implies that the sum of environmental cost and benefits must be zero. The constrained optimizing problem is given by maximising net benefit of development minus cost of restoration subject to NNL in environmental values:

(24)
$$\begin{aligned} &Max \quad B_1(e_1) - C_1(x_1) + (N + a_1 + \gamma a_2)(x_1 - e_1) \\ &+B_2(e_2) - C_2(x_2) + (N + a_2 + \gamma a_1)(x_2 - e_2) \\ &s.t. \quad (N + a_1 + \gamma a_2)e_1 + (N + a_2 + \gamma a_1)e_2 = (N + a_1 + \gamma a_2)x_1 + (N + a_2 + \gamma a_1)x_2 \end{aligned}$$

We find the following first order conditions:

(25)
$$\frac{B_1'(e_1)}{(N + a_1 + \gamma a_2)} = \frac{C_1'(x_1)}{(N + a_1 + \gamma a_2)} = \frac{B_2'(e_2)}{(N + a_2 + \gamma a_1)} = \frac{C_2'(x_2)}{(N + a_2 + \gamma a_1)} = 1 + \lambda_P \,,$$

where λ_p is the shadow value of the NNL in environmental values constraint. In the constrained optimum, the marginal economic benefit per unit environment value per km^2 should equal the marginal cost per unit environmental value per km^2.

Optimal taxes and subsidies, denoted with supscript *ED*, per unit km^2 developed/restored are given by

(26)
$$\begin{aligned} t_1^{ED} &= s_1^{ED} = (N + a_1 + \gamma a_2)(1 + \lambda_P) \\ t_2^{ED} &= s_2^{ED} = (N + a_2 + \gamma a_1)(1 + \lambda_P) \end{aligned}$$

From the optimizing constraint we see that

(27)
$$\frac{B_1'(e_1)}{B_2'(e_2)} = \frac{C_1'(x_1)}{C_2'(x_2)} = \frac{(N + a_1 + \gamma a_2)}{(N + a_2 + \gamma a_1)} = -\frac{e_2 - x_2}{e_1 - x_1}$$

Thus, if the value of the local environmental degradation per km^2 developed differs across municipalities, the net development of land will be non-zero ($-\frac{e_2 - x_2}{e_1 - x_1} \neq 1$).

Proposition 8. *Given cooperation on NNL in environmental values across municipalities, and heterogeneity in environmental valuation, taxes and subsidies on land (km^2) developed/restored should differ across municipalities and net development of land, measured in km^2, will be non-zero.*

In the next section we show how the optimal solution for no net environmental degradation can be achieved through so-called ambient permits.

3.5. Ambient pollution rights in an offset market:

The net development of land within each municipality reduces the overall sum of environmental values. To create a tradable market that enables an optimal balance between development and restoration across municipalities, it is necessary to introduce a transfer coefficient. This coefficient links the geographical origin of both restoration and development activities to their aggregate impact on environmental values.

Each developer needs to hold a permit per unit km[2] development corresponding to the environmental degradation following from that development (ambient permit). Each restoration agents have the right to issue a permit per unit km[2] restored corresponding to the environmental value of the restoration. The permits are sold and purchased on the ambient permit market.

Let q_1 and q_2 denote the ambient permits hold by developers 1 and 2, respectively, and let l_1 and l_2 denote the ambient permits produced by the restoration agents. The land development/restoration and ambient environmental degradation are connected by the transfer coefficients $((N+a_i+\gamma a_j) \quad i=1,2, \quad j=1,2, \quad i \neq j)$:

(28)
$$\begin{aligned}(N+a_1+\gamma a_2)e_1 &= q_1\\(N+a_2+\gamma a_1)e_2 &= q_2\\(N+a_1+\gamma a_2)x_1 &= l_1\\(N+a_2+\gamma a_1)x_2 &= l_2\end{aligned}$$

Let the price on offset permits be denoted p^a.

The optimizing problems for developers are given by

(29)
$$Max\ B_i(e_i)-p^a e_i(N+a_i+\gamma a_j), \quad i=1,2, \quad j=1,2, \quad i\neq j$$

The optimizing problems for restoration agents are given by

(30)
$$Max\ p^a x_i(N+a_i+\gamma a_j)-C_i'(x_i), \quad i=1,2, \quad j=1,2, \quad i\neq j$$

First order conditions are:

(31)
$$\frac{B_i'(e_i)}{(N+a_i+\gamma a_j)} = p^a,$$
$$\frac{C_i'(x_i)}{(N+a_i+\gamma a_j)} = p^a, \quad i=1,2, \quad j=1,2, \quad i \neq j$$

This makes the development and the restorations of land functions of the price of ambient permits. Equilibrium in the permit markets implies that

(32)
$$(N+a_1+\gamma a_2)e_1(p^a)+(N+a_2+\gamma a_1)e_2(p^a)=(N+a_1+\gamma a_2)x_1(p^a)+(N+a_2+\gamma a_1)x_2(p^a)$$

The nine equations –see (28), (31) and (32) – are used to determine $e_1, e_2, x_1, x_2, q_1, q_2, l_1, l_2, p^a$. From the firsts order conditions and market equilibrium condition, we see that development and restoration outcomes must be the same as in the optimal outcome (section 3.4).

The ambient permit system ensures the optimal distribution of development and restoration across agents and municipalities, given environmental degradation neutrality (NNL of environmental value).

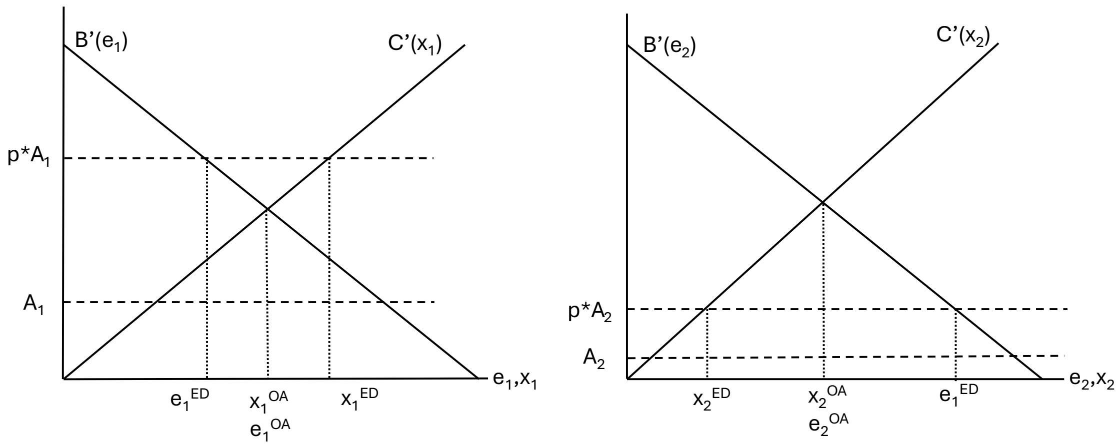
Proposition 9. *Given a target for NNL in environmental values, an ambient permit system can be designed to give the (constrained) welfare optimizing outcome of NNL of environmental values.*

Area neutrality ensures NNL of land (summarized over both municipalities) but will in general lead to positive or negative net loss of the local environmental values. Ambient pollution offsets ensure no net environmental degradation (summarized over both municipalities) but will in general not ensure NNL of developed land. The net loss of developed land can be positive or negative.

Consequently, a trade-off emerges between area neutrality and environmental value neutrality, particularly in contexts where local amenity values are significant—even when the biophysical characteristics of restored and developed sites are equivalent.

With a NNL in environmental degradation target, joint welfare can increase by shifting net development from municipalities with high value of local environment to municipalities with lower value of the local environment. Figure 4 shows an example where the ambient permit system leads to lower development in the municipality (1) with the highest local value of unspoiled land compared to area neutrality (and vice versa for the net development in municipality 2).

Figure 4 **Municipality cooperation on environmental neutrality. Heterogeneity in environmental values**



4. Numerical Illustration

This section presents a numerical illustration of the outcomes associated with various offset mechanism designs discussed earlier. Empirical data on restoration costs remain limited and exhibit considerable variation across countries and project types. The economic benefit of land development is contingent upon both the nature of the development and the geographical location. As outlined in the introduction, our analytical model assumes biophysical equivalence between developed and restored land on a per-area basis. The numerical example provided is based on approximate estimates and is intended solely for illustrative purposes. Justifications for the selected functional parameters are detailed in Appendix B. All monetary values (benefits, costs, and nature values) are expressed in million NOK, while land development and restoration are measured in km². One million NOK equals approximately 83 000 Euro.

We consider a stylized example involving potential property development (specifically, cabin construction) and restoration of wind power plant sites located in wetland ecosystems (mires), using Norwegian data. Cabin development represents a significant driver of natural land loss in Norway, with approximately 10% of existing cabins situated in mire areas. We illustrate two parameterizations of the following profit function:

(33) $B_i(e_i) = \overline{B}_i e_i - b_i e_i^2 \quad i = 1,2$.

For the outcome presented in Table 1, $\overline{B}_1 = \overline{B}_2 = 100, b_1 = b_2 = 12$. For the outcome presented in Table 2, $\overline{B}_1 = 200,\ \overline{B}_2 = 100, b_1 = b_2 = 12$, reflecting higher economic returns from land development in Municipality 1 relative to Municipality 2. We have assumed a somewhat lower economic gain from development compared to the levels observed in Norway's particularly high-priced areas (see Hanberg et al., 2022).

Wind power installations are frequently located in wetland areas. Restoration to a natural state entails the removal of roads and technical infrastructure, followed by ecological rehabilitation to restore original wetland conditions. Wetland restoration is among the most prominent nature restoration initiatives in Norway. Restoration cost estimates are based on data from Lauritzen (2025) and the Norwegian Water Resources and Energy Directorate (NVE, 2022). We use the following cost function:

(34) $C_i(x_i) = 5x + 2x_i^2$,

We examine two hypothetical adjacent municipalities differing in population size: Municipality 1 has 2,100 households, while Municipality 2 has 1,050. We assume that the per-household valuation of non-degraded land is constant across municipalities. Drawing on three local choice experiments (García et al., 2016; Dugstad et al., 2023; Iversen et al., 2024), we set a_1 = 14 and a_2 =7, as documented in Appendix B. The transfer coefficient is set to 0.2.

Table 1 **Outcome of optimization problems (Sections 2 and 4.1 – 4.5). Identical benefit and restoration cost functions across municipalities; higher nature value in Municipality 1. Values in million NOK and km²**

	Max Welfare. Section 4.1	No net area loss. Section 4.2	Area offset market. Section 4.3	No net env. value loss. Section 4.4	Ambient permit market. Section 4.5	No net area loss. Section 2.	No net area loss. Section 2	Sum Section 2
Sum Welfare	331,8	324,6	322,3	326,4	326,4			322,3
Welfare 1	161,8	158,2	161,2	158,1	158,1	161,2		161,2
Welfare 2	170	166,4	161,2	168,3	168,3		161,2	161,2
Tot. loss env. values	34,9	-4,6	0	0	0			0
Loss env. values 1	10,4	-13,4	0	-13,9	-13,9	0		0
Loss env. values 2	24,5	8,8	0	13,9	13,9		0	0
net area loss	2,9	0	0	0,4	0,4			0
e1-x1	0,6	-0,8	0	-0,8	-0,8	0		0
e2-x2	2,3	0,8	0	1,3	1,3		0	0
e1	3,5	3,3	3,4	3,3	3,3	3,4		3,4
x1	2,8	4,1	3,4	4,1	4,1	3,4		3,4
e2	3,7	3,5	3,4	3,6	3,6		3,4	3,4
x2	1,4	2,7	3,4	2,3	2,3		3,4	3,4

Obviously, maximization of joint welfare without any constraints will lead to the highest welfare (second column). We also see that an area-based offset market (column 4) fails to achieve the optimal joint outcome under a no net area loss constraint (column 3). This discrepancy arises because market participants do not account for inter-municipal differences in nature value. Consequently, net restoration efforts in Municipality 1—where nature value is highest—are insufficient, while net restoration in Municipality 2 is excessive relative to the optimal no net loss scenario. In contrast, an ambient permit market (column 6) aligns with the joint welfare optimum under a constraint of no net loss in environmental value (column 5). Furthermore, when restoration costs and development benefits are uniform across municipalities, a joint offset market (column 4) offers no welfare advantage over unilateral offset markets (columns 7 and 8).

Table 2 **Outcome of optimization problems (Section 2 and 4.1 – 4.5). Identical restoration cost functions across municipalities; higher development benefit and nature value in Municipality 1. Values in million NOK and km²**

	Max Welfare. Section 4.1	No net area loss. Section 4.2	Area offset market. Section 4.3	No net env. value loss. Section 4.4	Ambient permit market. Section 4.5	No net area loss. Section 2.	No net area loss. Section 2	Sum Section 2
Sum Welfare	888,5	850,5	843,4	841,1	841,1			840,2
Welfare 1	718,5	721,8	705,9	685,5	685,5	679,0		679,0
Welfare 2	170,0	128,7	137,5	155,6	155,6		161,2	161,2
Tot. loss env. values	103,2	4,2	11,7	0,0	0,0			0,0
Loss env. values 1	78,7	9,0	34,2	6,7	6,7	0,0		0,0
Loss env. values 2	24,5	-4,9	-22,5	-6,7	-6,7		0,0	0,0
net area loss	7,1	0,0	0,0	-0,2	-0,2			0,0
e1-x1	4,8	1,7	2,1	0,4	0,4	0,0		0,0
e2-x2	2,3	-1,7	-2,1	-0,6	-0,6		0,0	0,0
e1	7,7	7,2	7,3	7,0	7,0	7,0		7,0
x1	2,9	5,5	5,2	6,6	6,6	7,0		7,0
e2	3,7	3,1	3,1	3,3	3,3		3,4	3,4
x2	1,5	4,9	5,2	3,9	3,9		3,4	3,4

Table 2 illustrates the scenario where the economic benefit of property development is substantially greater in Municipality 1. Under these conditions, cooperative arrangements yield welfare gains, as joint welfare under cooperation (column 3) exceeds the aggregate welfare from individual no net loss policies (column 9). Nevertheless, Municipality 1 experiences a welfare reduction under cooperative no net area loss (column 3) compared to the unilateral optimum (column 7), due to increased net development beyond its preferred level. This outcome underscores the necessity of side payments or compensatory mechanisms to facilitate and sustain cooperative solutions.

5. Concluding remarks

This paper aims to elucidate key properties of nature offset schemes and the implications of setting targets for net loss of nature. Offset schemes offer several advantages: they eliminate the need for public financial transfers, can enable cost-effective achievement of NNL targets, and circumvent the necessity of assigning monetary value to pristine nature. However, a notable drawback is that NNL targets may diverge significantly from the socially optimal level of land development.

Our analysis demonstrates that interregional cooperation under NNL frameworks can reduce aggregate costs. Specifically, when a national NNL target is in place, decentralized municipal NNL policies tend to increase the overall cost relative to a centralized national offset scheme. Nonetheless, numerous municipalities and regions have independently adopted NNL targets.

Moreover, when local environmental values vary across potential sites for development or restoration, NNL targets measured solely in terms of area rather than environmental value, may lead to suboptimal spatial distributions of development and restoration from a municipal perspective. This reveals a fundamental trade-off between nationally aggregated benefits of NNL policies and locally situated environmental values. To make an agreement on NNL in environmental values may be more demanding than an agreement on NNL in unspoiled areas as it also needs consensus of the relative environmental value of the land developed and restored.

In this study, we abstract from the complexities of ecological metrics by assuming biophysical equivalence between developed and restored land. While this assumption simplifies the modeling framework, it overlooks one of the principal challenges in offset markets—ensuring ecological equivalence and identifying suitable offset projects, see, among others, Cole et al. (2021). However, importantly, even under biophysical equivalence, local recreational values introduce significant complications, as they depend on residents' access to and use of both developed and restored areas. National-level valuations of NNL policies may underemphasize the spatial distribution of land use changes, which can be of critical importance to local communities.

We have assumed that previously degraded land can be fully restored to its original pristine ecological quality. In practice, this is often not achievable. In such cases, the ecological value of restored land could be adjusted downward to ensure a fair comparison between undeveloped and restored nature.

For future research, the present framework could be extended to account for comparable ecological equivalence metrics and to facilitate a more comprehensive analysis of existing non-net loss policies implemented across various municipalities. Furthermore, development of some valuable areas affects the recreational benefits also for people living quite far away of the areas, see for instance Iversen et al. (2024). There is thus a need for national policy instruments that induce the municipality to also internalize these impacts in their nature development policies.

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Appendix A:

From total differentiating (15), we find

(35) $\beta \cdot e' \cdot \beta \cdot dp + \beta \cdot e' \cdot p \cdot d\beta + e \cdot d\beta = x' \cdot dp$,

such that

$$\frac{dp}{d\beta} = \frac{e(\beta \cdot p) + \beta \cdot e' \cdot p}{x' - \beta^2 \cdot e'} .$$

It follows from the assumption of the second order derivatives that the denominator is positive (x' >0 and $e' < 0$. Hence the sign of $\frac{dp}{d\beta}$ equals the sign of the nominator, which can be positive or negative. An increase in β has to opposite effects on the price. On the one hand, it leads to higher cost of development, which cet. par. decreases demand for restoration projects, and thus lower equilibrium price. On the other hand, an increase in β means that the developer must purchase more restoration project per unit development, which cet. par. leads to higher demand for restoration projects and thus higher equilibrium price.

Appendix B

Justification for the selected functional parameters in the numerical illustration (Section 4).

Restoration Costs

NVE (2022) provides estimates for the cost of restoring wind power plant areas to their natural state. This process involves the complete removal of roads and technical installations, as well as the rewetting of wetlands directly impacted by turbine foundations, roads, and buildings. Four specific wind power plants are used as case studies. Based on these data, restoration costs are estimated to range between 1.8 and 7.9 million NOK (2021 NOK) per km² of planning area, depending on the nature type, turbine specifications, and density of technical installations.

It is important to note that ecological impacts often extend beyond the immediate footprint of the installations. Development activities may disrupt mires and degrade extensive wetland areas, which must also be restored to achieve full ecological recovery. Drawing on data from 48 mire restoration projects compiled by Lauritsen (2025), restoration costs vary from 0.5 to 35 million NOK per km², with an average of 10.06 million NOK per km². These figures are slightly higher than those reported by Strzęciwilk and Grygoruk (2025), who estimate average restoration costs for bogs and fens in selected European countries at approximately 7.2 million NOK per km².

For the cost function applied in the numerical illustration (Equation (34), the marginal cost of restoration is assumed to range from 5 to 34 million NOK per km2 across the potential restoration area considered (see Tables 1 and 2).

Profit/Benefit Function for Property Development

The economic benefit of property development is primarily driven by the market value of plots designated for holiday cabins, which in turn depends on site attractiveness. Handberg et al. (2022) estimate the profit from undeveloped, regulated plots in the highly sought-after Norefjell mountain area to be approximately 0.46 million NOK per plot. Given an average plot size of 1000 m², this translates to a profit of 460 million NOK per km².

Since Norefjell represents a premium location, our numerical illustration assumes development in less attractive areas, with heterogeneity in plot desirability within each municipality. In Table 1, we model a scenario where profitability is uniform across municipalities, with a total of 4 km² of potentially attractive land. The willingness to pay (WTP) for the most desirable plot is set at 0.2

million NOK, while the least attractive plots approach zero. We assume a density of 500 cabins per km² (see Equation (33)).

Table 2 introduces spatial variation in development potential. Municipality 1 is assumed to have both a larger area (8 km²) and higher plot attractiveness, with the most desirable plots valued at 0.4 million NOK. The same cabin density of 500 per km² is applied.

Nature Valuation

To estimate the environmental value of undeveloped nature, we use data from Iversen et al. (2024), which reports household WTP for reducing the scale of large cabin development projects. Table 3 in Iversen et al. provides annual WTP estimates of 1900 NOK and 3112 NOK per household for downscaling by 3000 and 6000 cabins, respectively. Assuming a 100-year time horizon, a 4% discount rate, and a cabin density of 1000 per km², this yields net present values of 155,000 NOK and 127,000 NOK per household per km². Given the relatively small difference between these estimates, we adopt a constant marginal valuation and use the midpoint value of 141,000 NOK per household per km².

This valuation is interpreted as reflecting the perceived loss of pristine wetland due to property development, and by extension, the value of restored landscapes following wind turbine decommissioning and site rehabilitation.

While one might argue that the loss of pristine nature from cabin construction differs from the restoration of wetland areas post-wind farm decommissioning, choice experiment data suggest comparable valuations. Grimsrud et al. (2024) report an average annual WTP of €23 (276 NOK) per household to avoid the installation of a single wind turbine, based on two local choice experiments (García et al., 2016; Dugstad et al., 2023). Given an average turbine footprint of 0.5 km², this corresponds to 550 NOK per km² annually. The net present value over 100 years at a 4% discount rate is approximately 13,500 NOK per household per km²—closely aligned with the valuation derived from cabin development impacts.

Assuming an average household size of 2.1 persons, we apply the following function to calculate the total nature value:

(36) $$a_i = 0,014 \cdot \frac{H_i}{2,1},$$

where H_i is the number of inhabitants in municipality i.

The median population of Norwegian municipalities is 5100, corresponding to approximately 2400 households. For the numerical illustration, we assume 2100 inhabitants (≈1000 households) in municipality 1 and 1050 inhabitants (≈500 households) in municipality 2, yielding that a_1=14 and a_2 =7.