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Global hidden spillover effects among concurrent green initiatives

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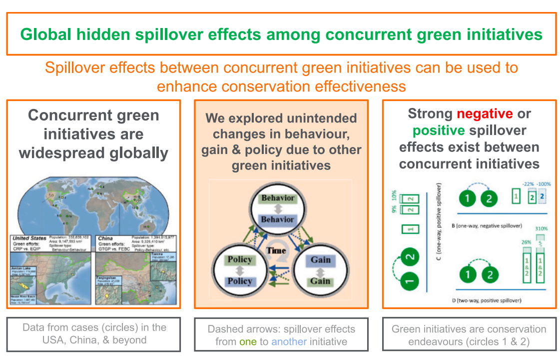
HIGHLIGHTS

- Multiple conservation programs are often implemented in same area(s) or involved same recipients.
- Spillover effects exist between concurrent green initiatives in terms of detractive or beneficial influences.
- Spillover effects are often ignored as if they do not among concurrent green initiatives.
- Leveraging such spillover effects could enhance the effectiveness of green initiatives.

GRAPHICAL ABSTRACT



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ABSTRACT

Concurrently implemented green initiatives to combat global environmental crises may be curtailed or even sacrificed given the ongoing global economic contraction. We collected empirical data and information about green initiatives from 15 sites or countries worldwide. We systematically explored how specific policy, intended behaviors, and gains of given green initiative may interact with those of other green initiatives concurrently implemented in the same geographic area or involving the same recipients. Surprisingly, we found that spillover effects were very divergent: one initiative could reduce the gain of another by 22 % ~ 100 %, representing alarming losses, while in other instances, substantial co-benefits could arise as one initiative can increase the gain of another by 9 % ~ 310 %. Leveraging these effects will help countries keep green initiatives with significant co-

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benefits but stop initiatives with substantial spillover losses in the face of widespread budget cuts, better meeting the United Nations' sustainable development goals.

1. Introduction

Humanity stands in an unprecedented era of climate change, environmental degradation, and rapid biodiversity loss. These interrelated crises threaten the very existence and survival of humanity (Hooper et al., 2012). In response, the United Nations launched the 2030 Sustainable Development Goals and the Green Climate Fund (Rosa, 2017), along with numerous geographically widespread and costly "green initiatives"—which we define as endeavors (e.g., programs, funds, payments, policies) that aim to restore, sustain, or improve nature's capacity to benefit human beings (detail in (An et al., in review), Section 1 or AS 1). Many green initiatives—be they in operation, such as the European Union's Green Deal (European Commission, 2019; von der Leyen, 2020), the United Nations Framework Convention on Climate Change (UNFCCC, 1992), and the United Nations' Green Climate Fund (Board of the Green Climate Fund, 2020), or suspended, such as the Green New Deal bill proposed to the United States Congress (Ocasio-Cortez, 2021)—all have ambitious goals to conserve the environment, including "climate neutrality" (von der Leyen, 2020), "net-zero global [carbon] emissions" (Ocasio-Cortez, 2021) by 2050, and conservation of biodiversity (IPBES, 2019).

Green initiatives are becoming increasingly widespread and popular across the globe to combat the aforementioned crises. For instance, the Reducing Emissions from Deforestation and Forest Degradation[1] (REDD+) program alone covered a forest area of approximately 1.49 billion hectares (37 % of the global forest area) as of July 2019 (Food and Agriculture Organization of the United Nations, 2019). Green initiatives also involve large amounts of investments: According to the Intergovernmental Panel on Climate Change (IPCC), transitioning the global energy system alone would warrant an average annual investment of approximately USD 2.4 trillion (equivalent to ~2.5 % of global yearly GDP) from 2016 to 2035 to meet the Paris Agreement's goal to 'limit the temperature increase to 1.5 °C or less (UNFCCC, 2015).

The growing impetus to balance ecological and human well-being worldwide has led to the simultaneous implementation of multiple green initiatives, which cover the same geographic area(s) and/or involve the same recipient(s). We define such green initiatives as *concurrent green initiatives*. To demonstrate the popularity of such concurrent green initiatives, we narrow our focus to concurrent *payments for environmental services* (PES), an essential type of green initiatives. Specifically, we focused on the 55 PES programs identified by Ezzine-de-Blas et al. (Ezzine-de-Blas et al., 2016b) and found that over half of these 55 selected PES programs have concurrent PES programs (An et al., 2022, pp. 25–26).

Many concurrent green initiatives were generally designed and/or implemented as if they were independent of each other, as in the case of the Environmental Quality Incentives Program (EQIP) and the Conservation Reserve Program (CRP)—two of the most significant concurrent green initiatives in the USA (Section 3). Ironically, this lack of coordination has happened in a context where calls have been made to explore cross-area or cross-program interactions (Table 1).

The COVID-19 pandemic wreaked a human tragedy, causing a global economic recession and subsequent budget cuts in nearly all sectors, including investment in green initiatives. At the global level, green initiatives received very little of the USD 9 trillion fiscal allotments towards pandemic relief (Barbier, 2020). Calls have been made to (re) evaluate green initiatives—regardless of concurrent ones or not—in terms of policy (re)design, spending and finance reforms, and improved integration of socio-economic and environmental goals so that green initiatives may support long-term sustainability (López-Feldman et al., 2020).

[1] Major acronyms used in this paper: REDD+—Reducing Emissions from Deforestation and Forest Degradation; CRP—Conservation Reserve Program; EQIP—Environmental Quality Incentives Program; GTGP—Grain-to-Green Program; FEBC—Forest Ecological Benefit Compensation program.

2. Theory/calculation

To (re)evaluate global green initiatives, concurrent green initiatives in particular, with a focus on what makes them succeed or fail, we propose a conceptual framework, along with an analytical framework with 15 case studies from around the world. Our aim is to detect and address spillover effects among concurrent green initiatives and thus improve their effectiveness globally. The term "spillover effect" refers to the phenomenon in which one initiative generates unintended impacts on a different initiative implemented in the same or nearby area(s) or contracted to the same recipient(s) (detail in Section 2.1).

2.1. Conceptual framework

Despite the differences in detail, green initiatives are largely comprised of the following three dimensions (Fig. 1A): launching a *policy,* engaging people in a particular *behavior* or change(s) in *behavior,* and achieving specific *gain(s)* in the form of, e.g., conserving natural capitals, protecting biodiversity, and/or achieving climate neutrality (Ocasio-Cortez, 2021). Currently, there exists abundant literature about the links between the three dimensions within the same given green initiative, which we define as internal effects (represented as solid arrows in Fig. 1). Such internal effects include how a specific *policy* may motivate people to adopt or abandon a particular *behavior* or make changes in previous *behaviors* (the arrow from Policy to Behavior; Fig. 1A), and whether and how such *behavior* or changes in behaviors may help achieve the intended *gain* (the arrow from Behavior to Gain; Fig. 1A). Occasionally, the researcher may explore how a certain *gain(s)* may loop back and influence/reformulate the original *policy* (the arrow from Gain to Policy; Fig. 1A ~1C). Undoubtedly, the studies about these dimensions and the relevant internal effects are valuable and necessary (for relevant literature, including examples, see (An et al., 2022, pp. 1–8).

When multiple green initiatives become implemented simultaneously in the same area or contracted to the same recipients (Fig. 1A, B), influences might spill over from one to the other. We define such

Table 1
Calls for cross-policy and cross-area interactions in green initiative studies.

Dimensions	Content	References
Policymix & policyscape	Policy-policy interactions	(Ezzine-de-Blas et al., 2016a)
Telecoupling	Impacts across geographic areas	(Liu et al., 2013)
Conservation crossovers	Leakage between protected areas	(Ewers and Rodrigues, 2008)
	Avoiding oversimplified design and implementation to minimize negative leakages from one initiative to another	(Wunder et al., 2018)
	Impacts of an intervention on non-targeted environmental services	(Naeem et al., 2015)
	Bundling and stacking of relevant conservation payments	(Gren and Elofsson, 2017; Program Evaluation Division, 2009)

cross-initiative influences as “spillover effects” (An et al., 2022; Liu et al., 2013). As there is a “lack of coordination” between concurrent green initiatives, this paper’s overarching goal is to examine whether spillover effects exist and how they can be leveraged in conservation science and practice. Under this goal, we have the following three objectives. First, we detect spillover effects between two initiatives on the same dimension, e.g., one initiative’s policy dimension affects a different initiative’s policy dimension (*Policy-Policy spillover effects*). In the same way, we explore *Behavior-Behavior* and *Gain-Gain spillover effects*. Second, we identify *spillover effects* across different dimensions, e.g., the policy dimension of one initiative may affect the behavior dimension of another initiative (*Policy-Behavior spillover effects*); similarly, we examine *Behavior-Gain and Gain-Policy spillover effects* (dotted arrows in Fig. 1C). The spillover effects can manifest in two ways: one green initiative benefits or harm another initiative in the relevant dimension(s), which we name beneficial or detractive spillover effects, respectively. Third, we seek insights into leveraging such spillover effects to support green initiatives (including the associated proposals or bills) that generate substantial co-benefits and/or suspend those that undermine other concurrent green initiatives. This is particularly important when the budgets are not sufficient or large-scale budget cuts are unavoidable (e.g., due to the pandemic).

2.2. Analytical framework

To detect potential influences between concurrent green initiatives, we adopt the Sustainable Livelihoods Framework, where a particular stakeholder’s (e.g., farm, household, community) human, social, natural, physical, and financial capitals may substantially affect relevant livelihood decisions (United Nations Development Programme, 2017). Under this framework, we collect relevant data (details in Sections 3.1 and 3.2) and use them in the corresponding regression analysis; subsequently, the framework also helps justify our choice of the dependent and independent variables and quantify the influences between them. To consolidate any detected influences (rather than simply correlations), we also leverage literature in relevant disciplines, field observations, and data (detail in Sections 3.1 and 3.2).

In this research, we explore how spillover effects can be leveraged to maintain the total amount of certain type of conservation areas under given critical situations (e.g., budget cuts, pandemic). For example, the conservation community has long considered protected areas an essential green initiative (Jonas et al., 2014; Maxwell et al., 2020a). More recently, ‘other effective area-based conservation measures’ (OECMs) are defined by the Convention on Biological Diversity as areas that are achieving the effective in-situ conservation of biodiversity outside of protected areas (Maxwell et al., 2020b). Following the concept of area-based conservation measures —with OECMs included—we designed scenarios to show how spillover effects may be leveraged for conservation purposes (detail in Section 3.3).

3. Materials and methods

Building on the literature (Section 1) and the hypothetical existence of concurrent green initiatives and corresponding spillover effects (Section 2), we present two case studies, one in the US and the other in China (Fig. 2), to support or oppose such hypothetical existence. If supporting evidence is found in the two cases, we expand the exploration to other parts of the world to reaffirm or rebut such hypothetical existence.

The first set of case studies on potential cross-initiative spillover effects is from the U.S. and China, the two largest economies, with six cases from local to national levels (Fig. 3). To assess the generality of such effects (if any), we performed a second set of case study analyses with nine additional cases that span different geographic regions, program sizes, urban-rural gradients, levels of economic development, and

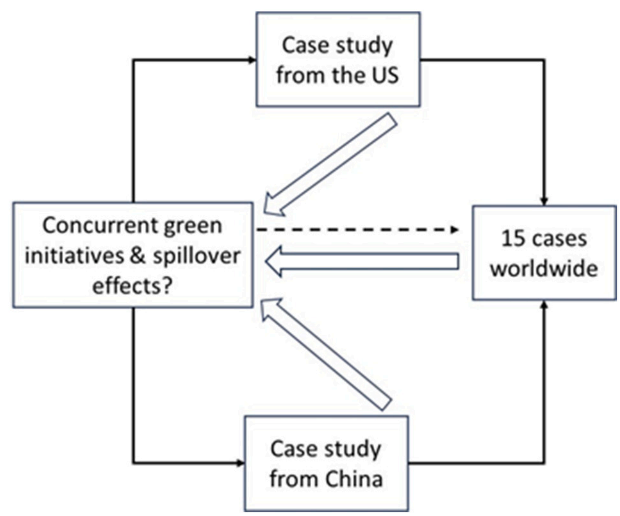

Fig. 2. Diagram for methodology. Single solid arrows represent the methodological “trigger” or “stimulate” actions starting from the research question to the two case studies (China and the US) and then to the 15 cases worldwide (the single dashed arrow represents a secondary action). Single hollow arrows stand for “reaffirm” or “rebut” steps or actions.

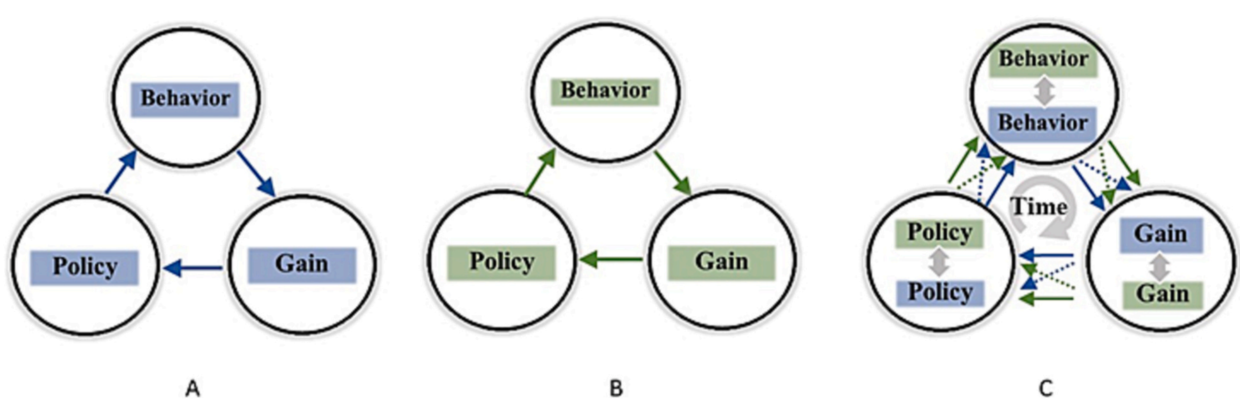

Fig. 1. Green initiatives with policy, behavior, and gain dimensions. Panels A and B represent two initiatives that are implemented in the same area or involve the same recipient(s), and considered independent, where only solid arrows (i.e., internal effects) are studied: how policy may affect behavior or changes in behavior, how behavior or changes in behavior may lead to gain(s) in the environment, and how such gain(s) may feedback to affect the original policy, which are represented by the Policy-Behavior, Behavior-Gain, and Gain-Policy solid arrows in Panels A and B. Panel C represents our conceptual framework, where two-way grey arrows or one-way dotted arrows (i.e., spillover effects between green initiatives) are explored in addition to the solid arrows (modified from (An et al., 2022, pp. 12–13)).

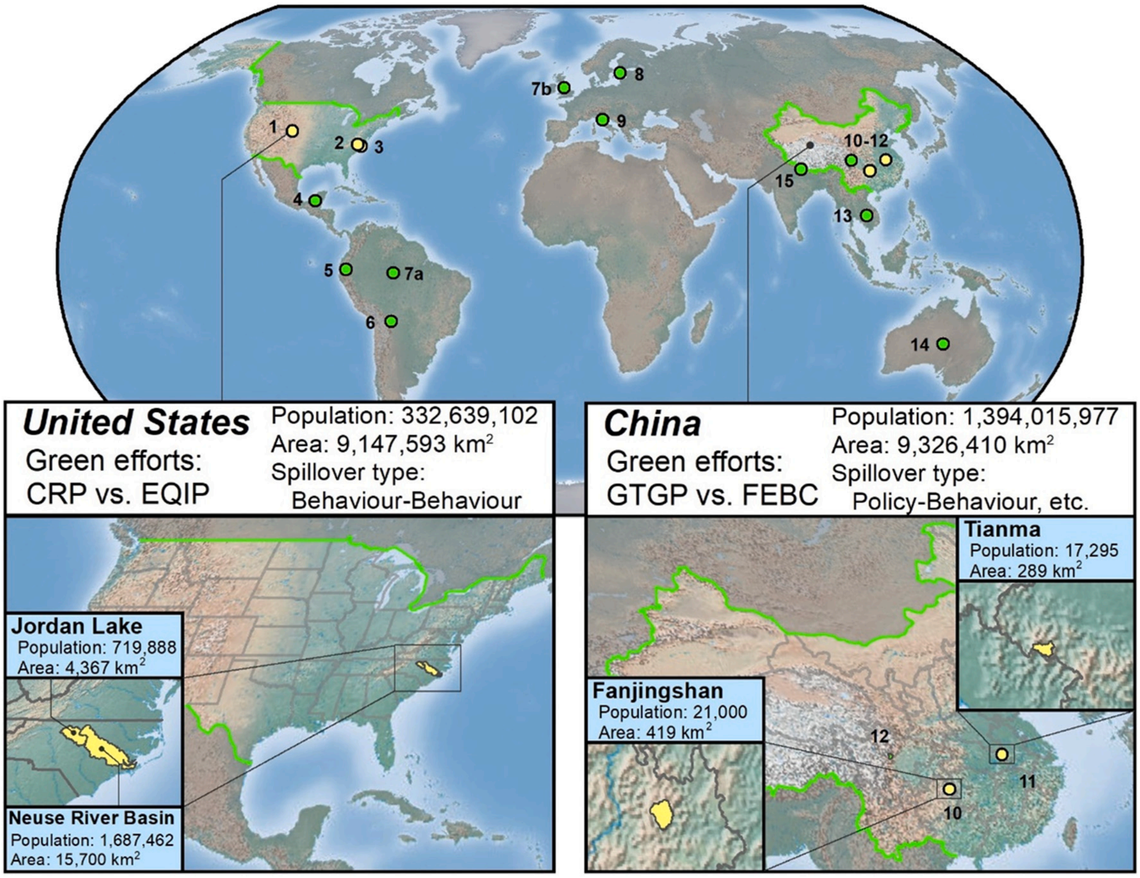

Fig. 3. Map of study sites. Circles with numbers 1 through 15 represent sites with concurrent green initiatives. Yellow circles are study cases with zoomed-in illustrations.

types of payment funders.

3.1. Cases in the U.S.

We first explore potential spillover effects in the U.S. between the Conservation Reserve Program (CRP) and the Environmental Quality Incentives Program (EQIP). These programs aim to 1) retire environmentally sensitive land and 2) adopt environmentally friendly practices on working lands, respectively. These two programs do not purposefully target the same area or same recipient(s) simultaneously by design, but some lands or farmers may be qualified for both programs, making EQIP and CRP concurrent green initiatives for these lands or farmers according to our definition in Section 1. Based on the evidence for the offsetting spillover effect from EQIP to CRP at some sites (e.g., Topashaw Canal watershed, Mississippi (Wilson et al., 2008)), the "slippage effects" (i.e., equivalent to spillover effects in our article) from CRP payments to changes in farmland (Wu, 2000), and a rapid decline in CRP enrollment in recent years (An et al., 2022, pp. 57), we hypothesize that participation in EQIP (Behavior 1) had a detractive spillover effect on CRP enrollment (Behavior 2; AS 2).

To test this hypothesis, we collected county-level data for the entire country from the U.S. Department of Agriculture (USDA Farm Production and Conservation Business Center, 2020) and performed regression analysis. As differentiation between causation and correlation is constantly a challenge in regression analysis, especially when no longitudinal dataset or large dataset exists to build a baseline or calculate the counterfactual rate, we made our choice (there is a causal link from EQIP to CRP) according to 1) the UN's Sustainable Livelihoods Framework (United Nations Development Programme, 2017), 2) empirical evidence mentioned above (Wilson et al., 2008), and 3) relevant literature in agricultural economics—e.g., CRP enrollment has "slippage effects" of increasing farmland acreage in the central United States (Wu, 2000). The multivariate linear regression takes the following form:

$$y = b_0 + b_1 X_1 + \sum_{i=2}^{4} b_i X_i + e \quad (1)$$

where y is the dependent variable CRP_Area that represents land enrolled in CRP (acres) in each county (the remaining independent variables are county-level measures); b_o is the intercept; b_1 is the coefficient of X_1 (EQIP_Area), the variable that represents contracted land in EQIP (acres), and b_i are the coefficients of the three control variables (i = 2, 3, and 4 for total planted farmland area (acres), median household income, and county population size (Table 2). To examine whether the spillover effects are scale-specific (e.g., only at the national scale as shown in the CRP-EQIP case vs. local scale), we collected data at the Neuse River basin and Jordan Lake in North Carolina to further explore spillover effects at a local scale (AS 2.3).

3.2. Cases in China

Next, we examined potential spillover effects between China's Grain-to-Green Program (GTGP) and Forest Ecological Benefit Compensation (FEBC) program, two concurrent green initiatives that pay local stakeholders to 1) restore vegetation on marginal farmland or grassland and 2) conserve selected natural forestlands through a logging ban, respectively (for details of GTGP and FEBC, see AS 3). We collected data at Fanjingshan National Nature Reserve and Tianma National Nature Reserve in China (AS 3.1). We handled the causation vs. correlation challenge and made our choice (there is a causal link from FEBC to

Table 2
The relationship between EQIP enrollment and CRP enrollment with several selected variables under control.

Variable	Description	Parameter Estimate	Standard Error	t Value	Pr > |t|	Variance Inflation
Intercept		5070.8004	2914.5547	1.74	0.0826	0
EQIP_Area	Area of EQIP land (acres)	−0.2178***	0.0509	−4.28	<0.0001	1.2061
Farmland_Area	Total planted farmland area (acres)	0.0312***	0.0025	12.71	<0.0001	1.2087
M_HH_Inc	Median household income	−0.0605	0.0542	−1.11	0.2656	1.0584
CountyPop	County population size (1000 people)	−1.3009	2.3583	−0.55	0.5815	1.0594
R^2 (adjusted R^2)		0.2832 (0.2764)				

Note: * $p < 0.10$; ** $p < 0.05$; *** $p < 0.01$.

GTGP) in the same way as we did for the EQIP-CRP case (Section 3.1): 1) the UN's Sustainable Livelihoods Framework, 2) empirical evidence and observations in the field, and 3) relevant literature provide the guidelines and support for this choice. For instance, the amount of land enrolled in FEBC was found to significantly reduce the landowner's willingness to participate in GTGP under a set of hypothetical conditions (Yost et al., 2020). We hypothesized that FEBC payments might have a spillover effect on GTGP participation, a *Policy-Behavior* spillover effect. Also, following the previous analytical framework (Section 2.2), we modeled the area of cropland enrolled in GTGP as a function of payment from FEBC (at Tianma only; area of forestland enrolled in FEBC at Fanjingshan) with a set of controlled variables that represent various capitals as in the CRP and EQIP case (Section 3.1).

To test whether the above FEBC-GTGP spillover effects may vary over time, we surveyed local farmers regarding their willingness to participate in GTGP under several hypothetical conditions at Fanjingshan. We then modeled how the FEBC payment amount may affect the corresponding interviewee's stated choice (a binary variable for willingness to enroll a land parcel in GTGP) with several control variables that represent similar capitals as above. The model is similar to Yost et al. (2020), except that a more recent dataset is used. Furthermore, we examined the results from a published paper (Yang et al., 2016) regarding local villagers' income growth at Wolong Nature Reserve in China to explore potential spillover effects (detail in AS 3.3).

3.3. Reallocation scenario analysis

The conservation community has long considered protected areas, an essential type of green initiative, as the foundation of biodiversity conservation and has more recently started recommending area-based conservation measures for conservation purposes (Jonas et al., 2014; Maxwell et al., 2020b). Under this concept, the total area under different conservation initiatives is a key indicator of conservation effectiveness. To explore how spillover effects can be leveraged to reduce the amount of financial support with zero or minimized decrease in the total amount of area-based conservation initiatives (including 'other effective area-based conservation measures'; Section 2.2), we perform scenario analysis to reallocate various amounts of land enrolled in one program to the other program. As the two programs— CRP vs. EQIP in the U.S. or GTGP vs. EQIP in China—have very different pay rates, such a reallocation should maintain the sum of land enrolled in the two programs the same but reduce the total amount of payments. We did such scenario analysis in both the U.S. (AS 2.2) and China (AS 3.2) to calculate the potential for reducing payments whilst maintaining the total amount of land enrolled in the two programs unchanged.

3.4. Cases worldwide

We examine whether spillover effects can be found in other parts of the world beyond those found in the U.S. (Section 3.1) and China (Section 3.2). This study continues with a literature search under the "topic on payment(s) for ecosystem services, payment(s) for environmental services or PES" and a review based on several online data sources and archives, including *Web of Science*, *Google Scholar*, and the journal *Ecosystem Services* (for details see AS 4).

4. Results

4.1. Spillover effects between EQIP and CRP in the U.S.

The regression results indicate that enrolling each hectare of land in EQIP was associated with a loss of 0.22 ha of land enrolled in CRP with a 95 % confidence interval ranging from 0.12 to 0.32 ha ($p < 0.0001$; Table 2, AS 2.1), representing a detractive *Behavior-Behavior* spillover effect. This effect could have led to an average reduction of 4.5 million acres or 20.45 % of total CRP land (AS 2.2).

The hypothetical reallocation scenarios show the consequences of reallocating varying proportions of the "extra" EQIP farmland that has been taken away from CRP possibly (4.5 million acres in total). This "varying proportions" choice hinges upon the uncertainty in the amount of EQIP land that can be converted back to CRP. Suppose we reallocate a large portion of such "extra" EQIP land back to CRP. In that case, we receive enhanced biodiversity and ecosystem services because this large portion of land, presumably best for enrolling in CRP for biodiversity and ecosystem services but was attracted to participate in EQIP, is switched back to CRP. On the other hand, if we reallocate less of such EQIP land, more emphasis is placed on the socio-economic benefits for landowners due to EQIP's higher pay rate ($340.94/ha or $137.98/acre) compared to CRP ($188.68/ha or $76.36/acre). The results suggest that with varying levels of EQIP land reallocation, the total payment can be reduced by 1 % ~ 7 % without affecting the total acreage of EQIP and CRP land (AS 2.2).[2] Note that the 1– 7 % cost-saving comes from the switch-back decision only (i.e., from EQIP to CRP), which does not account for the huge subsequent ecological benefits (e.g., carbon sequestration due to increased forest cover under the CRP). For evidence of the *Gain-Policy* and *Gain-Gain* spillover effects at Neuse and the *Policy-Policy* and *Gain-Gain* spillover effects at Jordan Lake, we refer to AS 2.3.

4.2. Spillover effects between FEBC and GTGP in China

Our data analysis revealed a beneficial spillover effect from FEBC to GTGP at both Fanjingshan and Tianma. Specifically, we found a significant *Policy-Behavior* beneficial spillover effect from FEBC to GTGP enrolment: FEBC payments increased GTGP enrollment at Fanjingshan (FEBC payment's coefficient = 0.4393, $p = 0.0703$; Table A2); similarly, total land enrolled in FEBC at Tianma also increased GTGP enrollment (FEBC area's coefficient = 0.4669, $p = 0.002$; Table A3). Based on the findings from these two sites, our conservative extrapolative analysis (AS 3.2) suggests that an average of 9.5 % of total GTGP land may have come from FEBC enrollment. Applying this rate across China, around 0.46 million ha of GTGP land was a co-benefit of the FEBC program. Like our U.S. case, we performed a scenario analysis that switches varying proportions of FEBC land from areas eligible for both GTGP and FEBC – a

[2] The global GDP contraction was projected to be 2 % ~ 8 %. Note that I.M.F. projects that GDP will fall by 4.3 % in the U.S., and an increase by 1.9 % in China (International Monetary Fund, 2020).

total of 0.47 million ha – to areas eligible for FEBC alone (AS 3.2 and Appendix 1). The increase in carbon sequestration due to the FEBC-GTGP spillover effect (i.e., 0.47 million ha of "extra" GTGP land) is estimated to be 1423.07 billion t C (Appendix 1). In Wolong Nature Reserve, we found evidence for both the *Policy-Behavior* and *Behavior-Behavior* spillover effects; for details, we refer to AS 3.3.

4.3. Spillover effects among green initiatives worldwide

Spillover effects are also evident in other parts of the world (Table 3; AS 4). Below, we present findings from places other than the U.S. and China but refer readers to AS 4 for more details. A *Behavior-Gain* spillover effect in Australia showed that the behavior of planting native trees and shrubs (Behavior 1) had twofold gains, with not only the intended gain in biodiversity (Gain 1) but also high levels of carbon sequestration (Gain 2), which was the sole target of a different program.

Policy-Policy spillover effects were found in the Baltic Sea case, where payments for nitrogen (Policy 1) and phosphorus abatement (Policy 2) must be stacked together to be cost-effective (AS 4.4). *Behavior-Behavior* spillover effects were found to be prevalent in Australia, where planting fast-growing Eucalyptus monocultures (Behavior 1) and planting a mix of native trees and shrubs (Behavior 2) were subject to a quantitative restriction: the total land area covered by these two types of planting could not exceed a certain maximum land area (AS 4.5). *Gain-Gain* spillover effects were evident in the New World and Great Britain, where carbon sequestration (Gain 1) and increases in biodiversity (Gain 2) could be achieved simultaneously through adjustments in the related behaviors due to heterogeneous spatial distributions of—and site-specific connections between—biodiversity and carbon gains (AS 4.6). For spillover effects with changes in their direction over time (i.e., *Time-Time* spillover effects) and multiple spillover effects that are stacked together, we refer to AS 4.7.

Table 3
Cross-initiative spillover effects from the 15 case studies worldwide.

Linkage type	Description[a]	Case names	Detail in:
Policy -Behavior	Policy 2 ➔ Behavior 1a (+) & Behavior 1b (−)	Fanjingshan & Tianma	SI 3.1
	Policy 1 (or 2) ➔ Behavior 1 Policy 1 plus Policy 2 ➔ Behavior 3	Wolong	SI 3.3
Behavior - Gain	Behavior 2 ➔ Gain 1 (+)	Australia	SI 4.2
	Behavior 1 ➔ Gain 2 (−)	Páramo	SI 4.2
Gain - Policy	Gain 1 ➔ Cancelation of Policy 2 (−)	Neuse	SI 2.3
Policy - Policy	Policy 1 and Policy 2 must coexist	Baltic Sea countries	SI 4.4
	Policy 1 ➔ downgrades or nullifies Policy 2 (−)	Rio Grande	SI 4.4
	Policy 1 and Policy 2 subject to relative amount of restrictions	Jordan Lake	SI 2.3
Behavior - Behavior	Sum of Behavior 1 and Behavior 2 are subject to a numerical constraint;	Australia	SI 4.5
	Behavior 2 (new) to replace Behavior 1	Wolong	SI 3.3
	Behavior 1 ➔ Behavior 2 (+)	Tianma	SI 3.1
	Behavior 1 ➔ Behavior 2 (−)	USA	SI 2.1
	Behavior 1 ➔ Behavior 2 (+)	Yucatán and Chiapas	SI 4.5
Gain – Gain	Gain 1 and Gain 2 are a function of the same processes	Marecchia & Foglia	SI 4.6
	Gain 1 and Gain 2 can be achieved simultaneously by one modified action	New World and Great Britain	SI 4.6
	Gain 1 entails Gain 2	Neuse	SI 2.3
	More examples	Jordan Lake, Neuse	SI 2.3
Time-Time & intertwined	The sign of Policy - Behavior spillover effect changes with time	Fanjingshan	SI 3.1
	Policy 1 and Policy 2 occur in sequence	PVPF-KPWS	SI 4.7
	Detractive Gain ➔ Gain and Behavior ➔Gain (−) are intertwined	Nepal	SI 4.7

Notes: a. The sign (+) or (−) indicates beneficial or detractive influence; numbers 1 and 2 represent initiatives 1 and 2, e.g., Policy 2 and Behavior 1 represent the policy dimension of initiative 2 and the behavior dimension of initiative 1, respectively.

5. Discussion

Spillover effects among green initiatives appear to be common worldwide (AS 1). Concurrent green initiatives are rarely coordinated with one another despite the increasingly recognized need to do so (Barton et al., 2013; Ezzine-de-Blas et al., 2016a). Examining and leveraging such spillover effects—as in the cases of the U.S. and China—may help uncover undocumented losses or unrecognized co-benefits, creating scope for budget cuts with minimized or no sacrifice of environmental gain. Although budget cuts in green initiatives for various reasons (e.g., GDP contraction during the pandemic) are spatially variable, leveraging spillover effects among concurrent green initiatives (e.g., converting some EQIP land back to CRP in the US) may still preserve those area-based conservation initiatives–or, at least, minimize their loss.

To visualize our findings, we illustrate the potential impacts of spillover effects (shown in Fig. 1) on the final gains (Fig. 4). Here we show exemplary relationships between two green initiatives (equivalent to the two initiatives in Panels A and B of Fig. 1) that have A) no spillover effects; B) one-way, detractive spillover effects, where initiative 1 reduces the gain of initiative 2 from 20 % (U.S. CRP/EQIP case, AS 2.1) to 100 % (Neuse case, AS 2.3); C) one-way, beneficial spillover effects, where initiative 1 increases the gain of initiative 2 from 9 % (Fanjingshan, AS 3.2) to 10 % (Tianma, AS 3.2); and D) two-way, beneficial spillover effects, where initiatives 1 and 2 jointly increase the overall gain (labeled as 1 & 2) from 26 % (Wolong case, AS 3.3) to 310 % (New World & Great Britain case, AS 4.6). We do not have data for two-way detractive spillover effects (so not shown as a category above).

If scientists and policymakers can identify major co-benefits (e.g.,

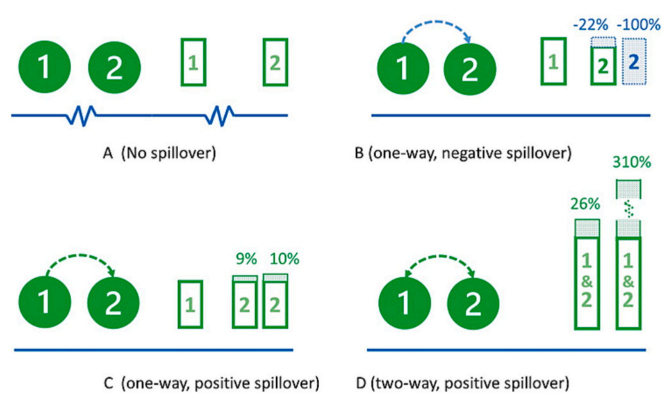

Fig. 4. Exemplary relationships between green initiatives that have A) no spillover effects; B) one-way, detractive spillover effects; C) one-way, beneficial spillover effects; and D) two-way, beneficial spillover effects. Due to data limitation, the evidence for two-way negative spillover effects is still incomplete and not presented here. The blue line represents the area that receives green initiatives (represented as green circles 1 and 2) and the corresponding gains (green rectangles 1 and 2). The percentage numbers above rectangles are minimum and maximum spillover effects under each of the four categories based on our 15 cases (Table 2). The size of a circle (or rectangle) is symbolic, representing a green initiative (or its gain) in whatever magnitude before spillover effects occur, but the size of a green (or blue) dotted rectangle is proportional to the corresponding gain (or loss).

Fig. 4D) of concurrent green initiatives, lawmakers may be greatly empowered to defend them. Similarly, concurrent green initiatives with big detractive spillover effects (e.g., Fig. 4B) can be replaced with positive, more impactful initiatives.

The limitations of our work may come from the following aspects. First, no systematic framework can be adopted to address and quantify the above spillover effects. Therefore, we have established a pioneering framework (Fig. 1) in this regard, which may need additions and modifications in the future. For instance, we may consider expanding our framework to include spillover effects not only across initiatives but also across geographic areas, e.g., leakage or spillovers of conservation effectiveness over space (Ewers and Rodrigues, 2008; Fuller et al., 2019; Shen et al., 2022). Second, we acknowledge that correlation does not imply causality (Meyfroidt, 2016). For this reason, we have examined the spillover effects by carefully choosing the dependent and independent variables, following the United Nations' Sustainable Livelihoods Framework and relevant literature (AS 2.1, 3.1). It would be more convincing if other theories or frameworks could be employed to examine such spillover effects. Finally, our evidence for spillover effects, although coming from local to sub-continent scales in various regions of the globe (Table 2), is still in an early, fledging stage. For instance, several studies (e.g., the Wolong case in Table 2) did not intentionally focus on spillover effects, making direct analysis difficult; we had to rely on reinterpreting existing results, limiting our ability to perform further analysis (e.g., calculating the confidence interval of some parameters).

6. Conclusions

The essence—and novelty—of this research lies in the following aspects. First, we bring the concept of concurrent green initiatives to the conservation community and the public's attention, which is defined as multiple conservation programs or endeavors implemented in the same area(s) or involving the same recipients. Second, we show strong spillover effects exist between concurrent green initiatives in divergent (detractive or beneficial) forms from one to the other based on evidence from the US (Section 3.1), China (Section 3.2), and many other countries across the world (Section 3.4). Third, we point out that spillover effects are often ignored as if they do not exist among concurrent green initiatives. Lastly, such spillover effects can be tapped to enhance the effectiveness of green initiatives by, e.g., supporting green initiatives that generate substantial co-benefits and/or suspending those that undermine other concurrent green initiatives.

Our research is a timely contribution to the conservation community in an era when "the biosphere, upon which humanity as a whole depends, is being altered to an unparalleled degree across all spatial scales" (IPBES, 2019). The year 2021 witnessed the inauguration of the Decade of Action initiative within the U.N.'s Sustainable Development Goals and the European Union's Green Deal. Moreover, the U.N. has embarked on its Decade of Ecosystem Restoration project (UNEP, 2019) and approved the Post-2020 Global Biodiversity Framework (CBD, 2020). By leveraging the opportunities—and challenges—from widespread yet mostly hidden spillover effects, governments and other relevant organizations can make these green initiatives more effective and more resilient to disturbances (e.g., COVID-19), continuing to sustain ecosystem services.

CRediT authorship contribution statement

Li An: Writing – review & editing, Writing – original draft, Project administration, Methodology, Funding acquisition, Formal analysis, Data curation, Conceptualization. **Jianguo Liu:** Writing – review & editing, Resources. **Qi Zhang:** Writing – review & editing, Formal analysis, Data curation. **Conghe Song:** Writing – review & editing, Resources, Methodology, Data curation. **Driss Ezzine-de-Blas:** Writing – review & editing, Data curation. **Jie Dai:** Investigation. **Huijie Zhang:** Investigation. **Rebecca Lewison:** Investigation. **Eve Bohnett:** Writing – review & editing, Investigation. **Douglas Stow:** Writing – review & editing, Investigation. **Weihua Xu:** Investigation. **Brett A. Bryan:** Writing – review & editing, Investigation.

Declaration of competing interest

The authors declare that there are no competing interests that could inappropriately influence (bias) their work.

Data availability

We will publish data once we prepare the DIB paper

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Appendix A. Supplementary data

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