Integrating climate change mitigation and adaptation in agriculture and forestry: opportunities and trade-offs

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Advanced Review

Integrating climate change mitigation and adaptation in agriculture and forestry: opportunities and trade-offs

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Although many activities can jointly contribute to the climate change strategies of adaptation and mitigation, climate policies have generally treated these strategies separately. In recent years, there has been a growing interest shown by practitioners in agriculture, forestry, and landscape management in the links between the two strategies. This review explores the opportunities and trade-offs when managing landscapes for both climate change mitigation and adaptation; different conceptualizations of the links between adaptation and mitigation are highlighted. Under a first conceptualization of 'joint outcomes,' several reviewed studies analyze how activities without climatic objectives deliver joint adaptation and mitigation outcomes. In a second conceptualization of 'unintended side effects,' the focus is on how activities aimed at only one climate objective—either adaptation or mitigation—can deliver outcomes for the other objective. A third conceptualization of 'joint objectives' highlights that associating both adaptation and mitigation objectives in a climate-related activity can influence its outcomes because of multiple possible interactions. The review reveals a diversity of reasons for mainstreaming adaptation and mitigation separately or jointly in landscape management. The three broad conceptualizations of the links between adaptation and mitigation suggest different implications for climate policy mainstreaming and integration. © 2015 The Authors. *WIREs Climate Change* published by Wiley Periodicals, Inc.

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INTRODUCTION

The idea of pursuing adaptation and mitigation jointly in climate change projects and policies is gaining prominence.[1,2] Mitigation aims to reduce emissions or enhance the sinks of greenhouse gases, while adaptation aims to reduce the vulnerability of people and ecosystems to climate variation and change, i.e., the degree to which they are susceptible to, and unable to cope with, adverse impacts of climate.[3] Although they share the ultimate aim of reducing climate change impacts, each climate change strategy has different objectives and delivers benefits at different scales and rates.[4,5] However, many activities and policies can produce both adaptation and mitigation outcomes. The

Supporting Information: **Appendix S1**. Systematic review protocol.

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Fourth and Fifth Assessment Reports of the IPCC have dedicated sections on synergies and trade-offs between mitigation and adaptation,[6,7] and the interest in the links between the two strategies (particularly evident in landscape management) has been growing since the Fourth Assessment.

A landscape is a spatially heterogeneous land area that encompasses a mosaic of interacting ecosystems and includes cultural and institutional attributes.[8] Activities within the different land uses in the landscape (such as agricultural and forest management) affect and depend on the spatial and socioeconomic interactions among people and natural resources.[9] The management of agriculture and forests in a landscape can contribute to mitigation by storing carbon, reducing carbon emissions from deforestation and forest degradation, or reducing non-CO_2 emissions from agriculture. Landscape management can also help people adapt to climate variations:[10] e.g., adequate agricultural management enhances food security, forests regulate the microclimate locally (in cities) and water regionally (in watersheds), and mangroves buffer the impacts of extreme climate events in coastal areas. In addition, adaptation measures can be implemented to reduce the vulnerability of agriculture and forestry to climate change.[11] Landscape management can thus be an effective response to climate change and new approaches such as climate-smart landscapes, agriculture or forestry have been proposed[12–14] (Figure 1). However, trade-offs between adaptation and mitigation can occur (e.g., when gains in carbon sequestration lead to an increase in the vulnerability of people or ecosystems).

Adaptation and mitigation policy instruments consider activities related to landscape management. The clean development mechanism includes agricultural projects and reforestation or afforestation for their contribution to mitigation, while the REDD+ instrument (reducing emissions from deforestation and forest degradation) aims to reduce carbon losses from forest degradation and deforestation (often caused by agriculture expansion), and to conserve or enhance carbon stocks through sustainable forest management. The Nationally Appropriate Mitigation Actions policies also include actions related to agriculture and deforestation in different countries.[15] Agriculture is a priority sector in many adaptation activities and the ecosystem-based approach to adaptation considers the role of ecosystem services in reducing vulnerability—an approach strongly connected to landscape management. Such projects can be found in the National Adaptation Programmes of Action in a number of African and Asian countries.[16]

Early studies on the links between adaptation and mitigation have explored optimal mixes of adaptation and mitigation, which have been considered by some as substitutes at the global scale; for example a larger global effort on mitigation would require a smaller effort on adaptation because of reduced climate impacts.[17,18] In this case, the best possible combination of adaptation and mitigation strategies comes from optimization analysis. Synergies is an alternative, more recent idea.[19] It is based on the assumption that adaptation and mitigation actions can interact 'so that their combined effect is greater than the sum of their effects if implemented separately'[7] (p. 749). Some authors have suggested that integrating adaptation and mitigation objectives limits unwanted negatives consequences, e.g., the potential negative consequences of REDD+ projects on the adaptation of people and ecosystems.[20]

Following the framework proposed in Figure 1, we define the integration of adaptation and mitigation

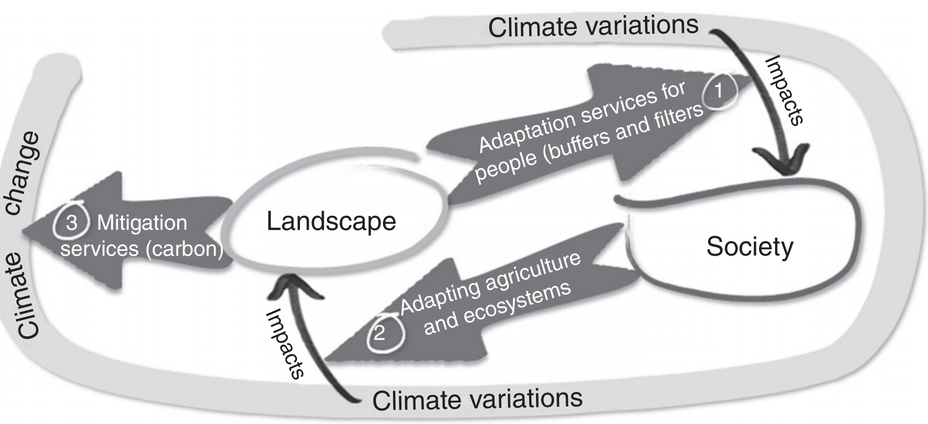

FIGURE 1 | Conceptual framework of the integration of adaptation and mitigation into landscape management. Landscapes deliver services that contribute to the adaptation of society (1); society manages landscapes for adapting agriculture and ecosystems (2); and landscapes contribute to climate change mitigation through enhanced carbon storage and reduced greenhouse gas emissions (3).

in landscape management as the design and implementation of management practices that deliver the three outcomes of climate-smart landscapes (societal adaptation, ecological adaptation, and climate mitigation) and recognize and minimize the trade-offs between these outcomes. Landscape management presents many opportunities for integrating adaptation and mitigation simultaneously,[21,22] but few initiatives have harnessed them.[7] One of the barriers for broader implementation of integrated adaptation and mitigation strategies is the lack of information on how adaptation can benefit mitigation (and *vice versa*) in landscape management, what added values integrated strategies bring, under what context they should be pursued, and whether mitigation and adaptation should be mainstreamed separately or jointly into land-use policies.[5] Here we present the results of a systematic review of scientific literature of climate change projects, measures and policies, where we explored the opportunities and trade-offs of managing landscapes for both climate change mitigation and adaptation. We first present the approach of the review and we then describe and illustrate the three different conceptualizations of the links between adaptation and mitigation that we found in the literature. We finally explore the policy implications of these conceptualizations.

REVIEW APPROACH

We searched for journal articles in English in the databases ISI Web of Knowledge, Scopus, Science direct and JSTOR, with three groups of keywords linked with the AND operator. The groups referred to landscape management (e.g., keywords such as forest, agriculture, ecosystem, watershed), mitigation (e.g., keywords such as carbon sequestration, REDD, greenhouse gas), and adaptation (e.g., keywords such as vulnerability, resilience, risk reduction). We used the OR operator within each group to differentiate between keywords (see Appendix S1, Supplementary Information for the detailed protocol for searching papers, filtering results, and extracting data).

The search we conducted in June 2013 resulted in 3486 references after removing duplicates and selecting only recent papers (published between 2000 and June 2013). We screened the references and kept only the 142 articles that dealt with all three themes: climate change mitigation, adaptation to climate variations, and landscape management (including management of different land uses and land-related activities such as forestry, agriculture, and livestock management). We identified 274 cases in the analyzed papers. (A case is defined here a statement about the links between adaptation and mitigation.)

For each case, we recorded the type of intervention considered (e.g., ecological restoration), the main objective(s) of the intervention (i.e., mitigation, adaptation, or other objectives), its outcomes on different climate objectives and how these outcomes were justified. We examined the way the links between adaptation and mitigation were conceptualized in each case and we developed a typology of conceptualizations.

DIFFERENT CONCEPTUALIZATIONS OF THE LINKS BETWEEN ADAPTATION AND MITIGATION

In the reviewed literature, we found that the links between adaptation and mitigation were viewed in three different ways, which we named joint outcomes, unintended side effects, and joint objectives (Figure 2). Some articles analyzed the delivery of joint adaptation and mitigation outcomes by activities that had no primary climatic objectives. Other articles showed that, even when activities aimed at only one climate objective (either adaptation or mitigation), they could produce an outcome for the other objective (unintended side effects): a 'service' in the case of positive outcome or a 'disservice' in the opposite case. Some articles described the possible effects of considering adaptation and mitigation objectives jointly. For example, adding adaptation objectives to a mitigation project could strengthen its mitigation outcomes or weaken it. In some cases, associating adaptation and mitigation

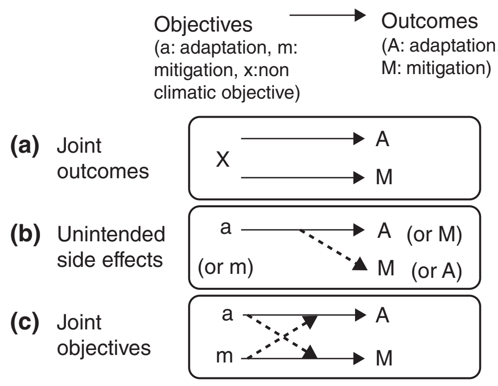

FIGURE 2 | Three main conceptualizations of the relationships between adaptation and mitigation. (a) Joint outcomes (activities with nonclimatic primary objectives deliver joint adaptation and mitigation outcomes); (b) Unintended side effects (activities aimed at only one climate objective—either adaptation or mitigation—also deliver outcomes for the other objective); (c) Joint objectives (associating both adaptation and mitigation objectives leads to interactions that strengthen or weaken outcomes).

could lead to worse outcomes for both objectives (competition) or better ones (synergy) (Table 1).

The three conceptualizations were used in 43, 33, and 24% of the reviewed cases, respectively. In the second conceptualization ('unintended side effects'), there were more cases on services (20%) than disservices (13%) and more on effect of mitigation on adaptation (22%) than the opposite (11%). In the third conceptualization ('joint objectives'), there were more cases about strengthening (16%) than weakening (2%), competition (1%) or synergy (5%) (Table 1).

JOINT OUTCOMES: LANDSCAPE MANAGEMENT CAN CONTRIBUTE TO BOTH ADAPTATION AND MITIGATION

Even in the analyzed cases where landscape management was not motived by climate-related objectives, it delivered both adaptation and mitigation benefits as joint outcomes. For example, conservation agriculture practices in the Mediterranean region reduced greenhouse gas emissions from soils or fertilizers as well as the vulnerability of crops to rainfall variability, thus contributing to both mitigation and adaptation.[23] Another case from this region showed how soil management increased soil organic carbon, which in turn built crop resilience to climate while also sequestering carbon.[24] Planting multipurpose trees in New Zealand provided both adaptation and mitigation outcomes[25]; in Australia, woody biomass production for renewable energy reduced emissions and was less vulnerable than agricultural practices in a drought context.[26]

Some cases highlighted how adaptation and mitigation outcomes could be unintendedly produced while pursuing nonclimatic objectives, such as soil conservation or sustainable food production. In other cases, the analysis of climate-related outcomes was done for prioritizing activities: in this case, the adaptation and mitigation outcomes were analyzed as secondary objectives and the joint outcomes were considered intended. In an example of agriculture in Australia, several measures were selected for their contribution to both adaptation and mitigation, such as tree planting that increased shade and shelter for a more resilient livestock and sequestered carbon for climate

TABLE 1 | Different Conceptualizations of the Links between Adaptation and Mitigation in the Reviewed Papers

Conceptualization	Objective(s) of Land-Use Management	Outcomes	Simple Representation of the Links	Frequency
Joint outcomes: Nonclimate activities contribute to both A and M				****
Joint outcomes	Nonclimatic	A and M	x → +A+M	****
Unintended side effects: activities for one climate objective contribute to the other objective				****
Service	a	Positive M outcomes	a → +A+M	**
	m	Positive A outcomes	m → +M+A	***
Disservice	a	Negative M outcomes	a → +A−M	**
	m	Negative A outcomes	m → +M−A	**
Joint objectives: managing intentionally for both climate objectives affects overall outcomes				***
Strengthening	a (with m secondary)	Increased A outcomes by adding M objectives	a[m] → +AA + M	**
	m (with a secondary)	Increased M outcomes by adding A objectives	m[a] → +MM + A	**
Weakening	a (with m secondary)	Decreased A outcomes by adding M objectives	a[m] → −AA + M	*
	m (with a as secondary)	Decreased M outcomes by adding A objectives	m[a] → −MM + A	*
Competition	Both a and m	Decreased A or M outcomes by managing for A and M jointly	am → −AA−MM	*
Synergy	Both a and m	Increased A and M outcomes by managing for A and M jointly	am → +AA+MM	*

a, adaptation objective; m, mitigation objective; x, nonclimate-related objective; [ ], secondary objective; →, results in; +, positive outcome; −, negative outcome; A, adaptation outcome; M, mitigation outcome; +AA or +MM, increased outcome as a result of an interaction between A and M; −AA or −MM, decreased outcome as a result of an interaction between A and M; frequency or percentage of cases found in the review; *,less than 5% of the 274 cases; **, 5–10%; ***, 10–25%; ****, more than 25%.

mitigation.[27] Similarly, agroforestry and the restoration and sustainable management of ecosystems were highlighted for their joint adaptation and mitigation outcomes.[28] But these cases did not analyze how adaptation outcomes affected mitigation outcomes (or *vice versa*), as in the two other conceptualizations.

The analyzed cases showed a diversity of landscape management activities contributing to adaptation and mitigation. The most frequent cases were related to agriculture, soil management, ecosystem conservation, and forestry (Figure 3). Ecosystem conservation and management in landscapes were often presented as a way of contributing to both adaptation and mitigation, through improving carbon storage in ecosystems and conserving watersheds for the protection of downstream populations against climatic variations.[29] These ecosystem-based strategies included soil management, with benefits for soil carbon storage and soil fertility (increasing the resilience of agriculture), and water infiltration (improving aquifer recharge and buffering the effect of climate variations on water availability). In these cases, the links between adaptation and mitigation resulted from the synergies and trade-offs between ecosystem services:[30] carbon sequestration for mitigation and a series of ecosystem services for adaptation, such as water regulation or coastal protection.[10]

UNINTENDED SIDE EFFECTS: ADAPTATION AFFECTS MITIGATION, MITIGATION AFFECTS ADAPTATION

Many analyzed cases highlighted that adaptation activities could affect emissions by increasing or decreasing

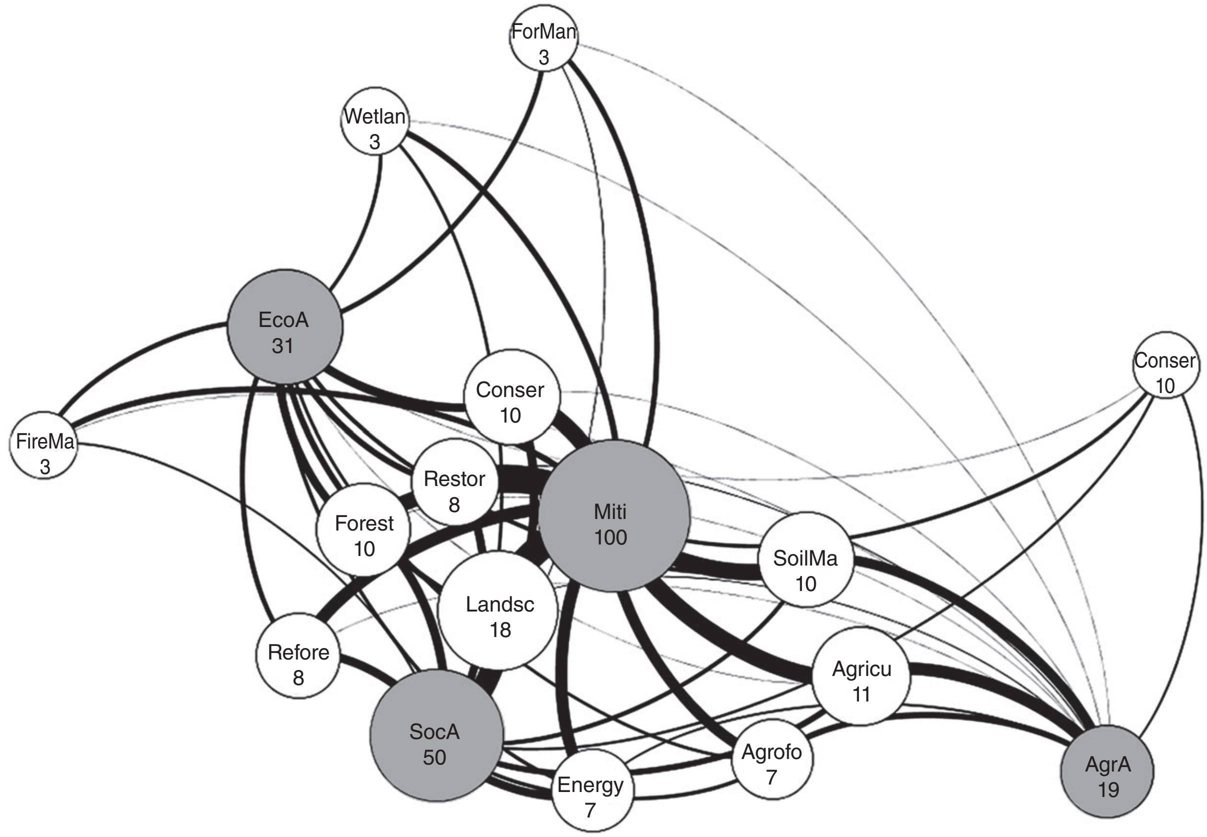

FIGURE 3 | Network representation of the linkages (either positive or negative) between activities and climate outcomes in the reviewed papers on both adaptation and mitigation. Edges are wider and pairs of nodes are closer when linkages are more frequent in the reviewed papers. Nodes are larger when the activities or the outcomes are more frequent in the papers (numbers show the frequency in percentage of analyzed cases). Outcomes are related to the contribution of landscape to climate change mitigation (Miti) and to people's adaptation (SocA), and the contribution of landscape management activities to improve ecosystem resilience (EcoA) and agricultural resilience (AgrA). Activities are related to agriculture (Agricu), agroforestry (Agrofo), conservation (Conser), bioenergy and biomaterials (Energy), fire management (FireMa), forestry in general (Forest), forest management (ForMan), management of multiple land uses in the landscape (Landsc), livestock and pasture (Livest), reforestation (Refore), restoration (Restor), soil management (SoilMa), and wetland management (Wetlan).

them and mitigation activities could affect vulnerability likewise, even when these effects were not planned. Adaptation measures in landscape management were shown to produce mitigation services in several ways (Table 2). In agriculture, such adaptation measures included soil conservation, which protected soil carbon,[31] water saving and the reduction of fertilizer use, which reduced energy-related emissions.[32] For

TABLE 2 | Example of Unintended Side Effects of Adaptation Activities on Mitigation or *Vice versa*

Name	Details	References
Adaptation activities can reduce climate change (mitigation services)		
Agricultural emissions	Adaptation measures in agriculture through changes in fertilizer and pesticide use, water saving, and soil conservation can contribute to mitigation, particularly with carbon sequestration in soils and reduced emissions from energy use	31–35
Ecological resilience, carbon permanence	Measures for increasing the resilience of ecosystems to climate change also protect carbon	1,36–38
Livestock emissions	Adaptation through livestock supplementation and reduction in stocking densities may reduce methane emissions	31,39
Ecosystem-based adaptation	Protecting vegetation for reducing flood risk in watersheds or heat stress in cities will benefit multiple ecosystem services, including carbon sequestration	1,40
Activity displacement	Adapting agriculture to climate change can reduce the need to convert new lands into agriculture and the associated emissions of land-use change	41
Adaptation activities can increase climate change (mitigation disservices)		
Agricultural emissions	Adaptation measures in agriculture can increase emissions (e.g. nitrogen fertilization, energy-intensive irrigation technology, cooling and ventilation systems for livestock) or reduce carbon stocks (land-use change caused by the displacement of agriculture required for its adaptation)	18,27,31,42
Carbon stocks	Adaptation measures in forestry can decrease carbon stocks or increase the vulnerability of carbon stocks in the long term (e.g., shortening plantation rotation, suppressing fire)	31,43,44
Mitigation activities can reduce vulnerability to climate variations (adaptation services)		
Ecosystem-based adaptation	Conserving carbon also protects other ecosystem functions and services, which facilitate the adaptation of society: microclimatic regulation for protecting people from heat stresses and crops from climatic variations, wood and fodder as safety nets, soil erosion protection and soil fertility enhancement for agricultural resilience, coastal area protection, water regulation	5,20–22,45–52
Ecological resilience	Mechanisms for forest carbon protection (such as REDD+) improve forest resilience to climate change by conserving biodiversity, increasing landscape connectivity, reducing fire risks	5,36,53–59
Livelihood impact of carbon projects	Initiatives aiming at carbon sequestration in forests or emission reduction in energy can facilitate people's adaptation to climate change by diversifying local livelihoods, enhancing incomes or health and strengthening local institutions	22,46,50,53,54,60
Carbon payments and diversification	Carbon payments can diversify livelihoods and improve economic resilience to climate shocks	21,47
Mitigation activities can increase vulnerability to climate variations (adaptation disservices)		
Socioeconomic impacts of carbon projects	Forest and biofuel plantations for climate change mitigation may impede the adaptation of communities (because of decreased food security, competition for land, short-term benefits for few stakeholders)	20,28,31,53,61–63

TABLE 2 | Continued

Name	Details	References
Water	Forest and biofuel plantations for climate change mitigation may reduce water availability, particularly in arid regions	5,18,20,64–67
Ecological resilience	Maximizing carbon may lead to management that reduces options for ecological adaptation (e.g., fast-growing tree monoculture)	1,18,68
Socioeconomic impacts of clean energy projects	Hydropower projects may lead to population displacement and social vulnerability to multiple stressors	69

livestock, adaptation measures included feed supplements and reduction in stocking densities, which also reduced methane emissions.[39] In conservation and forest management, measures that increased ecosystem resilience to climate also increased the permanence of carbon.[36] In ecosystem-based adaptation, protecting vegetation for reducing flood risk in watersheds or heat stress in cities affected multiple ecosystem services, including carbon sequestration for mitigation.[40] Finally, an indirect impact of adaptation on mitigation occurred when adapting agriculture to climate change reduced the need to convert new lands for farming, which influenced land-use change emissions.[41]

But adaptation measures in landscapes can also affect mitigation negatively. For example specific adaptation measures for reducing agricultural vulnerability to climate variations were showed to increase emissions through nitrogen fertilization or energy-intensive irrigation technology.[31] In plantation forestry, shortening plantation rotation can be an adaptation measure but it decreases carbon stocks.[43] Fire suppression can be also an adaptation measure in some places but, if it is poorly planned, it can jeopardize the permanence of carbon stocks in the long term.[44]

Similarly, mitigation measures in landscape management were shown to deliver adaptation services by reducing the vulnerability of ecosystems, agriculture, or the broader landscape. Conserving ecosystems for their carbon also conserved the ecosystem services relevant to adaptation—such as microclimatic regulation for people and crops, wood and fodder for livelihoods, soil erosion protection and soil fertility enhancement for agricultural resilience, coastal area protection, and water regulation.[45,46] Mechanisms for forest carbon conservation (such as REDD+) could also improve forest resilience to climate change by conserving biodiversity, increasing landscape connectivity and reducing fire risks.[53] Initiatives that aim to achieve carbon sequestration in forests or emission reduction in energy could diversify local livelihoods, enhance incomes or health, and strengthen local institutions, which can sometimes facilitate adaptation to climate change.[54,60] Finally, carbon payments were seen as an alternative livelihood that could improve economic resilience to climate shocks.[21]

Negative impacts of mitigation actions on adaptation included cases where forest and biofuel plantations impeded community adaptation as they decreased food security, competed for land, and provided only short-term benefits for a few stakeholders.[20,61] Plantations could also reduce water availability, particularly in arid regions.[64] In addition, maximizing carbon sometimes led to management that reduced ecological resilience through fast-growing tree monocultures.[68] Finally, hydropower projects for mitigation could lead to population displacement and increase social vulnerability to several exposures, including climate variations.[47]

JOINT OBJECTIVES: THE WHOLE IS GREATER (OR SMALLER) THAN THE SUM OF ITS PARTS

The cases examined analyzed landscape management activities that integrated both adaptation and mitigation objectives, one being sometimes prioritized over the other. Several analyzed cases showed that the addition of adaptation objectives to a mitigation project strengthened the mitigation outcomes (and *vice versa*) (Table 3). The addition of adaptation objectives could strengthen mitigation projects for several reasons. Some were similar to the unintended side effects of adaptation on mitigation, such as carbon permanence (enhancing ecosystem adaptation improves the permanence of carbon storage in mitigation projects and reduces climate risks for projects) or avoided activity displacement (adapting agriculture or other livelihood activities to climate change may improve the sustainability of REDD projects by reducing pressures on forests).[70–72] Another example was related to ecosystem services for clean energy: adaptation programs in watershed conservation and in feedstock production could make clean hydropower and bioenergy production more sustainable.[73,80,82]

TABLE 3 | Example of the Effects of Considering Adaptation and Mitigation Objectives Jointly

Name	Details	References
Considering adaptation in mitigation initiatives enhances mitigation outcomes (strengthening)		
Ecological resilience for carbon permanence	Enhancing ecosystem resilience improve the permanence of carbon storage in mitigation projects and reduce climate risks for projects	1,5,17,28,56,70–79
Local and national priorities	Integrating adaptation into mitigation can encourage the engagement of national policy makers and local stakeholders when adaptation responds to national and local priorities, which can enhance project acceptance and sustainability	5,22,80,81
Ecosystem services for clean energy	Protecting watershed for adaptation can benefit hydropower and clean energy production. Adapting feedstock production can ensure the sustainability of clean energy initiatives.	5,66,82
Avoided activity displacement	Adapting agriculture or other livelihood activities to climate change may improve the sustainability of REDD+ projects by reducing pressures on forests	5,73
Considering adaptation in mitigation initiatives reduces mitigation outcomes (weakening)		
Cost inefficiency	Considering adaptation in mitigation projects will increase mitigation costs, thus reducing mitigation outcomes	65
Considering mitigation in adaptation initiatives enhances adaptation outcomes (strengthening)		
Carbon funding	Adaptation initiatives that consider mitigation can benefit from mitigation funding and carbon markets (e.g., REDD+ money can be used to pursue adaptation objectives)	5,17,28,35,55,61,70,80,81,83–86
Policy support	Building a low emission economy may have more political support than adaptation, which is less understood	80,81
Project appeal	Additional mitigation outcomes may improve adaptation project image, solvency and profitability, thus increase its appeal	29
Considering mitigation in adaptation initiatives reduces adaptation outcomes (weakening)		
Path dependency	Mitigation objectives may restrict opportunities for livelihood adaptation in the long term (e.g., by restricting the conversion of forests to more productive activities)	47
Target groups	Additional mitigation objectives may change the target groups of an adaptation project, from the most vulnerable to the most responsible for emissions	55
Integrating mitigation and adaptation increases outcomes (synergy)		
Minimized trade-offs	Integrated initiatives will assess and minimize trade-offs between adaptation and mitigation, resulting in increased outcomes	28,48
Ecological reciprocal interactions	Adaptation and mitigation outcome can reinforce each other, e.g., increased soil carbon (mitigation) can increase crop resilience (adaptation), which in turn protects soil carbon	31,48
National political economy	Integrated initiatives contribute to sustainable development, are more integrated into national policies and reconcile national and global interests, increasing their likelihood of success	80,87
Similar drivers	As the factors enabling societies to adapt and mitigate are similar, integrated policies can act together on these factors and increase their effectiveness	18
International processes	Integration of adaptation and mitigation would give developing countries a more active role in international climate policies	17
Packaging	The attractive language of low emission and resilient development can make mitigation and adaptation happen	18

TABLE 3 | Continued

Name	Details	References
Mainstreaming	Adaptation and mitigation integration creates new opportunities for adaptation (or mitigation) where it would not have necessarily happened	57,88
Cost efficiency	Integrated initiatives can be more cost-efficient, facilitating their implementation	22
Integrating mitigation and adaptation reduces outcomes (competition)		
Perverse incentives	A strong emphasis on integration may create perverse incentives: mitigation activities may be labeled adaptation (or *vice versa*) even though they do not deliver enough adaptation outcomes; activities that are very good in delivering one outcome only may be neglected	18,89
Complexity	Integration will lead to greater institutional complexity, which could reduce efficacy, make project difficult to implement and cost-ineffective and weaken adaptation and mitigation outcomes	89

An additional perspective was described in the cases in which the proactive inclusion of adaptation into a mitigation initiative benefited the stakeholders of an initiative or facilitated its implementation. Arguments related to local acceptance (integrating adaptation into mitigation could encourage the engagement of local stakeholders or increase project sustainability from a socioeconomic perspective) and the political economy at the national scale (integrating adaptation into mitigation could encourage the engagement of national policy makers when adaptation responds to national priorities). However, the integration of adaptation into mitigation can also have negative effects on mitigation outcomes by increasing project costs and diverting efforts from the primary objective.[65]

Several cases discussed how additional mitigation objectives could facilitate the implementation of adaptation projects. The most frequent argument was that by adding mitigation, adaptation initiatives could benefit from mitigation funding and carbon markets; REDD+ money could be used to pursue adaptation objectives.[55,83] In some cases, building a low-emissions economy was perceived to have more political support than adaptation, which was less well understood by policy makers. Finally, additional mitigation outcomes were seen as a way of improving adaptation project image, solvency and profitability, thus increasing its appeal.[80,81] But negative effects were also reported in the analyzed cases: adding a mitigation objective could restrict opportunities for livelihood adaptation in the long term by restricting the conversion of forests to more productive activities.[47] Furthermore, additional mitigation objectives could change the target groups of an adaptation project, from the most vulnerable to the most responsible for emissions.[55]

Several analyzed cases described potential benefits of integrating adaptation and mitigation in landscape management and related policies. Integrated initiatives at the national level contributed to sustainable development, were more strongly linked to national policies, and reconciled national and global interests, increasing their likelihood of success.[87] As the factors enabling societies to adapt and mitigate are often similar, integrated policies should act together on these factors and increase overall effectiveness.[18] More integration of adaptation and mitigation at the international level was reported to be a way of giving developing countries a more active role in international climate policies.[17] At various scales, the new language of low emissions and resilient development, and related terms such as climate compatible development, was perceived as a way of making mitigation and adaptation more attractive.[18] At the local scale, examples were given of adaptation and mitigation reinforcing each other in both directions, such as when soil carbon is increased (mitigation) crop resilience is increased (adaptation) that in turn protected soil carbon (mitigation).[31] One proposed reason for adaptation–mitigation integration was that it would create new opportunities of doing adaptation (or mitigation) where one of the two would not have happened otherwise,[29] with a cost efficiency that would facilitate their implementation.[22]

However, considering both adaptation and mitigation objectives in a project or a policy can have drawbacks. For example, it was suggested that a strong emphasis on integration may create perverse incentives—and activities that are good at delivering only one outcome would be neglected.[18] Another proposed drawback was that integration would lead to greater institutional complexity, which could reduce efficacy, make projects difficult to implement, increase costs, and weaken adaptation and mitigation outcomes.[89]

DISCUSSION AND POLICY IMPLICATIONS

The review showed a diversity of links between adaptation and mitigation in landscape management, including: (1) the joint delivery of adaptation and mitigation outcomes by activities that are not primarily motivated by climate objectives; (2) the positive or negative side effects of activities aimed at either mitigation or adaptation objectives on the other objective; and (3) the benefits or drawbacks of the integration of adaptation and mitigation objectives, which can lead to improved or weakened outcomes. However, empirical knowledge is missing: many links between adaptation and mitigation were described in conceptual or opinion papers or were illustrated with examples from other papers or with hypothetical examples. Only 40% of the papers were empirical (i.e., included field measurement, modeling, perception analysis) and 11% assessed adaptation or mitigation projects and activities on the ground. We used these papers in most of the examples in this review. In addition, most reviewed cases (84%) reported positive interactions between adaptation and mitigation: unintended side effects were often positive (more 'service' cases than 'disservice' in Table 1) and managing for joint objectives generally improved outcomes (more 'strengthening' and 'synergy' than 'weakening' and 'competition' in Table 1).This result may suggest that win–win situations are more frequent than win–lose or lose–lose ones but it can also come from a bias in the research on this topic. Because of the limited number of empirical papers and trade-off analyses, the analyzed literature informs on what is possible (e.g., soil management *can* lead to mitigation and adaptation outcomes), but does not allow a deeper analysis of either the management issues associated with joint adaptation and mitigation or the patterns in the practices needed to secure these outcomes.

The three broad conceptualizations of the links between adaptation and mitigation suggest a number of policy implications which are important for framing political debates and negotiations on this topic, one example being the joint mitigation and adaptation approach proposed by Bolivia to the UNFCCC.[90] The first conceptualization (joint outcomes) highlights that many landscape management activities can lead to adaptation and mitigation outcomes (either positive or negative) even if these outcomes are not intentional. A more conscious approach to these interactions between nonclimate specific landscape approaches and climate change objectives would suggest that adaptation and/or mitigation should be mainstreamed in agricultural or forestry policies. This mainstreaming is needed to manage trade-offs between nonclimate and climate policy objectives, and to be able to exploit positive interactions.[7] But should mitigation and adaptation be mainstreamed separately into land-use policies or jointly?

There are a number of advantages in mainstreaming adaptation and mitigation separately within sectoral policies. These relate primarily to the difference in terms of temporal and spatial scale at which mitigation and adaptation actions are effective, the difficulty of aggregating costs and benefits, and the fact that some sectors are more relevant for either mitigation (industry and transport)—or adaptation (health, disaster management, and coastal areas).[4,7] In landscape management, adaptation and mitigation could be also mainstreamed separately, with adaptation and mitigation outcomes being delivered side-by-side rather than by the same activities.

The high number of cases of unintended side effects shows that within the land-use sector, adaptation actions and policies often have positive or negative outcomes on mitigation and *vice versa*. This suggests that it might be beneficial to mainstream mitigation and adaptation jointly into land-use policies and planning processes: as the same activities can deliver both outcomes, it would be redundant to have separate processes.[5] This is particularly true in the forestry and agricultural sectors which are often considered priority sectors for both mitigation and adaptation policies.[6] Such an approach would require that the positive and negative interactions between the two climate change objectives and land-use planning and policy objectives are considered from the outset.

An explicit approach that considers such interactions has not been extensively pursued to date. The instances related to 'joint objectives' appear only sporadically in the literature, suggesting that few current approaches consider the dual objectives of achieving both adaptation and mitigation outcomes simultaneously. The reviewed cases show that addressing adaptation and mitigation together in policies related to landscape management provides benefits, but can also have drawbacks. There is a knowledge gap on the implications of intentionally managing for one versus two climate outcomes.

Adapting the definition of environmental policy integration given by Lafferty and Hovden[91] to the case of adaptation and mitigation, climate policy integration could be defined as the incorporation of adaptation and mitigation objectives into policy-making of sectoral policies (e.g., agriculture), the aggregation of adaptation and mitigation outcomes into policy evaluation, and the minimization of contradictions between both adaptation, mitigation and sectoral policy objectives. Policy integration also requires the removal of internal contradictions among climate change policies: these contradictions are clear in some analyzed cases where integrated approaches led to lose–lose rather than win–win situations.

The best way to achieve this aim is through a type of climate policy integration that considers both potential trade-offs and mutual benefits between adaptation and mitigation when mainstreaming climate change into land-use planning and policies.[92–94] Climate change policy integration is both a 'process of governing' and a 'policy outcome.'[95] To ensure climate policy integration, we need to move from the traditional 'end-of-pipe' approach to a preventative approach that considers both adaptation and mitigation from the stage of policy formulation and includes consideration of specific institutional structures and procedures that can facilitate such integration.

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