Opinion

Climate change, carbon market instruments, and biodiversity: focusing on synergies and avoiding pitfalls

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Edited by Josef Settele, Domain Editor, and Mike Hulme, Editor-in-Chief

Fundamental economic and societal transformations are necessary to avoid dangerous climate change. One broad policy approach that addresses the close relationship between conservation and climate change mitigation is based on correcting a market failure, that is, to establish a price signal for carbon, or more generally, greenhouse gas emissions. While many synergies between climate policy instruments and biodiversity conservation do exist, current policies often fall short of harvesting this potential. Here, we present six key challenges: (1) establishing a strong price signal for greenhouse gas emissions from all emission sources (including land-use and the terrestrial biosphere) that takes into account long-term societal and ecological costs; (2) expand carbon market instruments to cover the full range of greenhouse gases; (3) develop an ambitious, yet accountable architecture for rising emission prices; (4) develop guidelines and ensure enforcement to avoid greenhouse gas leakage; (5) improve greenhouse gas emission measurements from land-use and the biosphere; and (6) integrate emission reduction as a priority into relevant policies. Substantial synergies, but also trade-offs between climate policy and conservation exist, and we identify key risks and challenges. We call for (1) evidence-based evaluations of policy options; (2) avoiding too narrow framings of contested issues such as forest plantations, biofuels, or land-use decisions that exclude (or downplay) indirect effects (e.g., indirect land-use changes or creating carbon debts); and (3) strengthening integrated analyzes beyond sector policy goals. We conclude that avoiding bio-perverse impacts of climate policies on biodiversity will be crucial for the success of global climate change mitigation.

How to cite this article:
WIREs Clim Change 2018, 9:e486. doi: 10.1002/wcc.486

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Conflict of interest: The authors have declared no conflicts of interest for this article.

INTRODUCTION

Beyond scientific doubt, climate change will become one of the defining features of global change in the decades to come, and it has the potential to cause transformative and devastating impacts on the environment and human societies alike.[1–3] Thus, it is widely acknowledged that tackling climate change to avoid the full deleterious impacts is of eminent importance and urgency.[1–3] Despite this, action to mitigate climate change has so far been slow and has fallen far short of the scale of the strong action needed. There are many reasons for these policy failures, reviewed, for example, in Refs 2 and 4.

The fundamental economic and societal changes needed to avoid dangerous climate change will have to include a wide range of measures. Although it has already been frequently noted that biodiversity conservation and climate change mitigation are closely intertwinned,[5,6] there has been a number of calls on the danger of sending the wrong market signals based solely on carbon emission mitigation, which may pose important threats to biodiversity.[7,8] On the other hand, the full potential of harnessing synergies between climate change mitigation and biodiversity is still insufficiently appreciated, *inter alia* because global institutions have been designed to deal separately with conservation (e.g., CBD, IPBES) and climate change (e.g., UNFCCC, IPCC). However, it has become increasingly evident that climate change mitigation will only be successful, when biodiversity is appropriately accounted for.[9]

One broad policy approach that reflects the close relationship between conservation and climate change is based on correcting a market failure, that is, to establish a price signal for carbon, or more generally, greenhouse gas emissions. This can be achieved by a variety of instruments such as carbon caps, taxes, and credits, which have become crucial elements in global climate change mitigation policies[2,10,11] (Table 1). Specifically, ecosystem-based carbon credit approaches, which aim to reduce greenhouse gas emissions by halting or reversing land-use changes (e.g., REDD+, peatland climate credits) have been developed and tested. However, often these measures solely focus on carbon sequestration and thus disregard the value of biodiversity for ecosystem functioning and services.

Here, we discuss the interaction of biodiversity and climate change mitigation policies. We distil and shortly summarize key insights that are particularly relevant to this topic. Subsequently, we provide recommendations which we consider crucial, but currently insufficiently considered, to ensure that biodiversity and climate change policies become mutually supportive. In particular, we focus on five key questions in the following sections: (1) What is the role of the terrestrial biosphere and ecosystems to secure long-term climate change mitigation goals? (2) Which synergies between biodiversity conservation and climate change mitigation policies can be tapped by carbon market instruments? (3) What is the potential of ecosystem-based climate change mitigation measures for delivering co-benefits for biodiversity conservation? (4) Which measures are necessary to avoid that carbon market instruments become distorted and negatively impact on biodiversity? (5) Which challenges lay ahead for improving carbon market instruments in the twin contexts of climate change mitigation and biodiversity conservation? Finally, we provide six recommendations to ensure that greenhouse market instruments provide twin benefits for climate change mitigation and biodiversity conservation.

TERRESTRIAL ECOSYSTEMS, THE CARBON CYCLE AND CLIMATE CHANGE: AN OVERVIEW

Terrestrial ecosystems play a key role in the global carbon cycle as they store in total ca 2400 Gt of carbon, with an annual exchange rate of ca 200 Gt.[1] Natural carbon fluxes of the terrestrial biosphere are roughly 20 times larger than the ones caused by industrial activities of humans. The largest terrestrial carbon pools are forests (mostly above ground carbon stored in wood), mires, and grasslands, which both store carbon predominantly in organic soils (Figure 1). These pools are of roughly of equal size. Currently, the terrestrial biosphere is an important carbon sink by sequestering 1.5 ± 0.9 Gt per year of carbon from the atmosphere. This amounts to ca 29–38% of the carbon released annually by humans.[20,21] However, the climate cooling potential of the terrestrial biosphere by the uptake of atmospheric carbon currently is more than offset by the climate warming potential of other greenhouse gases (e.g., methane, nitrous oxide) released predominantly from anthropogenic land-use.[21]

In the last decades, the amount of carbon sequestered by terrestrial ecosystems has increased mainly due to higher uptake of atmospheric carbon by ecosystems due to increasing CO_2 fertilization and atmospheric nitrogen deposition.[22] This is evidenced by a persistent trend of 'global greening.'[23] However, there is scientific consensus that climate warming will weaken the capacity of the terrestrial biosphere to act as carbon sink, and many projections show that terrestrial ecosystems may turn into a net carbon source in the second half of the 21st century.[24]

WHAT IS THE RIGHT PRICE? THE IMPORTANCE OF ESTABLISHING APPROPRIATE PRICE SIGNALS FOR GREENHOUSE EMISSIONS

As the atmosphere is a common public good, no market and thus no prices for using it as a dump of greenhouse gases exist. Therefore, carbon market instruments depend on the creation of price signals

TABLE 1 | Carbon Market Instruments, Their Characteristics, Their Interaction with Biodiversity Conservation, and Their Main Synergies and Risks for Conservation that are Strongly Associated with the Respective Instruments

Instrument	Description	Interaction With Biodiversity Conservation	Synergies	Risks	References
Carbon caps	Caps define a maximum amount of carbon to be emitted, which is allocated to the relevant sectors and actors.	Caps that include land-use reduce losses of natural ecosystems that store high amounts of carbon.	Reduced losses of high-carbon ecosystems benefits conservation.	Low flexibility to respond to unexpected changes in emissions may cause under- or over-allocation to actors. Low incentive to reduce emissions more than required by targets.	Lippke and Perez-Garcia[12]
Carbon emission trading	Issuing carbon emission certificates that allow for limited emissions and that can be traded between actors (e.g., companies).	Carbon emission trading may include the land-use sector (e.g., fertilizer production, land-use-decisions).	Increasing efficiency in allocation of mitigation measures towards those that are cheap and effective (e.g., many ecosystem-based restoration measures).	Risk of over-allocation of allowances resulting in low carbon prices, highly fluctuating prices are common. Difficult to include many small actors (e.g., farmers) and thus likely to exclude these.	Bonn et al.,[13] Newell et al.[14]
Carbon taxes	Taxes add specified costs to the carbon emission caused by human activities.	Taxes introduce emission-related price signals to land-use decisions.	Carbon taxes may create incentives for conserving high carbon storage ecosystems.	Creation of incentives for conversion of high biodiversity but low carbon ecosystems into, for example, plantations or for biofuel production.	Caparrós and Jacquemont,[7] Lindenmayer et al.[8]
Carbon credits	Credits evaluate the amount of carbon kept in the biosphere because of human action (including nonuse of ecosystems).	Includes, for example, ecosystem-based instruments such as REDD+ and peatland carbon credits that aim to keep carbon stored in the biosphere (e.g., in forests, wetlands).	Restoring of degraded and conservation of intact ecosystems to decrease carbon emissions and increase carbon storage and sequestration mostly co-benefit biodiversity.	Conversion of high biodiversity but low carbon ecosystems into, for example, plantations or for biofuel production.	Ebeling and Yasué,[5] Strassburg et al.,[6] Angelsen et al.,[11] Searchinger et al.,[15] Tanneberger and Wichtmann[16]
Carbon offset	Reduction in emissions of carbon dioxide made in order to compensate for or to offset an emission made elsewhere.	Emissions from, for example, industrial activities create revenues that may be used for ecosystem-based restoration measures.	Harnessing money for conserving or managing ecosystems to increase carbon storage and sequestration often will deliver twin benefits for climate change mitigation and biodiversity conservation.	Conversion of high biodiversity but low carbon ecosystems into plantations or areas for biofuel production, shifting emissions towards other sources beyond the scope of the carbon offset project.	Gordon et al.,[17] Bekessy and Wintle[18]

Note that the list of synergies and risks is not comprehensive. Selected key references are provided.

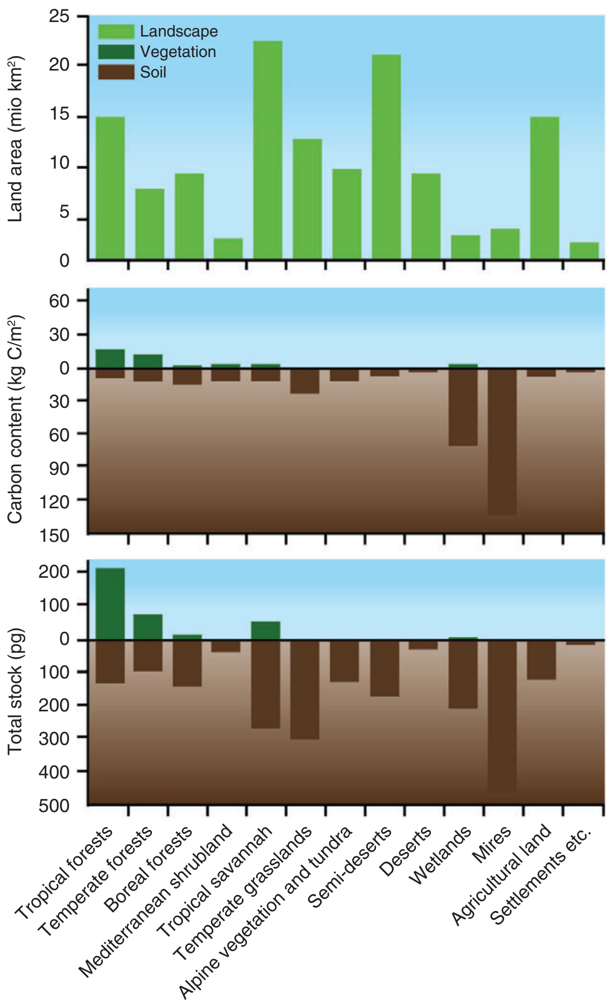

FIGURE 1 | Area, stored carbon (in kg/m^2) and total global above and below ground carbon (Petagramm, Pg) of the most important biomes worldwide. Modified from Ref 19.

by public interventions of some sort such as issuing a limited amount of emission credits or by taxing activities that cause carbon emissions. Ideally, such prices should factor in the full extent of long-term climatic impacts per unit carbon (or other greenhouse gases) released on human societies and the biophysical environment.[10] However, as is evident from the complexities and uncertainties of climate change, and due to varying boundary conditions that may be considered (e.g., time horizons, discount rates, the range of impacts included), a wide range of carbon prices from ca 7 to 1000 US$/t $CO_{2\text{-eq}}$ has been suggested as adequate (Table 2), and associated uncertainties are extreme, spanning orders of magnitude.[25]

However, low-range carbon prices have been calculated using integrated economic impact assessment models based on conservative assumptions of risks and impacts of climate change.[2] They often additionally apply high discount rates, which effectively eliminate long-term costs from the analyzes, and hence have become heavily—and as we believe, rightly—criticized for evaluating long-term environmental changes.[4,10] Thus, if these low estimates are excluded, recently suggested carbon prices converge at around 35–100 US$/t $CO_{2\text{-eq}}$ (Table 2).

However, these mid-range values still seem conservative as they do not fully incorporate mounting scientific evidence on appropriate damage functions under severe climate change,[32,33] and they are still based on applying substantial discount rates (e.g., 2.5–5% per year).[30] Combining high climate sensitivity, higher, but plausible and likely more appropriate damage functions, and a low discount rate, the social cost of carbon could be as high as almost 900 US$/t CO_2.[31] So, it is obvious that values of social costs of carbon are extremely sensitive to the underlying assumptions taken. The plausible medium- to high-end estimates of costs provide a clear policy description of reducing carbon emissions as quickly as feasible as most abatement costs are substantially cheaper,[34] including many ecosystem-based measures that provide co-benefits for biodiversity conservation (see below). Establishing strong and accountable price signals for greenhouse gas emissions can cause substantial changes in consumer behavior,[35] depending on the specifics of implementation. However, it is essential to closely monitor the phasing in of price signals for greenhouse gases for early detection of and response to unforeseen side effects.

CLIMATE POLICY INSTRUMENTS AND BIODIVERSITY: SIX KEY RECOMMENDATIONS

A number of carbon market instruments have been developed to mitigate carbon emissions and their effects on climate change. While these instruments share ultimate goals and some common features, they have specific characteristics that lead to different synergies and risks with biodiversity conservation (Table 1). These instruments also differ substantially in the political and economic consequences they may have, but these are beyond the scope of this publication and not considered here. Carbon market instruments have either direct or indirect effects on biodiversity conservation. Basically, carbon market instruments can be divided in those that focus on avoiding emissions (i.e., carbon caps, carbon emission trading, carbon taxes) and those that also aim to

TABLE 2 | A Selection of Different Recommended Carbon Emission Prices Calculated to Cover the Full Extent of Long-Term Consequences

Recommended Carbon Emission Prices (Monetary Units Per t $CO_{2\text{-eq}}$)	Included Costs And Assumptions	Remarks	References
>35 (in £ per t C) (ca 0–1000)	Based on sensitivity analyzes of values of two integrated assessment models (PAGE, FUND).	Recommended for global decision-making; sensitivity analyzes show that carbon prices vary over orders of magnitude depending on the assumptions made.	Downing et al.[25]
85 (in US$)	Using low to no discount rates.	Recommended for global decision-making.	Stern[10]
7–81 (in 2007 US$)	Using different (but high) discount rates (2.5–5%) and integrated socio-economic assessment models.	To be used for regulatory impact analysis in the USA.	Interagency Working Group on Social Cost of Carbon[26]
80 (40–120) (in 2010 €)	Based on estimated emission avoidance costs to reach the maximum +2°C climate target.	Calculated and recommended for use in decision-making Germany.	UBA,[27] Wille et al.[28]
18.6–47.6[1] (in 2005 US$)	Using the DICE integrated assessment model, and a 3% discount rate.	To be used for regulatory impact analysis in the USA (update).	Nordhaus[29]
11/36/56/105 (in 2015 US$)	Using different (but high) discount rates (2.5–5%) and socio-economic integrated assessment models.	To be used for regulatory impact analysis in the USA (update).	Interagency Working Group on Social Cost of Carbon[30]
900 (in 2010 US$)	Based on higher damage values, higher climate sensitivity and low discount rate	Assumptions reflect the scientific evidence on the scale of climate change impacts.	Ackerman and Stanton[31]

[1] The higher value is consistent with limiting climate warming to 2°C.

increase sequestration (i.e., carbon credits, carbon offset). Carbon market instruments that aim to reduce land-based carbon emissions can have substantial synergies with biodiversity conservation largely because many measures aim to increase carbon storage and sequestration of ecosystems which result in restoration, better management, or protection of high biodiversity value ecosystems (see Box 1). However, these instruments may have negative impacts on biodiversity, if they are designed without careful consideration of biodiversity.[7,35] Instruments focusing on carbon sequestration may have co-benefits for biodiversity when well-designed and -implemented, but, again, disregarding biodiversity may cause ecosystem loss and deterioration (e.g., conversion of natural forests into plantations).

Clearly, even moderate calculations of the full societal costs of carbon emissions vastly exceed current CO_2 prices (e.g., prices in the EU emission trading scheme have reached a low of ca 4 €/t CO_2 in September 2016, https://ec.europa.eu/clima/policies/ets_en). All emission pathways that are consistent with the Paris Climate Agreement,[41] that is, ensuring that global temperature rise remains 'well below 2°C' compared to preindustrial levels, require rapid declines in emissions.[42] It is obvious that one key element for achieving this climate policy goal is raising CO_2 prices gradually and predictably until the full long-term environmental and societal costs are reflected in adequate carbon prices (Table 3, recommendation 1). Similarly, given the substantial contribution of land-use to carbon emissions, this sector has to be included, and consequently, the recognition of ecosystems for climate change mitigation would be strengthened.

For other greenhouse gases (e.g., methane, nitrous oxides) with considerable contribution to climate change, price signals have to be created based on their global warming potential relative to the one of carbon ($CO_{2\text{-eq}}$), and subsequently, carbon market instruments have to be expanded to cover the full range of greenhouse gases (Table 3, recommendation

BOX 1

PEATLAND CLIMATE CREDITS

Worldwide, wetlands are hotspots of biodiversity and in particular, intact peatlands slowly accumulate organic matter and sequester carbon over long time periods.[36,37] Contrarily, degraded peatlands turn into persistent CO_2 sources that are responsible for annual emissions that may exceed 2 Gt CO_2 per ha.[38,39] However, even following severe disturbance, release of carbon and other greenhouse gases from peatlands may be strongly reduced by proper restoration. Emission factors for different peatland types as well as for different vegetation types that reflect different levels of anthropogenic impact on peatlands have been established,[39] and provide an efficient and easy to measure proxy for measuring greenhouse gas emissions. Testing these vegetation-derived emission factors has shown that they allow to measure, report, and verify greenhouse gas fluxes with reasonable accuracy under wide range of conditions,[40] which is a prequisite for establishing climate credits.

In recent years, an incipient market for peatland climate credits has been created.[39] Policy-wise, a compliance market has been established by Art. 3.3 and 3.4 of the Kyoto protocol which define activities and conditions under which peatland drainage and rewetting need to be recorded. Alternatively, voluntary carbon markets are based on private funding and they have a greater emphasis on co-benefits than the compliance market.[39] For instance, in Germany, several federal states have established voluntary instruments to finance the rewetting of drained peatlands, and in the UK, a regional standard for sponsoring peatland restoration projects is being developed.[39]

2). Such an inclusive approach will strengthen the protection and sustainable management of ecosystems that are highly relevant for greenhouse gas balances other than carbon (e.g., wetlands). Furthermore, this step will be imperative as strong price signals for one or a subset of greenhouse gases while ignoring others may lead to emission leakages that may considerably weaken (or even jeopardize) the effectiveness of carbon pricing. However, associated challenges are substantial: (1) sources of other greenhouse gases and their contribution to emissions are less well understood; (2) monitoring and enforcement often is complicated and difficult; (3) political and public awareness is relatively low; and (4) thus only little experience for implementing emission prices has been gained yet.

As the difference between existing carbon prices and appropriate greenhouse gas emission prices that include the full societal costs is very substantial, phasing in of these prices must be based on a stepwise climate policy that provides accountability and a long-term planning and investment perspective (Table 3, recommendation 3), that is also essential for developing, introducing and expanding ecosystem-based mitigation measures. Politically and socio-economically, a transition to higher emission (and thus energy) prices is highly challenging. However, it also creates a vast range of new opportunities and generates large public revenues that may be used to assist this transformative process.

All climate policy instruments must be accompanied by stringent rules of implementation, greenhouse gas accounting and monitoring[8,43] (Table 3, recommendation 4). In particular, for instruments, which aim for a global coverage, this is an enormous task with substantial challenges, particularly for activities involving often many actors such as ecosystem-based mitigation measures. These challenges include: (1) the highly dispersed spatial distribution of carbon stored in ecosystems; (2) unresolved or disputed ownership of land in many regions; (3) substantial intra- and inter-annual fluctuations of carbon pools in some ecosystems (e.g., semiarid grasslands) resulting from climatic variability; (4) natural disturbances that are a pronounced feature of many ecosystems; this leads to problems in establishing a baseline for a reference carbon status. In addition, disturbances may release a high proportion of carbon but may be beyond the control of the landowner (e.g., forest fires); and finally (5) the temporal scale (the greenhouse gas balance of ecosystems may change over time, for example, as a function of succession, after ecosystem restoration, or after internal reorganizations due to the invasion of alien species).

In addition, ensuring good governance and accountability (including political stability and the opportunity of political participation) is crucial (Table 3, recommendation 5), but particularly difficult in many nations with highest deforestation rates as forest ownership rights often are insufficiently documented (and secured), and forest-dwelling indigenous people often are marginalized and thus *de facto* excluded from forest ownership.[44] For ecosystem-based measures in particular, the participation of local stakeholders and the appropriate allocation of revenues are key features in this context.

TABLE 3 | Six Key Recommendations to Ensure That Greenhouse Market Instruments are Effective and Deliver the Expected Twin Benefits for Climate Change Mitigation and Biodiversity Conservation

No.	Recommendation	Rationale	Relevance For Biodiversity Conservation
1	Define and agree on greenhouse gas prices from all emission sources that take into account the likely full long-term environmental and societal costs.	Internalizing the full long-term impacts of greenhouse gases, including emissions from land-use activities.	Storage and sequestration of greenhouse gases in the terrestrial biosphere becomes a market good, creating incentives for ecosystem protection and restoration.
2	Expand carbon market instruments to cover the full range of greenhouse gases.	Taking into account all climate-relevant emissions is pivotal for comprehensive climate change mitigation.	Strengthens ecosystems that play a vital role in noncarbon greenhouse gas cycling (e.g., wetlands).
3	Develop an ambitious, yet realistic and accountable architecture for rising emission prices that account for the full social costs.	Providing long-term security is key for the uptake of greenhouse gas instruments. Accountability and agreed trajectories of emission pricing are crucial for long-term decision-making.	Land-use decisions are often made under long-term planning horizons.
4	Develop climate accounting policies, guidelines, and ensure enforcement and monitoring to avoid greenhouse gas leakage (i.e., shifting emissions to other sources or to other greenhouse gases).	Standardized accounting and monitoring of greenhouse gas emissions is essential for assessing effectiveness of mitigation policies, and to avoid shifts of emissions towards unaccounted emission sources.	Accounting and monitoring are essential to avoid unintended negative consequences (e.g., indirect land-use changes, carbon leakage).
5	Improve greenhouse gas emission measurements from land-use and the biosphere, and implement monitoring standards.	Developing a better understanding of greenhouse gas emissions and developing easy-to-measure proxies for emissions (e.g., groundwater table level in wetlands). Developing and implementing effective monitoring is essential for assessing effectiveness.	An accurate understanding of biosphere-based emission sources, and developing easy-to-apply tools for assessment and monitoring are crucial for developing and applying climate policy tools.
6	Integrate greenhouse emission reduction as a priority into relevant policies (e.g., agriculture, forestry, nature conservation, spatial planning, energy production).	Greenhouse gas emission reduction must be integrated horizontally in relevant political fields to ensure that sectoral policies are consistent with climate change mitigation.	Horizontally integrating climate policy goals into land-use relevant sectoral policies will strengthen the recognition of the importance of biodiversity and ecosystems.

Finally, climate policy goals need to be integrated into the wider context of land-use relevant policies (Table 3, recommendation 6). Consensus has emerged that policy mainstreaming fosters policy coherence across sectors and stakeholders, and is pivotal for developing effective measures in complex fields such as climate change mitigation.[45,46] If such integration of sectoral policies is done appropriately, this allows to (1) avoid or reduce conflicts between competing policies; (2) steer resources towards overarching political goals while avoiding mal-spending; and (3) increase the recognition of the importance of biodiversity in climate and land-use policies. Clearly, there are many political difficulties in factoring climate change goals into existing policies, thus regional to national solutions might be most appropriate.

AVOIDING RISKS AND HARNESSING THE POTENTIAL OF CO-BENEFITS FOR BIODIVERSITY

Currently, 20% of global carbon emissions are estimated to be caused by land-use changes, mainly forest degradation and destruction.[1,47] In this context, REDD+ (Reducing Emissions from Deforestation and Forest Degradation in Developing Countries) has been developed in the framework of the UNFCCC as a key instrument to add monetary value to the carbon stored in (mainly tropical) forests, and thus to contribute to reduce deforestation and degradation rates.[5,6] It also considers measures, which aim to enhance carbon storage in forests such as sustainable forest use and reafforestation.

While REDD+ has the potential to contribute to global deforestation rates and thus may deliver important biodiversity co-benefits,[6,11,43,48] it also bears several risks for biodiversity.[49] To avoid mal-implementation of REDD+, the UNFCCC adopted safeguards[50] stress the need to provide co-benefits for climate change mitigation, local communities and biodiversity. However, several risks for mal-implementation still remain. In particular, the forest definition as adopted by the UNFCCC[51] allows that forests of low biodiversity value may become eligible for REDD+, which may contribute to creating incentives to replace high biodiversity forests (and other ecosystems) by forest plantations (Table 4).[8,15,52] For instance, this is the case in the fynbos of South Africa, where fast growing *Pinus radiata* plantations have been established, displacing the natural biodiversity-rich shrublands.[52] On the other hand, only around 20% of the REDD+ projects are currently engaged in actual carbon transactions and of these, only a few rely solely on finances from such transactions.[53] The development of a co-benefit-centered REDD+ concept that is closely linked to biodiversity and local communities[54] holds particular promise for the future.

However, there is an urgent need to account for other relevant, currently neglected sources of land use-related emissions. In particular, emissions from degraded wetlands and organic soils are of particular importance as they provide a substantial fraction of anthropogenic greenhouse gas emissions. In the last years, approaches that provide a basis for incorporating these emissions into pricing tools have been developed and tested (Box 1). Compared to greenhouse gas emissions from aboveground vegetation (like in forests), accounting and monitoring of greenhouse gases released from soils provides additional challenges,[55] but relatively easy to measure metrics (e.g., ground water height, vegetation type) may provide suitable proxies for greenhouse gas balance.[40]

Agricultural land-use causes greenhouse gas emissions by affecting the carbon content of soils, by changes between agricultural land-uses (e.g., from grasslands to fields), while intensive land-use (e.g., via fertilization) and some production systems (e.g., ruminants such as cattle, rice cultivation) heavily contribute to noncarbon greenhouse gas emissions[1] (Box 2). There is substantial potential in reducing these emissions by modifying agricultural land-use,[56] and many of these measures are beneficial for biodiversity of agricultural landscapes. However, so far, these emissions have been largely excluded in climate policy instruments, partly because of the diffuse nature of emission sources. Factoring in emission balances of land-use activities into agricultural policies (e.g., the European Union Common Agricultural Policy) would be a powerful tool to steer agriculture towards reducing greenhouse gas emissions while securing biodiversity.

Finally, all climate change scenarios that aim to keep global warming below dangerous levels by the end of this century rely heavily on capturing and removing carbon from the atmosphere. Thus,

TABLE 4 | Forest Definitions Used by the UNFCCC[51] and Their Potential Negative Consequences on Biodiversity Conservation

Forest Definitions[51]	Potential Negative Impacts On Biodiversity	Measures Necessary To Avoid Negative Biodiversity Impacts
'Forest' is a minimum area of land of 0.05–1.0 ha with tree crown cover (or equivalent stocking level) of more than 10–30% with trees with the potential to reach a minimum height of 2–5 m at maturity *in situ* (…).	Degradation of forests up to a tree cover of 10% basal area is allowed.	Develop and implement guidelines that fully account for the impacts of forest degradation on biodiversity and greenhouse gas emissions.
Young natural stands and all plantations (…) are included under forest, as are areas normally forming part of the forest area which are temporarily unstocked as a result of human intervention such as harvesting or natural causes but which are expected to revert to forest.	Plantations (e.g., oil palms, *Pinus radiata*, teak) are included as well as afforestations (e.g., of high value ecosystems such as seminatural grasslands).	Use marginal and unused land of low conservation value for establishing plantations, while sparing ecosystems of high nature conservation value.
	Conversion of natural forests into forest plantations is possible.	Develop and implement guidelines that forbid the conversion of natural forests into plantations for climate change mitigation.

BOX 2

LAND-USE, CLIMATE, AND BIODIVERSITY: A CONUNDRUM

Land is a finite resource (the terrestrial ice-free surface amounts to approximately 130 Mio km^2) and around four-fifth of it are currently used by humans with more or less strong effects on ecosystem properties.[57] More than one-third of all pristine terrestrial ecosystems have been converted to human-controlled, permanently managed ecosystems, and one-quarter of global potential net primary production, the basis of heterotrophic live on Earth, is appropriated by humans.[58] Land-use provides the nutritional basis and many essential ecosystem services to society. In particular, the characteristic of ecosystems, to absorb and store large amounts of carbon has been identified as key for climate change mitigation strategies, albeit, due to the fact that the ensuing carbon sinks saturate.

Because of growing human population and increasing demand for land-based products and services, food and feed but also the need for climate change mitigation (e.g., the provision of biofuel or setting land aside for carbon storage and sequestration), the finite land resource is increasingly subject to land competition.[59] Land-use intensification has been suggested as a powerful means to increase production without proportional increase in land demand, with potential benefits for biodiversity and carbon storage in terrestrial ecosystems via reducing the pressure for land-use change. However, land-use intensification is also a central driver of biodiversity loss[8] and requires substantial input of resources. Thus, balancing strategies that aim at reserving land for conservation associated with the high carbon and biodiversity cost of land-use intensification with strategies that aim at integrating production targets with biodiversity and carbon conservation targets at the expense of increased land demand will become pivotal.

implicitly these scenarios assume substantial expansions of biofuel plantations, which are critical for large-scale net carbon removal from the atmosphere via the implementation of carbon capture and storage technologies. However, recent years have shown that expanding biofuel plantations often has been detrimental for biodiversity and climate change mitigation if indirect land-use changes and carbon debts are accounted for.[8,15] In addition, plant traits that are favorable for carbon sequestration are those that confer invasiveness. Species with fast growth and vegetative reproduction that tolerate a wide range of climatic conditions are preferentially selected for biofuel production and can become invasive in a wide range of environments, with detrimental impacts on biodiversity.[60] Thus, the potential for biofuel expansion will critically depend on avoiding bio- and climate-perverse outcomes (e.g., by using appropriate life cycle emission analyzes and stringent rules of implementation) and thus may be lower than currently assumed.

To conclude, climate policy instruments may yield funding that is several times larger than available by traditional stand-alone conservation measures, and therefore they provide opportunities for implementing critically needed conservation actions. Because of their global reach, they may also help to reduce inequality in conservation, providing resources to less developed regions. However, allocating these resources efficiently requires a more comprehensive understanding of the role of biodiversity in ecosystem functioning and how that relates to greenhouse gas cycles.

CONCLUSIONS

While many synergies between climate policy instruments and biodiversity conservation do exist, current policies often fall short of tapping this potential. We present a set of key challenges that need to be addressed, but likely, the most severe difficulties in implementing these are societal and political.[2,4] Thus, building political coalitions, securing public support, and maneuvering politics through the myriads of competing interests will be decisive for climate policy success.

However, substantial areas of trade-offs between biodiversity conservation and maximizing carbon storage exist. In many situations, these are the outcome of differences in values, interests and risk perceptions that lead to differences in the framing of contested issues.[61] For instance, narrow framings of contested issues such as forest plantations, biofuels, or land-use decisions may consequently exclude (or downplay) indirect effects in the analysis such as the full impact on carbon/greenhouse gas balances via, for example, indirect land-use changes or creating carbon debts.[15] Based on the scientific evidence, we argue that appropriate evaluations of policy options often will reduce trade-offs in favor of conservation friendly policy solutions.[62]

The failure of appropriately recognizing the mutual co-benefits of climate change mitigation policies and biodiversity conservation and related fields (e.g., long-term food security) can be partly attributed to the design of relevant international institutions. Firstly, until recently, high-profile bodies that bridge the science-policy domains such as the UNFCCC and IPCC were not matched by similar institutions for biodiversity. Establishing IPBES closed this gap, but still its profile and visibility has to be increased. Secondly, integrated analyzes beyond sector policy goals need to be strengthened. This could be achieved by establishing joint commissions with specific tasks that are responsible to both the climate and biodiversity communities, respectively, institutions. The launch of Future Earth (www.futureearth.org) provides a model for such an integrated high-profile approach that should be emulated.

Finally, we stress that recognizing that bio-perverse impacts (*sensu* Lindenmayer et al.[8]) of climate policies on biodiversity have to be avoided will be crucial for the success of global climate change mitigation.

ACKNOWLEDGMENTS

We are grateful to Josef Settele and Mike Hulme for the invitation to write this paper. We appreciate comments by Stefan Dullinger and Wolfgang Rabitsch to the previous version of the manuscript. AP was funded by the Institute of Ecology and Biodiversity by the grants of the Ministry of the Economy ICM P05-002 and CONICYT PFB-23. We greatly appreciate the constructive advice by two anonymous reviewers.

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