Offsetting is a dangerous smokescreen for inaction

Offsetting carbon emissions – the approach of trading "credits" that represent a benefit intended to equally compensate for harmful emissions, in exchange for continuing to burn fossil fuels – is receiving increased attention (eg Anderson *et al.* 2017; Laville 2019). Large corporations, including Google, Apple, and Shell, along with airlines, US states, international cricket teams, and even music bands, plan to or already use this strategy, in attempts to reduce the impact of their business choices on the climate.

Most offsetting schemes follow the principle that the buyer is allowed to emit carbon in exchange for paying for emissions that have already been captured or avoided elsewhere. These schemes are controversial due in part to the complexities of ensuring that the carbon remains captured, a lack of oversight on the schemes' comprehensive environmental or social impacts (Cushing *et al.* 2018), and uncertainty over whether the carbon offset is additional to what would have been stored in absence of the offset program (Anderson *et al.* 2017). There is also evidence that offsetting schemes, despite their original intent, may actually discourage reductions in emissions, or even facilitate their unabated increase (Anderson 2012).

This situation is complicated by the dynamic nature of, and the interactions and feedbacks within, the Earth system, which can undermine the effectiveness of offsetting approaches. Once released, carbon dioxide (CO_2) immediately begins to warm the atmosphere. It then takes between 6 months to 1 year for a subset of that atmospheric CO_2 to equilibrate across the ocean's surface (Gattuso *et al.* 2010). Once absorbed by the ocean, this CO_2 will only return to the atmosphere a few hundred years later, due to the slow internal movement of water. This long-term absorption has helped to slow the impact of global warming, but is also driving ocean acidification (Raven *et al.* 2005). Many marine organisms are already being negatively impacted; some are coping, but future resilience is unclear (IPCC 2019).

Consider a single transatlantic flight taken during 2018. One year later, ~44% of the flight's CO_2 emissions are likely still in the atmosphere, ~30% have been absorbed by terrestrial plants, but ~23% have been absorbed and locked away by the ocean (Friedlingstein *et al.* 2019). In the time between the release of emissions and attempts to "re-capture" those emissions, they are already warming the atmosphere, and a portion will have been locked away in the ocean and will already be negatively affecting marine life.

Because the majority of offsetting services pay for carbon already captured (as the credit applies to historical emissions that have already been absorbed or avoided), they do nothing toward capturing the emissions of the person paying for the offset. Therefore, if everyone chooses to offset their emissions, the current rates of ocean acidification and atmospheric warming are likely to continue. The only sources of carbon that will have a net zero impact on the climate are those that are not emitted to the atmosphere and are not made available to the ocean. By overlooking the difference between the timescale of the Earth system's response to emissions and the timescales relevant to offsetting schemes, proponents of offsetting may have inadvertently transformed it into a method of avoiding emissions reductions, which could lead to inaction.

Reputable carbon offsetting schemes that are endorsed by leading pro-environmental groups may provide long-term benefits to the environment and society. Even so, investors in and users of offsetting schemes must realize that no scheme genuinely offers a solution for achieving net zero emissions, or a net zero impact on the climate. To transition to net zero emissions they should instead not only invest in technologies and supply chains that minimize emissions but also use renewable sources of energy. This tactic would support rapid and strong mitigation of CO_2 emissions. Otherwise, investors and users must accept that their decision to solely offset is at the expense of our ocean, the food it provides, and ultimately our climate.

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Changing climate in Brazil's "breadbasket"

Marks *et al.* (2020) critiqued the paper by Costa *et al.* (2019), which warned that Amazonian deforestation would lead to a lengthening dry season in the northern part of the Brazilian state of Mato Grosso. Marks *et al*. found no relationship between forest clearing within 50 km of weather stations in Mato Grosso and the number of dry days recorded. They also criticized Costa *et al*.'s conclusions regarding how to confront changes in rainfall that threaten the area's ability to produce two crops of soybeans every year. I disagree with Marks *et al*.'s interpretations for the following reasons.

Marks *et al*. (2020) implied that deforestation is not the cause of the changes documented by Costa *et al*. (2019). One complication is that Marks *et al*.'s analysis was based on data from weather stations positioned throughout Mato Grosso, whereas Costa *et al*. (2019) focused on climatological data from only the northern portion of the state, which is where the state's tropical forest is located. Marks *et al*. also considered vegetation clearing only in the vicinity of the weather stations; however, changes in precipitation are predominantly attributable to distant deforestation and changes in global circulation patterns influenced by global warming. Using models of deforestation across all of Amazonia, including but not limited to Mato Grosso, Costa *et al*. (2019) compared one scenario (with deforestation halted at the extent it had reached in 2005) with another scenario (that simulated continued deforestation through 2029). Costa *et al*. (2019) made clear that the impacts stem from deforestation throughout Amazonia and pointed to the importance of region-wide land-use change on rainfall in northern Mato Grosso as demonstrated by their previous model (Costa and Pires 2010).

The regional landscape plays an important role in determining weather patterns. In most of Amazonia, prevailing winds blow from east to west due to the Earth's rotation; these winds retain water vapor not only from the Atlantic Ocean but also from the forest via evapotranspiration (eg Marengo *et al*. 2002; Arraut *et al*. 2012; Zemp *et al*. 2014). Unable to pass over the Andes Mountains, especially in the austral summer, the winds are deflected across Mato Grosso, thereby supplying critical rainfall to population centers such as São Paulo (see review in Fearnside [2015]).

Marks *et al*. also criticized Costa *et al*. for implying that farmers in Mato Grosso would limit their deforestation out of self-interest. Costa *et al*. are open to criticism on this point, but it is a minor part of their paper, mentioned in a single sentence: "If people are not provided with sufficient reasons to protect the ecosystems in which they reside, then habitat destruction and degradation are expected to continue". Almost everyone would agree with this general principle, but the mention of "people" diverts attention from other actors that are more relevant here. Throughout the rest of the text Costa *et al*. repeatedly referred to governments, agribusiness associations, and companies (large international purchasers, not individual soy growers) as those who must act in response to the authors' warnings. Maintaining high agricultural productivity in Mato Grosso is of paramount interest to Brazil's federal government due to its contribution to national gross domestic product (GDP) and export earnings. Taking action to stop deforestation in the rest of Amazonia outside of Mato Grosso should be high on the government's agenda (Fearnside 2017).

Marks *et al*. were correct in their claim that, out of self-interest to avoid a lengthening dry season, individual farmers are unlikely to refrain from clearing. In addition to the "tragedy of the commons" problem they highlighted, there is also the value of time. Destroying any potentially sustainable resource for short-term profits can be a rational financial choice, assuming that the actors are free to move elsewhere and/or switch to other economic activities (Clark 1973, 1990). Self-interest is also unlikely to limit farmers' deforestation because clearing a hectare of forest on any given property would affect rainfall at other locations downwind of the property.

Marks *et al*. suggested that the impact of the projected alterations in rainfall could be countered by intensifying agriculture through the promotion of pivot irrigation. This option was recommended on the grounds that "growth in crop production through such intensification could also conceivably reduce the pressure on clearing remaining forests". They called for government agencies and financial institutions to support this, implying that a subsidy from "green" money was justified on the basis of avoiding deforestation. However, the degree of land-sparing required to achieve this outcome will likely not materialize, and would not represent a wise use of limited funding as compared to directly confronting deforestation. Theoretically, land-sparing would apply if the farmers were satisfied with their increased production. This logic holds for isolated subsistence groups that would stop expanding agriculture when their stomachs are full, but it does not apply to modern economies. Instead, when an activity such as intensified agriculture shows itself to be profitable, the response is to expand that activity (eg Fearnside 1987), which implies still more deforestation.

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The curious case of the blue-footed booby nest

The nesting ecology of boobies – including but not limited to the iconic blue-footed booby (*Sula nebouxii*) – has received relatively little scientific attention. Blue-footed boobies nest in colonies on tropical oceanic islands. Eggs are laid in a small bowl-shaped "scrape" on bare ground, which the birds surround with excrement, an efficient way of demarcating a nest, as shown here on the Galápagos Islands.

During the breeding season, males establish territories, and females assess potential mates by their foot color: brighter turquoise hues are indicative of superior health and are hence more attractive. Blue-footed boobies have few natural predators, which should allow for mate assessment and egg laying to occur in relative safety. Yet the red-footed booby (*Sula sula*), which also relies on foot color for mate assessment, usually nests in trees. So it's unclear whether the blue-footed booby's ground-based arrangement of nests is driven in part by the ease of visually assessing fitness. Alternatively, given that both sexes are known to engage in extra-pair liaisons, open areas on bare ground could facilitate cheating by allowing for unobstructed travel between interested parties.

After courtship, blue-footed boobies lay one to three eggs asynchronously, thereby promoting the chance for "facultative siblicide" during food shortages. Under such conditions, older siblings may kill younger ones by forced starvation or by dragging them out of the nest. Anderson (*Auk* 1995; doi.org/10.2307/4089018) maintains that the blue-footed booby's bowl-shaped scrapes limit the older hatchlings' success in ejecting siblings. Their scrapes are steeper and longer than those of the Nazca booby (*Sula granti*), which engages in "obligate siblicide". Yet Drummond (pers comm) offers that blue-footed fledglings do not forcefully push siblings from the nest, stressing that whether a chick is expelled depends on behavior rather than nest architecture.

A comprehensive understanding of the blue-footed booby's nesting ecology, which is influenced by multiple factors, awaits further study.

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