LETTER

Which forests could be protected by corporate zero deforestation commitments? A spatial assessment

Floris Leijten1,2, Sarah Sim1, Henry King1 and Peter H Verburg1,3

1 Safety and Environmental Assurance Centre, Unilever R&D, Colworth Science Park, Sharnbrook, Bedfordshire, United Kingdom
2 Environmental Geography Group, Institute for Environmental Studies (IVM), Vrije Universiteit Amsterdam, Amsterdam 1081HV, The Netherlands
3 Swiss Federal Institute for Forest, Snow and Landscape Research (WSL), Birmensdorf, Switzerland

E-mail: floris.leijten@unilever.com

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Abstract

The production of palm oil, soy, beef and timber are key drivers of global forest loss. For this reason, over 470 companies involved in the production, processing or distribution of these commodities have issued commitments to eliminate or reduce deforestation from their supply chains. However, the effectiveness of these commitments is uncertain since there is considerable variation in ambition and scope and there are no globally agreed definitions of what constitutes a forest. Many commitments identify high conservation value forests (HCVFs), high carbon stock forests (HCSFs) and forests on tropical peatland as priority areas for conservation. This allows for mapping of the global extent of forest areas classified as such, to achieve an assessment of the area that may be at reduced risk of development if companies comply with their zero deforestation commitments. Depending on the criteria used, the results indicate that between 34% and 74% of global forests qualify as either HCVF, HCSF or forests on tropical peatland. However, we found that the total extent of these forest areas varies widely depending on the choice of forest map. Within forests which were not designated as HCVF, HCSF or forests on tropical peatland, there is substantial overlap with areas that are highly suitable for agricultural development. Since these areas are unlikely to be protected by zero-deforestation commitments, they may be subject to increased pressure resulting from leakage of areas designated as HCVF, HCSF and tropical peatland forests. Considerable uncertainties around future outcomes remain, since only a proportion of the global market is currently covered by corporate commitments. Further work is needed to map the synergies between corporate commitments and government policies on land use. In addition, standardized criteria for delineating forests covered by the commitments are recommended.

1. Introduction

Commodity-driven deforestation is a major driver of global forest loss accounting for approximately 27% of global forest loss (Curtis et al 2018). Recognizing this, many multinationals sourcing deforestation-risk commodities have adopted goals to eliminate or reduce deforestation from their supply chains (Lambin et al 2018). These zero-deforestation commitments (ZDCs) typically focus on the four agricultural commodities most strongly associated with tropical deforestation: beef, palm oil, soy, paper and pulp (Henders et al 2015, Newton and Benzeev 2018). In recent years, the number of companies adopting ZDCs has grown rapidly to at least 484, representing an unknown market share (Donofrio et al 2019).

However, the effectiveness of ZDCs is uncertain since there is considerable variation in ambition and scope (Jopke and Schoneveld 2018, Taylor and Streck 2018). In addition, there are no globally agreed definitions of what constitutes a forest; variations arise from consideration of tree density, tree height, ecological properties etc (Chazdon et al 2016). The choice of forest definition influences estimates of forest areas globally and therefore deforestation estimates. As an example, Romijn et al (2013) demonstrated the total...
area estimated to have been deforested between 2000 and 2009 in Indonesia increased by 27% when using Indonesia’s national forest definition instead of the Food Agricultural Organization (FAO) definition.

Many companies identify high conservation value forests (HCVFs) (Brown et al 2013) and high carbon stock forests (HCSFs) (Rosoman et al 2017) as priority areas for conservation within their ZDCs. HCVFs are defined as forests of outstanding biological, ecological, social or cultural significance and divided into six categories: four focus on biodiversity, habitat and ecosystem conservation, and a further two on community needs and cultural values (Brown et al 2013). HCSFs are defined by a practical, field-tested methodology—the high carbon stock approach (HCSA)—that prioritizes forests for conservation based on their above-gound biomass (AGB) carbon, while respecting communities rights to their lands and typically integrating the findings of an HCV assessment (Rosoman et al 2017). In addition, many companies have also committed to the protection of forest on tropical peatlands (Newton and Benzeev 2018). The adoption of these so-called ‘No Deforestation, No Peat and No Exploitation’ (NDPE) commitments has been limited to the oil palm sector in Southeast Asia where 74% of the palm oil refining capacity is now covered by such commitments (Steinweg et al 2017). Recently, the Roundtable on Sustainable Palm Oil (RSPO) integrated the HCSA into its Principles and Criteria (RSPO 2018). Discussions are ongoing as to whether the HCS approach should also be included by other standard bodies, including the Roundtable on Responsible Soy (RTRS), the Forest Stewardship Council (FSC) and the United Nations Reducing Emissions from Deforestation and forest Degradation (REDD+) Programme (Cheyns et al 2019).

Although commitments to protect HCVF and HCSF have been recognized as potentially effective approaches for implementing a ZDC (Garrett et al 2019), the spatial extent of HCVFs and HCSFs is unknown (Pirker et al 2016, Carlson et al 2018). Both approaches were developed for local, case-by-case application requiring on-the-ground field visits and stakeholder consultation. As a result, mapping has been conducted mainly at the local scale, leaving unclear what the global coverage of the ZDCs is. In addition, concerns around deforestation extend to the development of new production areas on forests and other biomes which fall outside of the HCVF and HCSF classifications—a phenomenon often referred to as activity leakage (Meyfroidt et al 2018, Bastos Lima et al 2019). Therefore, the primary objective of this paper is to make an estimate of the global land area that could be classified as HCVF, HCSF or forest on tropical peatland, and hence at reduced risk of development if companies comply with their ZDCs. A secondary objective is to identify the remaining forest areas that are at risk of conversion due to agricultural development or forestry.

2. Methodology

A stepwise approach was adopted to estimate the global forested land area that can be classified as HCVF, HCSF or forest on tropical peatlands. First, a forest reference map for the current situation was created (section 2.1.1). Then, HCVFs (section 2.1.2), HCSFs (section 2.1.3) and tropical peatland forests (section 2.1.3) were identified separately by matching a variety of data sources to the official definitions and descriptions listed in the HCV guidelines and HCSA toolkit.

The forested areas that were not classified as HCVF, HCSF or tropical peatland forest were intersected with several maps displaying agricultural suitability for the four main deforestation-risk commodities, market accessibility, future land use change projections and areas where commodity-driven deforestation and forestry are considered the main driver of forest loss (sections 2.2.1–2.2.3).

2.1. Estimating the global extent of HCVF, HCSF and forests on tropical peatland in 2017

2.1.1. Mapping forest areas.

To create a forest reference map for the current situation, the binary forest map from (Schulze et al 2019) was used. This 1 km² resolution map is based on a hybrid forest map created by (Schepaschenko et al 2015) and represents the year 2000, calibrated with the most recent FAO statistics. We modified the forest extent to represent the year 2017 using 1 km² raster data on tree cover gain (2000–2012) and tree cover loss (2000–2017) from (Hansen et al 2013, 2019), accessed through Google Earth Engine. Recognising that tree cover loss data from Hansen et al do not distinguish between temporary loss and permanent conversion (Curtis et al 2018) and that tree cover gain data include plantation forests and herbaceous crops (Tropek et al 2014), we tested the sensitivity of the mapped forest area using both the original and our updated Schulze map. In addition, we tested the sensitivity of mapped forest areas arising from the choice of forest map by using nine alternative global forest maps (table 1). Finally, all spatial data were converted to an equal-area Eckert IV projection as advocated in (Šavrič et al 2015).

2.1.2. Mapping HCVF forests.

We used the HCV guidelines (Brown et al 2013) to identify and map HCVFs using 12 distinct indicators that together cover the full range of HCV categories, as shown in table 1 (see also table 1 available online at stacks.iop.org/ERL/15/064021/mmedia of the supplementary material for an extended ver-
Table 1. List of indicators and data sources to identify HCSF, HCVF and forest on tropical peatlands.

| Indicator | Thresholds | Data sources |
|-----------|------------|--------------|
| Forest extent 2017 | Hybrid forest map for the year 2000 that integrates eight different forest products, validated with crowdsourced data, consistent with FAO statistics, updated to the year 2017 based on remotely sensed data of tree cover loss and gain between 2000–2017. As a sensitivity analysis, nine different forest maps are considered. Percentage tree-cover maps from (Hansen et al 2019) and (Sexton et al 2013) were converted to binary forest maps (forest/no forests) by applying a 10% and 30% threshold, following the official forest definitions of the (FAO 2012) and the United Nations Framework Convention on Climate Change (UNFCCC 2006), respectively. | Schulze et al 2019 and Hansen et al 2019 |
| High conservation value | HCV 1 Species diversity | Biodiversity Hotspots |
| | | Key Biodiversity Areas |
| | | Nationally Designated Protected Areas |
| | | Intact Forest Landscapes |
| | HCV 2 Landscape-level ecosystems and mosaics and Intact Forest Landscapes | Areas of high forest biodiversity significance |
| | HCV 3 Ecosystems and habitats | Chaplin-Kramer et al 2019, Stehfest et al 2014 and CIESIN 2018 |
| | HCV 4 Ecosystem services | Areas of high overlap of nature’s contributions and people’s needs in terms of coastal risk reduction, crop pollination, erosion protection, reduction of flood risk, water quality and water supply. |
| | HCV 5 Community needs | Presence of Indigenous Community |
| | HCV 6 Cultural values | UNESCO World Heritage Sites (part of Nationally Designated Protected Areas) |
| High carbon stock | Above-ground biomass (t C ha$^{-1}$) within tropical forest areas. | Santoro and Cartus 2019 |
| Pan-tropical peatlands | Presence of peatland in the tropics. | Gumbricht et al 2017 |
three HCV categories. The different levels of coverage were used to represent the uncertainty in the final HCVF classification and illustrate the sensitivity of the mapped spatial extent to the indicator selection. We assumed that areas with multiple overlapping categories are more likely to qualify as HCVF.

2.1.3. Mapping HCS forests.
According to the HCS Toolkit Version 2.0 (Rosoman et al 2017), potential HCSF can be identified based on an above-ground biomass (AGB) threshold of 35 t C ha\(^{-1}\). Although some potential HCSF may still be released for development, all tropical forests containing more than 75 t C ha\(^{-1}\) are generally designated as HCSF (Rosoman et al 2017). We used both thresholds to indicate the range of uncertainty in the classification of HCSF and its mapped spatial extent. Above ground biomass data from (Santoro and Cartus 2019), representing the year 2017, were resampled from a resolution of 1 ha to a resolution of 1 km\(^2\). To estimate the uncertainty in the final HCSF map, the majority resampling approach was applied. For sensitivity analyses, two alternative AGB carbon maps were considered (see table 1). Since the HCS approach is not applicable for forests outside the tropics (Rosoman et al 2017), these were not classified as HCS.

2.1.4. Mapping forests on tropical peatland.
Tropical peatland forests were mapped using data on the pan-tropical extent of peatlands in 2011 from (Gumbricht et al 2017).

2.2. Evaluating forests at risk of agricultural development.
We evaluated the deforestation risk of forest areas not designated as HCVF, HCSF or tropical peatland. Forests designated as HCV or HCS were for this analysis defined as forests with at least two overlapping HCVF categories or at least 75 t C ha\(^{-1}\) if located in the tropics (section 2.1). The risk of potential future conversion of forest was assessed using three alternative approaches to account for the uncertainty in future development: (1) by identifying and overlaying suitable and accessible expansion areas for the 4 main deforestation-risk commodities (section 2.2.1), (2) by using integrated assessment model predictions (section 2.2.2), and (3) by masking areas where commodity-driven deforestation and forestry are considered the main drivers of forest loss (section 2.2.3).

2.2.1. Overlap with suitable and accessible expansion areas for the 4 deforestation-risk commodities.
Data on agro-ecological suitability for oil palm, soybean and pasture were sourced from the International Institute for Applied Systems Analysis/Food and Agriculture Organization (2012) and Van Velthuizen et al (2007), and resampled to a resolution of 1 km\(^2\) using the majority resampling approach (a list of all data sources can be found in table 2 of the supplementary material). These suitability maps include eight different suitability classes for current agricultural or pastoral production areas as well as those which could be developed for future production. To identify suitable areas for forestry, a similar suitability map for potential production forests was made by classifying a continuous suitability map from (Schulze et al 2019) into eight suitability classes. For each commodity, potential areas for expansion were identified by excluding areas already under production. For oil palm, soybean and pasture, only the estimated fraction of any given grid cell currently under cultivation was known (Ramanikuttu et al 2010, International Food Policy Research Institute 2019). We therefore excluded grid cells where cropland or pastureland already extend over more than 50% of the area (a sensitivity analysis towards this assumption is provided in the supplementary material). Grid cells comprising urban land were also excluded, using data from (Schneider et al 2003). Forest areas outside the HCV, HCS and tropical peatland areas overlapping with suitable expansion areas were assumed to be at risk of conversion.

As inaccessible lands may face lower risk of development (Busch and Ferretti-Gallon 2017), we refined the analysis by mapping the joint distribution of market accessibility and agricultural suitability for forests falling outside the HCV, HCS and tropical peatland areas. Data from (Weiss et al 2018) on travel time to the closest port or the closest city with at least 50,000 inhabitants—resampled to a resolution of 1 km\(^2\) using bilinear interpolation—were used as a proxy for market accessibility. To obtain an overall measure of agricultural suitability for the 4 commodities, a raster layer was created indicating, for each grid cell, the highest overall suitability class of the 4 suitability layers (a separate map for each of the 4 commodities is presented in the supplementary material).

2.2.2. Overlap with land use projections.
An alternative estimate of the conversion risk placed on areas falling beyond the HCVF, HCSF and tropical peatland forests classifications was derived using spatially explicit land use projections of cropland and pastureland expansion at 5 arc minutes resolution from the Integrated Model to Assess the Global Environment (IMAGE) 3.0 model (Doelman et al 2018). These projections were made for the period 2020–2030 and based on the second Shared Socioeconomic Pathways (SSP2) scenario (a ‘middle-of-the-road’ scenario for future climate mitigation action) (O’Neill et al 2014). Forest areas that were not classified as HCVF, HCSF or tropical peatland forest and were found to overlap areas of projected cropland or pastureland expansion were considered to be at additional risk of development.
2.2.3. Overlap with areas where commodity-driven deforestation and forestry are dominant drivers of forest loss.

Finally, we assessed the overlap between forests not classified as HCS, HCV or tropical peatland and areas where forestry and commodity-driven deforestation are classed as the main drivers of forest loss. Data on the drivers of forest loss at 10 km$^2$ resolution were sourced from Curtis et al (2018). This provides an indication of the forest areas that are at additional risk of development, assuming these forests will indeed be subject to forestry or commodity-driven deforestation.

### 3. Results

#### 3.1. The estimated extent of HCVF, HCSF and forests on tropical peatland in 2017

Based on the updated Schulze et al map for the year 2017, the global forest area amounts to 39.4 million km$^2$ (this compares with an area of 40.3 million km$^2$ if the Schulze et al map is not updated). Figure 1 shows the variation in the spatial extent of HCVF and HCSF, depending on the stringency of the criteria. The total extent of HCVF and HCSF combined comprises between 34% and 74% of global forests, of which between 28% and 34% has already been designated as protected area (UNEP-WCMC 2018). The global extent of HCVF alone encompasses between 7% and 65% of global forests (table 2), with indigenous lands accounting for the largest part of potential HCVF (i.e. 43% of all potential HCVF, see figure 1 of the supplementary material).

Since HCSFs are by definition limited to the tropical zone, the total extent is much smaller than the extent of HCVF and varies in the range of 31%–43% of global forests, which equates to 66%–91% of all tropical forests, depending on the choice of AGB map and whether an AGB threshold of 35 or 75 t C ha$^{-1}$ is applied. Within the tropical zone, there is an overlap between HCVF and HCSF, with the percentage of total tropical forest for which the two classifications converge—measured by the Jaccard Similarity Index (Intersection over Union)—varying between 14% and 67%, depending on both the AGB threshold and minimum number of overlapping HCVF categories. Tropical peatland forests comprise 3% of all tropical forests, of which between 82% and 98% overlap with HCVFs and HCSFs.

At a regional or country level, the large sensitivity of the extent of HCVF and HCSF to the choice of criteria can lead to dramatic differences (see figures 2 and 3 of the supplementary material). For example, the total extent of HCVF, HCSF and tropical peatland forest in Sub-Saharan Africa varies in the range of 51%–84% of all forests.

To test how sensitive the results are to the choice of forest map, figure 2 shows the variation in the extent of HCVF, HCSF and tropical peatland forest when different forest maps are considered. Forests designated as HCVF or HCSF are here defined as forests containing at least two overlapping HCVF categories or exceeding the AGB threshold of 75 t C ha$^{-1}$. To account for the uncertainty in the extent of HCSF and HCVF, the error bars in figure 2 denote the upper and lower range of the extent of HCSF, HCVF and tropical peatland forest using the full range of criteria shown in figure 1 (see table 3 of the supplementary material for a detailed comparison of the 10 forest maps based on the Jaccard Similarity index). The total extent of forests designated as HCVF, HCSF or tropical peatland depends to a large extent on the choice of forest map and varies in the range of 11–40 million km$^2$, notably because large areas considered forest by some maps are classified as closed shrublands or woody savannahs by others.

#### 3.2. Forest at risk of agricultural development

Figure 3 shows the extent to which potential suitable expansion areas for the 4 deforestation-risk commodities overlap with forest areas and forest areas designated as HCVF, HCSF or tropical peatland, based on different land suitability thresholds. Depending on the suitability classes included, 39%–92% of the
area suitable for forestry expansion and 57%–80% of the areas suitable for the expansion of oil palm plantations overlap with forests designated as HCVF, HCSF or tropical peatland. The total forest area outside HCVFs, HCSFs and tropical peatland forests that is suitable for forestry ranges between 0.57 to 17.81 million km$^2$, while the area suitable for oil palm plantations ranges between 0.30 and 6.82 million km$^2$. Potential suitable expansion areas for pasturelands and soybean fields are much more abundant resulting in a lower percentage overlap with forests (36%–52% and 6%–36%, respectively). Still, given their overall larger extent, the total forest area not covered by HCVFs, HCSFs and peatland forests is as high as 19.73 million km$^2$ for pastureland and 10.61 million km$^2$ for soybean fields.

To assess where pressures from forestry and agricultural expansion are especially high, figure 4 displays the joint distribution of market accessibility—classified into eight octiles—and agricultural suitability, based on the highest land suitability class for the four commodities (see figure 5 of the supplementary material for four separate maps per commodity). Forests not designated as HCVF, HCSF or tropical peatland forest with high market accessibility and agricultural suitability tend to be clustered in the Eastern United States, Central Europe, East China, the Gran Chaco in Latin America and near
Figure 2. Total extent of forests and forests designated as high conservation value forest (HCVF), high carbon stock forest (HCSF) or located on tropical peatland, based on 10 different forest maps. Forests designated as HCV or HCS are here defined as forests with at least two overlapping HCVF categories or at least 75 t C ha\(^{-1}\) if located in the tropics. Error bars denote the upper and lower range of the total extent of HCVF, HCSF and tropical peatland forest using the other criteria to delineate HCVF and HCSF shown in figure 1. CCT denotes canopy cover threshold.

Figure 3. Overlap of agro-ecological suitability for four main deforestation-risk commodities with forests designated as high conservation value forest (HCVF), high carbon stock forest (HCSF) and tropical peatland forest. The error bars denote the uncertainty in the total extent of HCVF, HCSF and tropical peatland forests. Suitable areas outside forests do not include urban areas or areas already under cultivation or used for production.

the Swahili Coast in Sub-Saharan Africa (see figures 6(a)–(c) of the supplementary material for three zoom maps of Latin America, Sub-Saharan Africa and Southeast Asia; the three main global deforestation regions (FAO 2018)). Around 36% of these forest areas with the highest market accessibility and agricultural suitability are estimated to be already used as production forests, based on data from (Schulze et al 2019).

These results merely indicate risk based on agro-ecological suitability and accessibility and do not account for projected changes in land use linked to anticipated growth in demand, population density and market accessibility. Projections from the IMAGE
Figure 4. Joint distribution of market accessibility and agricultural suitability across forests not designated as high conservation value forest (HCVF), high carbon stock forest (HCSF) or tropical peatland forest. Market accessibility is based on travel time to the nearest port or city with at least 50,000 inhabitants and classified into eight octiles. Agricultural suitability is determined by taking the highest suitability class for each grid cell after overlaying four suitability layers for forestry, oil palm cultivation, soybean cultivation and pastureland—each comprising eight suitability classes. A separate map for each commodity is presented in figure 5 of the supplementary material.

3.0 model for crop and pasture expansion between 2020 and 2030, reflect drivers of land use change. These projections indicate that 38% of the total forest area not designated as HCVF, HCSF or tropical peatland forest, may be subject to land use change for agricultural production. Assuming these predictions provide a reasonable indication of the location of future production for the four deforestation-risk commodities, the total forest area at risk of becoming converted to oil palm plantations, soybean fields or pastureland becomes much smaller—especially in the temperate zone—and decreases on average by 59% (see figure 7 of the supplementary material). It is important to note though that these estimates do not account for potential leakage effects from protecting HCVFs, HCSFs and tropical peatland forests.

Alternatively, focusing only on areas where commodity-driven deforestation or forestry is considered the main driver of forest loss, the total forest area at risk amounts to 56% of the total forest area not classified as HCVF, HCSF or tropical peatland forest, of which 17% overlaps with areas where commodity-driven deforestation is considered the main driver of forest loss.

4. Discussion and conclusions

This study provides a first approximation of the global forest area that may be covered by corporate zero deforestation commitments (ZDCs), defined on the basis of three commonly used criteria: protection of high conservation value forests (HCVF), high carbon stock forests (HCSF) and tropical peatland forests. The results show that between 34% and 74% of all forests may classify as HCVF, HCSF or peatland forest. This large range indicates the level of uncertainty in the extent of forest that could be at reduced risk of development if these commitments were fully adopted. However, given that market coverage of the corporate commitments is less than 100%, the protected area will be much smaller in reality and deforestation can move to supply chains falling beyond the scope of the corporate commitments (Garrett et al. 2019). Moreover, even in case of full uptake, legally protected forest accounts for only 28%–34% of the forest area that we identified as meeting our ZDC criteria.

In comparison with individual site-based local assessments conducted by companies, our global assessment of the spatial coverage of HCVF and HCSF is likely to identify some different areas for conservation. First and foremost, this is because the methods used to identify HCVFs and HCSFs were developed for local assessments requiring extensive field work and free, prior and informed consent from local communities, meaning they are not easily applied at larger scales (i.e. the 1 km² resolution we use) (Lake et al. 2016, Pirker et al. 2016). In addition, many of the criteria documented in the HCV guidelines contain ambiguous and subjective terms that depend on individual assessors’ discretion. This has led to an inconsistency between various local HCV assessments (Senior et al. 2015), meaning that there is no consensus on what potential HCV indicators are most appropriate. There are also no spatial data sets available on areas already designated as HCVF and HCSF (Carlson et al. 2018, HCSA Steering Group 2019) to enable validation. Finally, all indicators used to
approximate the spatial extent of HCVF and HCSF had to be resampled to a resolution of 1 km², which inevitably leads to some loss of spatial detail (Zhu et al. 2017). To reduce uncertainty in the spatial extent of forest protected under the corporate commitments, standardized criteria for delineating forests and defining areas of HCVF and HCSF at the global scale and across tropical and temperate forests are recommended. In addition, advances in remote sensing and biodiversity mapping should be exploited to produce more accurate and up-to-date indicators of HCVFs and HCSFs.

Despite these uncertainties, our results are relatively consistent with previous attempts to map HCV and HCS areas at larger scales. For example, Miranda et al. (2003) estimated that 37% of all areas designated as forest according to our reference map are potentially HCVF, which compares with our estimate of 27% (for two overlapping HCVF categories), and Austin et al. (2017) estimated the total extent of HCSF in Gabon to be between 80% and 87% of Gabon’s land, which compares with our estimate of 83% (regardless of the choice of carbon threshold).

Our analysis has also shown that the extent of HCVF, HCSF and tropical peatland forests is contingent on the choice of forest map, resulting in a range from 11 to 40 million km² according to the criteria specified in figure 2. This finding adds to a growing body of literature showing that the definition of forest significantly impacts estimates of forest cover and forest cover change (Chazdon et al. 2016, Sexton et al. 2016, Mermoz et al. 2018). The lack of a well-agreed forest definition led nine environmental and social NGOs to launch the Accountability Framework initiative in 2016; a framework that has been developed to provide companies with detailed guidance to implement their commitments and standardize definitions of forest, deforestation, and related terms (Weber and Partzsch 2018). Greater consensus on forest classification is needed to reduce the uncertainty in the area covered by the corporate commitments and facilitate more effective monitoring (Lyons-White and Knight 2018).

Even if the ZDCs are fully implemented across all commodity markets, some of the environmental and social benefits associated with the protection of HCVF, HCSF and tropical peatland forest may be undermined if agricultural expansion is displaced to forests that are not covered, hence resulting in activity leakage (Meyfroidt et al. 2018, Bastos Lima et al. 2019). Using data on land suitability for the four main deforestation-risk commodities, we have shown here that many forest areas not designated as HCVF, HCSF or tropical peatland forest are highly suitable for the production of these commodities, indicating an increased potential risk of development due to ZDCs. Hence, with a growing world demand for all four commodities (Corley 2009, Masuda and Goldsmith 2009, Thornton 2010, Johnston 2016), pressures on potential expansion areas will likely increase and could possibly come at the expense of forests or other biomes, including savannahs and grasslands, not designated as HCVF, HCSF or tropical peatland forest, in particular when market accessibility is high (Atmadja and Verchot 2012). In addition, pressures may be higher at local scales due to imperfect substitution between commodities originating from different sources (Hertel 2018). However, the total area at risk of development may be much smaller when accounting for future land use change scenarios or historic trends in commodity-driven deforestation or forestry.

It should be noted, though, that there are many factors that we have not been able to consider in our assessment of the areas at risk of future agricultural development. For example, there are a range of interacting socio-economic factors—including mobility of capital and labour, easy access to credit and differences in price and terms (Atmadja and Verchot 2012)—policy and governance factors (Fernandes et al. 2015) as well as crop-to-crop cascade effects (Lambin and Meyfroidt 2011), which are all likely to affect future land use outcomes. Further work to map synergies between corporate commitments and government policies influencing land use outcomes is recommended. This will help to refine estimates of the potential effectiveness of national and supply chain governance levers for halting deforestation and for the identification of complementary strategies which may accelerate efforts towards zero deforestation.

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Data availability

Data on current production forests and forestry suitability estimates can be obtained from Katharina
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