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1 **Key role of forests in meeting climate targets but science needed**
2 **for credible mitigation**

3

4

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16 **ABSTRACT**

17

18 **Forest-based climate mitigation may occur through conserving and enhancing the carbon sink**
19 **and through reducing greenhouse gas emissions from deforestation. Yet the inclusion of forests**
20 **in international climate agreements has been complex, often treated separately or considered a**
21 **secondary mitigation option. In the lead up to the Paris Climate Agreement, countries**
22 **submitted their (Intended) Nationally Determined Contributions ((I)NDCs), including climate**
23 **mitigation targets. Assuming full implementation of (I)NDCs, we show that land use, and forests**
24 **in particular, emerge as a key component of the Paris Agreement: turning globally from a net**
25 **anthropogenic source during 1990-2010 (1.3 ± 1.1 GtCO₂e/y) to a net sink of carbon by 2030 (up**
26 **to -1.1 ± 0.5 GtCO₂e/y), and providing a quarter of emission reductions planned by countries.**
27 **Realizing and tracking this mitigation potential requires more confidence in numbers, including**
28 **reconciling estimates between country reports and scientific studies. This represents a challenge**
29 **and an opportunity for the scientific community.**

30 **MAIN TEXT**

31

32 In December 2015, 195 countries adopted the Paris Climate Agreement¹ at the 21st Conference of
33 Parties (COP-21) of the United Nations Framework Convention on Climate Change (UNFCCC). As
34 part of the process, 187 countries, representing more than 96% of global net emissions in 2012²,
35 submitted their Intended National Determined Contributions³ (INDCs, which become NDCs with the
36 ratification of the Paris Agreement⁴). The NDCs are the basis for implementing actions under the
37 Agreement, and the vast majority include commitments in the land-use sector.

38 Land use, including agriculture and forests, accounts for about 10% of global greenhouse gas (GHG)
39 emissions as CO₂, and nearly quarter including CH₄ and N₂O⁵⁻⁹. Also, about one third of the current
40 anthropogenic CO₂ emissions are removed by terrestrial ecosystems, mainly forests. While
41 deforestation is estimated to be the main GHG source in many tropical countries, forest sinks are
42 important globally with net sinks dominating in temperate and boreal countries¹⁰.

43 Including land use in the UNFCCC process has been long and complex. For forests, uncertainties of
44 GHG estimates and methodological issues such as additionality (i.e. showing that proposed mitigation
45 efforts go beyond Business-as-Usual (BAU) and separation of non-anthropogenic effects) and leakage
46 (displacement of land-use activities to other areas) have often led to controversies and compromises¹¹.

47 The UNFCCC requires that all countries report GHG inventories of anthropogenic emissions and
48 removals using methodologies developed by the Intergovernmental Panel on Climate Change (IPCC)
49 and adopted by UNFCCC¹². Developed countries report annual GHG inventories¹³, using mandatory
50 and voluntary land-use activities towards meeting their emission reduction targets where applicable
51 under the Kyoto Protocol¹⁴. Developing countries' GHG inventories have historically been reported
52 less frequently¹⁵, though biennial updates are now required¹⁶, and may undertake voluntary mitigation
53 activities, notably through the REDD+ process (Reducing Emissions from Deforestation, forest
54 Degradation, and other forest activities).

55 The Paris agreement is a potential game changer for land use mitigation. It calls explicitly for all
56 countries to make use of a full-range of land-based mitigation options, and to take action on REDD+.
57 Based on country information, this analysis quantifies the expected GHG mitigation role of the land-
58 use sector in the (I)NDCs to the year 2030, including activities conditional on finance, technology and
59 capacity-building support. It does not assess specific country policies. It focuses on CO₂ emissions
60 and removals and non-CO₂ emissions from Land Use, Land-Use Change and Forestry (LULUCF,
61 primarily deforestation and forest management), encompassing most of the land-use sector identified
62 in (I)NDCs. Harvested wood products are included for most developed countries. Non-CO₂ emissions
63 from agriculture are not included.

64

65 **Country mitigation targets are expressed in different ways**

66 Countries express their (I)NDC targets with different combinations of the following elements¹⁷⁻¹⁹
67 (Supplementary Tables 1-2), reflecting different national circumstances, i.e.:

- 68 • Quantifier - targets are expressed as either an *absolute quantity* e.g. amount of GHG reduction in
69 tonnes of CO₂ equivalent (tCO₂e), or as a change in the *emission intensity*, e.g. China and India
70 express a reduction of emission intensity per unit of GDP.
- 71 • Reference point – Emissions in the target year (e.g. 2025 or 2030) are compared to either a historic
72 base year (e.g. 1990, 2005) or to the target year in a BAU scenario. The BAU scenario assumes
73 either no mitigation activity, or some existing mitigation activity.
- 74 • Conditionality - While developed country (I)NDC targets are unconditional, most developing
75 countries expressed at least part of their targets as conditional on finance, technology or capacity-
76 building support.

77 The (I)NDCs vary in the way they include LULUCF. It may be fully included as part of the overall
78 target like other sectors, or partially included (e.g., only deforestation), or considered separately with

79 special mitigation actions or accounting rules. Consequently, evaluating the expected effect of
80 LULUCF on the (I)NDC mitigation targets is complex.

81 Our analysis is based on information provided on LULUCF in the (I)NDCs³, and also (in order of
82 priority) other country reports to UNFCCC^{13,15,16,20,21}, other official country documents, and FAO-
83 based datasets for forest^{8,22} and for other land uses²³ (Supplementary Tables 4-5). Given the Paris
84 Agreement context of our analysis, we prioritized (I)NDCs and those country reports which are
85 formally reviewed or technically assessed by UNFCCC, with FAO-based datasets used for gap filling,
86 allowing global estimates covering 195 countries (see Methods). We found sufficient information to
87 analyse the LULUCF mitigation contribution for 68 countries (or 41 (I)NDCs, with the EU's NDC
88 representing 28 countries), representing around 78% of global net emissions in 2012² and 83% of the
89 global forest area²². For the remaining countries, where LULUCF is not expected to offer a large
90 mitigation potential (Supplementary Section 1), the future LULUCF mitigation contribution was
91 assumed to be zero.

92

93 **Historical and projected forest emissions and removals**

94 Fig. 1 shows, for all 195 UNFCCC countries, historical and future anthropogenic LULUCF emissions
95 and removals from this analysis, based on official country data. The Supplementary Sections 2 and 3
96 provide, respectively, additional country-specific assessments and an analysis of uncertainties for the
97 absolute level of net emissions and their trend^{24,25}, based on information from countries' reports.

98 While country information on uncertainty up to 2030 is not available, we conservatively assumed that
99 the uncertainty estimated for historical net emissions would also hold for the future.

100 Historically, global LULUCF net emissions decreased from 1.54 ± 1.06 GtCO₂e/y (95% CI) in 1990
101 to 0.01 ± 0.86 GtCO₂e/y in 2010 (slope of linear trend: -0.08 GtCO₂e/y). The trend and the inter-
102 annual variability over this period are influenced by: (i) deforestation in Brazil, with peak years in
103 1995 and 2002-2004 followed by a steep reduction of emissions by about -1.3 GtCO₂e/y till 2010; (ii)
104 high deforestation rates (1997-1999) and peak years in peat fire emissions (e.g., 1997) in Indonesia;

105 (iii) an increasing sink in managed temperate and boreal forests, of about $-0.8 \text{ GtCO}_2\text{e/y}$ from 1990 to
106 2010. By splitting the 1990-2010 period (average emissions: $1.28 \pm 1.15 \text{ GtCO}_2\text{e/y}$) into four sub-
107 periods, we conclude that the historical trend is statistically significant after 2000 (Supplementary
108 Section 3).

109 The wide range of future LULUCF net emissions depends on policy scenarios (Fig. 1). The ‘country-
110 BAU’ scenario foresees a marked increase in global net emissions (Supplementary Table 6), reaching
111 $1.94 \pm 1.53 \text{ GtCO}_2\text{e/y}$ in 2030. This is because several developing countries assumed BAU to be a no-
112 measures scenario, e.g. ignoring the existing policies to reduce deforestation. Under the ‘pre-(I)NDC
113 scenario’, i.e. considering policies in place prior to COP-21 (including the earlier Copenhagen
114 pledges²¹), global net emissions increase moderately, up to $0.36 \pm 0.94 \text{ GtCO}_2\text{e/y}$ in 2030. For the
115 ‘unconditional (I)NDC scenario’ the global net emissions slightly decrease, reaching a sink of $-0.41 \pm$
116 $0.68 \text{ GtCO}_2\text{e/y}$ in 2030. An additional reduction of net emissions is estimated for the ‘conditional
117 (I)NDC’ scenario, leading to a sink of $-1.14 \pm 0.48 \text{ GtCO}_2\text{e/y}$ in 2030.

118 The analysis of the emission trend over the entire period shows that the difference between the 1990-
119 2010 average and the net emissions in 2030 is not significant for the pre-(I)NDC scenario, but is
120 significant (95% CI) for both the unconditional and the conditional (I)NDC scenarios (Supplementary
121 Figure 3b). This indicates that the reduction of net emissions assumed by the (I)NDCs relative to the
122 historical period, if achieved, is statistically robust.

123

124 **Comparison with global datasets**

125 Fig. 2 compares the historical LULUCF trend from our analysis to other three well-known global
126 LULUCF datasets: (i) latest country reports to UNFCCC (ref^{13,15,16,20}); (ii) FAOSTAT for all land
127 uses²³; and (iii) IPCC Fifth Assessment Report (AR5) Working Groups (WG) I⁵ and III⁶ data used for
128 the global carbon budget.

129 The difference between this analysis and the UNFCCC country reports is because several (I)NDCs
130 updated past datasets, and because we used FAO-based data for gap-filling, instead of pre-2010
131 National Communications.

132 Differences between this analysis and FAOSTAT include the definition of forest (UNFCCC vs.
133 FAO); coverage of areas and of carbon pools; and differing estimation methods by reporting
134 agencies⁸ (see Methods).

135 There is a large difference of about 3 GtCO₂e/y between this analysis, based on country reports
136 following the IPCC Guidelines for national GHG inventories^{25,26} (IPCC GL), and the scientific studies
137 summarized by the IPCC AR5^{5,6}. For the period 2000-2009, the level of net emissions is on average
138 0.90 ± 1.11 GtCO₂e/y (95 % CI) in our analysis and 4.03 ± 2.93 GtCO₂e/y (90 % CI, reflecting both
139 methodological and terminological choices²⁷⁻²⁹) in IPCC AR5 (Fig. 2). The above differences are
140 linked to different scopes of the two IPCC work streams³⁰: the GL focus on internationally agreed
141 methodologies for national anthropogenic GHG estimation, recognizing different countries'
142 definitions and technical capabilities, whilst the AR5 focuses on assessing the state of the science on
143 the global carbon budget using globally applied data, definitions and modeling methods.

144 Specifically, LULUCF in the IPCC GL includes estimates of GHG emissions and removals from all
145 land uses, reported under either a stable or changed land-use status (typically in the last 20 years), e.g.
146 “forest remaining forest” or “forest converted to cropland” (or vice versa). There is a large scientific
147 challenge of providing a practicable methodology to factor out direct human-induced mitigation
148 action from indirect human-induced and natural effects^{31,32}, such as the natural aging of forests,
149 natural disturbances and environmental change (e.g. climate change, extended growing seasons,
150 fertilizing effects of increased [CO₂] and nitrogen deposition). Therefore, the IPCC GL^{25,26} use the
151 category of “managed land” as a default first order approximation of “anthropogenic” emissions and
152 removals, based on the rationale that the preponderance of anthropogenic effects occurs on managed
153 land³². The GHG inventories should report all emissions and removals for managed land, while GHG

154 fluxes from unmanaged land are excluded. What is included in “managed land” varies from country
155 to country, although the countries’ definition must be applied consistently over time.

156 In contrast, global models such as those used in IPCC AR5 and the Global Carbon Project take a
157 different approach to separate anthropogenic from natural effects. Anthropogenic fluxes (referred as
158 “net land-use change”^{5,9}, or “Forestry and Other Land Uses”⁶), are estimated by a bookkeeping
159 model²⁷ or by dynamic global vegetation models⁹ based on changes in land cover (i.e. between forest
160 and agriculture), forest regrowth and, depending on the modeling capability, some forms of
161 management (wood harvest and shifting cultivation). The difference between this modeled
162 “anthropogenic” flux and the estimated total net flux of CO₂ between the land and atmosphere⁹ is the
163 “residual terrestrial sink”^{5,6,9}, which is generally assumed to be a natural response of primary or
164 mature regrowth forests to environmental change^{9,27}.

165 The above methodological differences are reflected in the net emissions from developed countries,
166 where most of the ≈ 3 GtCO₂e/y difference between our analysis and IPCC AR5 occurs for the period
167 2000-2009: while these countries report a substantial “anthropogenic” sink (-1.9 GtCO₂e/y in
168 “UNFCCC Annex 1” countries), the bookkeeping model (IPCC AR5) finds a small net source (0.1
169 GtCO₂e/y, “OECD” in Fig. 11.7 of ref.⁶). This difference lies essentially in whether the large sinks in
170 areas designated by countries as “managed forest” (following IPCC GL), well documented in forest
171 inventories¹⁰, are attributed to “anthropogenic” (in the GHG inventories) or to “natural” fluxes (in
172 IPCC AR5).

173 To explore, at least in part, the impact of these different attribution methods, Fig. 3a compares what is
174 considered undisputedly “anthropogenic” by both IPCC AR5 (land-use change) and the country
175 reports (land converted to other land uses). These estimates, both predominated by tropical
176 deforestation, are of similar magnitude, especially after 2000. The other fluxes, where the attribution
177 differs more between IPCC AR5 and the countries, are shown in Fig 3b. Thus much of the sink that
178 countries report under ‘forest remaining forest’, the global models consider part of the natural flux.
179 This disaggregation suggests that the residual sink is at least partly influenced by management

180 practices not captured by global carbon models³³, but also that countries consider anthropogenic what
181 is partly influenced by environmental change and by recovery from past disturbances.

182 There are many reasons for the lower sink reported by countries in Fig 3b compared to the residual
183 sink from IPCC AR5³⁰, including the fact that countries do not report sinks for unmanaged lands (e.g.,
184 a large sink in tropical and boreal unmanaged forests¹⁰) and their reporting for managed land may be
185 incomplete, i.e. ignoring fluxes (e.g. sink in grasslands, wetlands or forest regrowth) or carbon pools.
186 There would be other factors to consider, including treatment of legacy fluxes from past land-use and
187 other definitional and methodological differences. These would require a more detailed analysis,
188 which is outside the scope of this paper.

189 Finally, the projections from this analysis can be compared to RCP scenarios used in IPCC AR5 up to
190 2030 (Fig. 3, dashed lines). For the undoubtedly “anthropogenic” fluxes (Fig. 3a), our country data
191 analysis falls broadly within the IPCC AR5 scenarios, supporting previous qualitative findings³⁴.

192 Overall, our analysis shows 1) that various global LULUCF datasets may be more consistent than
193 apparent at first glance, 2) unless the scientific and GHG inventory community appreciate these
194 definitional and methodological issues, conflicting numbers and messages are likely to appear in the
195 coming years, and 3) that several reasons for the differences among datasets can be further reconciled
196 in collaboration between the two communities, which would be a very useful contribution to science
197 and policy.

198

199 **Different perspectives on mitigation contribution by forests**

200 To reflect the complexity of approaches to (I)NDCs, this analysis assesses three different perspectives
201 on LULUCF mitigation:

202 (A) 2030 (I)NDC vs. 2005, i.e., the expected impact of full (I)NDC implementation. The year 2005 is
203 chosen as historically reliable in terms of data. Fig. 1 shows that the global LULUCF net emissions to
204 the atmosphere would transition from an estimated net anthropogenic source of +0.8 GtCO₂e/y in

205 2005 to a net sink of -0.4 GtCO₂e/y (unconditional (I)NDCs) or -1.1 GtCO₂e/y (conditional (I)NDCs)
206 in 2030.

207 (B) 2030 (I)NDC vs. 2030 alternative scenarios: country-BAU or pre-(I)NDC, i.e., the additional
208 LULUCF contribution relative to alternative scenarios (Fig. 1). The magnitude of the difference
209 between country-BAU and pre-(I)NDC (1.6 GtCO₂/y) may raise concerns about the expected results-
210 based payments under REDD+, which should be based on credible baselines and not on a no-
211 measures scenario. Clarification of the role of REDD+ in (I)NDCs should therefore be seen as a
212 priority by countries. Compared to the estimated pre-(I)NDC scenario, net emissions in 2030 are
213 lower by 0.8 GtCO₂e/y or 1.5 GtCO₂e/y for unconditional and conditional (I)NDCs, respectively. For
214 the ‘conditional (I)NDC vs. 2030 pre-(I)NDC’ scenario (Fig. 4a), this LULUCF contribution of 1.5
215 GtCO₂e/y (Fig. 4a, last column) represents 26% of the total mitigation expected from all GHG sectors
216 (5.9 GtCO₂e/y³⁵, Fig. 4a, third column). The countries contributing most to LULUCF mitigation
217 under this perspective are Brazil and Indonesia, followed by other countries focusing either on
218 avoiding carbon emissions (e.g. Ethiopia, Gabon, Mexico, DRC, Guyana and Madagascar) or on
219 promoting the sink through large afforestation programs (e.g. China, India).

220 (C) Country perspective on emissions reduction in the (I)NDC, i.e. what each country might consider
221 its “LULUCF contribution to the overall (I)NDC”, as part of its mitigation package, e.g. if a country
222 commits to reduce its all-sectors emissions by $x\%$ relative to y (reference point: base year or BAU-
223 scenario), what fraction of x is attributable to LULUCF? This approach looks at the way countries
224 define their (I)NDCs (e.g. reference point) and the way LULUCF is included within the (I)NDC (as
225 any other sector or with special accounting rules). Globally, under this perspective the LULUCF
226 contribution is 3.1 GtCO₂e/y (unconditional) or 3.8 GtCO₂e/y (conditional). The latter case (Fig. 4b,
227 last column) corresponds to 24% of total all-sectors emission reduction relative to the reference point
228 (i.e. 15.8 GtCO₂e/y, Fig. 4b, third column).

229 The emission reductions from a country perspective (Fig. 4b) are greater than the deviation from the
230 pre-(I)NDC scenario (Fig. 4a), because countries’ choices of reference point in their (I)NDCs tend to

231 maximize the accounted mitigation, i.e. countries that already reduced emissions used a historical
232 base year, whereas countries expecting a future increase of emissions used a future BAU-scenario.
233 This is evident under perspective C, where nearly one third of the contribution comes from Brazil,
234 followed by Indonesia and Russia (Fig 4b, last column). In Brazil, where total emissions have
235 declined after 2004 due to successful implementation of policies to reduce deforestation³⁶, the NDC
236 target (-43%) is relative to 2005. Our analysis suggests that in Brazil the LULUCF contribution to
237 NDC is greater than the all-sectors NDC target for 2030, i.e. the NDC allows emissions from other
238 sectors to increase. In Indonesia the conditional NDC target (-41%) is relative to the BAU-scenario in
239 2030. LULUCF represents about 65% of current (2010) total emissions and is expected to contribute
240 nearly two-thirds of the NDC emission reduction (relative to BAU) foreseen in for 2030. Brazil and
241 Indonesia are representative examples of GHG emission trends in developing countries: with an
242 expanding and industrializing economy, the currently high LULUCF emissions are expected to
243 decrease, and be superseded by growing emissions from the energy sector. The (I)NDC target of
244 Russia (-30%) is relative to 1990, with LULUCF contributing by about two-fifths to this emission
245 reduction. Russia is more important in perspective C than in B because its specific accounting method
246 for LULUCF gives prominence to the contribution of the current forest sink to climate mitigation.

247 The (I)NDCs of the three countries above may be assessed also in terms of clarity and trust of
248 information provided (see Supplementary Section 2). Overall, Brazil's NDC is transparent on the
249 land-use sector and the underling GHG estimates are based on a well-developed monitoring system.
250 The recent relevant upward revision of historical deforestation emissions in Brazil opens new
251 questions on the implementation of the NDC target and on how and when data consistency between
252 NDC, REDD+ and National Communications will be ensured. The relative ambiguity of Indonesia's
253 NDC on how it would address land use emissions is improved by the information in more recent
254 documents. Furthermore, recent monitoring efforts have improved the GHG emission estimates,
255 especially from peatland drainage and from forest degradation, whereas emissions from peat fires
256 remain very uncertain. These improvements are mainly due to the REDD+ process, which in many
257 developing countries is triggering unprecedented monitoring efforts. The challenge is increasingly to

258 transfer these improvements into the NDC process, and to clarify the often uncertain relationship
259 between the financially-supported REDD+ activities and the NDCs. For Russia, transparency of
260 mitigation efforts will crucially depend on clarifying the accounting method chosen for LULUCF. In
261 addition, credible GHG estimates will require reconciling or explaining the currently large difference
262 in the forest sink between the reports submitted by Russia to UNFCCC and to FAO.

263 In summary, the full implementation of (I)NDCs would turn LULUCF globally from a net source
264 during 1990-2010 (1.3 ± 1.1 GtCO₂e/y) to a net sink by 2030 (up to -1.1 ± 0.5 GtCO₂e/y). The
265 absolute LULUCF mitigation contribution in 2030 is very different depending on the way that
266 mitigation is calculated, ranging from 0.8 to 3.1 GtCO₂e/y for unconditional (I)NDCs and from 1.5 to
267 3.8 GtCO₂e/y for conditional (I)NDCs (Supplementary Table 3). However, in relative terms,
268 LULUCF would provide about a quarter of total emission reductions planned in countries' (I)NDCs
269 irrespective of the approach to calculating mitigation.

270 Whereas a similar trend of decreasing LULUCF net emissions with full (I)NDCs implementation has
271 been suggested also by other analyses (ref^{34,37}), the absolute level of net emissions differs
272 significantly: e.g., ref³⁷ reports net emissions about 3 GtCO₂e/y higher than ours, due to the
273 'harmonization' of different datasets (country projections and (I)NDCs were aligned to historical
274 FAOSTAT data). By contrast, our study is the first so far showing a global picture of country-based
275 LULUCF net emissions that is consistent between historical and projected periods, including
276 discussing the differences with other global datasets and different mitigation perspectives.

277

278 **Science can help countries to keep the forest mitigation promise**

279 Several studies suggest a theoretical mitigation potential from land use^{6,35,38} higher than in this
280 analysis, others suggest limits posed by ecological and socio-economic constraints (including land
281 availability)^{39,40}. Irrespective of the potential, in the past UNFCCC negotiations the LULUCF sector
282 has often been treated separately and considered as a secondary mitigation option, largely due to its
283 complexity and limited trust in data.

284 Our analysis shows a wide range of future LULUCF net emissions, depending on policy scenarios.
285 Through the implementation of (I)NDCs countries (especially developing ones) expect a key
286 contribution from LULUCF in meeting their (I)NDC targets, with a clear focus on forests. Achieving
287 this will require increasing the credibility of LULUCF mitigation, through more transparency in
288 commitments and more confidence in estimates. To this regard, the Paris Agreement includes a
289 “Framework for transparency of actions”, key for its credibility⁴¹, aimed at providing clarity on GHG
290 estimates and tracking of progress toward achieving countries’ individual targets.

291 More transparent commitments means that future updates of the NDCs should provide more details
292 on how LULUCF mitigation is calculated towards meeting the target and how the financially-
293 supported REDD+ activities contribute to the pledges. More confidence in LULUCF estimates will
294 require improving the country GHG inventories in terms of transparency, accuracy (including
295 information on uncertainties), consistency, completeness and comparability⁴², especially in
296 developing countries.

297 This is a challenge and an opportunity for the scientific community. Supporting country GHG
298 estimation includes regular reviews of the latest science (e.g. ref⁴³), expanding the scope of the
299 operational methods in the IPCC guidance, as has been done for REDD+⁴⁴, and incorporating
300 opportunities offered by emerging satellite data^{45,46} available through highly accessible products⁴⁷.

301 More confidence also requires independent checks of the transparency and reliability of data, e.g. by
302 reproducing and verifying countries’ GHG estimates. According to IPCC guidance²⁵, verification of
303 GHG inventories is key to improve scientific understanding and to build confidence on GHG
304 estimates and their trends. This can be achieved by comparing GHG inventories with scientific
305 studies using partially or totally independent datasets and/or different methods (e.g. ref⁴⁸), including
306 greater integration of modeling and measurement systems of land use-related net emissions⁹.

307 Meaningful verification requires improving mutual understanding and cooperation between the
308 scientific community and the developers of national GHG inventories.

309 Finally, increasing trust in proposed LULUCF mitigation options will require reconciling the current
310 differences in global LULUCF net emissions between country reports and scientific studies (as
311 reflected in IPCC reports). Among the many possible reasons for these differences^{30,49}, we suggest
312 that what is considered “anthropogenic sink” is key and deserves further analyses. While recognizing
313 differences in scopes among these communities, reconciling differences in estimates is a necessity, as
314 the “Global stocktake”, i.e. the foreseen five-yearly assessment of the collective progress toward
315 achieving the long-term goals of the Paris Agreement, will be based on both country reports and
316 IPCC reports. Without speaking the same language, the “balance between anthropogenic GHG
317 emissions by sources and removals by sinks in the second half of this century”¹, needed to reach the
318 ambitious “well-below 2°C” target, cannot be properly assessed.

319

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322 **Disclaimer:** The views expressed are purely those of the writers and may not in any circumstances be
323 regarded as stating an official position of the European Commission.

324 **Author Contributions** G.G. conceived the analysis on (I)NDCs, executed the calculations and
325 drafted the paper. J.H., F.D., M.d.E. and J.P. contributed to the analysis and to the writing of the paper.
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329

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466

467 **METHODS**

468

469 This analysis quantifies the mitigation role of Land Use, Land Use Change and Forestry (LULUCF,
470 mainly forests), based on the (I)NDCs^{3,4} submitted by Parties in the context of the Paris Climate
471 Agreement¹, complemented with information from other countries' official documents. This analysis
472 does not aim to assess specific country policies or the quality of country data in comparison with
473 independent sources.

474 Our analysis of LULUCF net emissions over time covered all 195 UNFCCC countries, with
475 assumptions necessary in some cases (i.e. using the latest historical data where no (I)NDC projection
476 was available, see below). However, due to constraints, our estimation of the LULUCF mitigation
477 contribution was possible only for 68 countries (41 (I)NDCs), covering 83% of global forest area
478 (based of FAO-FRA 2015²²). Other countries were not included either because LULUCF was not
479 clearly included in the target or because the LULUCF contribution was not entirely clear or directly
480 quantifiable (see Supplementary Section 1, Supplementary Information).

481 Our analysis is based on countries' documents submitted up to February 2016. However, the most
482 relevant recalculations made by countries after that date and before December 2016 (e.g. Brazil,
483 Indonesia and USA) are briefly discussed in the Supplementary Section 2.

484

485

486 **Information used in this analysis**

487 The methodological approach applied in this analysis required collecting information on:

- 488 (i) Countries' historical data and projections up to 2030 (for all 195 UNFCCC countries),
489 using countries' documents submitted up to end of February 2016, with the following
490 priority: (I)NDCs³; other country data submitted to UNFCCC (2015 GHG Inventories¹³)

491 (GHGI) for developed countries, and GHGIs included in recent National
492 Communications^{15,20} (NC) and in Biennial Update Reports¹⁶ (BUR) for developing
493 countries); other official countries' documents (e.g. ref.²¹); FAO-based datasets (for
494 forests^{8,22} and non-forest emissions²³). Despite gaps in country reports (especially for
495 non-forest land uses in developing countries), this priority is justified by the fact that
496 country reports to UNFCCC are formally reviewed or technically assessed by UNFCCC
497 (GHGIs of developed countries are formally reviewed annually, with biennial technical
498 assessment for developing country inventories), and are the means by which countries
499 assess their progress towards targets. Furthermore, FAO-FRA reports²² are not primarily
500 for reporting CO₂ emissions and removals, while UNFCCC country reports specifically
501 address emissions and removals. The range of historical country datasets (dotted line in
502 Fig. 1) reflects alternative selections of country sources, i.e. GHGIs for developed
503 countries (selected for both the lower and the upper range), plus FAO-based datasets
504 (upper range) or NCs (lower range) for developing countries. This alternative selection
505 assumes a high reliability of GHGIs for developed countries, while providing an idea of
506 the impact of choosing only NCs (including old NCs) vs. FAO-based datasets for
507 developing countries. See Supplementary Table 4 for an overview of historical datasets
508 used.

509 For **historical data**, GHGIs with a time series from 1990 to 2013 were available for all
510 developed countries, in most cases including Harvested Wood Products. For developing
511 countries, data are from BURs when available or from latest NCs, typically not including
512 Harvested Wood Products. When only few years were available (typically at least two
513 between 1990 and 2010), 5 or 10 years averages were used. Sometimes, especially for
514 older NCs, data from NCs contain ambiguities, or are not fully comparable across
515 countries (e.g. while most countries implicitly report only emissions and removals from
516 “managed forests”, in accordance with the recent IPCC guidance, a few countries include
517 the sink from apparently unmanaged forests). To reduce the risk of using old or

518 inappropriate data, the more recent FAO datasets were used instead of NCs prior to 2010.
519 Net emissions from forests (e.g., sink from forest management and emissions from
520 deforestation) usually dominate the LULUCF fluxes in country reports, although in some
521 case emissions from croplands and grasslands (rarely reported by developing countries)
522 are also relevant, especially from organic soils.

523 Based on available information from countries' reports to UNFCCC complemented by
524 expert judgment, we performed an analysis of the uncertainties for LULUCF absolute
525 GHG net emissions (level) and for the associated trends (see Supplementary Section 3,
526 Supplementary Table 7 and Supplementary Figures 2 and 3).

527 The FAO-based datasets include country data on forest carbon stock change from the
528 Forest Resource Assessment (FAO-FRA 2015²², as elaborated by ref⁸) and FAOSTAT²³
529 data on country-level non-forest land use emissions (CO₂, CH₄ and N₂O from biomass
530 fires, including peatlands fires, and from drainage of organic soils). The overall small
531 difference between the FAO-FRA 2015 forest carbon stock data used in our analysis
532 (based on ref.⁸) and the FRA-2015 forest carbon stock data included in FAOSTAT²³ is
533 that the gap-filling methods differ (although for the biomass pools such difference does
534 not impact the total net CO₂ emissions/removals across the time series), and that we
535 include both living biomass (above and below-ground) and dead organic matter if
536 reported by countries, while FAOSTAT only considers living biomass. Overall, for the
537 historical period we only used FAO-based datasets to fill the gaps for a relative large
538 number (60), but typically rather small developing countries (covering 11% of global
539 forest area). The significant difference between this analysis and FAOSTAT (Fig. 2 of the
540 paper) is due to several factors, including higher non-forest land use emissions in
541 FAOSTAT for developing countries (especially in Indonesia, Sudan, Zambia) and higher
542 forest land use emissions in FAOSTAT for both developing countries (e.g. Colombia,
543 Liberia, Madagascar, Myanmar, Nigeria, Philippines, Zimbabwe) and developed ones
544 (USA and Russia).

545 For **projections**, data from (I)NDCs (with some expert-judgment interpretation when
546 needed), or NCs²⁰ were available for almost all developed countries. For developing
547 countries, if no projection was available in the (I)NDCs, BURs or NCs, FAO-FRA 2015
548 country projections^{8,22} were used in few cases. Where no projection was available, the
549 latest historical country data available were used (i.e. continuing the recent estimates).

550 While almost no country provided formal information on uncertainties in their
551 projections, in the analysis of uncertainties (see Supplementary Section 3) we
552 conservatively assumed that the uncertainties estimated for the past will hold for the
553 future. In addition, the different scenarios that our analysis identified up to 2030 (Fig. 1)
554 may also give an order of magnitude of the uncertainties. The range “LULUCF
555 projections min-max” shown in Fig. 1 is slightly broader than the various scenarios (by
556 about 500 MtCO₂e/y, or 0.5 GtCO₂e/y, in 2030) because in few cases countries provide a
557 range of projections and not all the various projections can be associated with the four
558 scenarios analyzed. The overall difference of about 500 MtCO₂e/y is essentially due to
559 the range of projections from the US (the difference between the “high” and a “low”
560 sequestration scenario in their latest National Communication amounts to 370 MtCO₂e/y
561 in 2030), and due to Russia (the difference between the various sequestration scenario in
562 their latest National Communication amounts to about 150 MtCO₂e/y in 2030).

563 With regards to the GHGs considered, this paper focuses on CO₂ emissions and removals
564 and on available data on non-CO₂ emissions (CH₄ and N₂O), based on the information
565 included in countries’ documents. National GHGIs are required to report on all GHGs,
566 but in some developing countries the information on non-CO₂ gases is incomplete. Based
567 on available information, and excluding agricultural emissions, the importance of non-
568 CO₂ gases is typically small relative to the total GHG fluxes (see ref³⁰ for details),
569 representing about 2-3% of total CO₂-equivalent forest flux, with slightly higher values
570 found where forest fires are important in the overall GHG budget. This suggests that,
571 when comparing different datasets (Fig. 2), the possible different coverage in the

572 (I)NDCs and other documents of non-CO₂ gases does not represent a major reason for
573 discrepancy.

574 (ii) Type of mitigation target elaborated in each countries' (I)NDC (Supplementary Table 1),
575 i.e. change in absolute emissions or intensity, either relative to a base year or to a BAU
576 scenario (i.e. 2025 or 2030 scenario year); target 'unconditional' or 'conditional' (i.e.
577 related to the provision of finance, technology or capacity-building support). (I)NDCs
578 expressing only 'policies and measures' (without quantitative targets) were not taken into
579 account.

580 (iii) Modality of inclusion of LULUCF within each countries' (I)NDC (Supplementary Table
581 1), i.e. it may be treated in the same way as other sectors (fully included as part of the
582 overall target), or partially included (only forest activities), or considered separately with
583 special mitigation actions and/or accounting rules.

584 Some additional expert evaluation was included where necessary.

585

586 **(I)NDC cases**

587 The (I)NDCs were classified into four '(I)NDC cases' (Supplementary Table 2). Based on the
588 availability of country LULUCF information, enough information was found to assign 68 countries to
589 these different "(I)NDC cases", and to quantify directly the expected LULUCF mitigation. These 68
590 countries include all countries with a major forest coverage and correspond to 78% of global
591 emissions in 2012 (including LULUCF emissions and international aviation and marine emissions)².

592

593 **Different mitigation perspectives**

594 The quantification of the mitigation role of LULUCF has been undertaken using different approaches,
595 reflecting different perspectives, according to the questions addressed (Supplementary Table 3).

596

597 **Estimation of LULUCF mitigation**

598 Whereas estimates for perspective ‘A’ (LULUCF net emissions over time) could be made for all 195
599 UNFCCC countries, the information needed for the LULUCF mitigation contribution under
600 perspectives ‘B’ ((I)NDC compared to alternative future scenarios) and ‘C’ (country perspective on
601 calculating emissions reduction (I)NDC) was available only for the 68 countries (41 (I)NDCs)
602 included in Supplementary Table 1. For the remaining countries, the additional mitigation in
603 perspectives ‘B’ and ‘C’ were assumed to be zero relative to other sectors. This assumption is
604 probably conservative (see Supplementary Section 1).

605 Based on the four (I)NDC cases (Supplementary Table 2), and using the available country
606 information (generally with limited expert judgment), this analysis quantified the LULUCF mitigation
607 perspectives (Supplementary Table 3) following the method illustrated in Supplementary Fig. 1. In
608 the very few cases where the target is expressed for 2025, we assumed that the same target applies to
609 2030, allowing us to sum up all the countries’ contribution to 2030.

610

611 **Contribution of the land sector to mitigation activity across all sectors**

612 The LULUCF mitigation perspectives ‘B’ and ‘C’ were compared to the expected (I)NDC mitigation
613 efforts across all sectors, for each country and at a global level. The global-level all-sectors ‘pre-
614 (I)NDC’ and ‘(I)NDC unconditional + conditional’ are taken from UNEP³⁵. All-sector emissions at
615 the ‘reference point’ (i.e. base year or BAU scenario for target year 2025 or 2030) are from: (i)
616 countries or (ii) from ref¹⁸ (for the BAU estimates for China and India). These two sources of
617 information were sufficient for countries representing 87% of global GHG emission in 2012.
618 Emissions for the remaining countries were approximated by assuming the same ratio of emissions at
619 reference point (i.e. estimates from available sources were multiplied by 100/87).

620

621 **Comparison of this analysis with IPCC AR5**

622 In order to make a meaningful comparison of country data (this analysis) with IPCC AR5^{5,6}, we
623 disaggregated country data between “land converted to another land use” and “land remaining under
624 the same land use”. While this disaggregation was directly available in all developed country reports,
625 and was largely available for the most important developing countries (e.g. Brazil, Indonesia, India,
626 China, Mexico), for the remaining developing countries information was generally available only for
627 deforestation. In these cases, unless specified otherwise, the other emissions and removals were
628 assigned to “land remaining under the same land use”.

629

630 **Data availability**

631 This study is primarily based on countries’ (I)NDCs^{3,4} and other GHG reports submitted to
632 UNFCCC^{13,15,16,20,21}, complemented by FAO-based datasets^{8,22,23}. A large part of elaborated data used
633 to support our findings are available in the Supplementary Information, including:

634 (i) *Country-specific information* for 68 countries (41 (I)NDCs), in terms of general features
635 of the (I)NDCs (Supplementary Tables 1 and 2) and of data and sources of information of
636 LULUCF net emissions for the historical period 1990-2010 and for 2030, as expected for
637 unconditional and conditional (I)NDC targets (Supplementary Table 5).

638 (ii) *Aggregated information* on uncertainties (Supplementary Figures 2 and 3), on LULUCF
639 mitigation perspectives (Supplementary Table 3) and on LULUCF net emissions
640 (Supplementary Table 6).

641 Any other raw or elaborated data used in this study are available from the corresponding author upon
642 request.

643