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Independent data for transparent monitoring of greenhouse gas emissions from the land use sector – What do stakeholders think and need?

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ABSTRACT

The agriculture, forestry and other land use (AFOLU) sectors contribute substantially to the net global anthropogenic greenhouse gas (GHG) emissions. To reduce these emissions under the Paris Agreement, effective mitigation actions are needed that require engagement of multiple stakeholders. Emission reduction also requires that accurate, consistent and comparable datasets are available for transparent reference and progress monitoring. Availability of free and open datasets and portals (referred to as independent data) increases, offering opportunities for improving and reconciling estimates of GHG emissions and mitigation options. Through an online survey, we investigated stakeholders' data needs for estimating forest area and change, forest biomass and emission factors, and AFOLU GHG emissions. The survey was completed by 359 respondents from governmental, intergovernmental and non-governmental organizations, research institutes and universities, and public and private companies. These can be grouped into data users and data providers. Our results show that current open and freely available datasets and portals are only able to fulfil stakeholder needs to a certain degree. Users require a) detailed documentation regarding the scope and usability of the data, b) comparability between alternative data sources, c) uncertainty estimates for evaluating mitigation options, d) more region-specific and detailed data with higher accuracy for sub-national application, e) regular updates and continuity for establishing consistent time series. These requirements are found to be key elements for increasing overall transparency of data sources, definitions, methodologies and assumptions, which is required under the Paris Agreement. Raising awareness and improving data availability through centralized platforms are important for increasing engagement of data users. In countries with low capacities, independent data can support countries' mitigation planning and implementation, and related GHG reporting. However, there is a strong need for further guidance and capacity development (i.e. 'readiness support') on how to make proper use of independent datasets. Continued investments will be needed to sustain programmes and keep improving datasets to serve the objectives of the many stakeholders involved in climate change mitigation and should focus on increased accessibility and transparency of data to encourage stakeholder involvement.

1. Introduction

The agriculture, forestry and other land use (AFOLU) sectors play important roles in climate change and contribute with nearly 25% to the net total global anthropogenic greenhouse gas (GHG) emissions (estimated in 2010; IPCC, 2014a). AFOLU sectors emissions include those from deforestation, fire, wood harvesting, and agricultural emissions including croplands, paddy rice, and livestock (Roman-Cuesta et al., 2016a). Effective mitigation actions in these domains are needed in order to reduce the emissions from these sectors (UNEP, 2015; Grassi et al., 2017). A global agreement to combat climate change and to adapt to its effects was reached in Paris at the 21st Conference of Parties (COP21) of the United Nations Framework Convention on Climate Change (UNFCCC). The Paris Agreement creates a binding and

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progressive framework that obliges all countries to formulate climate mitigation strategies and goals to limit global warming to well below 2.0 degrees C (UNFCCC, 2016; Turnhout et al., 2017). Countries' strategies and actions are formulated in the nationally determined contributions (NDCs) and anthropogenic emissions and removals from the AFOLU sector should be communicated with the national GHG inventory reports. The accounting mechanism for NDCs includes all categories of anthropogenic emissions and removals and should comply with the requirement of the Intergovernmental Panel on Climate Change (IPCC) that estimates should be complete, consistent, comparable, transparent and accurate (IPCC, 2003, 2006, 2014b). The purpose of the "*enhanced transparency framework*" of the Paris Agreement (UNFCCC, 2016: Article 13) is to provide 'clear understanding of climate change action' including 'clarity and tracking of progress towards achieving Parties' individual nationally determined contributions' and 'Parties' adaptation actions' including 'good practices, priorities, needs and gaps'. With high levels of donor support and engagement of stakeholders, the Global Environment Facility established the Capacity-building Initiative for Transparency (CBIT) which will assist developing countries, pre- and post-2020 to strengthen their institutional and technical capacities to meet this essential element of the agreement. To understand what is being done and achieved in climate mitigation action, transparency of biophysical land and emission data and information in the submitted national communications and NDCs is key. Art. 13 also asks for "a full overview of aggregate financial support provided", but in the present paper we focus on data related to climate change action and do not address the question of finance data.

Data and methods should be able to support implementation of mitigation activities and encourage stakeholder engagement at different scales. Stakeholders can be divided into data users and data producers. Stakeholders have different roles and responsibilities and need different types of data related to climate change mitigation efforts and GHG emissions reporting (Böttcher et al., 2017). At national level, policy makers and mitigation planners frequently need national datasets for assessment of mitigation and adaptation options. This can, for example, include land use and land use change monitoring or improved accuracies for more effective mitigation strategies. Governmental stakeholders (e.g. national GHG experts) are seeking data at national level on forest area changes, forest carbon stock changes and GHG emissions, including uncertainty estimates, to compile national GHG inventories and to track progress on the commitments made under their NDCs. UNFCCC roster of experts need to perform technical assessment and independent reviews of national GHG inventories. These experts would benefit from independent datasets against which to compare national GHG trends and their uncertainties. NGOs and Civil Society commonly operate at local level. Especially those groups in charge of implementing the mitigation activities on the ground (i.e. farmers, forest owners, etc.) need reliable data on land use changes, associated emissions and information about uncertainties at a local level. Local communities (including indigenous groups) can be involved in monitoring implementation, to assess performance. They would require accurate local data and uncertainties, and could also benefit from independent data creation through community monitoring (i.e. forest plot monitoring of carbon stock changes) (Pratihast et al., 2013). However, often these groups are underrepresented and require improved capacities and training on data collection, monitoring and reporting. Other key stakeholders may include the private sector aiming for deforestation-free commodity supply chains (e.g. oil palm, cocoa, beef, coffee). These companies that have committed to zero-deforestation would benefit from accurate data on deforestation at local and regional scales. They may need to develop specific MRV systems, targeting different commodities and their supply chains. Academia (i.e. the global modelling and carbon science community) have a role in building confidence in land use and emission estimates by providing independent references for GHG emissions. This is important to improve scientific understanding. The data they provide help increase transparency, accuracy, consistency, completeness and comparability.

To monitor progress in achieving emissions reductions, accurate spatially explicit GHG emissions estimates and their associated uncertainties need to be produced at the scale at which appropriate mitigation actions are implemented (Roman-Cuesta et al., 2016a). A considerable amount of independent, publicly available, comprehensive spatial (regional to global scale) data on land cover, land emissions, land use, their dynamics and the associated carbon stocks and flows has become available (e.g., Global Forest Watch: http://www.globalforestwatch.org; Avitabile et al. 2016; Federici et al. 2015; Hansen et al. 2013; Roman-Cuesta et al., 2016b). Apart from national and local datasets, global datasets are of great importance for a wide variety of stakeholders involved in GHG emissions monitoring and reporting (e.g., Hansen et al., 2013; Baccini et al., 2012). However, these datasets also contain errors or misclassification problems (e.g. not being able to distinguish between forest re-growth and plantation) and therefore they need to be adapted for use at national scale and may need to be corrected for misclassifications or other data problems (GFOI, 2016). Policy makers and people involved in preparing the GHG inventories need to be aware of data quality as an issue. First, estimates of emissions and removals from AFOLU can have considerable uncertainties of up to 50% from the mean (Houghton et al., 2012; Smith et al., 2014; Tubiello et al., 2015), to which various sources of errors contribute. Second, different estimations diverge as they are based on different conceptual frameworks, forest and biomass definitions, methods, assumptions, sources of activity data (AD) and emission factors (EF) (Abad-Viñas et al., 2014; Federici et al., 2017; Grassi and Dentener, 2015; Roman-Cuesta et al., 2016b; Romijn et al., 2013). Furthermore, inappropriate scale, lack of data on uncertainties and limited guidance on how to and how not to use such information, limits their usefulness (e.g. Grassi et al. 2017). Also, differences in the countries' technical capacities in monitoring and reporting of GHG emissions lead to divergence and uncertainty in the reported data (Romijn et al., 2012).

Large uncertainties hinder progress in implementing, monitoring and verifying effective mitigation strategies. Our assumption is that data quality and data availability can be improved by making use of independent AFOLU datasets: datasets, tools, and portals that support countries' needs by providing complementary data to what is mandated by their own monitoring systems. In the context of the Paris Agreement, and given the bottom-up nature of the NDCs, we believe that independent data has many functions. They can be used for independent assessment of national estimates; i.e. as a reference dataset to improve national estimates. Moreover, by comparing national and independent datasets and harmonizing definitions, more insight can be derived on the sources of errors, and differences in estimating, allocating, and reporting GHG emissions (Federici et al., 2017; Harris et al., 2012; Roman-Cuesta et al., 2016b). Independent data can also be used as a data source for the various stakeholder groups with their varying needs involved in climate change mitigation efforts. Their use would promote better stakeholder engagement and participation, particularly from currently underrepresented groups such as indigenous peoples and forest-dependent communities, and promote greater transparency in GHG reporting. Independent data could make an important contribution to the implementation of the Paris Agreement and can support countries' mitigation planning and implementation, and related GHG reporting, in particular in cases where in-country capacities are lacking.

The purpose of this research is to analyse different stakeholder data requirements, needs and preferences regarding the use, accessibility and usefulness of different existing open data sources associated with *forest area and area change data*, *forest biomass and emission factors*, and *AFOLU GHG emissions*, through an online survey. Furthermore, based on evaluation of existing datasets from a stakeholder perspective, we aim to identify challenges and gaps currently limiting data availability and lastly, we evaluate readiness of approaches, including existing and future monitoring programs and datasets, for an independent use for comparing and reconciling of GHG estimates.

2. Methodology

2.1. Survey design

An online survey was used to analyse different stakeholder views and needs regarding the use, accessibility and usefulness of the following three open data sources: *forest area and area change data*, *forest biomass and emission factors*, and *AFOLU GHG emissions*. The survey was implemented online via the SurveyMonkey tool (https://www/surveymonkey.com) and was distributed through various networks and mailing lists.

One section of the survey addressed the background of the survey respondents in order to identify how different stakeholder groups were represented in the survey. Respondents could indicate their country of origin, continent of residence, scale of work, area of work, type of organization, and main data interests. Three main sections in the survey addressed data needs for a) forest area and area change datasets, b) forest biomass and emission factor datasets, and c) GHG emissions datasets for the AFOLU sector. Each section included questions related to dataset characteristics, methodologies applied, verification, data access, viability and sustainability, and users' awareness, use and appreciation of a number of proposed datasets.

2.2. Stakeholder dataset evaluation

First, stakeholder groups were defined based on the type of organization the survey respondents work for. The survey questions in the data sections were linked to different criteria and indicators which enabled us to assess the stakeholder needs and preferences. We decided to only analyse datasets that respondents were most aware of, as the analysis of all datasets would have been too extensive. We selected eleven key datasets for which the indicator "user awareness" was 40% or higher. Thus, for the three main sections, five key datasets were selected within the category *forest area and area change data,* three key datasets were selected within the category *forest biomass and emission factors data*, and three key datasets were selected within the category *AFOLU GHG emissions data.* More details on the selected key datasets can be found in Support Section Part A. More information about all datasets proposed in the survey, but not selected, the assessment criteria and indicators, the survey questions and answer options that were associated with these criteria are available in the Support Section Part B and Part C.

To assess how well the datasets match the users' expectations, the dataset characteristics were compared with the needs and preferences from the stakeholder groups, using the same assessment criteria and indicators (see data evaluation framework in Fig. 1). Per dataset and stakeholder group, a score was calculated for each indicator. The scoring system was based on a comparison of the indicator description for each dataset and the outcome of particular survey question summarized by stakeholder group. The score indicates how well the dataset matches the expectation of the users, in %. Thus, for example, if a dataset has a spatial resolution of 500 m, then the percentage of respondents that chose the answer options 500 m or larger as preferred spatial resolution, was the outcome for this indicator. For some of the survey questions, multiple answers were allowed, and the total score could be more than 100%. In these cases, the scores were normalized, so that all answer options added up to exactly 100%. An aggregate score was calculated for each criterion per dataset, which was the average of all indicator scores for each criterion. The scores show to what extent each criterion was met. So, for example, when the criterion "Methodologies applied" receives a score of 80%, this means that on average 80% of the respondents in one stakeholder group would be satisfied with all aspects (indicators) related to the methodologies applied for a particular dataset. Finally, an overall score was calculated for each dataset, which was the average of all scores for the five criteria. Furthermore, the range was indicated per criterion, which is a measure of the dispersion among stakeholder groups, calculated by subtracting the minimum average score from the maximum average score from the stakeholder group outcomes.

A separate analysis looked at user's awareness and appreciation of the datasets (see criterion 6 in Support Section, part C). Several survey questions asked users if they were aware of a certain dataset, if they had ever used the dataset and whether they found it useful for their research and/or business purposes. This gives an indication of the usefulness and popularity of a dataset.

3. Results

3.1. Stakeholder characterization

A total of 359 respondents completed the survey and 557 respondents filled in the survey partially and at least answered the questions in the first sections. Thus, the total number of responses varied between questions in the survey.

The background of the survey respondents varied widely. Respondents came from all continents; more than half came from Europe (26.8%) and Asia (23.4%). The remaining half came from Africa (18.1%), North America (16.5%), South America (11.5%), and Oceania (3.6%). Most (76.2%) respondents worked in the forestry sector, followed by professions in climate change (61.4%), agriculture (33.5%), biodiversity (31.4%) and nature conservation (27.4%). Survey respondents could indicate multiple areas of work.

Table 1 gives an overview of the various stakeholder groups addressed in the survey, at which scale they mostly work and whether they are mainly data users, data producers or consider themselves to be both. For "Scale at work" respondents could choose the options "global", "continental", "in multiple countries", "at country level", and "at regional/district level". The table provides information on the scale that was most often chosen by respondents in each stakeholder group. Respondent could choose from the options "data user", "data producer", "data user and producer" to describe their work. Again, the table shows the option that was most often picked by the respondents from a particular stakeholder group.

3.2. Overview of stakeholder needs and preferences

Most respondents (62.2%) were interested in data for the AFOLU sectors in general. With regard to REDD+ (the UNFCCC mechanism to reduce emissions from deforestation and forest degradation, and foster conservation, sustainable management of forests, and enhancement of forest carbon stocks), most respondents were interested in data about sustainable forest management activities (50.1%), followed by data related to either reducing emissions from deforestation (43.9%) or forest degradation (40.4%). Data related to enhancement of forest carbon stocks (32.0%) and forest conservation (28.7%) were of less interest. Respondents were mostly interested in forestland data (75.5%) and in carbon/biomass data (70.4%). A much smaller group (37.8%) showed interest in agricultural emissions data. Some respondents were also interested in different types of data related to safeguards information systems and co-benefits, e.g. data on ecosystems services (48.3%), natural disturbance (30.7%), livelihoods (34.6%), land tenure (33.8%), and economics (30.0%).

There was generally good agreement among all respondents regarding almost all criteria that datasets need to comply with (Table 2). Nearly all respondents found it important that datasets are produced in a transparent way, with associated uncertainty estimates, using methods that are publicly available. Most respondents prefer free data access (80%). There is a need for regular updates and improvements of datasets, as 83% of respondents found this important. The only criterion scoring very low was willingness to pay for the data.

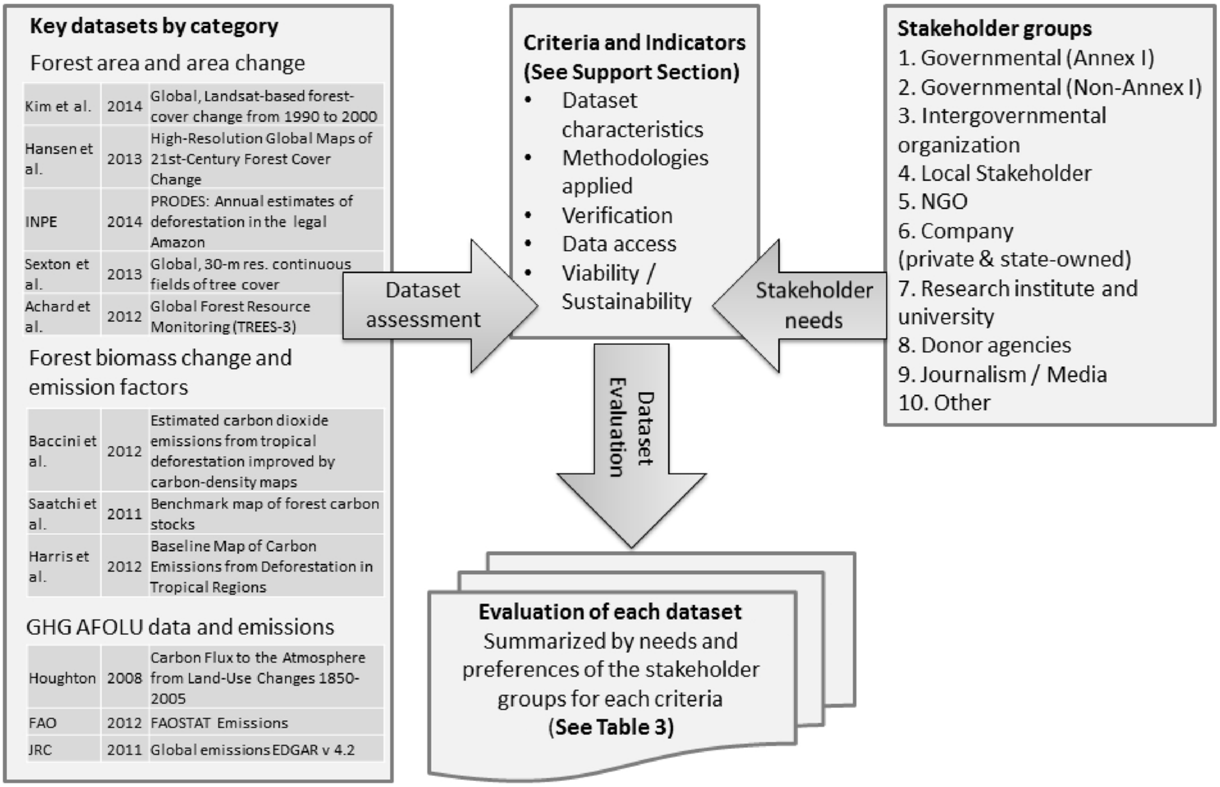

Fig. 1. Dataset evaluation framework.

Considering forest area and area change datasets, respondents preferred to use data with high spatial resolution of less than 30 m (62.5%). When the spatial resolution decreased, less people indicated that they would use it. Similarly, from the options proposed in the survey, open source Landsat-type data with around 30 m resolution were most preferred (91.8%). A fraction of 31.9% of the respondents need data with high temporal resolution of less than one year, and 45.2% need data that had time steps of 1–3 years. Only 22.9% would need data with a temporal resolution of more than 3 years.

Fig. 2 shows the data needs with regard to detail in thematic classes of forest area and area change datasets. Most respondents (nearly 75%) replied that they needed detailed data, consisting of all land use and land cover classes and/or forest classes with a sub-division into different forest types. In the Annex, the data needs for thematic detail are split up per stakeholder group.

With regards to forest biomass and emission factor datasets, data on

Table 2
Evaluation scores on data needs, summarized (average score) for all survey respondents and dataset types.

Criteria	Description	Evaluation
Transparency	Data sources, definitions, methodologies and assumptions should be clearly described to facilitate replication and assessment.	97%
Availability of methods	Datasets should be produced with publicly available methods.	96%
Uncertainty estimation	Uncertainty estimates associated with the data should be available.	94%
Access of datasets	• Preference of free data access	80%
	• Would register to access data	63%
	• Would pay to access data	7%
Updates and improvements	Regular updates and improvements of datasets are seen as important.	83%

Table 1
Stakeholder groups.

Stakeholder group	N	Scale of work	Data user / data producer
Governmental (Annex I)	69	Country level (46%)	Data user & producer (50%)
Governmental (Non-Annex I)	54	Country level (67%)	Data user & producer (49%)
Intergovernmental organization (International governmental organization; IGO)	37	Global (46%)	Data user & producer (54%)
Local stakeholder (incl. indigenous communities)	13	Regional/district level (53%)	Data user (64%)
Environmental concerned citizens and non-governmental organizations (NGOs)[a]	106	Global (25%) / country level (26%)	Data user (51%)
Company (private & state-owned)	59	Multiple countries (36%)	Data user (53%)
Research institute and university	179	Country level (39%)	Data user & producer (55%)
Donor agency	9	Multiple countries (38%)	Data user (56%)
Journalism/Media	7	Global (50%)	Data user (60%)
Other[b]	24	Global (27%) / country level (27%)	Data user (60%)
Total	557		

[a] "NGOs" included international non-governmental organizations (INGO), environmental non-governmental organization (ENGO) and other type of non-governmental organizations.

[b] "Other" included stakeholders that could not easily be placed into one of the existing groups. These comprised independent consultants, consultancy companies, independent experts and scientists, people working in industry, or in technical, and engineering professions, retired people, or otherwise.

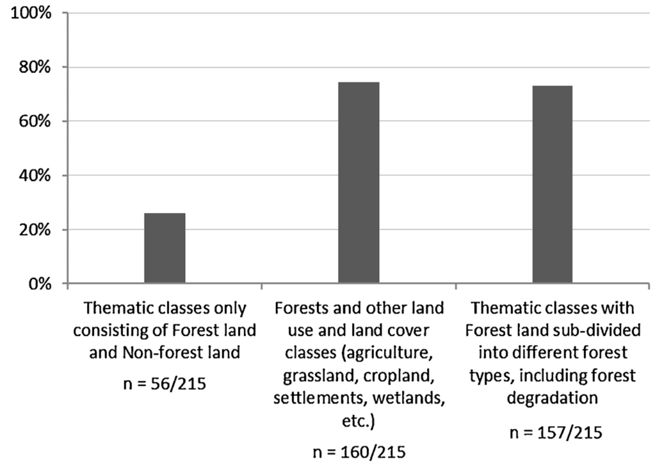

Fig. 2. Data needs with respect to thematic detail for forest area and area change datasets. (See Annex, Fig. A1 for data needs per stakeholder group). Multiple answers were possible.

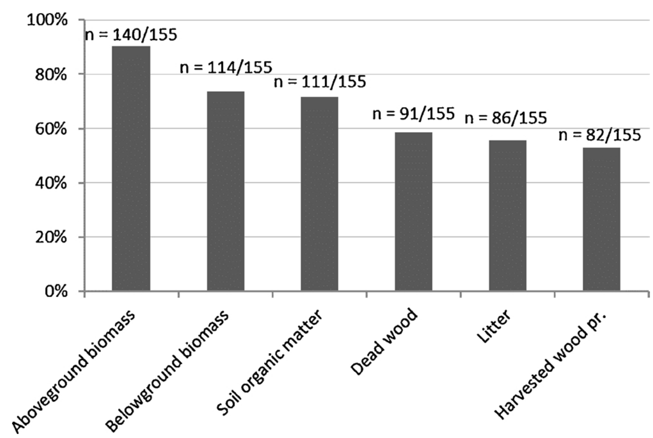

Fig. 3. Data needs with respect to thematic detail for forest biomass and EF datasets. (See Annex, Fig. A2 for data needs per stakeholder group). Multiple answers were possible.

aboveground biomass, belowground biomass and soil organic matter were of particular importance. For each of these carbon pools, more than 70% of respondents said they needed data (See Fig. 3). For the other carbon pools, dead wood, litter and harvested wood products, less than 60% of the respondents said they needed data. In general, 90% of all respondents would need higher Tier (2 or 3) data. This entails data

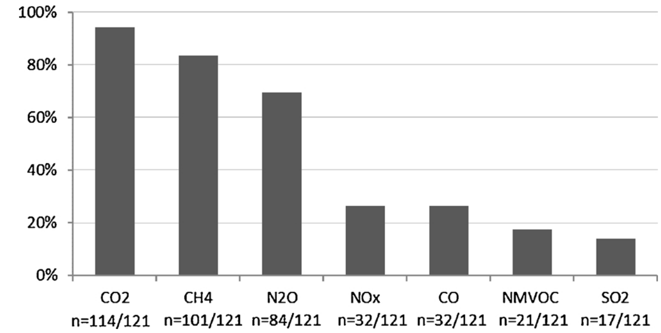

Fig. 5. Data needs with respect to thematic detail for AFOLU GHG datasets. (See Annex, Fig. A3 for data needs per stakeholder group). Multiple answers were possible.

with higher level of detail and accuracy (IPCC, 2003, 2006). However, this differed among stakeholder groups (See Fig. 4a). Around 20% of respondents from NGOs, 16% from the private sector and 14% from IGOs would be satisfied with Tier 1 data, while governmental organizations and researchers were more critical. Only 7% of respondents from research institutes and universities would like to use Tier 1 data, and none of the governmental organizations would use them.

Regarding AFOLU GHG emissions datasets, apart from CO_2 (94%), survey respondents said they most needed data on CH_4 (84%) and N_2O (69%) (See Fig. 5). Other GHG data, such as NO_x, CO, NMVOC, SO_2, were in less demand (< 30%). Similar to data on forest biomass and emission factors, the majority (87%) of all respondents prefer to use Tier 2 or Tier 3 data on AFOLU GHGs (Fig. 4b). Respondents from Governmental Annex-I organizations (45%) and research institutes and universities (59%) have the highest demand for Tier 3 data. About 20% of respondents from the private sector and NGOs seem to be satisfied with Tier 1 data.

For agricultural management, AFOLU GHG emissions data were mainly needed to estimate emissions from biomass burning (83.1%), followed by grassland management activities (63.6%). Estimating direct or indirect N_2O emissions data from managed soils was also in high demand (55.1% and 44.1% respectively) (Fig. 6). There were some regional differences. For example, data on rice cultivation were in higher demand (52%) in Asian regions than in all regions (40.7%).

3.3. Evaluation of existing datasets, based on stakeholder needs

3.3.1. Dataset evaluation by criteria

Table 3 shows the selected datasets and an aggregate score (%) of indicated stakeholder needs coming from the survey per criterion for each dataset. Most datasets scored relatively high on the criteria

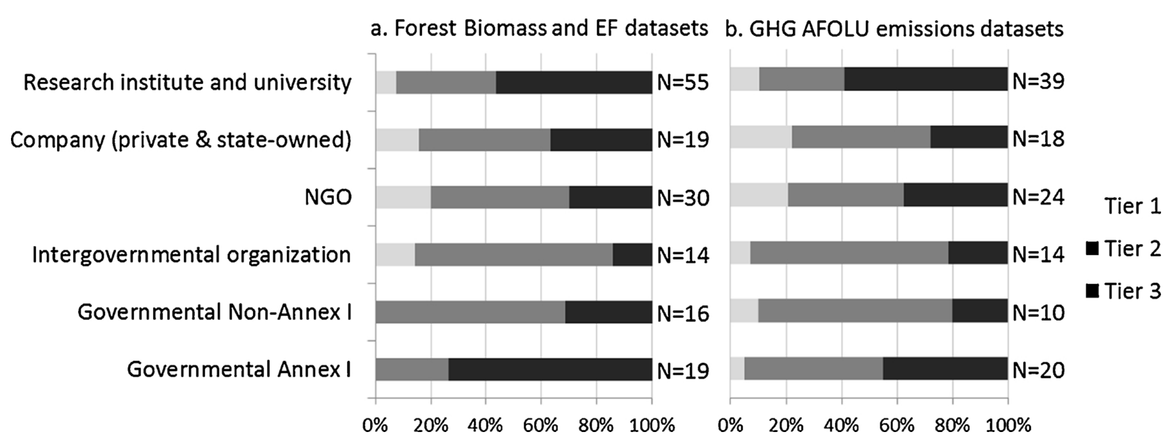

Fig. 4. Desired Tier levels for forest biomass and EF datasets and for AFOLU GHG emissions datasets by stakeholder group. Only those stakeholder groups were included where N ≥ 10.

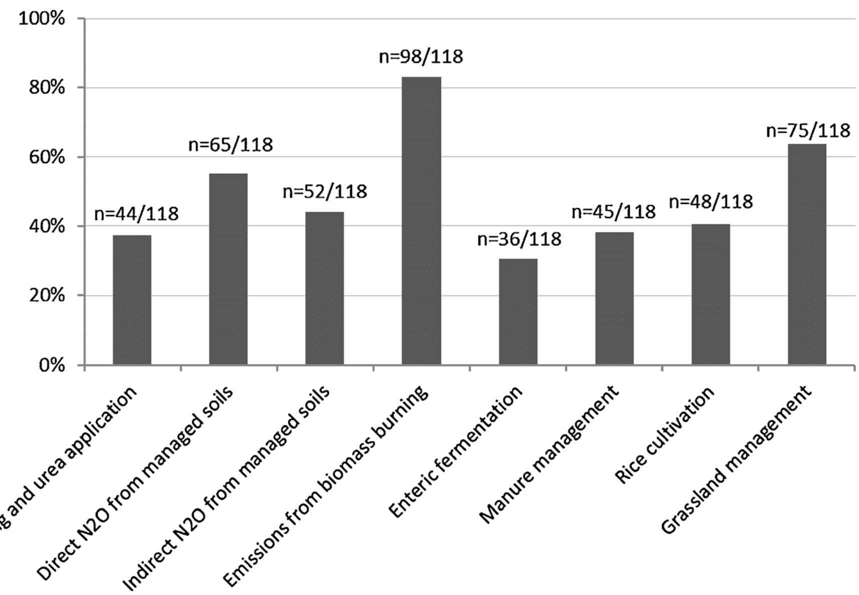

Fig. 6. Data needs with respect to agricultural management activities related to AFOLU GHG emissions datasets. (See Annex, Fig. A4 for data needs per stakeholder group). Multiple answers were possible.

"viability/sustainability" and "data access", with an exception for the forest biomass and EF datasets, which are indeed not easily accessible. The score for "methodologies applied" varied between 45–88% among the datasets. All datasets, except for INPE (PRODES) scored low (25%) on the criterion "verification". "Dataset characteristics" received an average score of 62% for all datasets, with Hansen et al. (2013) receiving the highest score of 75%.

The range (%) in Table 3 indicates that there was a certain degree of dispersion among stakeholder groups. For example, the criterion "verification" had a range of 35% for all datasets that were not verified by a third-party. Respondents from intergovernmental organizations were most critical and only 6.7% would accept to use data without third-party verification, while among respondents from companies (private and state-owned), 41.7% would use data without third-party verification.

Among the forest area and area change datasets, the dataset of Hansen et al. (2013) received the highest overall score (76%). The other datasets in this category received overall scores ranging from 63 to 75%. For the criterion "Dataset characteristics" the Hansen dataset received the highest score (75%), but for the other criteria the scores did not differ much from the other datasets. For the criterion "Methodologies applied" the Sexton et al. (2013) and Achard et al. (2012) received the highest scores of 85% and 87% respectively. The three forest biomass and EF datasets had relatively low overall scores. This was due to low scores on "dataset characteristics", "verification" and "data access". These datasets received high scores for the criteria "methodologies applied" and "viability/sustainability". The overall scores for these datasets ranged from 55–59%, which shows only a very small difference among datasets. Among the GHG AFOLU datasets the overall scores ranged from 57–70%, with the Global Emissions EDGAR v4.2 dataset having the highest score of 70%. Overall, these datasets scored high on the criteria "viability/sustainability" and "Data access", somewhat lower on "Dataset characteristics" and "Methodologies applied", and low on "Verification". This comparison of datasets shows that within each category, overall scores are very similar, and no dataset really stands out from the others.

3.3.2. Dataset evaluation based on users' awareness, use and appreciation

We looked at the popularity of the assessed datasets by using three different indicators: 1. Users' awareness of the datasets; 2. Users' use of datasets; and 3. Users' opinion on the usefulness of datasets. The first two indicators could only be answered with "yes" or "no". For the last indicator, respondents could choose from 5 categories to indicate if they found the datasets useful or not, ranging from "not at all useful" to "very useful". Only people who were aware of a certain dataset, filled in the question about the usefulness of the dataset.

Table 4 summarizes the outcome of these separate indicators used for the key datasets. For the indicator "Usefulness", we selected the percentage of users who indicated that they found the dataset useful or very useful (See Support Section, Part C, for more details). Awareness was highest for the Hansen dataset and the FAOSTAT emissions database. Also, these two datasets were among the most used datasets. However, users found the forest biomass and EF datasets from Baccini and Saatchi, together with the FAOSTAT emissions database, to be the most useful ones among these datasets.

Table 4 points out that datasets that are considered most useful, are not necessarily the ones that people are most aware of. Indeed, the Hansen dataset is found to be useful, but the INPE dataset is also found to be useful, while less people are aware of this dataset. Hansen is known and used more because it has been well advertised and is very easy to access. Packaging it the key to getting one´s products onto the market, and has been used to good effect in this case even though the product is in reality hardly better than others that are available, as became apparent in Table 3.

4. Discussion

4.1. Challenges and gaps in current datasets, and possible solutions

By analysing the use, accessibility and usefulness of key datasets on forest area and area change, forest biomass and EF, and AFOLU GHG emissions from a stakeholder perspective, we were able to identify challenges and gaps that need to be addressed to meet the evolving stakeholders needs.

In the category of forest area and area change datasets, in particular the UMD tree cover dataset (Hansen et al., 2013) scored high on most criteria because it is a high-resolution global dataset with yearly updates that is freely available online via the user-friendly portal of Global Forest Watch. It includes detailed documentation and metadata. Although many people are aware of this dataset (78%) and many people use it (61%, as compared to an average of 29.5% for the other datasets in the same category), it was not regarded as much more useful than

Table 3
Evaluation of datasets per criterion – Overall Score for each criterion: Average (%) and Range (% = "max% − min%" for all stakeholder groups).

DATASETS	CRITERIA										
Key author, Year, Name	Dataset Characteristics		Methodologies applied		Verification		Data access		Viability / sustainability		Average by dataset
Forest area change dataset	Average (%)	Range (%)	Average (%)	Range (%)	Average (%)	Range (%)	Average (%)	Range (%)	Average (%)	Range (%)	Average (%)
Kim et al., 2014. Forest-cover change from 1990 to 2000	59%	3%	79%	7%	25%	35%	100%	0%	50%	1%	63%
Hansen et al., 2013. 21st-Century Forest Cover Change	75%	9%	79%	7%	25%	35%	100%	0%	100%	0%	76%
INPE, 2014. PRODES: Annual estimates of deforestation in the legal Amazon	70%	8%	53%	12%	100.00%	0%	44%	22%	100%	0%	74%
Sexton et al., 2013. Global, 30-m resolution continuous fields of tree cover	64%	3%	85%	7%	25%	35%	100%	0%	50%	0%	65%
Achard et al., 2012. Global Forest Resource Monitoring (TREES-3)	64%	5%	87%	6%	25%	35%	100%	0%	100%	0%	75%
Forest biomass change and EF datasets	Average (%)	Range (%)	Average (%)	Range (%)	Average (%)	Range (%)	Average (%)	Range (%)	Average (%)	Range (%)	Average (%)
A Baccini et al., WHRC, US, 2012. Estimated CO2 emissions from tropical deforestation	55%	6%	81%	8%	25%	35%	44%	22%	90%	0%	59%
S. Saatchi et al., NASA, 2011. Benchmark map of forest carbon stocks	55%	3%	81%	8%	25%	35%	44%	22%	90%	0%	59%
N. L. Harris et al. Winrock, 2012. Baseline Map of C Emissions from Tropical deforestation	63%	8%	88%	5%	25%	35%	0%	0%	100%	0%	55%
GHG AFOLU datasets	Average (%)	Range (%)	Average (%)	Range (%)	Average (%)	Range (%)	Average (%)	Range (%)	Average (%)	Range (%)	Average (%)
R. A. Houghton, WHRC, 2008. C Flux to the Atmosphere from Land-Use Changes 1850-2005	53%	5%	45%	14%	25%	35%	100%	0%	60%	12%	57%
FAO, 2012. FAOSTAT Emissions	58%	5%	45%	14%	25%	35%	100%	0%	100%	0%	66%
JRC, 2011. Global emissions EDGAR v 4.2	62%	7%	63%	16%	25%	35%	100%	0%	100%	0%	70%
Average per criterion	62%		71%		32%		76%		85%		65%

Average score for criteria

(darkest)	91-100%
	81-90%
	71-80%
	61-70%
(lightest)	</=60%

many other datasets (64.3% for the Hansen dataset, compared to 57.5% for the other datasets in the same category). The fact that some people use this dataset more often than others probably has to do with the accessibility of the web platform. The web platform has a user-friendly interface. Also, advertising and publicity are important factors that may attract more users to this dataset.

Popularity of a dataset does not mean that it has less errors and lower uncertainties than other datasets. Especially in global datasets, accuracy varies regionally due to different factors and therefore they may not give good estimates for deforestation at national and regional levels (GFOI, 2016; Tyukavina et al., 2015). Many global land cover products show disagreement in either the individual land classes or in the spatial distribution of the land cover. Especially in the forest and cropland domain, and in mixed classes, spatial disagreement is high (Fritz et al., 2011; Herold et al., 2008; Congalton et al., 2014). Classification problems can have serious implications for policy makers as they could potentially impact the outcomes of a land cover change assessment or modelling exercise. For example, when a global map suggests that an irrigated rice field in Central Asia is actually a forest, this has a large impact on assessments and reporting on REDD+ results. Therefore it is important, to first carefully examine the sensitivity of these products within a specific application, and choose the best product for a specific region. Uncertainty in data has several implications for producing national estimates. For REDD+, countries need data on forest area changes and forest biomass changes to produce activity data (AD) and emission factors (EF). Both input datasets can have uncertainties. Emission reductions are calculated by multiplying AD × EF. During this process, uncertainties increase as the square root of the sum of the squared terms (GOFC-GOLD, 2016). Hence, reducing uncertainty in all parameters in the equation, will contribute to reducing the uncertainty of the end product. In the case of REDD+, the magnitude of reduced emissions and the associated uncertainties will have an effect on payments that countries may receive. Therefore, it is important to reduce uncertainties and report emissions data at higher Tier levels.

Table 4
User's awareness, use and appreciation of the datasets.

	Aware		Used		Useful	
Forest area change	% Yes	N	% Yes	N	% Yes	N
Kim et al., 2014. Forest-cover change from 1990 to 2000	48.1	187	28.0	132	50.0	64
Hansen et al., 2013. 21st-Century Forest Cover Change	77.9	208	60.8	186	64.3	154
INPE, 2014. PRODES: Annual estimates of deforestation in the legal Amazon	55.1	187	36.2	138	65.8	76
Sexton et al., 2013. Global, 30-m resolution continuous fields of tree cover	40.1	192	26.0	131	54.7	64
Achard et al., 2012. Global Forest Resource Monitoring (TREES-3)	44.8	192	27.8	133	59.4	64
Forest Biomass and EF	% Yes	N	% Yes	N	% Yes	N
A Baccini et al., WHRC, US, 2012. Estimated CO2 emissions from tropical deforestation	60.7	135	55.8	95	78.5	65
S. Saatchi et al., NASA, 2011. Benchmark map of forest carbon stocks	63.4	134	50.5	101	70.3	64
N. L. Harris et al. Winrock, 2012. Baseline Map of C Emissions from Tropical deforestation	46.6	131	42.2	83	66.0	47
GHG AFOLU	% Yes	N	% Yes	N	% Yes	N
R. A. Houghton, WHRC, 2008. C Flux to the Atmosphere from Land-Use Changes 1850-2005	57.0	107	33.3	75	65.8	38
FAO, 2012. FAOSTAT Emissions	77.8	117	60.2	98	74.2	62
JRC, 2011. Global emissions EDGAR v 4.2	44.8	105	37.9	66	64.7	34
Average for all datasets	56.8		43.1		66.4	

Legend (shading)
>70%
61-70%
51-60.9%
41-50.9%
<40.9%

While most global datasets present thematic classes consisting of forestland and non-forestland or percentage of tree cover, most survey respondents (nearly 75%) preferred to have more detailed data. According to our survey, respondents needed more region-specific information and more detailed thematic information on land use (changes), forest types and forest degradation. More region-specific information would require higher resolution data. 62.5% of respondents wanted data with spatial resolution of less than 30 m. The current global datasets that we analysed in this paper cannot provide such detailed information. The new Copernicus programme with the Sentinel satellites (https://scihub.copernicus.eu/) should be able to fill some gaps and provide the required data for forest area and area change. The Sentinel-2 satellite provides free and open access data for land monitoring with 10–20 m spatial resolution and at a high frequency of 10-day intervals. Very high-resolution data (< 10 m) are available from drones, airborne data or commercial satellites. These data are produced by commercial companies and there is a cost involved. Data users should consider making a comparison of cost versus accuracy and look at the cost-effectiveness before investing in this type of data.

Among the forest biomass and EF datasets, users found the datasets from both Baccini et al. (2012) and Saatchi et al. (2011) useful or very useful, but our survey also indicated the need for continued observations (e.g. yearly updates) in monitoring carbon fluxes and pools and the need for higher spatial resolution data of forest area changes and carbon densities (e.g. 30 m). These types of data are needed to produce estimates of forest emissions with reduced uncertainties, also pointed out by Ciais et al (2014) and Roman-Cuesta et al. (2016a). Future satellite programmes, provided that they make data open and freely available to countries with limited resources, may be able to fill some of the gaps: the ESA BIOMASS mission, using P-band radar measurements (ESA, 2012), which is expected to be launched around 2021; NASA's GEDI mission, using LiDAR measurements, expected to be launched in 2019 (NASA, 2016); and NASA's NISAR mission (launch 2021), which uses L-band polarimetric radar and is designed for forest change and biomass stock estimations in low-biomass (< 100 t/ha) ecosystems. Survey respondents also preferred the inclusion of more biomass pools, such as soil organic matter, in addition to AGB and BGB estimates. However, collecting such data is a huge effort not undertaken in many parts of the world, especially in developing countries, because it requires capacities, skills and resources that are not and may not soon be available. Among the AFOLU GHG emissions datasets, the FAOSTAT emissions database was most used and found most useful by the survey respondents. The portal and database are freely accessible and offer emissions data for various GHGs (CO_2, CH_4, N_2O, NH_3) with global coverage from 1990 onwards and with annual updates. The data in the portal are complemented with detailed metadata. Still, our survey indicated that such a portal would be seen as more useful if it offered higher Tier data (2 or 3), including uncertainty estimates, and produced at higher spatial resolution to differentiate by regions in a country. Several new scientific datasets may provide an opportunity to fill some of the gaps, as they include better data on uncertainties (e.g. Roman-Cuesta et al., 2016a), but more research in this area has to be done to develop higher Tier data.

In the future, to capture and keep track of the evolving stakeholder needs and ensure that the right issues are addressed, early engagement of different stakeholders from the data users and data producer communities, and continued dialogue between them is important (Ciais et al., 2014).

4.2. Increased transparency in available datasets and online platforms

Some 97% of all survey respondents required transparency in data and methods. In order to increase transparency, it is essential for data producers to provide more complete documentation of the data, including information on the accuracy of the products and description of metadata. Data sources, definitions, methodologies and assumptions should be clearly documented to facilitate replication and assessment, and the understanding of the limits of their applicability also by inexperienced data users. Independent data sources are useful if offered free and open, which was strongly preferred by all survey respondents. Data and information should be up-to-date and easy to access to ensure engagement of all relevant data users. Transparency in the data, methods and definitions used is a minimum requirement to start comparing and understanding differences in the various AFOLU GHG emissions estimates and to build trust among different stakeholders (both data users and producers) and countries (Federici et al., 2017).

Several online overview platforms that contain links and references to all available data sources have become available (e.g. Biomass Geo-Wiki, OpenForis and Global Forest Watch), allowing users to compare different data sets. OpenForis (http://www.openforis.org), supported by FAO, is a set of free and open-source software that facilitates flexible and efficient data collection, analysis and reporting, designed for environmental monitoring. http://Biomass.Geo-wiki.org is a platform that compiles /gathers freely available biomass datasets and collects feedback from the users. Periodically updated and with detailed description and metadata, these and similar platforms can increase visibility and awareness of available data and eventually encourage more stakeholders to get involved and use the data. Such platforms guide the users to the relevant and most appropriate dataset for their needs. This enables them to get a better overview of all available datasets and to make better informed decisions on which type of dataset to use and in which situation (Herold et al., 2008; Verburg et al., 2011; Mora et al., 2014; Tsendbazar et al., 2015; See et al., 2015; Schepaschenko et al., 2015). Efforts such as Global Forest Watch set standards but also prompt users to highlight the shortcomings and is subsequently encouraged to remove those problems and provide a better product. Having more independent datasets and portals available, creates some kind of competition which ensures continuous improvements of data. Communication with users should be encouraged in order to improve the data that are offered on the platforms.

4.3. The use of independent data for mitigation planning and national GHG reporting

Independent data should not substitute for mandated national efforts, but integrating these datasets into national ones can provide an opportunity to fill data gaps in countries and encourage continuous improvements. Integration of independent data is often not straightforward since there may be significant differences between independent studies and national reporting in terms of definitions, scope and methods. An example of data integration approaches is offered by Avitabile et al. (2016), who combined independent reference data with regional and global datasets to reduce bias at the local level. Using independent data sources requires capacity and skilled professionals who know how to deal with the differences in various sources of data and how they can be used at national scale. In countries with low capacities, capacity development and guidance are needed on how to integrate, analyse and interpret independent data as reference or input for national estimates, and how to link local monitoring and reporting on mitigation activities with national estimates (Romijn et al., 2012; 2015). We believe that UNFCCC modalities and guidelines should acknowledge the use of independent data and tools for reconciliation and validation, as they can offer complementary data for cost-effective national and sub-national MRV of GHG emissions. A challenge during technical assessment and independent review of submitted national communications on emissions, is to have high quality data to review national estimates. In this situation, independent, open-source data can be the basis for harmonized reference data and can be used for conflation analysis and uncertainty assessments.

5. Conclusions

Stakeholder satisfaction with the existing open source datasets on forest area and changes, forest biomass and EF and AFOLU GHG emissions is currently only moderate. On average, datasets scored high on the criteria “viability/sustainability”, “accessibility” (except for the biomass datasets), and “methodologies applied” (except for the AFOLU GHG emissions datasets), but lower on the criteria “dataset characteristics” and “verification”. Survey respondents in general indicated that they need more region-specific information and data with more detailed thematic categories and more regular updates. Most prefer data with higher spatial resolution (< 30 m), higher accuracy and reduced uncertainties compared to the existing ones. On average, user's awareness of the assessed datasets was rather low, except for a few datasets that are widely advertised and provided on user-friendly platforms. Centralized platforms that allow comparison are increasingly becoming available and are important for better stakeholder engagement. Data providers should make data uptake easy and should provide these data openly and freely, together with detailed metadata and guidance on how to use them and in which situation. This would increase transparency of data sources, definitions, methodologies and assumptions, important for implementation of the Paris Agreement. It would create more legitimacy with stakeholders and therefore increase opportunities for their participation, in particular those currently underrepresented. On the other hand, users should be aware of the quality of data and data products offered. Transparent documentation and adequate explanation will help users getting better insights into the types of errors and uncertainties and their implications.

Calculating unbiased GHG emission estimates, that comply with the IPCC reporting principles, often requires integration of national and independent data sources. Independent reference data, accompanied by harmonized, consistent descriptions, are essential to compare and assess the accuracy of national datasets and to understand their limitations and can help countries move faster forward towards “transparent monitoring” in the context of the Paris Agreement. For countries with low capacities, capacity development, guidance materials, and in-country training are essential to make best use of available datasets for national estimates.

Currently, science is not yet advanced enough to develop all types of requested data, like higher Tier biomass data for all pools and higher Tier AFOLU GHG emissions estimates. As technology is advancing, future satellite missions, complemented with in-situ measures on the ground, are more and more likely to provide the precise and targeted information that fulfils the various stakeholder needs. But continued dialogue between data users and providers is necessary in order to adapt datasets to the evolving user needs. Continued investments will be needed to advance programmes and improve datasets to serve the objectives of the many stakeholders involved in climate change mitigation. However, not always, the highest resolution data with highest accuracy is needed, particularly when the costs are high. National authorities should be aware of this and consider the cost vs. accuracy needed before making investments. Investments should rather be made into accessibility (free and open access) and transparency; clear indication of provenance of data, detailed, accessible documentation of procedures and uncertainties that are understandable even to people not familiar with the subject and help them take ownership of 'their' data (such as indigenous peoples and forest-dependent communities). Smart harmonization of monitoring with users in other domains (e.g. the monitoring of Sustainable Development Goals) may lead to synergies, thereby reducing costs.

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Annex Data needs presented in Figs. 2,3,5,6 – split up per stakeholder group

The group "Other" includes the stakeholder groups" Donor agencies" and "Journalism/Media" as well as "Others" (from Table 1). These three groups have been combined, because the total amount of respondents from each of the groups was rather low.

Stakeholder group	Forest land and Non-forest land	Forests and other land use and land cover classes	Forest land sub-divided into different forest types, incl. forest degradation	N
Governmental (Annex I)	16.0	68.0	60.0	25
Governmental (Non-Annex I)	21.7	78.3	73.9	23
IGO	46.7	80.0	80.0	15
Local stakeholder	25.0	50.0	75.0	4
NGO	23.9	73.9	73.9	46
Private sector	28.0	76.0	76.0	25
Research	21.6	73.9	70.5	88
Other	54.5	90.9	63.6	11
All	**26.0**	**74.4**	**73.0**	**215**

Fig. A1. Data needs with respect to thematic detail for forest area change datasets per stakeholder group. The numbers in the table represent the percentage of a certain stakeholder group that need a certain type of data.

Stakeholder group	Aboveground biomass	Belowground biomass	Soil organic matter	Dead wood	Litter	Harvested wood products	N
Governmental (Annex I)	89.5	84.2	84.2	84.2	84.2	57.9	19
Governmental (Non-Annex I)	93.8	62.5	75.0	68.8	56.2	56.2	16
IGO	85.7	78.6	78.6	64.3	42.9	42.9	14
Local stakeholder	100.0	50.0	0.0	0.0	0.0	50.0	2
NGO	86.7	63.3	70.0	40.0	46.7	50.0	30
Private sector	78.9	78.9	73.7	63.2	57.9	68.4	19
Research	94.6	80.4	69.6	58.9	57.1	50.0	56
Other	90.0	60.0	60.0	60.0	60.0	50.0	10
All	**90.3**	**73.5**	**71.6**	**58.7**	**55.5**	**52.9**	**155**

Fig. A2. Data needs with respect to thematic detail for forest biomass and EF datasets per stakeholder group. The numbers in the table represent the percentage of a certain stakeholder group that need a certain type of data.

Stakeholder group	CO_2	CH_4	N_2O	NO_x	CO	NMVOC	SO_2	Other	N
Governmental (Annex I)	95.0	95.0	90.0	45.0	40.0	35.0	10.0	5.0	20
Governmental (Non-Annex I)	87.5	75.0	62.5	25.0	25.0	0.0	12.5	0.0	8
IGO	93.3	80.0	66.7	26.7	13.3	13.3	6.7	0.0	15
Local stakeholder	NA	NA	NA	NA	NA	NA	NA	NA	0
NGO	95.7	82.6	52.2	13.0	21.7	13.0	13.0	4.3	23
Private sector	94.4	72.2	66.7	22.2	16.7	16.7	11.1	0.0	18
Research	92.7	82.9	73.2	24.4	29.3	17.1	17.1	0.0	41
Other	100.0	100.0	55.6	44.4	33.3	22.2	33.3	11.1	9
All	**94.2**	**83.5**	**69.4**	**26.4**	**26.4**	**17.4**	**14.0**	**2.5**	**121**

Fig. A3. Data needs with respect to thematic detail for AFOLU GHG emissions datasets per stakeholder group. The numbers in the table represent the percentage of a certain stakeholder group that need a certain type of data.

Stakeholder group	Liming and urea application	Direct N_2O from managed soils	Indirect N_2O from managed soils	from biomass burning	Enteric fermentation	Manure management	Rice cultivation	Grassland management	Other	N
Governmental (Annex I)	52.6	73.7	68.4	84.2	31.6	36.8	31.6	63.2	21.1	19
Governmental (Non-Annex I)	30.0	30.0	10.0	90.0	30.0	30.0	40.0	60.0	0.0	10
IGO	57.1	71.4	64.3	100.0	50.0	50.0	78.6	64.3	7.1	14
Local stakeholder	NA	NA	NA	NA	NA	NA	NA	NA	NA	0
NGO	30.4	52.2	39.1	82.6	21.7	34.8	39.1	60.9	8.7	23
Private sector	37.5	62.5	50.0	75.0	18.8	31.2	31.2	81.2	6.2	16
Research	37.5	52.5	32.5	77.5	35.0	42.5	40.0	52.5	2.5	40
Other	22.2	33.3	11.1	77.8	11.1	33.3	33.3	88.9	0.0	9
All	**37.3**	**55.1**	**44.1**	**83.1**	**30.5**	**38.1**	**40.7**	**63.6**	**6.8**	**118**

Fig. A4. Data needs with respect to agricultural management activities related to AFOLU GHG emissions datasets. The numbers in the table represent the percentage of a certain stakeholder group that need a certain type of data.

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