# CCI

# BIOMASS Phase 2

# User Requirement Document

# Year 1 – Phase 2

# Version 3.0

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# Symbols and Acronyms

| | |
|---|---|
| AD | Activity Data |
| AFOLU | Agriculture, Forestry and Other Land Uses |
| AFR100 | African Forest and Landscape Restoration Initiative |
| AGB | Above-Ground Biomass |
| AGC | Above-Ground Carbon |
| ALS | Airborne Laser Scanning |
| AWS | Amazon Web Service |
| C | Carbon |
| CCI | Climate Change Initiative |
| CCI-Biomass | Climate Change Initiative – Biomass |
| CEOS | The Committee on Earth Observation Satellites |
| CMUG | Climate Modelling User Group |
| CSR | Corporate Social Responsibility |
| EF | Emissions Factors |
| EO | Earth Observation |
| ESA | European Space Agency |
| ESM | Earth System Modelling |
| FCPFCF | Forest Carbon Partnership Facility's Carbon Fund |
| FFMIS | Forest Fire Monitoring Information System |
| FREL | Forest Reference Emission Level |
| GCF | Green Climate Fund |
| GEDI | Global Ecosystem Dynamics Investigation (GEDI) |
| GHG | Greenhouse Gases |
| GL | Guidelines |
| GPG | Good Practice Guidance |
| GPP | Gross Primary Productivity |
| GPS | Global Positioning System |
| IC-FRA | Improving Capacity in Forest Resources Assessment |
| IGCE | Institute of Global Climate and Ecology |
| IKI-RAS | Space Research Institute of Russian Academy of Sciences |
| IPCC | Intergovernmental Panel on Climate Change |
| JAXA | Japan Aerospace Exploration Agency |
| KFS | Kenya Forest Service |

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| KWS | Kenya Wildlife Service |
| KWTA | Kenya Water Towers Agency |
| LIDAR | Light Detection and Ranging |
| LPV | Land Product Validation |
| LSMGE | Laboratory for Satellite Monitoring of Ground Ecosystems |
| LULC | Land use, land cover |
| LULUCF | Land use, land use change, forestry |
| MAAP | Multi-mission Algorithm Analysis Platform |
| MDAs | Ministries, Department and Agencies |
| MEF | Ministry of Environment and Forestry |
| MOLI | Multi-footprint Observation LIDAR and Imagery |
| MRV | Monitoring, Reporting and Validation |
| NASA | National Aeronautics and Space Administration |
| NDC | Nationally Determined Contributions |
| NEMA | National Environment Management Authority |
| NF&WI | National Forest and Wildlife Inventory |
| NFI | National Forest Inventory |
| NGO | Non-Governmental Organisation |
| NISAR | NASA-ISRO SAR |
| NPP | Net Primary Productivity |
| RCP | Representative Concentration Pathway |
| REDD | Reducing Emissions from Deforestation and Degradation |
| RMSE | Root Mean Squared Error |
| SAR | Synthetic Aperture Radar |
| SERFOR | Peruvian National Forrest and Wildlife Service |
| SLEEK | System for Land based Emission Estimation for Kenya |
| SMAP | Soil Moisture Active and Passive |
| SMOS | Soil Moisture and Ocean Salinity |
| SSP | Shared Socio-Economic Pathways |
| UK | United Kingdom |
| UN | United Nations |
| UNCCD | United Nations Convention to Combat Desertification |
| UNFCCC | United Nations Framework Convention on Climate Change |
| VHR | Very High Resolution |
| VOD | Vegetation Optical Depth |


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# 1. Introduction

## 1.1. Purpose and scope

This document sets out the conclusions from the Second Climate Change Initiative (CCI) Biomass User Meeting held online on 28-30th July 2022 concerning user requirements for biomass information, together with additional comments arising from discussion at the Climate Modellers User Group (CMUG) meeting in Exeter on the 29-31st October 2018. It forms the basis for the Product Specification Document (D1.2).

## 1.2. Review of current knowledge

### 1.2.1 Existing information from international bodies, communities and organisations.

The First User Workshop was organised in Paris on Sep 25-26th September 2018 by LSCE and Aberystwyth University. The workshop was attended by over 80 participants and enabled a direct exchange between the project team and a large range of users for global biomass datasets, including researchers in the United States and Europe involved in the generation of global and regional satellite products, climate and terrestrial carbon cycle modellers and organizations involved in the implementation and financing of the United Nations (UN) Reducing Emissions from Deforestation and Degradation (REDD+) and land-based climate mitigation. That workshop allowed us to formulate the User Requirements for the CCI+ Phase 1.

A follow up workshop was organised online on 28-30th July 2022 to update these requirements, particularly in light of policy evolutions and new products delivered recently by the scientific community, such as biomass changes from a static map of biomass combined removal/gains activity data (Harris et al., 2021), multiple satellite datasets fusion using Airborne Laser Scanning (ALS) and field data (Xu et al. 2021) and annual Above Ground Carbon (AGC) change maps from Microwave L-band Vegetation optical depth data retrieved from Soil Moisture and Ocean Salinity (SMOS) and Soil Moisture Active and Passive (SMAP; Brandt et al., 2018; Fan et al., 2019), or new very high resolution (VHR) imagery tree-level crown area (Brandt et al., 2020), biomass and biomass (carbon,C) maps now available over different countries and even for some continents. This second workshop gathered 64 participants from different user communities, from which it was possible to analyse the following community requirements

- Climate Model Requirements for Biomass
- Climate Modellers and In Situ Data
- Climate Change Mitigation and country users

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- The Committee on Earth Observation Satellites (CEOS) Land Product Validation (LPV) Biomass Focus Area and Protocol

The key questions addressed during the discussion and the presentations were:

- Spatial resolution requirements.
- Spatial extent requirements.
- Update frequency of the products.
- Latency of the products compared to the current year.
- Accuracy and uncertainty documentation.
- Use of biomass change maps, and for which epochs.
- The types of data exploration tools users would like to have.

The conclusions of the Second User Workshop helped to refine the CCI global biomass dataset requirements from the perspectives of climate and carbon modelling, ecology, geography, resource assessment, climate policy and other user families. The workshop also provided an overview of other products such as those derived from spaceborne Synthetic Aperture Radar (SAR) and Light Detection and Ranging (LIDAR) and combined with or evaluated against *in situ* observations. No competing global biomass change product with a similar spatial resolution to that proposed from CCI-Biomass-Phase 2 was presented at the workshop. However future products, in particular from upcoming National Aeronautics and Space Administration (NASA) and Japan Aerospace Exploration Agency (JAXA) lidar missions, will be particularly useful in providing high resolution forest structure (e.g., height and cover) information.

The assumed requirement for Above-Ground Biomass (AGB) presented at the First User Workshop is based on:

- Wall-to-wall coverage of the entire globe for all major woody biomes at 500 m to 1 km spatial resolution.
- Temporal coverage on an annual to decadal basis.

The CCI Biomass product (Figure 1) was generated through the CCI+ Biomass project and is publicly available at 100 m resolution for the nominal years 2010, 2017 and 2018. The CCI+ Biomass project aims in Phase 2 to produce global AGB maps for 2005/7, 2010, 2015/16 and then annually for 2017-2022, together with inter-period AGB change maps.

Feedbacks about this requirement were documented from discussions during the workshop and the synthesis of an online survey (Mentimeter) provided to all participants and completed by them. The following sections synthesize the feedbacks received from the climate and carbon cycle modelling communities regarding spatial resolutions required, spatial extents required, accuracies and uncertainties

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documentation, use of biomass change maps, for which epochs, and what kind of data exploration tools users would like to have.

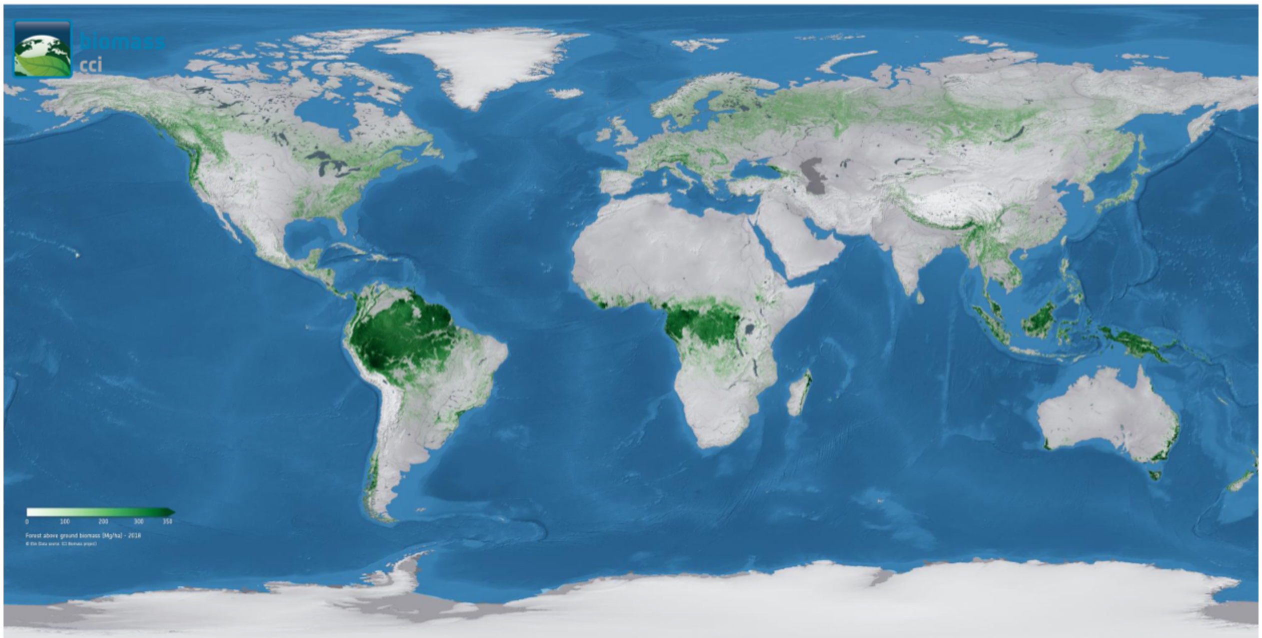

Figure 1: Global AGB estimates for the year 2018. Original spatial resolution: 100 m.

# 2. Analysis of feedbacks from second user workshop

The European Space Agency (ESA) CCI 2nd User Requirements workshop was held as half day sessions over three periods and allowed individuals and groups to present datasets and assess updates of requirements for i) biomass maps, ii) national use cases requirements, and iii) emerging requirements for newly available biomass change maps. The workshop also included a 15 minute discussion guided by an online interactive poll (Mentimeter) for each session to collect feedback from the participants regarding their preferences on biomass and biomass change products. The workshop was attended by 22 carbon cycle scientists, 9 climate modelers, 15 land management stakeholders and 24 people involved in land conservation (Figure 2). The following provides a summary of the question responses from the different attendees and an interpretation of these.

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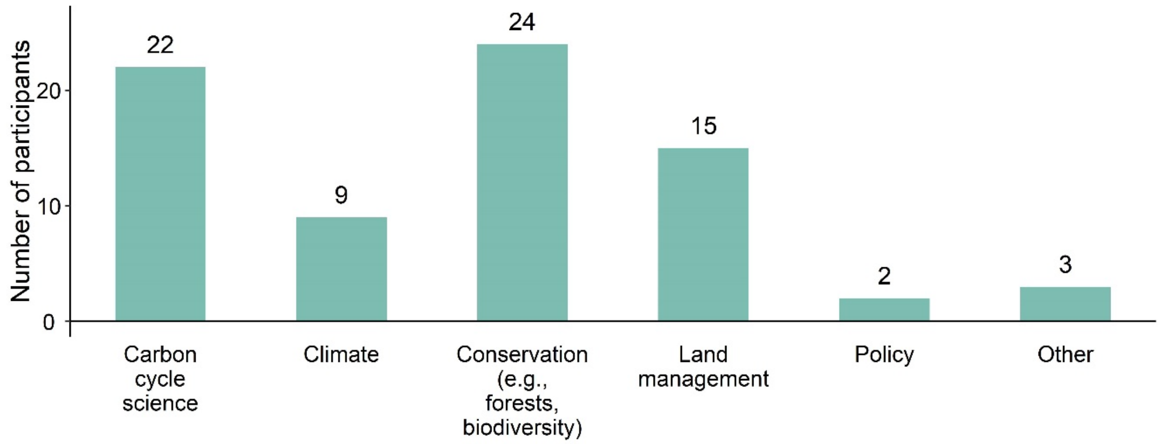


Figure 2: The primary research field of the attendees.

## 2.1. Session 1 on Global Biomass Datasets

The answers to the biomes of interest for biomass datasets were rather evenly distributed across biomes, yet with a majority of answers expressing an interest for tropical forests and a significant interest for mangroves (Figure 3). For national determination of biomass, current datasets used were largely obtained from forest inventories but also global biomass products, showing the value of consistent wall to wall gridded high-resolution information (Figure 4). It also appeared that CCI Biomass and Global Ecosystem Dynamics Investigation (GEDI) Biomass datasets were the most commonly used global gridded biomass datasets from the users present at the workshop. Last, to what sensors were viewed as most important for future quantification of biomass, the answers were rather evenly distributed between L-band radar, P-band radar and spaceborne Lidar.

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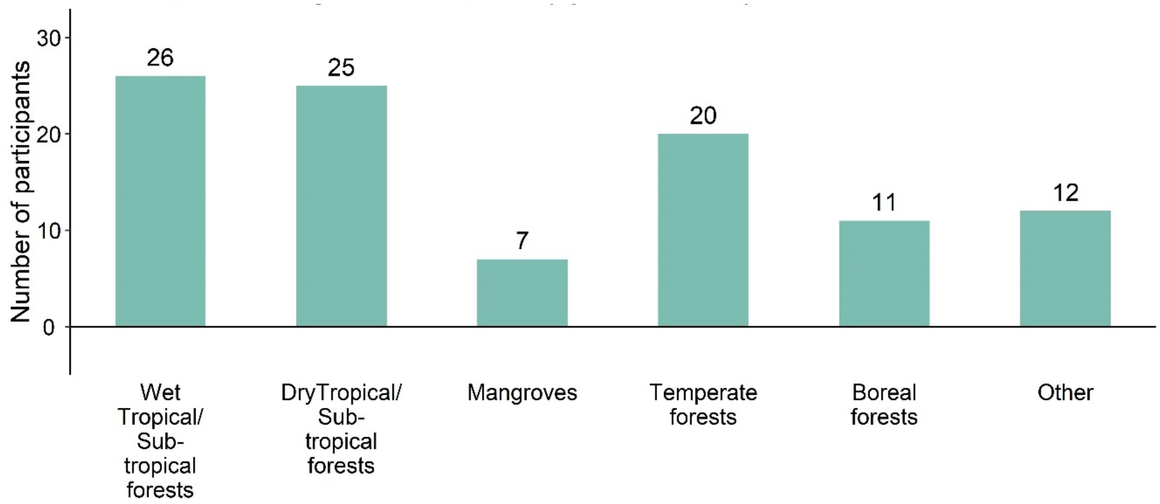


Figure 3: Poll results on the biomes in which the participants are interested.

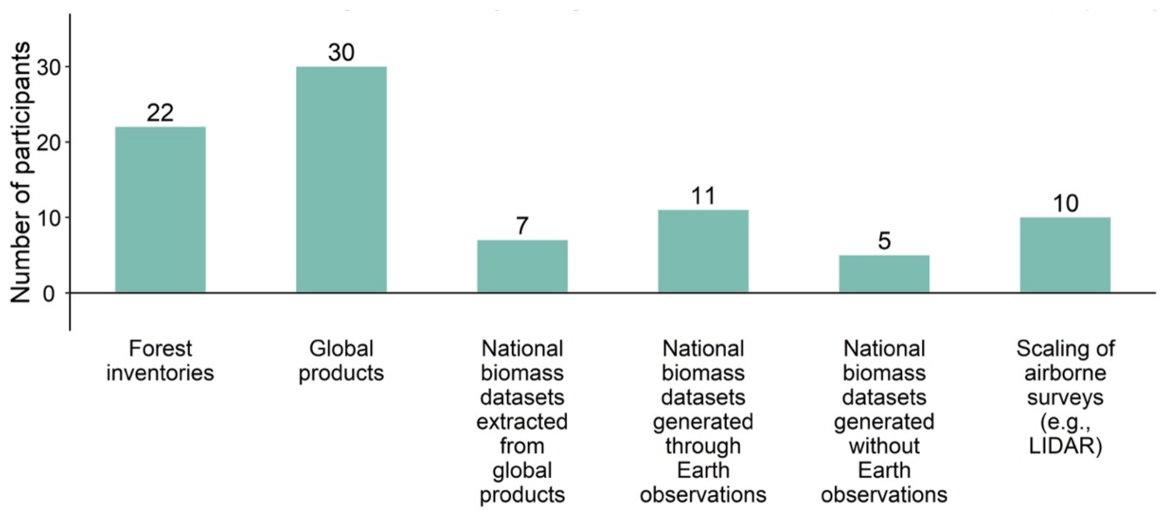


Figure 4: Poll results on the current biomass products commonly used by the participants for national use.

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## 2.2. Session 2 on emerging user requirements for biomass products at national scale

Users' purposes were assessed to be diverse, ranging from C change assessments due to deforestation and degradation, enhancing the accuracy and data coverage for national greenhouse gas inventories, using biomass data as an independent dataset for validation, and using biomass data for research. The dominance of non-research users illustrates the interest for practitioners of biomass data at national scales. Regarding attributes of highest priority for national biomass and biomass change datasets, the most important was long term consistent coverage, followed by high accuracy for biomass estimation and finally spatial resolution. Another important upgrade of national users was the spatial resolution requirement. The answers were rather distributed, but favoured high spatial resolution, down to the scale of individual forest plots in National Forest Inventories (NFI). This is important for the future of CCI Biomass products being currently made available at a spatial resolution of 1 ha. Finally, the temporal revisit most desirable by national landscape users was clearly annual, yet there was an interest for near real-time updates on weekly to monthly scales. Lower revisit, comparable to NFIs, were of lower priority.

## 2.3. Session 3 on emerging user requirements for a biomass change dataset

The main purpose for using biomass change data (with a focus on climate users) was for calculating carbon budgets (39%), followed by assessing the carbon loss in the deforestation process (29%). The rest involved show an interest in evaluating the models as well as assessing forest resources. Most of climate users highlighted the importance of the accuracy and the long temporal coverage of biomass change datasets, showing that a reliable and consistent long-term biomass dataset is in urgent demand (Figure 5). For the temporal revisit time, the biomass change datasets provided annually were most desirable for the climate users (68%), with some scientists also showing interest in products updated in near real time (20 %).

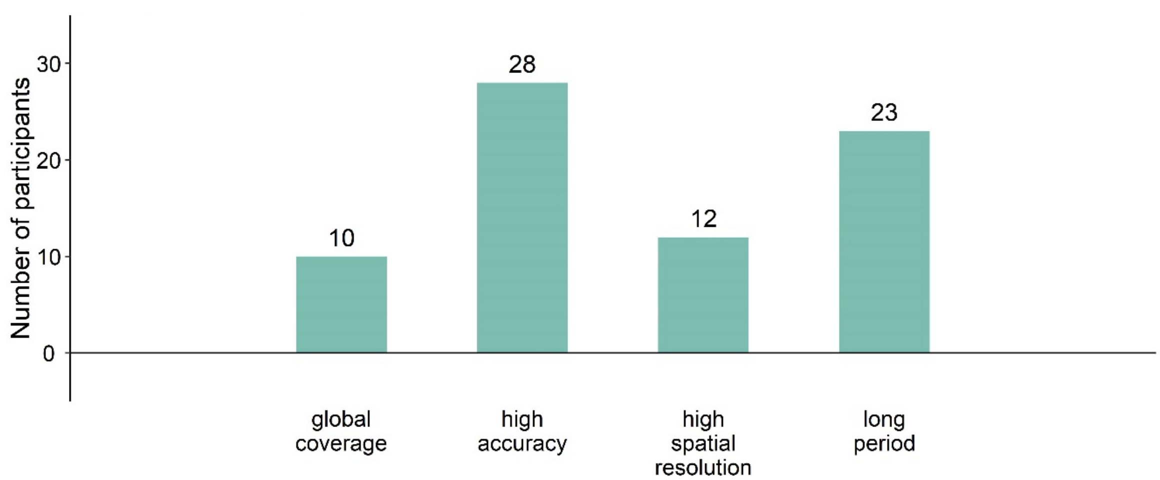


Figure 5: Poll results on the attributes in priority of the biomass and biomass change datasets

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# 3. Results: User requirements

## 3.1. Climate community

The climate modelling community works with global Earth System Models (ESM) that include land surface model components simulating the dynamics of biomass. Initial biomass is calculated from a model spin-up in equilibrium with climate and natural disturbances. Not all climate models include disturbances, but fire is a component in some climate models, with drought-induced mortality relevant to a few (often from empirical parameterization). Windthrow and dieback and loss resulting from pathogens or insect herbivory were generally not included. Transient biomass change is calculated in each grid-cell based on the balance between growth from the allocation of Net Primary Productivity (NPP) to different biomass compartments and mortality. Human disturbance from harvest or biomass gathering is included partly in offline C models used by the climate community, but are not coupled with forest demography models.

NPP in ESMs is calculated as a function of climate, atmospheric $CO_2$ and nutrient limitations in models that include carbon-nutrient interactions. In the CMIP6 ESM ensemble, only some models include carbon-nitrogen interactions, and no model includes carbon-nitrogen-phosphorus interactions. Several models do not include fire disturbance. However, all include anthropogenic land cover change based on annual prescribed land cover maps obtained from historical reconstruction and harmonised with future land cover change scenarios provided by Integrated Assessment socio-economic models for different Shared Socio-Economic Pathways (SSP) storylines and Representative Concentration Pathway (RCP) climate warming targets.

The typical spatial resolution of global ESMs is 0.5° to 2° with a temporal resolution of 1 hour (although output data are only archived on monthly scale, sometimes daily in some models). For historical and future simulations of the coupled climate-carbon cycle system, biomass is an essential variable as it determines the residence time of anthropogenic carbon in the terrestrial reservoir, land use change carbon losses and climate feedbacks. In models, land use change emissions are obtained by the difference between a model run where annual land cover change forcing is applied to the models and a run where land cover is kept constant at the pre-industrial distribution. This modelling definition of “land use change emissions” includes a foregone atmospheric sink (Gasser et al. 2020) which makes it not possible to evaluate modelled land use change emissions against Earth Observation (EO) data.

Climate modellers indicated that seamless biomass information at the spatial resolution of the ESMs, possibly with sub-grid distribution of biomass, would be valuable for model evaluation. These maps may correspond to forest cover data for evaluation of biomass density per vegetation type (plant functional types in models).

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Biomass change products would allow the uncertainty in trends of biomass during the recent period to be reduced. It was also recognised that to constrain land use change carbon emissions, pre-human 'potential' biomass maps, obviously not retrievable from EO, are needed, but the values of potential biomass have large uncertainty.

With respect to uncertainties, the climate modellers above all need unbiased estimates with uncertainties (typically described by a precision) provided for each grid-cell. Of less importance is that uncertainties should be lower than 20 %. In the recent user workshop, climate modelers expressed strong interest for annual biomass change maps to be able to evaluate decadal trends in models.

The preferred file format is netCDF with ftp-based delivery.

<u>Feedbacks from climate modellers about spatial resolution</u>

- Climate models run at ~0.5-1 degree for century scale simulations, ~1-10 km for annual-decadal predictions in the case of regional models. Resolution of data should be higher to filter land cover types, i.e., compare simulation and observation for 'pure' land cover types prescribed to the model. We note here that the definition of land cover types itself can be improved and changed with very high-resolution biomass datasets, for instance to assess the tree cover and biomass of trees outside forests in land cover classes currently classified as 'cropland' or 'grassland' but that in fact contain isolated trees, e.g. in semi-arid regions.
- Disturbance areas are possibly not simulated by models. A 0.25 to 1 ha global product is suggested to be appropriate in order to capture small scale disturbances
- Most modellers may use 1 km data, but if high resolution biomass maps can be related to maps of age since disturbance, these maps could also provide an age map to force models using cohorts of forest age.
- More users expressed interest at the Second User Workshop for 0.25 to 1 ha global datasets compared to 1 km datasets as in the First workshop
- Sub-grid cell scale distributions of biomass i.e., forest area within biomass categories (e.g., 20 categories defined by biomass min/max range) were also listed as a desirable product to be derived from the ESA CCI-Biomass maps. In this case the locations of sub-grid-cell size biomass estimates within a grid-cell are not needed: rather it is the histogram of biomass values within the cell that matters.

<u>Feedbacks from climate modellers about spatial extent</u>

- Global: to ensure consistency of biomass in space needed for assessing impact on climate.
- A focus solely on the tropics is considered to be a limitation. Whilst carbon stocks in vegetation are much larger in this region, changes in biomass in boreal forests will affect soil carbon and permafrost carbon, which could have an even stronger impact on the global carbon balance. In

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addition, coverage of temperate forests is important, for instance because of possible changes in species distribution and forest management strategies in response to climate change and associated effects on the carbon balance.

Feedbacks from climate modellers about temporal frequency

- Users expressed a need for consistent annual products, perhaps produced through a combination of approaches. The provision of wall-to-wall biomass maps at high spatial resolution every year must be considered.
- In view of different biomass change products, many climate users expressed a need for inter-comparison of products, leading to identify agreements and discrepancies, possibly future consensus products, and identification of biases of each specific biomass product e.g., against in-situ field data
- The best suited temporal frequency depends on the frequency of disturbances in each ecosystem. For disturbances, annual maps would be required for measuring change if the biomass uncertainty between timesteps is smaller than biomass changes caused by disturbances.

Feedbacks from climate modellers about temporal extent

- A recommendation is to cover the period since 2000 (possibly earlier, though data may be of limited availability) with complete repeat biomass maps (possibly using spaceborne lidar) and use of optical and/or radar to infer annual dynamics. Mimicking of the best field-based inventories is considered useful but wall to wall coverage is essential. This is in part based on practical considerations and assumes growth will be relatively slow and hard to detect compared to losses.
- Maximize overlap with legacy EO products (Landsat, AVHRR) for extension prior to 2000.

In summary, the requirements proposed for CCI-Biomass products in terms of spatial resolution and global extent were found to be suitable for meeting the needs of the climate modelling community, based on the users represented at the Second User Workshop. Emphasis on the production of annual maps is notable.

## 3.2. Carbon cycle scientists

Carbon scientists cover a large range of research activities, from small scale ecological studies to large-scale regional and global budget assessments. Biomass change is a critical variable for evaluating carbon cycle models. The drivers of this change can be either slowly varying global drivers indirectly affecting biomass through their effects on NPP (e.g., nitrogen deposition, changes in forest demography, atmospheric $CO_2$ increase and climate change), or rapidly varying drivers (e.g., forest management, land use change or mortality events occurring as a consequence of disturbances).

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The major advantages of higher resolution retrieval of AGB is that there is greater comparability with plot data and hence better opportunities to relate observed spatial patterns to underlying (turnover) processes.

Ideally, observation-based annual maps of biomass are most valuable for global and regional carbon cycle budgets, and the recently generated L-band Vegetation Optical Depth (VOD) products (Fan et al., 2019), multiple sensor products (Xu et al., 2021), and Tier-1 high resolution products (Santoro et al., 2021) presented at the workshop received particular attention as a first and significant step in that direction. A possible way forward could be to compare regional biomass changes from these products, to assess agreements between them and against independent ALS and field repeated measurements of biomass changes (Araza et al., 2022).

With respect to uncertainties, the carbon modellers above all need unbiased estimates with uncertainties (expressed as precision) provided for each grid-cell. Of similar importance is in-depth evaluation of products using *in situ* data (inventory data at plot and regional level). Of less importance is that uncertainties should be less than 20 %.

The preferred file format is netCDF with ftp-based delivery for global products, and GeoTIFF and webservices for regional data sets.

In summary, the requirements proposed for CCI-Biomass products were found suitable for the carbon cycle modelling community, although their uncertainty will remain high in the wet tropics. The use of biomass data in estimating land carbon turnover by combining them with EO-based NPP or Gross Primary Productivity (GPP) products was recognised as a powerful approach to diagnose biases in current generation carbon cycle models.

<u>Feedbacks from carbon modellers about spatial resolution (additional to feedbacks from climate modellers listed above)</u>

- Resolution between 0.1 and 1 ha with uncertainties provided at coarser scales. Resolution finer than 100 m may be required for small scale disturbances.
- The major advantages of higher resolution include greater comparability with plot data and better potential to relate observed spatial patterns to underlying carbon turnover processes.
- The resolution of global carbon models is typically 0.5-0.25 degree, with fractional representation at sub-grid scale. Some regional models run at much higher resolution to capture fine scale. heterogeneity and provide results at very high spatial resolution. NASA pre-mission modelling studies suggest a resolution of 1 ha.

<u>Feedbacks from carbon modellers about temporal frequency</u>

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- Annual maps of biomass for global and regional carbon cycle budget assessments such as those performed by the Global Carbon Project each year and regional carbon cycle assessment initiatives (e.g., RECCAP2)

Feedbacks from carbon modellers about other requirements

- Detection of change in forest biomass needs observations every 10+ years. Continuous observation over this period is not feasible and is most likely not needed. Two points in time (of 10+ y apart) could be sufficient, e.g. 1980 and 2000.

## 3.3. EO and in situ community

For remote sensing observations, it was acknowledged regarding spatial resolution and extent that:

- Resolution affects data rates and size of images. Hence it is important to get the correct order of magnitude. For SAR, it is of the order of 25 m multi-looked output products provided at hectare level, since this is the order of size at which variations are meaningful. Higher resolution will give tree-by-tree level information, which may be less useful than assemblages at the hectare level.
- Consistent data provided at extended spatial scales (e.g., continental at a minimum) is desired, preferably using the same viewing geometry and mode. Mixing data types over time can cause difficulties in interpretation. Multi-season and multi-year data are also important in order to aid interpretation of how seasons, weather and moisture affect the inferred results.

Regarding temporal frequency and temporal extent:

GEDI will be a ~2020 snapshot in time of structure (height, cover). There may be data continuity from JAXA's forthcoming Multi-footprint Observation Lidar and Imager (MOLI).

- MOLI data will be needed for assessing change.
- High frequency SAR observations (> monthly) are required to separate moisture from the biomass signal and increase accuracy of change estimates
- For the NASA-ISRO SAR Mission (NISAR), the temporal resolution will be twice (ascending and descending) every twelve days. As ecosystems are driven by the hydrological cycle, and for the low-biomass regime of L-band, it will be important to make a sufficient time-density of measurements in order to remove the time-dependent variations of the SAR signature. Of course, more coverage would be preferable, but it is generally recognised that the repeat period of ALOS-1 of 46 days (with changing modes) is far from optimal. Time series, such as that currently being provided by Sentinel-1, are much more relevant for ecosystems and biomass.

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- From a satellite mission point of view, the long-term plans of the Sentinel time series are excellent. Scientifically, it is hard to rely on a satellite that may only be around for a few years. Long-term predictability of data availability allows investments to be made at the scientific level for making best use of the data resource. This is much more powerful than the "ideal" measurement that many of us may want for a single measurement; the guarantee of a long-term time series means that we can develop and invest in new and inventive algorithms that can make use of such data sets.

For *in situ*, the main priority is to start creating a database of openly available forest biomass plots, to which the community can contribute. This can be used for regional calibration of the global map. Ground plot size for calibrating and validating the remote sensing products must follow some general protocols (Duncanson et al., 2021):

- Size of the plots must be sufficiently large to provide accurate estimates of biomass.
- NFI or other inventory plots that are small in size will be used for regional estimates of biomass and cannot be used individually for calibration and validation.
- The size of the plot must also be sufficiently large to match the pixel size of remote sensing data. For example, if biomass is being estimated at 1-ha, the size of the plot must be larger than or equal to 1-ha.
- The effect of plot orientation and Global Positioning System (GPS) location error with respect to pixel location and size will become smaller when the plot size is larger than the pixel size.
- If plots are used in conjunction with high resolution lidar data, then the size of the plot must be large enough to make sure the lidar-biomass model is unbiased.
- It is important that the plot size is at least 3-4 times the canopy height. For example, 25 m plots are too small to produce robust estimates of biomass.
- Plots should be considered a component part of the missions and programs (either directly or via partnerships). We need to stop seeing these as an externality. This means that direct engagement and collaboration with the plot community is essential.

Erik Naesset's and Ron McRoberts' talks on the calibration of biomass maps and use of height maps helped to clarify the use of *in situ* data. Something that would be interesting to pursue and to publish along with ESA CCI-Biomass maps are estimates of the spatial extent over which the calibration can be applied. The NISAR team (including Sassan Saatchi) have been looking into this using Ice, Cloud and Elevation Satellite (ICESAT) data to test the relationships between backscatter and biomass, but this should be addressed within CCI Biomass.

With respect to uncertainties, the EO/*in situ* community stress the need to arrive at a clear idea of how uncertainties can be combined when inference is made across an aggregation of pixels. McRoberts and Healey gave insights on how to achieve this, but a clear and consistent approach still needs to be developed.

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Sensors such as the GEDI lidar can deliver additional derived information on forest structure (e.g., at 1 km resolution), which must be provided to the users such that they can generate tailored products for their own needs. The users should not have to deal with low level data to do so.

The large & increasing amount of raw data poses the need for cloud-based application of algorithms to avoid high cost and low efficiency associated with downloading large datasets (e.g., from lidar and SAR sensors) to local machines. The NASA-ESA Multi-mission Algorithm and Analysis Platform (MAAP) has been designed purposefully to deal with these issues. Furthermore, algorithms need to be tested prior to the launch of new sensors to avoid reprocessing large datasets, which would inflate costs.

## 3.4. Modelling community

Feedbacks on *in situ* data

The role of *in situ* data in climate modelling was assessed from the point of view of both climate modellers and *in situ* data providers. For the modellers, the data considered as most useful are forest/tree density and species wood density. Both variables are necessary to assess and map biomass. For model calibration and validation, it is important that the data are representative of the EO pixel size when used conjointly; the sampling is often too sparse, and the requirements are to better fit the minimum pixel size. It was noted that it would be useful to differentiate primary and secondary forests, especially in the tropics where this is a significant challenge.

The *in situ* community considers that the modellers mainly use the information provided on forest structure and composition to develop and test their models at fine scale and that improved use of *in situ* data by climate modellers requires more discussions and interactions in order to better match data collection to the model outputs and structural parameters.

**Table 1: Product specifications for climate and carbon modelling. The requirements for both communities are sufficiently similar for them to be covered in a single table, but issues for which there is not commonality are noted.**

| Global biomass mapping product specifications | | |
|---|---|---|
| | Threshold (minimum) Requirements | Target (desired) Requirements |

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| | | |
|---|---|---|
| Product | Map of aboveground biomass with associated precision. This should be unbiased but if this cannot be achieved with current sensors, information on likely bias should be provided | • Map of aboveground biomass (and belowground biomass) with associated precision and information on possible bias<br>• Map of biomass change with associated precision and information on possible bias |
| Spatial Coverage | Global | Global |
| Spatial Resolution | 1 km x 1 km | 100 m resolution is desirable and 30 m resolution data could be used by the carbon modelling community. An issue of concern would be whether finer resolution products might be biased; they would almost certainly have larger dispersion (poorer precision) than the 1 km product. For most modellers, the locations of sub-grid-cell size biomass estimates within a grid-cell are not needed: it is the histogram of biomass values within the cell that matters. |
| Temporal Extent | One time coverage for most recent period | 2000 to present |
| Temporal Frequency | Every 5 – 10 years | Annual |
| Reference System | Lat-Long | Lat-Long |
| Accuracy | Accuracy should be higher than existing maps. Continental-scale uncertainty estimation is needed. | Data should be unbiased and with known precision. |
| Delivery Mode | ftp for global products<br>Web Service for regional products | ftp for global products<br>Web Service for regional products |
| Data Format | netcdf for global products<br>GeoTIFF for regional products | netcdf for global products<br>GeoTIFF for regional products |

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| | | |
|---|---|---|
| Other Requirements | • Fully documented mapping methods<br>• Robust and standardised validation scheme with documented protocol<br>• Full reporting of validation results and implications for possible product bias and precision<br>• Metadata available<br>• Free and open access | • Fully documented mapping methods,<br>• Robust and standardised validation scheme with documented protocol<br>• Full reporting of validation results and implications for possible product bias and precision<br>• Metadata available<br>• Access to underlying data in an accessible processing system<br>• Biomass change products need to be consistent with forest area change data<br>• Free and open access |

# 4. User requirements for climate change mitigation, REDD+ and country case studies

## 4.1. Background

Multiple international policies that require biomass information have been developed and adopted in recent years. Multilateral agreements include performance-based incentive systems to curb trends in forest loss in the tropics and to stimulate reforestation and forest restoration, and to enhance the goods and services provided by forests (collectively called REDD+). Most prominently, international negotiations related to climate change led to increased interest in monitoring forest biomass using space-based data. Biomass measurements are of particular significance for policies related to the United Nations Framework Convention on Climate Change (UNFCCC), as countries must monitor emissions related to gains and loss of biomass and report on these regularly. Data and information on forest biomass stocks are not only required for international information/data needs, but also for national needs to support national policy formulation and mitigation activities.

While the Biomass-CCI project mostly targets climate and carbon cycle science users, ESA noted a lack of a proposed project approach for climate change mitigation and REDD+ users as a "secondary objective". This document summarizes the current knowledge on user needs and on potential next steps for how to integrate biomass maps (such as those developed by Biomass-CCI) in national greenhouse gas (GHG) inventories.

## 4.2. Biomass maps for estimation and reporting using IPCC Good Practice Guidelines

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Guidelines for reporting emissions and removals on the national level are provided by the Intergovernmental Panel on Climate Change (IPCC) Good Practice Guidance (GPG) and guidelines (GL), which countries use when reporting through their GHG Inventories or other reporting avenues to the UNFCCC. The 2019 Refinement to the 2006 IPCC Guidelines for National Greenhouse Gas has been released (Buendia et al., 2009), as the first update of the Agriculture, Forestry and Other Land Use (AFOLU) guidelines since 2006. Updates include additional information on tropical and sub-tropical forest biomass factors, as a result of recent efforts by REDD+ countries, and more information on the role of space-based data in biomass monitoring. More specifically, the guidelines include a new section introducing the use of biomass estimates from maps generated from space-based data. The use of biomass maps is increasingly important, as these wall-to-wall datasets have the potential to complement plot-based biomass measurements available through NFIs. The characteristics and usefulness of biomass maps produced using space-data for national GHG inventories depend on multiple factors:

- The definitions for forest and biomass or AGB used to produce the map and how this definition relates to the one used in the national GHG inventory;
- The type of space-based data sources in terms of spatial resolution, temporal coverage and the degree to which the signal responds, or is sensitive to AGB;
- The method used to construct the map. Methods can range from simple interpolation of field estimates of biomass using spatial covariates to more complex modelling of AGB using field estimates, and observed space-based data signals;
- The availability and reliability of biomass-related field data, which are of better quality than the map, and are needed to produce and validate the biomass map;
- The degree to which map uncertainty is characterised and the manner in which it is used to assess systematic deviation and precision for large area estimates in support of national GHG inventories.

With these factors in mind, biomass maps can improve the stratification of field-based biomass inventories, increase data in under-sampled or inaccessible areas, and serve as an independent data source for verification purposes (provided that the field data were not used to calibrate the biomass maps used).

In general, net carbon emissions from land use change are estimated by multiplying activity data (area of change) by an emission factor (the carbon stock change per unit of change) (IPCC 2006). In this respect, the use of biomass maps for the estimation of carbon emissions at IPCC Tier 2 and Tier 3 levels can be achieved in three ways.

First, biomass maps can provide the base to estimate carbon stocks. Such analyses require consistency among the activity data and biomass maps concerning definitions, geolocation, and spatial and temporal characteristics. The use of regionally aggregated carbon stocks (e.g. using average estimates for different forest types) helps to reduce inherent pixel-level uncertainties in biomass map data for national-scale

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estimations. Countries have used this approach to increase data density in areas under-sampled by field inventories.

Second, biomass change and carbon emissions can be estimated directly from multi-date biomass maps. This approach provides an assessment of carbon stock changes in AGB from land use change and, in particular, includes changes within forests remaining forests such as degradation and regrowth, management and harvest, and natural disturbances. This method requires consistent and well-calibrated biomass maps using field measured and space-based data to accurately estimate biomass changes; a quality requirement that has so far not been achieved for national GHG inventories. Improvements in both the field estimates of biomass change and remote sensing technologies in the coming years could lead to such approaches becoming efficient and accurate for GHG inventory purposes.

Third, biomass maps can be integrated with remote sensing-assisted time series of land use change and/or with IPCC Tier 3 models to derive emissions estimates. This way the biomass map data can be linked to land use to better reflect the complexity of forest-related carbon fluxes. A critical element of this type of application is the consistency among the various data sources and models concerning definitions (e.g. forest, biomass pools), and spatial and temporal data characteristics. Map unit prediction uncertainties in biomass maps propagate to larger area estimates and can lead to substantial uncertainties in national emissions estimation if not properly considered, particularly in relation to the effect of spatial autocorrelation. The application of these three approaches requires maps which are well-calibrated for national circumstances. Many available large-area biomass maps might not be consistent with national definitions of forest and/or biomass pools, and often exhibit large systematic deviation in the estimation of carbon stock and changes for national and local assessments.

Incorporating biomass maps in national GHG inventory efforts requires a long-term perspective, such as establishing a data protocol to assure accessible data in the future. Comparability across timescales is essential to meet the IPCC guidance for consistency. Developing countries in particular have been making significant progress in using space-based data for providing activity data and national forest inventories for estimating emission factors. These increasing capacities should help the potential uptake of novel biomass mapping and estimation possibilities by countries but so far few examples exist; additional national-scale efforts are needed to demonstrate that potential.

## 4.3. Result-based schemes including multilateral, bilateral and project based voluntary initiatives

Efforts to reduce emissions from deforestation and degradation, sustainably manage forests, and conserve and enhance forest carbon stocks (REDD+) in developing countries have been moving into accessing result-based payments (third REDD+ phase), which requires robust and credible systems for measuring, reporting and verification (MRV). REDD+ efforts have been re-enforced as one of the mitigation foci of the Paris

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Agreement. The result-based nature of REDD+ requires that GHG emissions and removals related to REDD+ activities are benchmarked against a reference level to estimate their impact in units of $CO_2$-equivalent. In many cases, emissions are calculated using activity data or land use change area (e.g., forest cover gain or loss), and an emissions factor, which is essentially the carbon stock or biomass of the forest. Biomass maps offer opportunities to not just look at loss or gain in the context of forests, but to look at change which can occur to varying degrees (for example in the case of degradation or regrowth). Reporting under REDD+ frameworks is very much related to national GHG inventories; however, the objectives and requirements vary across frameworks, as outlined in Table 2.

Table 2 Various REDD+ related reporting fora, their purpose and considerations of uncertainties

| CONTEXT | PURPOSE | REQUIREMENTS/CONSIDERATION OF UNCERTAINTIES |
|---|---|---|
| REDD+ related submissions and National GHG inventories to UNFCCC | Regular reporting required at the national level, REDD+ reports, in developing countries in the context of result-based finance, and biennial update reports (BURs) for all countries. | Key GHG source categories should be reported on Tier 2 level (using national emissions factors) in the national GHG Inventory. REDD+ FREL/FRLs and REDD+ Annexes to the BURs are assessed through specific technical assessments and reviews by UNFCCC roster of experts. The stepwise approach allows continuous improvements including uncertainty. |
| Green Climate Fund (GCF) | Finance for forest transformation for climate change mitigation and adaptation. Result-based payments for REDD+. | In the case of result-based payments for REDD+, these are based on the UNFCCC Technical Assessment and Technical Reviews and a further assessments through a score card where uncertainty is part of the scoring system to allocate payments. |
| Forest Carbon Partnership Facility’s Carbon Fund (FCPF CF) | Pilot market transactions for REDD+. | An IPCC Tier 2 is required to estimate emissions and removals. Uncertainty needs to be assessed and reported. Verification of Emission Reductions by an independent third party. Potential discount based on overall uncertainty of reported and verified Emission Reductions. |

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| | | |
|---|---|---|
| Other standards (e.g. Verified Carbon Standard) | Issuance of emission reduction units for the voluntary carbon market. | Varies by standard but uncertainties should be assessed and considered. Independent verification is often part of the process. Often a preference for conservative approaches. |

REDD+ readiness efforts have triggered significant investments in improving developing countries' technical and institutional capacity for forest monitoring, including the capacity to utilize space-based data and remote sensing technologies which are seen as cost-effective methods. These investments and interest have spurred the forest observation community to develop new data sources through targeted research and methods (see, for example, http://www.gfoi.org/rd/), provide justification for space missions (incl. those for forest biomass) and develop improved guidance (for example: www.gofcgold.wur.nl/redd/).

## 4.4. Transparency and broader stakeholder engagements for the Paris Agreement

Enhancing transparency is fundamental to realize the bottom-up nature of the Paris Agreement, and should be understood as a catalyst for action by providing, in the context of biomass data, open and consistent time series, transparent definitions, and assumptions and methodologies that will enhance the credibility and reliability of land use sector mitigation activities in both developing and developed countries. Transparency is already one of the principles of the IPCC guidance for GHG inventories together with accuracy, completeness, comparability and consistency. Open and transparent estimations are also required in cases where results have to be assessed and verified. This includes publicly available input data sources, and the full transparency of methods, including algorithms. This builds public trust in reported results and encourages cooperation among multiple stakeholders including the collaborative design of interventions.

To better understand the user needs, a survey was undertaken with the aim of assessing stakeholders' data needs when monitoring GHG emissions in the land use sector (Romijn et al. 2018). A total of 557 answered the questionnaire and provided information on the type of organization for whom they were working. The survey results show that current open and freely available biomass datasets are not able to fulfil all stakeholder needs completely. Users were found to require detailed documentation regarding the scope and usability of the data (97 % of all survey respondents), data sources which are comparable with alternatives, uncertainty estimates for evaluating mitigation options (94% of all survey respondents), more region-specific data with greater accuracy and detail for sub-national application, and regular updates and continuity for establishing consistent time series (83% of all respondents) (Romijn et al. 2018). Specifically, on biomass data needs, the survey shows that different user groups required different levels of accuracy in terms of IPCC Tiers (Figure 6). The government groups all required Tier 2 or Tier 3, with Annex 1 (developed) country experts having greatest preference for Tier 3 (74%); even more so than the research community.

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The Non-Governmental Organisation (NGO) community were more likely to use Tier 1 information (20%). On average, 43% of respondents preferred Tier 3, while 47% of respondents preferred Tier 2.

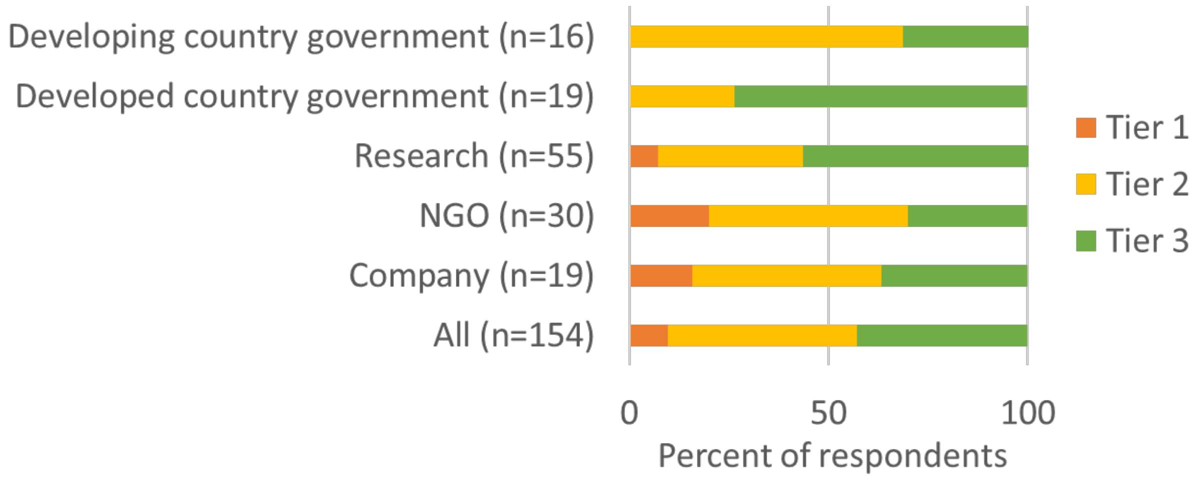


Figure 6: Desired level of IPCC tiers. Tier 1 emission factors are default values for broad continental forest types, e.g. from IPCC Emission Factor Data Base, Tier 2 emission factors are country specific data for key factors, e.g. from field inventories, permanent plots, and Tier 3 emission factors are based on detailed national inventory of key C stocks, comprehensive field sampling repeated at regular time intervals, soils data, and use of locally calibrated models. Responses are divided into groups, and ALL relates to all respondents, including the other groups, such as "local stakeholders", "donor organisations", "intergovernmental organizations", and others. Developing country governments include Non-Annex 1 governments, and developed country governments include Annex-1 governments according to the UNFCCC definition. "Research" includes universities and research institutes, and NGOs includes International (I) NGOs. Amended from (Romijn et al. 2018).

Multiple datasets are available which can be used by stakeholders to estimate biomass (Figure 7). Several differences were found in the awareness and usefulness of these datasets. While almost all stakeholders are aware and use the IPCC guidance, the knowledge and uptake of biomass maps was much less. This emphasized the current status that available maps are not used in GHG reporting by countries. There is a significant gap between stakeholders being aware of certain data sources and whether they actually found them useful for their purpose. This highlights the large divide between what is available and what is used. NGO respondents were more likely to be aware and users of these biomass datasets than other user groups.


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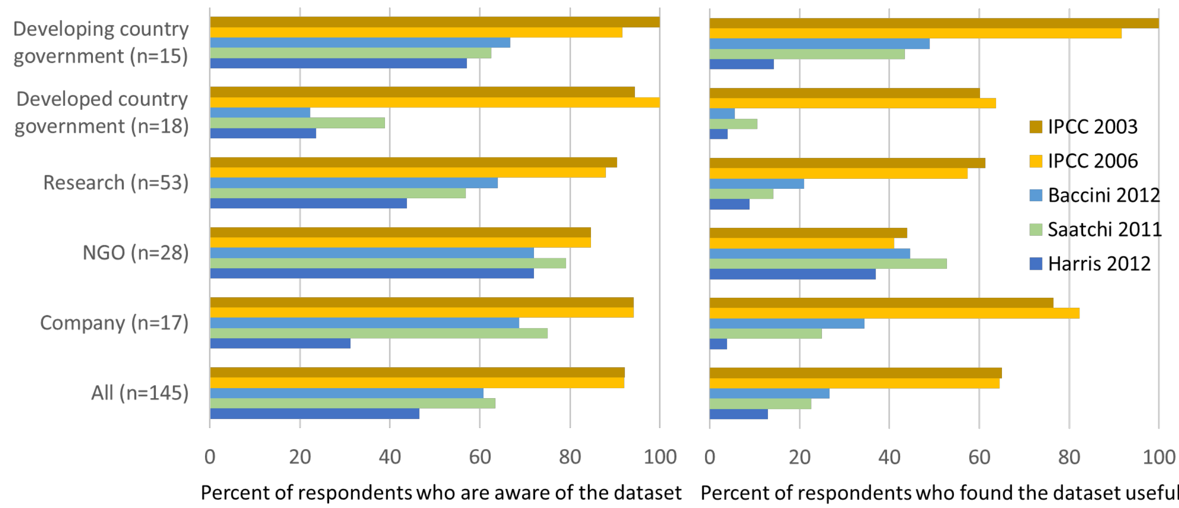


Figure 7 The top five datasets which the questionnaire respondents were aware of when asked "Are you aware of this dataset" (data in left panel). These datasets are IPCC 2003 (IPCC 2003), IPCC 2006 (IPCC 2006), Baccini 2012 (Baccini et al. 2012), Saatchi 2011 (Saatchi et al. 2011), and Harris 2012 (Harris et al. 2012). The bars show the proportion of respondents who were aware of the dataset, and the proportion who both used it and found it "useful" or "very useful" when responding to the question "Was this dataset useful for your research and/or business purposes?" Other response options were "somewhat useful", "not very useful" and "not at all useful". Responses are divided into groups, and ALL relates to all respondents, including the other groups. Developing country governments include Non-Annex 1 governments, and developed country governments include Annex-1 governments according to the IPCC definition. 'Research' includes universities and research institutes, and non-governmental organizations (NGO) includes International (I) NGOs.

## 4.5. Current gaps in using biomass map data for REDD+

While there is large need to improve biomass and carbon stock (change) estimation in developing countries, there is so far little use of existing biomass maps for national estimation and reporting. In the second Biomass-CCI user meeting, there were some initial examples of countries generating and using biomass maps for the REDD+ related estimation, i.e., as part of the Worldbank FCPF process. There some countries use biomass maps (in combination with other data) to improve quality of Emissions Factors (EFs). It was also noted that there is need for further enhancements for some countries (i.e. for degraded forests). However, the gaps and barriers for the use of biomass estimates using biomass maps for REDD+ purposes includes:

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**Insufficient level of detail:** Different users related to different policy and management processes require different level of detail in spatial terms that should be sufficient to link with national plot data and eventually activity data. Most maps are global and the interest of countries is national estimation. In terms of temporal coverage, the reference period for historical emissions by countries varies. Some users prefer a particular year, some want data that are most recent (near-real time information) or available for longer time series. There is variability in needs in terms forest definitions and in which vegetation components are considered for biomass/carbon stock estimation and whether dead biomass is included or not.

**Biomass maps versus change:** Most regional and global biomass maps exist as one-time products. While there is value in and need for high-quality biomass stocks data, there is an inherent interest in biomass and carbon stock change information. It is only recently that estimation of biomass change over large areas from space-based data is starting to appear in the scientific literature.

**Conflicting information:** Urgency by researchers and scientists to improve space-based monitoring capabilities has naturally led to a diversification of methods, with positive implications in terms of innovation, and demonstrating the potential. Different datasets are available and often provide inconsistent information which confuses users. Identifying the sources of differences in these maps is difficult, due to lack of detailed descriptions/transparency, different definitions, temporal coverage, and also the lack of information on the uncertainty of the maps.

**Limitations in the complementary use of field / airborne and space data:** Biomass monitoring still suffers from the conceptual and technical divide between space-based data, and traditional means of gathering biomass data (i.e., collecting data in the field as part of NFIs). However, the lack of in-situ data in certain locations, use of different definitions of forests and biomass, and uncertainties in both field and space-based data have led to limited complementarity. Current biomass mapping from space remains largely disconnected from plot-based national forest inventory efforts.

Lack of capacity of key stakeholders: One of the main barriers to progress in general and particular relating to the uptake of space-based biomass derived data for national forest carbon monitoring, is the capacity of users such as country experts and non-technical experts to access and use the data. Despite efforts to increase capacities, a capacity gap remains in many developing countries which continues to limit the uptake of new technologies. The use of biomass maps by key stakeholders is also hindered by the lack of capacity to understand the methods that were used to produce them.

**Gaps between theoretical opportunities and policy and management praxis:** An often-overlooked limitation of biomass and forest monitoring capabilities arises from a gap between what is needed by users, what has been successfully demonstrated in a research environment, and what can be developed and maintained in an operational environment, such as a country's National Forest Monitoring System. The technologies offered may not meet the user requirements or be practical for operational implementation, and an analysis of user requirements should be undertaken to ensure that what is offered can be adopted

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successfully. In particular, investments to develop new data sources and methods are significant and often do not consider how such novel approaches can be scaled geographically and then reliably maintained at a reasonable cost by users. This problem is often especially acute in countries with low technical capacity. Unclear institutional arrangements and turnover of technical staff can create problems for responding to new requirements and technical opportunities and for sustainability of monitoring efforts.

Uncertainty characterization is missing or not suited: Currently global maps are available, but using these datasets to estimate biomass at national scale does not meet the level of uncertainty required for REDD+. Some do not provide adequate uncertainty estimates so these have to be calculated by the users, which can be difficult, and this process relies on assumptions and thus is uncertain in itself. To add to the challenge, most biomass mapping accuracy varies by forest type and biomass range. Biomass mapping typically performs poorly in high biomass and dry regions of the tropics, and uncertainties are particularly large there. Users have specific requirements on what they expect from uncertainty characterization and such user-targeted uncertainty characterization is essentially lacking from all large area biomass mapping products.

## 4.6. Summary of discussions and recommendations from the Biomass CCI user meeting

### 4.6.1 Summary of the user interaction session of phase 1

A dedicated REDD+ user interaction session was held during the Biomass-CCI user meeting. The session showed general interest and need for using newly available biomass mapping and estimation efforts for REDD+ purposes. The 2019 refinement of the IPCC GPG includes a new section on use of biomass maps that includes several options and potentials but overall, there is little use so far of existing biomass maps for national estimation and reporting. There were some initial examples of countries generating and using biomass maps for the REDD+ related estimation, i.e., as part of the World Bank FCPF process. Many countries have generated EF data with some of them of rather limited quality and with rather little intentions to continuously improve them over time; although the idea of stepwise improvement of monitoring capacities is foreseen as part of the REDD+ readiness and implementation process.

A key consideration is to understand the role of CCI+ Biomass products for improving national-scale estimation. Generic global products have often limited use for such national estimations unless calibrated or integrated in ongoing national mapping efforts. Since IPCC requires consistency in reporting, the incorporation of new data requires potential reconsideration of the estimation and can result in general reluctance of national organizations to explore such new opportunities. To improve that situation the following key next steps have been discussed and proposed:

Need for partnerships for joint initiatives and data exchange:

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- Modes of engagements between (global) biomass expert mapping community and country experts – explore the win-wins:
    - Country data/efforts supporting global cal/val
    - Use global information/knowledge to provide (independent) feedback and training/capacity building to national efforts
    - Frameworks for uncertainty assessments to understand sources of error and areas for improvements (national and global)
    - Concepts for countries to generate better estimates (on their own) using space-based data and enhance the efficiency and long-term sustainability of their NFI
- Develop a policy and mechanism for data sharing building upon the positive experience of the 2019 refinement

More practical country examples are needed

- Develop practical experiences on how biomass maps and other RS can improve national estimation following new IPCC guidance:
    - Bridge the divide between maps and statistical estimation for reporting.
    - Compare and assess C-stocks and EF to produce emissions estimates, including to increase data density in under-sampled or inaccessible areas.
    - Integration with Activity Data (AD) to produce wall-to-wall maps/estimations and direct estimation of biomass change (i.e., for Tier 3).
    - Verification purposes.
- Aim to achieve country ownership in context of evolving opportunities:
    - Co-creation of estimates among producers and users.
    - "National calibration" of global data (NFI vs. Remote Sensing).
    - Access to data through an (open-source) processing system to produce their "own" data.

Approaches for continuous improvement and sustainability for national forest monitoring

- Engagement with the global biomass mapping community, space agencies, and related cal/val processes (CEOS).
- Concepts and tools for countries to generate better estimates (on their own) using existing and upcoming space-based data and enhance the efficiency and long-term sustainability of their NFI.
- Improved guidance and training materials based on practical experiences and their use in capacity development programs.

### 4.6.2 Summary of the user interaction workshop of phase 2

The ESA CCI Biomass project team organized the first Biomass User Workshop of the second phase between the 28th – 30th of June 2022. The workshop's objective was to reach a better understanding about the

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different user communities needs to be reflected in the global biomass datasets currently under development by the ESA's CCI biomass project. The second day of the workshop was dedicated to national users, where more than seven countries identified their needs and opportunities for embracing biomass maps in the monitoring and reporting of their forest-related GHG emissions and removals. It was a 2-hour enriching online event, in which around 65 people participated.

We heard experiences from Australia, Peru, Russia, the United Kingdom (UK), Kenya, Rwanda and France on the current country forest biomass monitoring strategies as well as their requirements for the uptake of biomass maps for GHG monitoring and reporting efforts. Additionally, a brief glance at the CEOS/Silvacarbon country workshop on biomass measurements allowed the participants to learn about the challenges and opportunities in biomass monitoring and reporting from the perspective of 5 additional Latin American countries including Paraguay, Colombia, Ecuador, Guatemala, and Mexico. The workshop also included a 30 minute discussion guided by an online interactive poll in which more than half of the participants reflected their preferences on biomass and biomass change products.

In the poll, the participants rated the use of biomass data as an independent source of verification as the main possible application for national monitoring purposes (Figure 8). On that note, within the ESA CCI-Fire presentation, the use of Earth observation data to help reconcile GHG Inventories with atmospheric inversions was pointed out. Furthermore, Australia indicated the opportunity of applying global biomass products as an input to the budget models currently developed by the country for their forest-related GHG accounting system. Russia reflected on the potential use of biomass products to compare and validate current national biomass and biomass change estimates. Additional applications of biomass maps appointed by the audience were assessing carbon changes associated with deforestation and degradation (a demand seconded by the Latin American group) as well as the use of biomass products for research activities (Figure 1). Regarding the former, two (sub)national explorative studies were shown during the workshop: i) a nation-wide mapping of carbon stocks from individual trees in Rwanda and ii) using remote sensing data, such as GEDI and Sentinel 1 and 2, to create canopy height and biomass maps at high resolution (10 m) in a region of France. It seems that less appealing options to the audience included using biomass maps as a source of auxiliary data for enhancing the precision of estimates of emissions/removals factors based on ground plot reference or complementing ground-based forest inventory measurements (Figure 1). Nonetheless, examples from Peru and Paraguay stressed the opportunities of using global biomass products (i.e., the CCI biomass map in the case of Peru and GEDI for Paraguay) to enhance national aboveground biomass estimates. Kenya was also keen on exploring the use of biomass maps for potentially augmenting/ replacing the country's limited number of forest inventory plots (about 120). Additional applications and opportunities of biomass maps for GHG monitoring included localizing emissions and removals estimates by integrating biomass density and/or density change maps with other spatial data and/or Tier 3 models (Australia); enhancing the data coverage in under-sampled areas of the country (Siberia-Russia); and assessing biomass change considering disturbance type attribution (i.e., clear cuts, windthrows, wildfires, pest, etc.) (UK and Russia).

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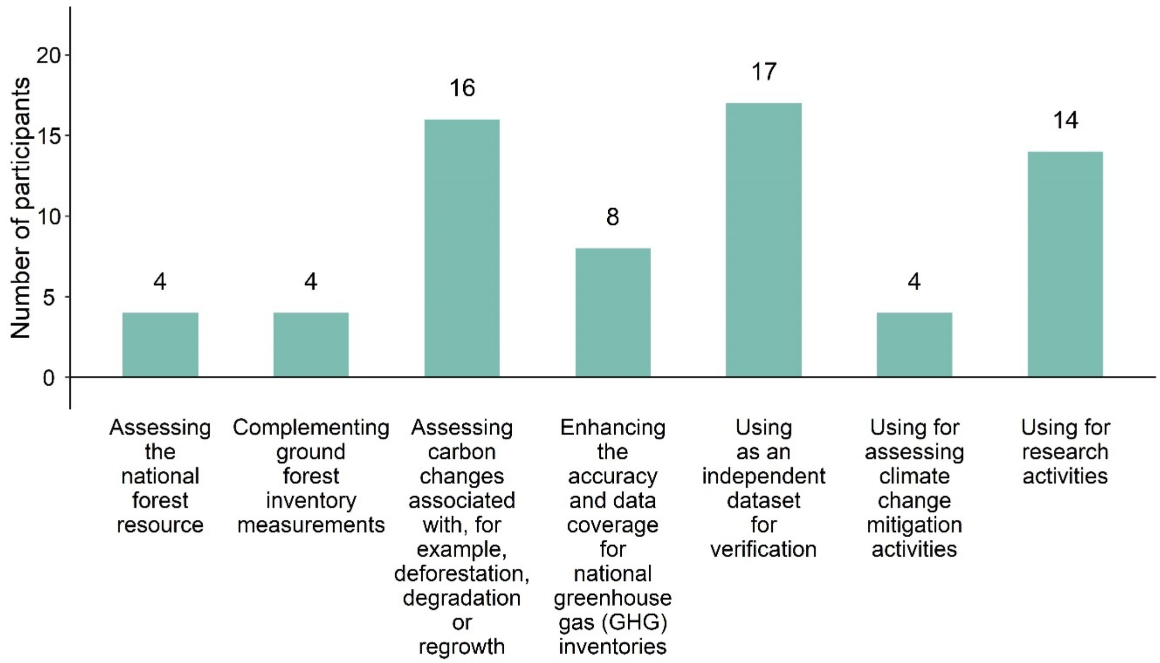


Figure 8 Poll results on the main purpose for using biomass and biomass change data for national monitoring

Among other user preferences for biomass and biomass change products, it seems long-term consistency outweighed any other products' attributes, followed by high accuracy and spatial resolution. Latin American countries pointed out the importance of accounting for uncertainties in their GHG monitoring and reporting and recognized difficulties in computing confidence intervals from existing biomass maps to report uncertainties. Also, Australia expressed the importance of accounting for uncertainties and pointed out the need for including pixel-level pairwise covariances if aggregating the product over space. Additionally, the poll revealed that most users preferred meso spatial resolution (0.25 – 1 ha) or higher (< 0.25 ha) to coarser resolution (more than 1 ha) biomass space-based products. Countries including Australia and Russia expressed similar preferences. As did the UK, although specifying that scaling 100 m to 10 m resolution maps using land cover maps would be useful. As for quantifying change, most participants preferred annual updates, followed by seasonal and 1-5 year updates.

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## 4.7. Updated general product specifications for REDD+

Based on the assessment of user needs and input and feedback from user meeting, the following product specifications have been developed for Biomass-CCI project with respect to climate change mitigation and REDD+ users

Table 3 Updated product specifications for REDD+

| Global biomass mapping product specifications | | |
|---|---|---|
| | Threshold (minimum) Requirements | Target (desired) Requirements |
| Product | Map of aboveground biomass with associated uncertainty | • Map of aboveground biomass (incl. belowground)<br>• Map of change in biomass<br>all with uncertainty estimated, definition of biomass might vary for different countries circumstances |
| Spatial Coverage | Global | Global with targeted/calibrated products for specific countries or other areas of interest |
| Spatial Resolution | At least 100x100 m / 1 ha resolution | 0,25-1 ha - resolution might vary depending on forest and ecosystem type, and country needs |
| Temporal Extent | One time coverage for most recent period | 2000-now |
| Temporal Resolution | One time | 1 year (annual maps) |
| Reference System | Lat-Long (WGS-84) and equi-area projections | Provided in country-specific reference grids |
| Accuracy | Accuracy should be higher than existing maps. Continental-scale uncertainty estimation. | Data should unbiased and with high precision (≥ 90% rel. RMSE) for target estimation regions (i.e. countries) |
| Delivery Mode | FTP or Web Service | FTP or Web Service and combined with training materials on how to use the data and within country capacity development |
| Data Format | GeoTIFF | GeoTIFF (or other country preferred formats) |

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| | | |
|---|---|---|
| Other Requirements | • Fully documented, transparent and standardised mapping methods<br>• Robust and standardised global validation scheme with protocol<br>• Metadata available<br>• Free and open access | • Fully documented, transparent and standardised mapping methods,<br>• Metadata available,<br>• Robust calibration and validation using available national data sources (i.e. NFI data)<br>• Access to underlying data in an accessible processing system to produce their "own" data<br>• Clear and transparent reporting of regional accuracy/uncertainty<br>• Consistent spatial-temporal coverage<br>• Consistency with forest area change data<br>• Free and open access |

## 4.8. User requirement and specifications for different country case studies

### 4.8.1 Peru: National Forest and Wildlife Service

The Peruvian National Forest and Wildlife Service (SERFOR, by its acronym in Spanish) is the forest national authority and is in charge of establishing the national policy and technical guidelines for the sustainable development of the forest and wildlife sector in the country. SERFOR is responsible for implementing the National Forest and Wildlife Inventory (NF&WI) in the country, and with it, it generates the forest-related carbon information to support the MRV of REDD+ activities and the land use, land use change and forestry (LULUCF) national GHG and accountability system. In Peru, the LULUCF sector is the main contributor to the national GHG emissions, simultaneously, it is where the country is expecting the most emission reductions.

The NF&WI divides the country into six subpopulations, with four of them located within the Amazon basin. Peru started implementing the NF&WI in 2013, and by 2020 it had completed around 32% of the target sample. The sampling units are spread over each stratum, so even if the NF&WI is still incomplete, national estimates and reports are possible at a reduced precision. Overall, Peru is interested in including spatially explicit biomass and biomass change information that could contribute to more comprehensive and continuous biomass information for LULUCF GHG monitoring and reporting. More specifically, Peru is keen to explore how global biomass maps in combination with ground-based data can contribute to enhance national forest-related AGB estimates, for instance, by defining more efficient national sampling efforts. Ongoing research is currently using a locally calibrated CCI Biomass map as an auxiliary source of information to the NF&WI inventory data to assess the gain in precision of AGB in the Peruvian Amazonia. Results show that even when the map tends to overestimate the AGB found on the ground, after calibrating the product with the NF&WI data, the CCI Biomass map contributes to substantially increase the precision of sub-national AGB estimates (by as much as 150%). SERFOR is interested in consolidating those findings

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and seeing whether more precise sub-national estimates of biomass stocks can be derived from a combination of CCI Biomass and NFI data sources using a proper statistical framework.

Moreover, in the latest update of the Forest Reference Emission Levels (FREL), the country also recognized the need to better account and propagate the sources of uncertainties of the LULUCF-GHG emissions and removals estimates, in accordance with the IPCC good practice guidelines. Hence, SERFOR would like to explore the different sources of uncertainty that result from the integration of earth observation products with ground information data. For which purpose, the user expects that the uncertainty information accompanying the biomass map should be accounted for and transparently reported. The user would like to consider uncertainties in both the NF&WI ground data plots and the biomass map data.

Additionally, the SERFOR currently uses a 2014 100 m resolution biomass map of the Peruvian Amazon basin for natural resources planning and environmental services schemes. The user is eager to have a locally calibrated biomass map, as recent as possible and at equal or better spatial resolution as mentioned, to continue to support the country forest policies. At the same time, the user aims to have a better understanding of the spatial distribution of biomass within the Amazon to support the delimitation of disturbed forests based on biomass density criteria. They have targeted 2010 as a baseline year for such an exercise, for which having a locally calibrated biomass map of the same year would be ideal. The mapping methods of all products should be transparently documented and, ideally, as standardized and consistent as possible, to additionally explore biomass change consistently between the different epochs.

### 4.8.2 Russian stakeholders and requirements

Russia remains an important player in carbon sequestration and climate mitigation policy, covering a large portion (over 20%) of global forest area, with increasing risk of permafrost melting, wildfire and other disturbances. Russia has been following its obligations on climate mitigation, and keeps developing national forest and GHG inventories, as well as legislation development.

We identified three major stakeholders (see below), who operate at national scale.

1) The Laboratory for Satellite Monitoring of Ground Ecosystems (LSMGE), one of the subordinate laboratories of the Space Research Institute of Russian Academy of Sciences (IKI-RAS) (http://www.iki.rssi.ru/eng/index.htm), is established for the creation, implementation and support of specialized EO systems to study the dynamics of terrestrial ecosystems. To obtain various characteristics and the state of the terrestrial ecosystems, the laboratory led by Sergey Bartalev produces a series of satellite-based products including the annual land use land cover (LULC) datasets (from 2002- onwards), forest species composition maps, as well as the burnt area maps using MODIS observations. Moreover, the laboratory also develops an operational near real time fire monitoring service, named the Forest Fire Monitoring Information System (FFMIS).

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The LSMGES currently develops the MODIS-derived national above ground biomass datasets at 230m resolution for natural system and disturbance monitoring. The user is eager to validate their national biomass estimates with CCI Biomass dataset. The change information is also required to explore and compare the biomass change information in different epochs, which highlights the importance of the consistency and long-time coverage for the CCI Biomass dataset. Additionally, LSMGES also shows their interest for downscaling their biomass map at coarse resolution (230m) by calibrating the CCI Biomass dataset at higher (100m) spatial resolution. In summary, the user would expect an accurate, up-to-date and consistent biomass product and is satisfied with the current announced CCI Biomass projects with regards to the annual frequency and 100m resolution.

2) Yu. A. Izrael Institute of Global Climate and Ecology (IGCE) (http://www.igce.ru/) is a non-profit scientific institution in Moscow, Russia. IGCE is responsible for implementing the national GHGs inventory in the country and is also contributing to the national GHG database from UNFCCC.

Currently, IGCE reports the national forest status (e.g., above-ground biomass and biomass change) based on ground inventories. However, the institute found there is a gap between the national statistics and remote sensing products. This could be explained by the delay with forest inventory which is time- and labor-consuming. The limited coverage of the ground inventory also leads to the missing of disturbance (e.g., logging, wildfires, etc.) and may thus cause the differences in the ground measurements and satellite observations. In that case, the institute is keen to use CCI Biomass datasets to compare with their national biomass and biomass change estimates as additional validation for the National Inventory Reports.

Since the forest ecosystem is strongly regulated by disturbances like wildfires and insects in Russia, IGCE aims to explore the carbon stock before the disturbance and further account for the emissions by the forest disturbances. The pre-level above-ground biomass stock can be derived from the CCI Biomass data with full data coverage of Russia.

Moreover, IGCE expresses interest in improving the understanding of the spatial distribution of biomass change at the sub-nation level. This could be reached by calibrating the spatially explicit biomass change information from CCI Biomass datasets with the ground-based inventory. By combining the space-borne observations and the ground inventories, the institution would like to explore the uncertainty of biomass change from the different data sources at the sub-national level.

3) Roslesinforg (https://roslesinforg.ru/en/) is an all-Russian organization specializing in the comprehensive solution of forest accounting and forest management tasks in the interests of the state. Specifically, the organization conducts assessments of the state's forests and provides necessary information and designs to support the reproduction, protection and sustainable use of forests in any region of Russia.

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Responsible for the NFI of the country, Roslesinforg accomplished the first cycle of NFI investigation during 2007-2020. A stratified sampling design was conducted during the first NFI collection by implementing the target forest samples in different climatic and topographic regions. The forest attributes recorded include the dominant species, age class, productivity level, tree density, above ground biomass density. In total, 69,100 sample plots were collected with a sampling unit of 0.05 ha. Among which, 80% of the NFI samples are expected to be permanent and will be remeasured in the future round. The total forested area in Russia is estimated at 820.9 x$10^6$ ha and the growing stock volume is estimated at 112 x$10^9$ $m^3$.

Currently, the second round of the NFI has started from 2021. By June 2022, Roslesinforg has completed around 15% of the target samples with an improved equal-area hexagonal sampling stratification strategy. Moreover, Roslesinforg also revised the old inventory based on the satellite data to improve the consistency of the existing and the old records. With continuous improvements of such an abundant sample database, the organization is interested in the cross validation between the ground measurement and the remote sensing-based estimates from CCI Biomass. The user would also expect the wide reputation and international appreciation of the NFI database after the application in the validation of CCI Biomass.

Currently all major interactions with Russian Institutions are on hold.

### 4.8.3 Wales

The UK's current GHG inventory currently uses annually modelled carbon stocks, with these validated against NFI and research plot data. The NFI are samples within more than 15,000 1 ha plots that are distributed across the UK.

The estimates of carbon stocks (and hence biomass) for forests are not spatially explicit and so the generation of annual maps of AGB would provide the opportunity to evaluate the correspondence between the modelled outputs and the estimates from EO data, particularly for earlier years (e.g., 1990s onwards) but also throughout the time-series where gaps in knowledge exist. However, the models will still be required for projection of emission estimates and also to support policy development.

The users' requirements for the UK included wall-to-wall maps of AGB for the forest estate, with this currently being desirable rather than essential. The production of maps at 100 m (1 ha) resolution, as undertaken by ESA CCI, was considered appropriate as was an annual update frequency. However, there was a requirement for the attribution of change, such as clear cuts, windthrow and removal following disease. For this, consistent descriptions of change impacts and driving pressures was desirable and there was an increasing need for information on changes in condition as well as extent. Downscaling the estimates of AGB from 100 m to 10 m would also be useful, particularly given the fragmented nature of the landscape, which could be achieved through reference to existing land cover maps.

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A number of challenges have been identified in relation to quantifying emissions from the LULUCF sector. In particular, the NFI reflects land use rather than land cover and early in the time-series, there have been difficulties in identifying and quantifying the contribution of fallow land waiting restocking following clearing. In terms of EO provision, competing biomass products presenting different values was leading to uncertainty as to which was best to use and so there is a requirement for the provision of robust validation statistics with all estimates produced. The mechanism by which uncertainty is calculated also needs to be clarified.

For Wales, through a collaboration with ESA CCI Biomass (cci.biomass.int) and Living Wales (wales.livingearth.online), estimates of AGB for over 1500 NFI plots have been used to validate the CCI global AGB product by using the plot2map tool within the ESA-NASA Multi-mission Algorithm Analysis Platform (MAAP), and other NFI plots are in the process of being completed. Living Wales has generated detailed maps of land cover for multiple years and these provide the opportunity to better establish where biomass is distributed across the landscape and to identify areas of changes in extent and condition.

There was a strong desire to contribute to global efforts towards the generation and validation of AGB products, including through the biomass harmonisation activities. The UK is also involved in international forestry activities, including those aimed at reducing GHG emissions by reducing climatic and economic pressures. There was particular interest in helping countries develop approaches for establishing forest biomass reference levels and also determining biomass feedstock supply chains by providing independent measures of carbon stock change in supply catchments to inform whether forestry practices were sustainable or otherwise.

### 4.8.4 Kenya

Forests (excluding dry woodlands) cover approximately 7-8% of Kenya's land area, depending on the spatial resolution of the imagery used to create the forest cover map. Finer spatial resolution from Planet imagery (3-5 m) gives closer to 8% forest cover while Landsat imagery (30 m) shows the forest cover as around 6-7%. Kenya has four forest cover types: Western plateau/Guinea- Congolian rainforest, afro-montane (1.14 million ha.), dryland and coastal forests as well as plantation and farm forests. They are diverse and include the Eastern Arc Mountain Range forests, Mount Elgon's forests, mangrove and coastal forests and remnants of Guinea-Congolian rainforest are found in western Kenya (Kakemega forest). Bamboo and mixed indigenous afro-montane forests occupy Kenya's major 'water towers' which are Mount Nyiro, Mount Elgon, Mount Kenya, Mount Kulai, Mount Marsabit, Mau Forest Complex, Cherangani Hills, the Aberdares and the Mathews range (Mwangi et al., 2018). These forests not only contribute significantly to local economy, livelihoods of rural poor and forest dwelling and forest-adjacent communities but also provide most of Kenya's water supply; providing an estimated 15,800 million cubic metres of water annually through lakes and rivers (UNEP 2012).

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According to the Forests 2020 project, which was funded by the UK Space Agency, deforestation continues to be a key problem in Kenya. It loses about 12,000 hectares of forest each year through deforestation. About 12% of the land area, which was originally covered by closed canopy forests, has been reduced to about 1.7% of its original size. The deforestation of Kenya's Water Towers is undermining their ability to provide water. Forest loss, estimated at approximately 50,000 ha in 2000-2010, has led to a decline in water availability by approximately 62 million cubic meters annually (UNEP 2012).

Key drivers of deforestation and forest degradation are agricultural expansion, charcoal production, poor governance, weak institutions, corruption, illegal logging, weak law enforcement, allowing grazing in forest reserves and fire. Deforestation has the potential to rollback strides towards the attainment of the Government of Kenya's Vision 2030 and the Government's Big Four Agenda of food and nutritional security, affordable and decent housing, universal healthcare and manufacturing, if it is not urgently addressed.

Kenya is a party to the UNFCCC, it is adapting to climate change impacts to secure the country's economic development, including water and food supplies. Climate change strategies have been developed, including the National Climate Change Response Strategy (NCCRS), the National Climate Change Action Plan (NCCAP) 2013-2017 and the Green Economy Strategy and Implementation Plan and Intended Nationally Determined Contribution 2015 (INDC; https://www4.unfccc.int/sites/ndcstaging/PublishedDocuments/Kenya%20First/Kenya_NDC_20150723.pdf). Together with the Climate Change Act (2016), these documents all highlight forestry as one of the priority areas to move Kenya towards a low-carbon, climate-resilient development pathway.

Kenya has established a Forest Reference Level to get ready for receiving financial rewards for REDD+ activities. FRELs were calculated based on preliminary forest inventory plot data of aboveground biomass together with 10 years of forest cover change data derived from land cover change maps from Landsat imagery held by the Kenya Forest Service, which is the government agency in charge of all state-owned forest land in Kenya. The FRELs were submitted in 2020 to the UNFCCC Secretariat and were estimated at around +52M t $CO_2$eq/year (Ministry of Environment and Forestry, 2019; https://redd.unfccc.int/submissions.html?country=ken). The System for Land based Emission Estimation for Kenya (SLEEK) program supported the development of the land cover maps used to generate the FRELs. Kenya's NFI is in its infancy, and only a small number (a few hundred) of plots were established and measured. EFs for changes in carbon stocks were based on data from only 121 plots for the 10 forest strata established using the Improving Capacity in Forest Resources Assessment (IC-FRA) methodology (Kenya Forest Research Institute, 2016) from the pilot inventory. The data show a high uncertainty of the mean and extremely high standard deviations due to the small sample size and the large natural variation in woody cover and vegetation types. A comparison of data with other independent research in Kenya shows great variation in carbon and biomass values (Ministry of Environment and Forestry, 2019).

Forest conservation and restoration are important priorities for Kenya and there are a number of recent international and government-led initiatives aimed at forest restoration. For example, the government has

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moved forward its deadline for the 10% tree cover (5.1 million ha of forests) target from 2030 to 2022. It has committed to the following international initiatives:

- Restoring 5.1 million hectares of degraded and deforested landscapes by 2030, as its contribution to the African Forest and Landscape Restoration Initiative (AFR100), a pan-African, country-led effort to restore 100 million hectares of deforested and degraded landscapes.
- 50% reduction of greenhouse gases from the forest sector by 2030, as part of its Nationally Determined Contribution (NDC).
- Achieving land degradation neutrality by 2030 as a commitment to United Nations Convention to Combat Desertification (UNCCD) .
- Although increased government funding for restoration initiatives has not yet been forthcoming (Ministry of Environment and Forestry, 2019).

The Government of Kenya has committed to the following Presidential Directives to support achievement of the 10% tree cover:

- Accelerated attainment of 10% national tree cover by 2022.
- Commitment at One Planet Summit during the UNEA4 Conference to achieve and surpass Constitutional target of 10% National tree cover by 2022 .
- Clear milestones and indicators on progress on the 10% target.
- Review of teaching curriculum to include sustainable forest management.
- The gazettement of the Kenya Water Towers Agency (KWTA) in 2012.
- Allocation of 10% Corporate Social Responsibility (CSR) budget for tree growing by all Ministries, Department and Agencies (MDAs) (Ministry of Environment and Forestry, 2019).

Forest restoration is aligned with Kenya's domestic restoration targets, e.g., the 2012 Agriculture Bill requires agricultural land owners and occupiers to establish and maintain a minimum of 10% tree cover through farm forestry and Vision 2030's Premium Parks Initiative aims to create wildlife corridors and the rehabilitation and protection of water towers and catchment areas (https://afr100.org/content/kenya).
Both the Kenya Forest Service (KFS) and Kenya Wildlife Service (KWS) have forest management mandates, and they work together closely in areas of common jurisdiction. KWS is responsible for forest management inside protected areas. Forest management is decentralized to county-level government in Kenya with county administrators managing local government forests and supervising private and community forests. Other key institutions associated with forest management are the Ministry of Environment and Forests, the KWTA and the National Environment Management Authority (NEMA).

The Ministry of Environment and Forestry (MEF) imposed a blanket ban on logging in February 2018 which continues to date. This prohibits logging in public and community forests and the transportation of timber, so timber is being increasingly sourced from the private sector and imported from Tanzania from sustainable forest plantations.

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Together with the National Centre for Earth Observation in the UK, the Kenya Forest Service has produced a map of remotely sensed forest aboveground biomass derived from the preliminary forest inventory plot data and satellite remote sensing using machine learning (Rodríguez-Veiga et al., 2020).

The primary requirements for forest aboveground biomass data by stakeholders and users in Kenya hence are for the purpose of calculating accurate FRELs and monitoring the implementation of deforestation and forest degradation reduction pledges under the REDD+ initiative with a view to unlocking financial rewards for preserving and expanding Kenya's forest lands.

# 5. Conclusions

The user requirements derived from the First CCI+ Biomass User Meeting in Paris from (25-26 September 2018) and the CMUG meeting in Exeter on the 29-31st October 2018 covered the needs of two different communities, the climate and carbon modelling community (the primary focus for CCI+ Biomass) and the REDD+ community. Although these two communities agree on many of the major desirable properties of the products, there are significant differences because the models are based around the grid-cell structure of climate models (which typically means that spatial resolutions of 500m or coarser are acceptable) whereas REDD+ is country-based and needs resolution of 1 ha or better. This has strong implications for whether the project can deliver the validation, accuracy and biomass change estimation needed for REDD+.

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# Appendix

The figures below are the Mentimeter pull results from the second User Requirement Workshop.

## Session 1 - Mapping global biomass (28 June)

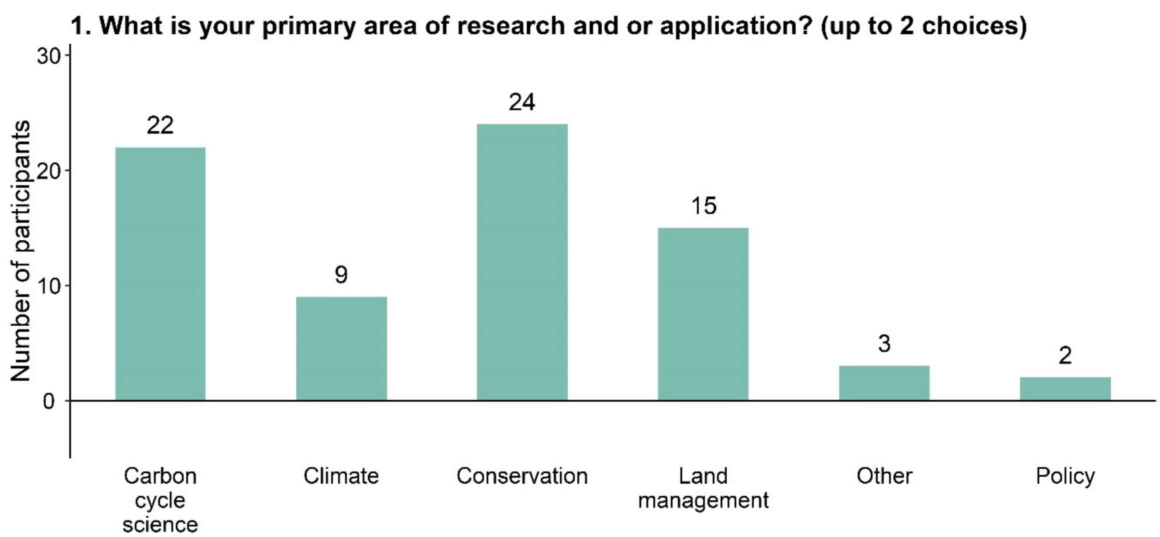


Figure A 1 Poll results on the main research area of the participants

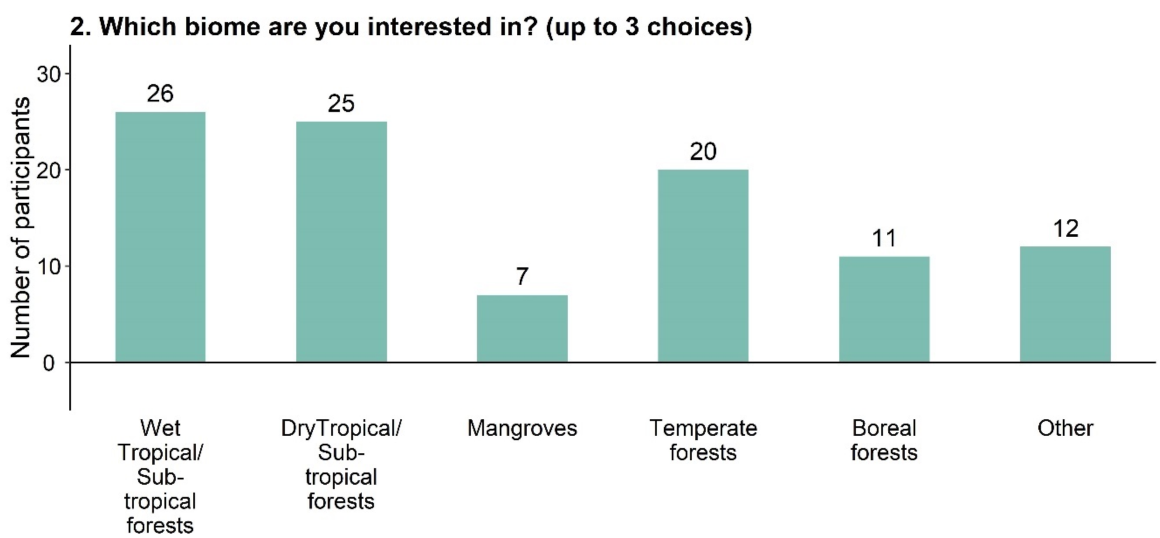


Figure A 2 Poll results on the biomes that the participants are interested in.


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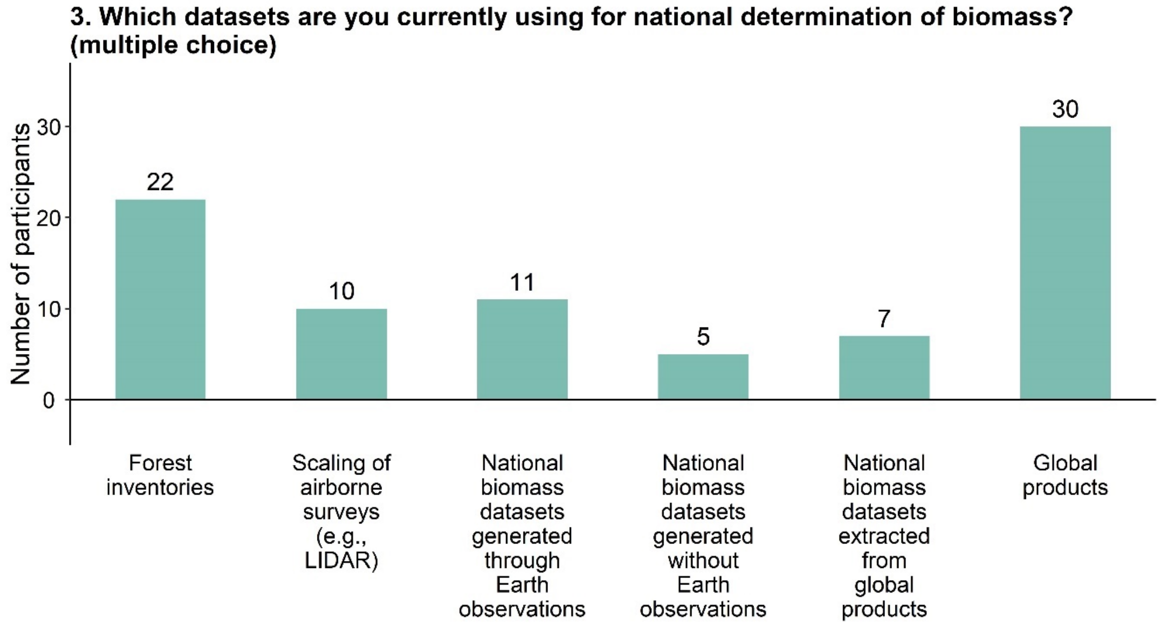


Figure A 3 Poll results on the datasets which the participants use for national determination of biomass.

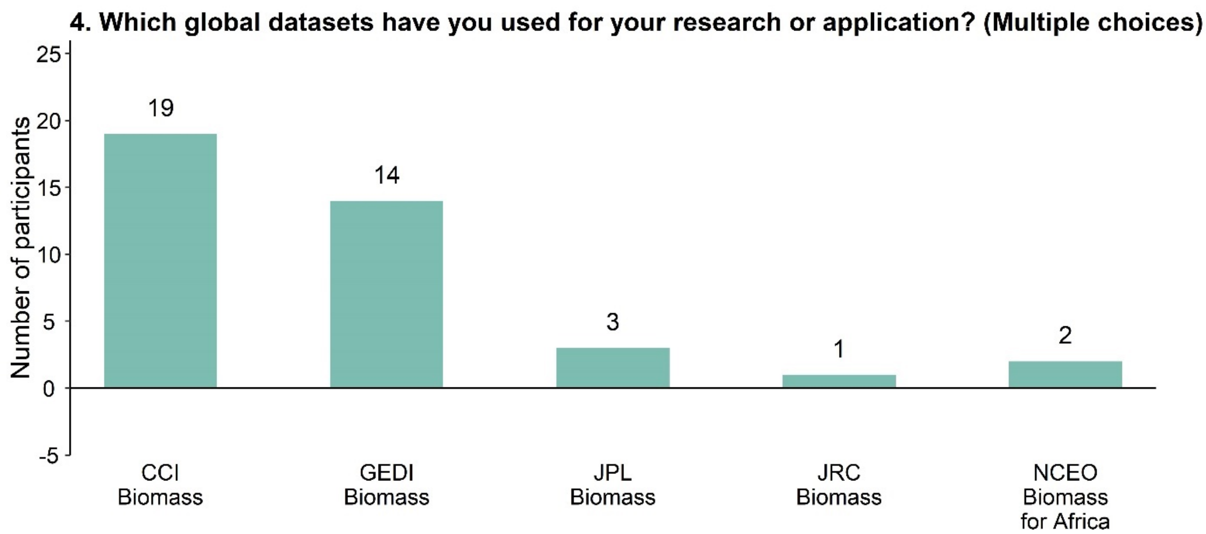


Figure A 4 Poll results on the datasets which the participants use for the research or application.

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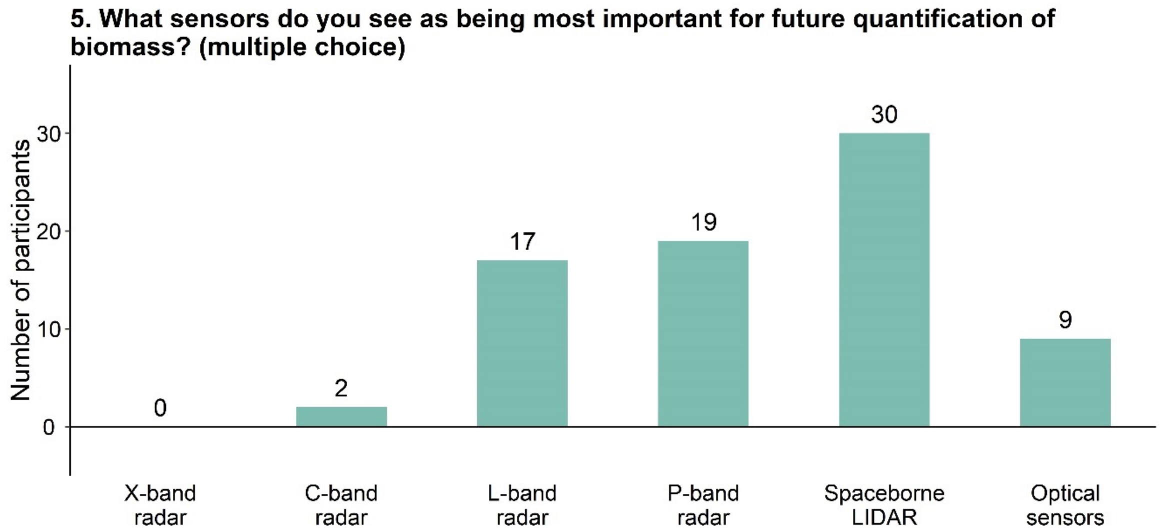


Figure A 5 Poll results on the desirable sensors for quantifying biomass in the future.


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## Session 2 - Evolving needs from national users (29 June)

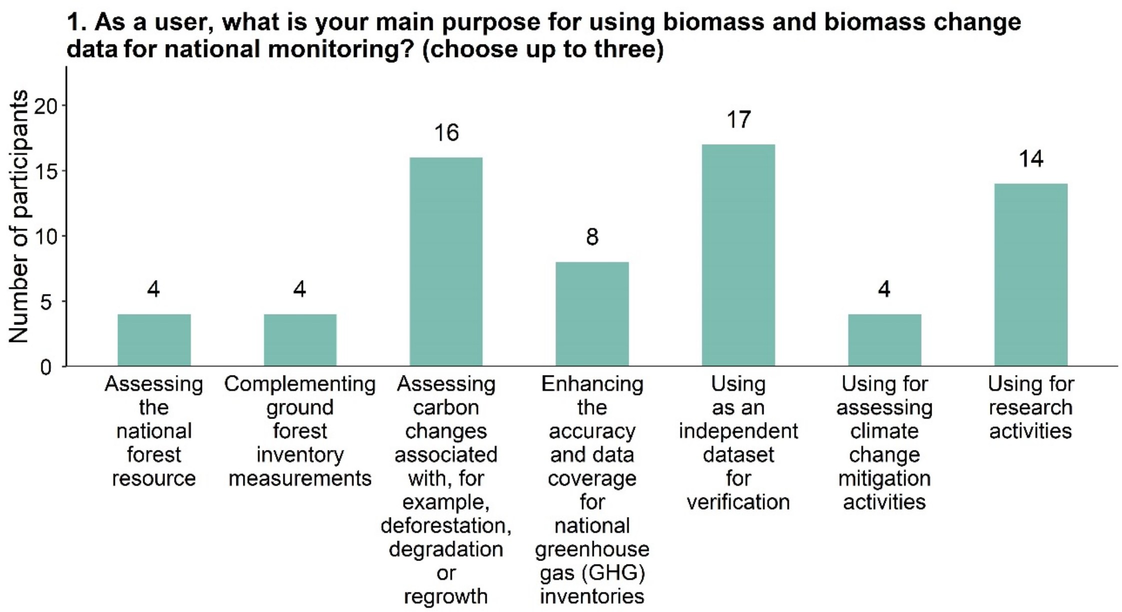


Figure A 6 Poll results on the main purpose for using the biomass data in national monitoring.

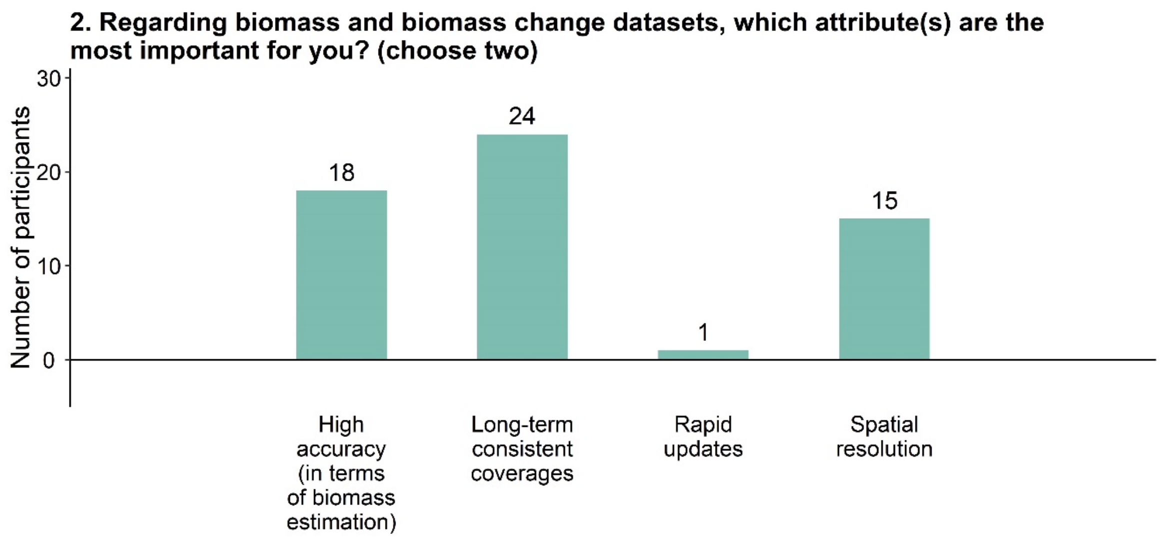


Figure A 7 Poll results on the attributes in priority of the biomass and biomass change datasets

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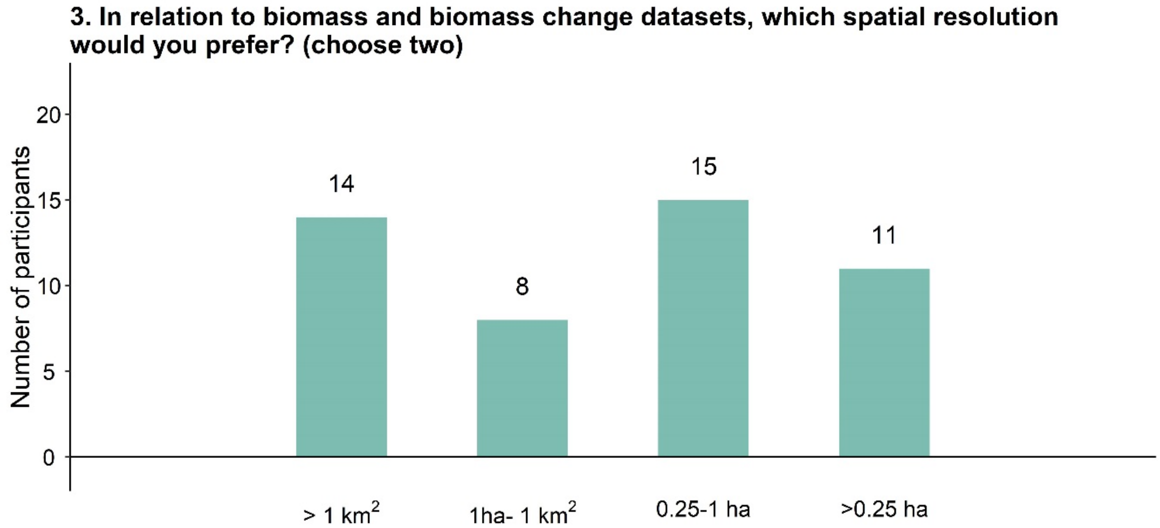


Figure A 8 Poll results on the preferable spatial resolution of the biomass and biomass change datasets

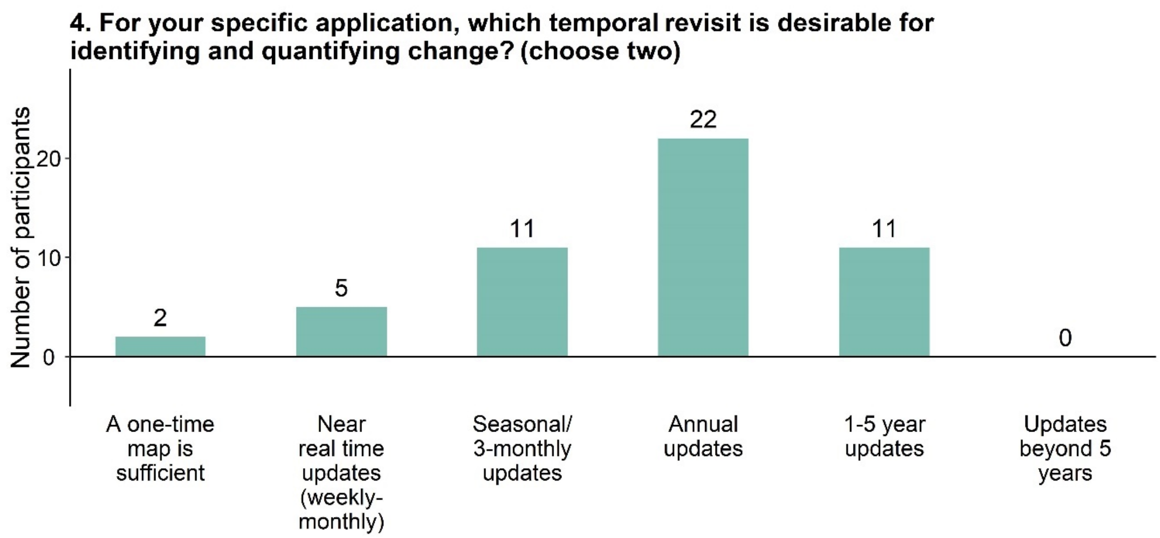


Figure A 9 Poll results on the preferable temporal revisit frequency for identifying the biomass change.

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## Session 3 Evolving climate user needs for biomass change (30 June)

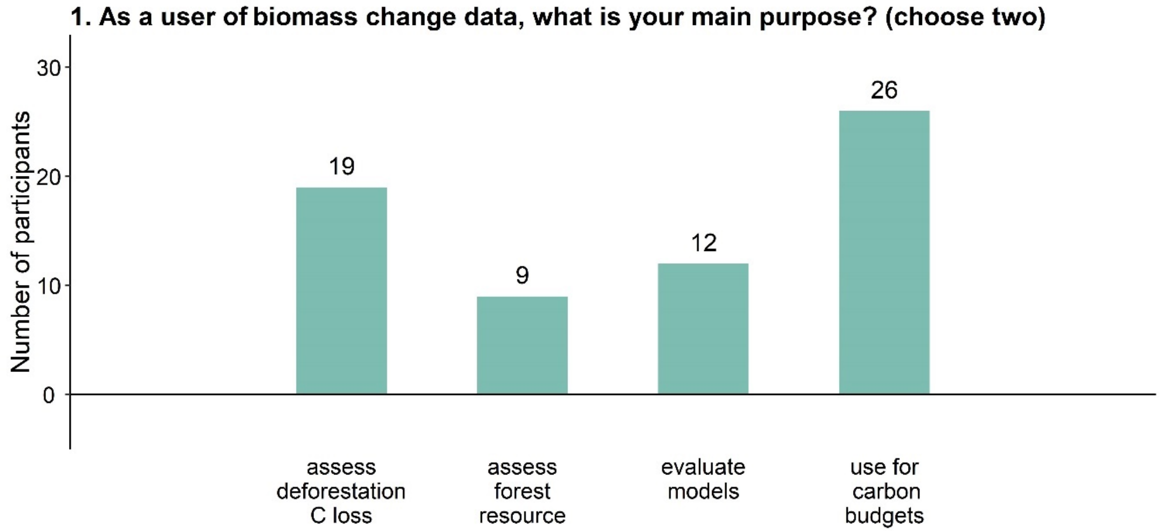


Figure A 10 Poll results on the main purpose for using the biomass change data

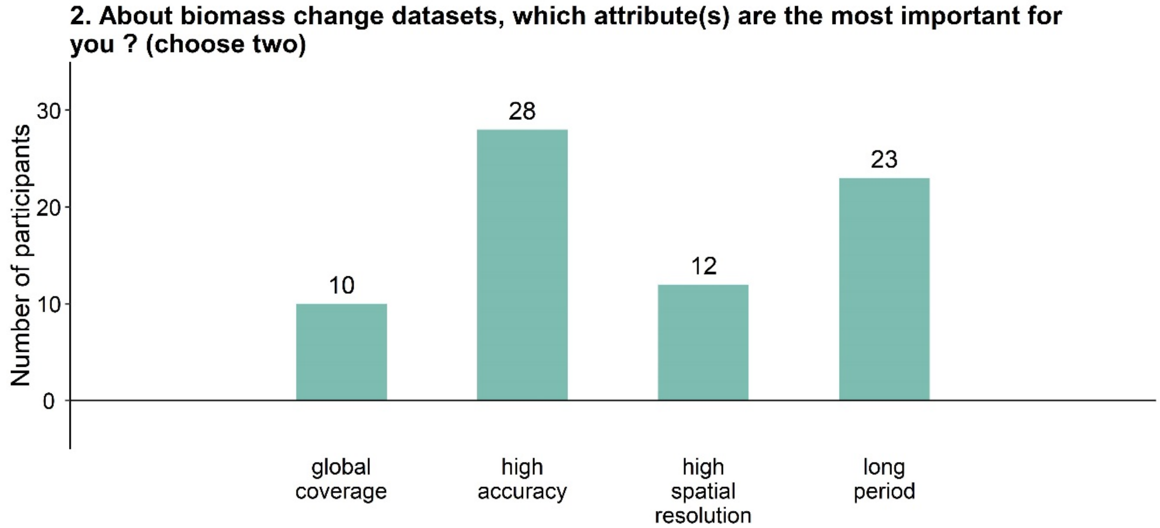


Figure A 11 Poll results on the attributes in priority of the biomass and biomass change datasets

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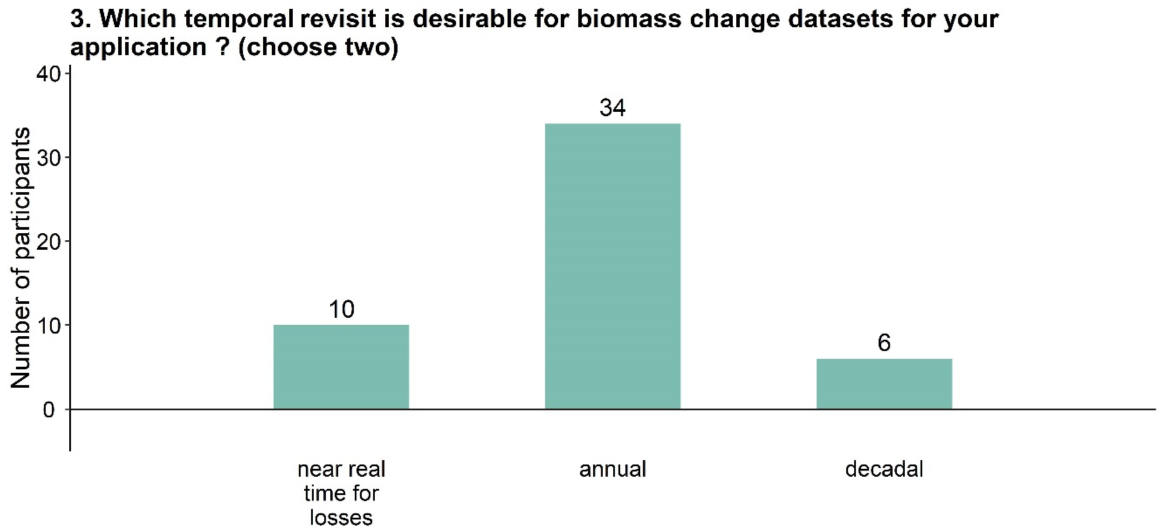


Figure A 12 Poll results on the preferable temporal revisit frequency for the biomass change datasets


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