Independent Monitoring: Building trust and consensus around GHG data for increased accountability of mitigation in the land use sector

Final report

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AUTHORS

Hannes Böttcher, Lara Mia Herrmann

Öko-Institut e.V.

Martin Herold, Erika Romijn, Rosa Maria Roman Cuesta, Valerio Avitabile, Veronique De Sy

Wageningen University (WUR)

Christopher Martius, David Gaveau

Center for International Forestry Research (CIFOR)

Steffen Fritz, Dmitry Schepaschenko, Antonia Dunwoody

International Institute for Applied Systems Analysis (IIASA)

Independent Monitoring:

Building trust and consensus around GHG data for increased accountability of mitigation in the land use sector

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TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

LIST OF ANNEXES

ABSTRACT

The Paris Agreement stresses the importance of the land use sector and many countries have included land use sector targets in their nationally determined contributions (NDCs). They will need to account for emissions and removals from the sector in a manner that promotes transparency, accuracy, completeness, comparability and consistency.

Stakeholders involved have therefore called for "**independent monitoring" (IM)** approaches, i.e. authoritative, unbiased sources of information that they could rely on for their specific needs. More and more datasets and portals that serve these needs have recently emerged (e.g. Global Forest Watch, OpenForis).

A **stakeholder survey** was carried out to identify the level of satisfaction with existing datasets and portals. These were also assessed in a **SWORG analysis**. We identified common misunderstandings and **challenges**, such as technical data issues, difficulties regarding data use and interpretation and issues of access and capacities. There is also a lack of awareness and capacities to use IM approaches. In four **case studies** we illustrate possible pathways to overcome these challenges.

We present key **elements** that are considered to be essential for effective use of IM approaches for land use sector MRV. Bringing the assessment of user needs, opportunities for existing approaches and identification of gaps together, we formulate concrete **recommendations** for specific stakeholder groups, including data providers and users.

RESUME

L'accord de Paris met en avant l'importance du secteur de l'usage des sols, et de nombreux pays ont inclus des objectifs liés à ce secteur dans leur NDC. Ces pays devront prendre en compte les émissions et absorptions du secteur de façon transparente, précise, complète, comparable et cohérente.

Il y a donc une demande pour un "**monitoring indépendant**" **(IM)**, fournissant une information fiable et non-biaisée aux parties prenantes. De plus en plus de jeux et de portails de données répondant à ce besoin se développent (comme Global Forest Watch ou OpenForis).

Nous avons mené une **enquête auprès des parties prenantes** pour identifier le niveau de satisfaction quant aux données existantes; et ces données ont subi une **analyse SWORG**. Nous avons identifié des **défis** à relever, concernant des incompréhensions récurrentes, des aspects techniques, des difficultés à utiliser ou interpréter les données, ou à y avoir accès. Pour quatre **études de cas**, nous proposons un moyen de pallier à ces problèmes.

Nous présentons des **éléments clés**, essentiels à l'efficacité de l'IM pour le MRV dans le secteur de l'usage des sols. Ayant analysé les besoins des usagers et les opportunités et manques existants, nous formulons des **recommandations** concrètes pour les différentes parties prenantes, notamment pour les producteurs et les usagers des données.

EXECUTIVE SUMMARY

The Paris Agreement stresses the importance of the land use sector and many countries have included land use sector targets in their nationally determined contributions (NDCs). They will need to account for emissions and removals from the sector in a manner that promotes transparency, accuracy, completeness, comparability and consistency.

Stakeholders involved have therefore called for "**independent monitoring" (IM)** approaches, i.e. authoritative, unbiased sources of information that they could rely on for their specific needs. More and more datasets and portals that serve these needs have recently emerged (e.g. Global Forest Watch, OpenForis).

A **stakeholder survey** was carried out to identify the level of satisfaction with existing datasets and portals. These were also assessed in a **SWORG analysis**. There are differences in stakeholder views; however, in essence most stakeholders agree that IM approaches broaden stakeholder participation and confidence by providing (free and open) information which complements mandatory reporting by national governments.

IM does not constitute one single system or a one-serves-all approach. Instead, IM relies on access to a diversity of inter-operable approaches, datasets and initiatives. Independent monitoring approaches can help to detect, anticipate and resolve potential conflicts or discrepancies between datasets.

However, we identified common misunderstandings and **challenges**, such as technical data issues, difficulties regarding data use and interpretation and issues of access and capacities. There is also a lack of awareness and capacities to use IM approaches.

In four **case studies** we illustrate possible pathways to overcome these challenges. They are addressing 1) an assessment of global land use emission datasets regarding patterns, uncertainties and drivers, 2) an assessment of forest change, deforestation and degradation datasets in Indonesia and Borneo, 3) an assessment of forest biomass mapping uncertainties and their integration into regional estimation and national reporting, and 4) an analysis of gaps and opportunities for using biophysical soil models for GHG reporting.

We synthesized the results from the stakeholder survey, case studies and other evidence collected from literature into a list of nine **key elements** of IM approaches:

- **Element 1: Transparency and clarity**
- **Element 2: Accuracy and uncertainty**
- **Element 3: Consistency and completeness**
- **Element 4: Comparability and interoperability**
- **Element 5: Complementarity and scale**
- **Element 6: Reproducibility and adaptability**
- **Element 7: Access and distribution**
- **Element 8: Participation and equity**
- **Element 9: Responsibility and accountability**

All key elements form ingredients for independent monitoring approaches towards increased transparency and accountability. It would be ideal if IM approaches would not have any negative effects on any of these key elements, but in reality, trade-offs will be unavoidable. Accuracy levels might be lower with increased comparability and interoperability, e.g. due to data aggregation or harmonisation.

Independent monitoring should be considered an important mechanism for enhancing particularly one high-level goal: transparency in the land-use sector. Stakeholders can engage and benefit from independent monitoring approaches to achieve transparency when starting to implement the Paris Agreement. Independent monitoring underpins in crucial ways the Paris Agreement's Transparency Framework, because monitoring achievements, at the heart of the Agreement, require independent approaches to be effective, efficient and allow for equity.

Bringing the assessment of user needs, opportunities for existing approaches and identification of gaps together, we formulate concrete **recommendations** for specific stakeholder groups, including data providers and users.

Independently of the dataset and application the following recommendations are fundamental to all providers and must be considered when providing data for enhancing transparent monitoring:

- All data need to be transparent including the original data sources. Definitions, methodologies and assumptions should be clearly described to facilitate replication and assessment. All datasets need to include accuracy assessments and uncertainties;
- Methods for data production need to be publicly available and preferably published in peer-reviewed papers;
- Data systems require regular update data and consistent estimates over time; including long-term sustainability of production;
- The institutional background of the data producer should be known and understood by all stakeholders involved.

Important recipients of the recommendations are EU institutions and programmes that are managing spatially explicit data sources or acting as data providers. **Copernicus** is the European Earth observation programme[1], successor of GMES (Global Monitoring for Environment and Security). It aims at collecting and providing environmental information and services for policymakers and public authorities. Specific recommendations to EU Copernicus are:

1. We recommend the development and long-term operation of three dedicated Copernicus services to address the needs from different stakeholder groups: (1) improving national REDD+ and AFOLU reporting, (2) a Copernicus global AFOLU transparency data system, and (3) Copernicus land use mitigation tracker service.
2. We recommend using the capabilities of Sentinels 1 and 2 to expand global monitoring for forest area change to include land use change (incl. drivers of forest change), land management, biomass burning, wetlands and peatlands, and for near-real time alerting.

[1] http://www.copernicus.eu/main/overview

3. We recommend enhancing participation and accountability of stakeholders through improved monitoring to fulfil the requirements from the Paris Climate agreement, in addition to meeting the known UNFCCC / IPCC TACCC criteria for estimation and reporting.

The **ESA Biomass mission** is the seventh ESA Earth Explorer to be launched in 2021[2]. It will be able to estimate forest biomass, canopy height and changes with a P-band synthetic aperture radar (SAR). Specific recommendations for biomass mapping from space using such technologies are:

4. Research and pre-operational demonstrations are required to improve the quality, consistency and complementarity of satellite-derived biomass map products before they can be useful for land use sector climate change mitigation assessments. Efforts should capitalize on the new dedicated satellite missions and aim for "best estimates" synergizing from the variety of space and ground-based data sources.
5. We recommend to the EC to ensure seamless continuity and consistency of biomass mapping from space after the ESA BIOMASS mission ends.
6. International research and UN organizations (such as IPCC, JRC, FAO, GFOI/GOFC-GOLD) are encouraged to provide demonstrations and community-consensus guidance to better harmonize space-based and NFI-based biomass estimations, and their integration with activity data to improve emission factors.

The implementation of the Enhanced Transparency Framework is a great opportunity to build confidence and legitimacy. This process can cause (initial) frustration but will enhance quality in the long-term. Transparency requires capacities. Circumstances and capabilities of countries and stakeholders vary, and flexibility is required to allow for step-wise improvements. Specific recommendations for **developers of good practice guidance** are:

7. We recommend providing guidance for integrating/combining global data with national inventory information for higher tier level reporting.
8. We recommend developing guiding principles for assessing uncertainties associated with these approaches and how to reduce them.

According to IPCC guidance, verification of GHG inventories is key to improve scientific understanding and to build confidence on GHG estimates and their trends. The global modelling and carbon science community can help in building confidence in land use emission estimates by providing independent references for GHG inventories. This will increase transparency, accuracy, consistency, completeness and comparability, especially in countries with limited own capacities. Meaningful verification requires improving mutual understanding and cooperation between the scientific community and compilers of national GHG inventories. A successful partnership between results from global models of GHG cycling and requirements for MRV and policy needs a clear formulation of the technical requirements for reporting purposes to be addressed by models. Specific recommendations to **global modelling and carbon science community** are:

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[2] https://earth.esa.int/web/guest/missions/esa-future-missions/biomass

9. We recommend considering reporting purposes much more as an application of models and to make models more consistent with current IPCC guidelines and country GHG reporting.
10. We recommend to model developers and model users establishing an infrastructure that allows for models to be independently parametrized, calibrated, run, and evaluated. Such infrastructures would not only increase transparency of model application but also allow for continuous improvement of model and data by users.
11. We recommend to the scientific community to help advancing IPCC guidance and contributing to improved emission factors.
12. We recommend a joint effort to reconcile the large differences between the AFOLU databases, scientific studies (as reflected in IPCC reports) and the country reported data. The IPCC should facilitate such a dialogue and develop consensus to ensure that AFOLU estimations in the following scientific assessment reports are also consistent and comparable with those provide by countries and independent remote sensing and modelling studies, and incorporate the findings in the methodological update of the IPCC GPG.
13. We recommend improving data sources and approaches underpinning a complete, comparative, timely, consistent and reproducible assessment of AFOLU flux estimations; including the use of Copernicus assets.

The availability of open and ready-to-use data and tools for independent monitoring increases opportunities for GHG reporting, planning and implementation of land-based mitigation policies. But such approaches might also be subject to misuse or misinterpretation. Independent monitoring opportunities for inventory compilers and reviewers, especially in developing countries, emerge from freely accessible tools for remote sensing analysis, such as the stratification of sampling for national forest inventories, data processing and modelling etc. However, national experts need to be aware of the limitations of global datasets to be able to integrate them appropriately into national inventory work. Specific recommendations to **government agencies, national inventory experts and reviewers** are:

14. We recommend that countries build and maintain institutional capacity capable of using independent monitoring approaches.
15. We recommend that data and tools and related documentation used in producing GHG inventory become open source as much as possible.

In order to qualify the main recommendations and provide some prioritization of recommended actions we provide more concrete suggestions for implementation. We give an indication of the time horizon needed (from short (1-2 years), to medium (3-5 years), and long (5-10 years)). We also give an indication of costs. Low costs means there are multiple benefits, use cases for other purposes, international coordination processes, guidance developments etc. of recommended activities. Medium costs occur for demonstration and collaboration projects, such as H2020 or Cost Actions. High costs are expected if significant investments are needed or long-term operation of services and new space assets are required.

SOMMAIRE EXECUTIF

L'accord de Paris met en avant l'importance du secteur de l'utilisation des terres, et de nombreux pays ont inclus des objectifs liés à ce secteur dans leur NDC. Ces pays devront prendre en compte les émissions et absorptions du secteur de façon transparente, précise, complète, comparable et cohérente.

Il y a donc une demande pour un "***monitoring* indépendant**" **(IM)**, fournissant une information fiable et non-biaisée aux parties prenantes. De plus en plus de jeux et de portails de données répondant à ce besoin se développent (comme Global Forest Watch ou OpenForis).

Nous avons mené une **enquête auprès des parties prenantes** pour identifier le niveau de satisfaction quant aux données existantes; et ces données ont subi une **analyse SWORG**. Les avis de ces parties prenantes divergent, mais généralement la plupart s'accordent sur le fait que l'IM favorise la participation et la confiance de ces mêmes parties prenantes, en fournissant des informations (gratuites et libres d'accès) qui complètent le *reporting* obligatoire fait par les gouvernements nationaux.

Le monitoring indépendant n'est pas un système unique ou une approche tout-en-un. Au contraire, l'IM repose sur l'accès à une diversité de techniques, données et initiatives, à la fois compatibles et complémentaires. L'IM peut aider à détecter, anticiper et résoudre des conflits ou incohérences entre jeux de données.

Cependant, nous avons identifié des **défis** à relever, concernant des incompréhensions récurrentes, des aspects techniques, des difficultés à utiliser ou interpréter les données, ou à y avoir accès.

Pour quatre **études de cas**, nous proposons un moyen de pallier à ces problèmes. Ces cas sont : 1) les *patterns*, incertitudes et *drivers* de jeux de données évaluant les émissions du changement d'utilisation des terres ; 2) des données évaluant la déforestation et la dégradation des forêts en Indonésie et à Bornéo ; 3) des cartographies de données de biomasse forestière, leur incertitude et la façon dont elles sont utilisées dans le *reporting* régional et national ; 4) une analyse des manques et opportunités quant à l'usage des modèles biophysiques de sol pour le *reporting* des émissions.

Nous présentons neuf éléments clés pour l'IM, résultant de la synthèse de notre enquête, des études de cas et de l'étude de la littérature sur le sujet. Ces éléments sont :

- **Elément 1: Transparence et clarté**
- **Elément 2: Précision et incertitude**
- **Elément 3: Cohérence et complétude**
- **Elément 4: Comparabilité et interopérabilité**
- **Elément 5: Complémentarité et échelles**
- **Elément 6: Reproductibilité et adaptabilité**
- **Elément 7: Accès et distribution**
- **Elément 8: Participation et équité**
- **Elément 9: Responsabilité et responsabilisation**

Tous ces éléments clés constituent des ingrédients pour un *monitoring* indépendant favorisant transparence et responsabilité. Il serait idéal que l'IM n'ait aucun effet négatif sur l'un ou l'autre de ces éléments, mais en réalité les compromis seront inévitables. La précision pourrait être plus faible afin d'assurer comparabilité et interopérabilités, par exemple vis-à-vis de l'agrégation ou de l'harmonisation de données.

Le *monitoring* indépendant devrait être considéré comme un mécanisme important pour renforcer l'objectif capital qu'est la transparence dans le secteur de l'utilisation des terres. Les parties prenantes peuvent ainsi s'engager et bénéficier de l'IM pour améliorer la transparence de l'implémentation de l'accord de Paris. L'IM soutient en effet de manière cruciale le cadre de transparence de l'accord de Paris car le *monitoring*, clé de l'accord, exigeant une approche indépendante, efficace et équitable.

Ayant analysé les besoins des usagers et les opportunités et manques existants, nous formulons des **recommandations** concrètes pour les différentes parties prenantes, notamment pour les producteurs et les usagers des données.

Indépendamment des données ou de leur application, les recommandations suivantes sont fondamentales pour tous les fournisseurs, et elles doivent être prises en compte afin d'améliorer la transparence du *monitoring*:

- Toutes les données doivent être transparentes quant à leurs sources. Les définitions, méthodologies et hypothèses doivent être clairement décrites pour en faciliter la reproduction et l'évaluation. Tous les jeux de données doivent inclure une évaluation de précision et d'incertitude ;
- Les méthodes de production des données doivent être disponibles publiquement, et de préférence publiées dans des articles évalués par des pairs ;
- Les systèmes de données nécessitent des mises à jour régulières, et ils doivent fournir des estimations cohérentes et durables sur le long terme ;
- Le contexte institutionnel du producteur de données doit être connu et compris par toutes les parties prenantes concernées.

Les institutions et programmes de l'UE qui gèrent ou fournissent des données spatialement explicites sont tout particulièrement concernés par ces recommandations. **Copernicus** est le programme européen d'observation de la Terre, successeur de GMES. Il vise à recueillir et à fournir des informations et des services environnementaux aux décideurs et aux autorités publiques. Nos recommandations spécifiques à l'UE et Copernicus sont :

1. Nous recommandons le développement et le fonctionnement sur le long terme de trois services dédiés de Copernicus, afin de répondre aux besoins des différentes parties prenantes : 1) une amélioration du *reporting* national pour REDD+ et l'AFOLU ; 2) un système transparent de données globales pour l'AFOLU ; 3) un service de suivi des efforts d'atténuation des émissions liées à l'utilisation des terres.
2. Nous recommandons d'utiliser les capacités de Sentinels 1 et 2 pour élargir la surveillance mondiale de la modification des zones forestières, afin d'y inclure les changements d'utilisation des terres (y compris les *drivers* du changement des forêts), la gestion des terres, la combustion de la biomasse, les zones humides et les tourbières, ainsi que pour l'alerte en temps quasi-réel.

3. Nous recommandons de renforcer la participation et la responsabilisation des parties prenantes en améliorant le *monitoring* afin de satisfaire aux exigences de l'accord de Paris sur le climat, en plus de satisfaire aux critères connus du TACCC du GIEC pour l'estimation et le *reporting*.

La **mission ESA Biomass** fait partie du septième ESA Earth Explorer, qui sera lancé en 2021. Il sera en mesure d'estimer la biomasse forestière, la hauteur du couvert et les changements. Nos recommandations spécifiques pour la cartographie de la biomasse à partir de l'espace utilisant cet outil sont :

4. Des démonstrations de recherche et pré-opérationnelles sont nécessaires pour améliorer la qualité, la cohérence et la complémentarité des produits cartographiques de la biomasse dérivés des satellites, avant qu'ils puissent être utiles pour évaluer les efforts d'atténuation réalisés dans le secteur de l'utilisation des terres. Le travail devraient capitaliser sur les nouvelles missions satellites spécialisées, et viser à produire les « meilleures estimations possibles » en combinant les diverses sources de données spatiales et terrestres.

5. Nous recommandons d'assurer une continuité et une cohérence totales dans la cartographie spatiale de la biomasse.

6. La recherche internationale et les organisations des Nations Unies (telles que l'IPCC, le CCR, la FAO, GFOI / GOFC-GOLD) sont encouragées à fournir des démonstrations et des aides pour mieux harmoniser les estimations de biomasse depuis l'espace, ainsi que leur intégration avec les données locales d'activité dans le but d'améliorer les facteurs d'émission.

La mise en œuvre du cadre de transparence renforcée est une excellente occasion de renforcer la confiance et la légitimité. Ce processus peut provoquer une frustration (initiale) mais améliorer la qualité à long terme. La transparence exige des capacités. Les contextes et les capacités des pays et des parties prenantes varient, et une flexibilité est requise pour permettre des améliorations par étapes. Les recommandations spécifiques à l'intention des **concepteurs d'orientations relatives aux bonnes pratiques** sont :

7. Nous recommandons de fournir des *guidelines* pour l'intégration / la combinaison de données mondiales et d'informations d'inventaires nationaux pour les rapports de niveau supérieur.

8. Nous recommandons d'élaborer des principes directeurs pour évaluer les incertitudes associées à ces approches et trouver comment les réduire.

Selon les directives IPCC, la vérification des inventaires d'émissions est essentielle pour améliorer la compréhension scientifique et renforcer la confiance dans ces estimations. La communauté mondiale de la modélisation et de la science du carbone peut y aider en fournissant des estimations indépendantes. Cela accroîtra la transparence, l'exactitude, la cohérence, l'exhaustivité et la comparabilité, en particulier dans les pays aux capacités propres limitées. Pour être significatif cela implique l'amélioration de la compréhension mutuelle et de la coopération entre la communauté scientifique et les inventoristes. Un partenariat réussi entre les modèles globaux des cycles des gaz à effet de serre et les exigences en matière de MRV nécessite une formulation claire des exigences techniques des modèles utilisés à des fins de *reporting*. Les recommandations spécifiques à la **communauté des modèles globaux et de la science du carbone** sont :

9. Nous recommandons d’envisager le *reporting* comme une application directe des modèles, et en conséquence de les rendre plus cohérent avec les *guidelines* IPCC et le *reporting* fait par les pays.

10. Nous recommandons aux développeurs et aux utilisateurs des modèles de mettre en place une infrastructure permettant de paramétriser, calibrer, faire tourner et évaluer les modèles de façons indépendante. Une telle infrastructure ne permettrait pas uniquement de rendre plus transparente l’utilisation des modèles, mais aussi d’améliorer en continue les modèles et les données par le biais des utilisateurs.

11. Nous recommandons à la communauté scientifique d’aider à améliorer les *guidelines* IPCC et les facteurs d’émission.

12. Nous recommandons un effort conjoint pour concilier les grandes différences entre les bases de données AFOLU, les études scientifiques (telles que reflétées dans les rapports IPCC) et les données déclarées par les pays. IPCC devrait faciliter ce dialogue et dégager un consensus pour s'assurer que les estimations de l'AFOLU contenues dans les rapports d'évaluation scientifiques à venir sont également cohérentes et comparables à celles fournies par les pays, les études indépendantes de télédétection et de modélisation, et modifier les *guidelines* IPCC si nécessaire.

13. Nous recommandons d'améliorer les sources de données et les approches qui sous-tendent une évaluation complète, comparative, opportune, cohérente et reproductible des estimations des flux AFOLU, y compris en utilisant les produits de Copernicus.

La disponibilité de données et d'outils ouverts et prêts à l'emploi pour un *monitoring* indépendant accroît les possibilités de *reporting* des émissions, de planification et de mise en œuvre de politiques d'atténuation liées à l’utilisation des terres. Mais de telles approches pourraient également être sujettes à une mauvaise utilisation ou à une interprétation erronée. Ainsi, les limites des jeux de données mondiaux doivent être connues, pour être en mesure de les intégrer de manière appropriée dans le travail d'inventaire national. Suivent nos recommandations spécifiques pour **les experts et *reviewers* des inventaires nationaux** :

14. Nous recommandons aux pays de créer et de maintenir des institutions capables d'utiliser les approches de monitoring indépendant.

15. Nous recommandons que les données et les outils et la documentation connexe utilisés dans la production d'inventaires d’émissions deviennent *open source* autant que possible.

Afin de classifier ces principales recommandations et de donner une priorité aux actions recommandées, nous proposons des suggestions plus concrètes de mise en œuvre. Nous donnons une indication de l'horizon temporel nécessaire (de court (1-2 ans), à moyen (3-5 ans) et long (5-10 ans)). Nous donnons également une indication des coûts. De faibles coûts impliquent de multiples avantages, et ces cas spécifiques peuvent être utiles à d'autres fins : processus de coordination internationale, développements de *guidelines*, etc. Des coûts moyens apparaissent pour les projets de démonstration et de collaboration, tels que H2020 ou Cost Actions. Des coûts élevés sont attendus si des investissements importants sont nécessaires, dans le cas d’exploitation à long terme des services, ou si des outils spatiaux doivent être déployés.

1 INTRODUCTION

1.1 Background

According to the most recent IPCC Fifth Assessment Report on Climate Change, global greenhouse gas (GHG) emissions must be cut by 41-72% below 2010 levels by 2050 for a likely chance of limiting the increase in the global mean temperature to 2°C (IPCC 2013). This requires inter alia substantial changes in land use. "*The **[land] sector** accounts for about a quarter of net anthropogenic GHG emissions mainly from deforestation, agricultural emissions from soil and nutrient management and livestock (medium evidence, high agreement).*" The 2015 Paris Agreement requires all countries to put forward nationally determined contributions (NDCs) to fight climate change. The Enhanced Transparency Framework was established to enable the tracking, comparing and understanding of national commitments. Countries will need to provide necessary information based on data to track progress towards implementing and achieving their NDCs and on reducing GHG emissions. This information will be used for a Global Stocktake conducted every five years. The Paris Agreement also encourages other stakeholders, including civil society and the private sector, to participate in efforts to address and respond to climate change.

Many countries have included agriculture, forestry and other land use (**AFOLU**) targets in their NDCs and they will need to account for anthropogenic emissions and removals from the AFOLU sector in a manner that promotes environmental integrity, transparency, accuracy, completeness, comparability and consistency. This is especially problematic in many developing countries where monitoring capacities are low, and the potential of mitigation in the AFOLU sector is high. In this context, NDCs for land use mitigation can only be effective if contributions from the land sector are quantifiable and progress can be tracked unambiguously. This requires:

- a shared understanding of specific emission sources and sinks and their mitigation potential, i.e. trust in data and definitions by recipients, donors and users (esp. in private sector),
- supported by objective tools to guide implementation at local, national and landscape scales,
- their transparent use and implementation, and finally
- **accountability** of all stakeholders.

Accountability: refers to the acknowledgment and assumption of responsibility for actions, products, decisions, and policies including the administration, governance, and implementation as the obligation to report, explain and be answerable for resulting consequences.

A considerable amount of independent, publicly available, comprehensive spatial (regional to global scale) **data** on land cover, land emissions, land use, their dynamics and the associated carbon stocks and flows has become available (e.g., Global Forest Watch; (Avitabile et al. 2016; Federici et al. 2015; Hansen et al. 2013; Roman-Cuesta, Herold et al. 2016). There is also a number of data portals that offer free access to such datasets and facilitate the analysis of data without much capacities required by the user (see Box 1 for examples). These datasets and portal have the potential for supporting the upcoming monitoring, reporting and verification tasks in the land use sector.

However, the discrepancies of estimates due to different conceptual and methodological approaches (e.g. Grassi et al. 2017), the inappropriate scale, the lack of data on uncertainties and limited guidance on how to and how not to use such information, limits their usefulness and may

Legitimacy: refers to the right and acceptance of an authority, i.e., a governing law or government system.

cause questions regarding the **legitimacy** of independently gathered information with various stakeholders.

Users have therefore called for **independent monitoring (IM) approaches**, i.e., authoritative, unbiased templates and sources of information that they could rely on for their own business, but which would also be perceived as convenient and legitimate when dealing with other users. While this silver bullet does not exist, and perhaps never will, existing approaches nonetheless leave significant room for improvement.

Independent monitoring (IM) approaches: refer to datasets, tools, and portals etc. that support countries' needs by providing complementary data to what is mandated by their own monitoring systems.

The existing challenges for a more effective and transparent use of independent monitoring approaches can be related to 1) technical data characteristics, 2) the use of data and its interpretation, and 3) the ability and capacity of stakeholders.

1.2 Methods

In 2015 the European Commission DG CLIMA commissioned a project on "Strengthening Independent Monitoring of GHG Emissions from Land Activities for Publishing, Comparing and Reconciling Estimates", short "Independent Monitoring". The project ran 27 months and aimed at "*developing a proof of concept for publicly available, comprehensive, global, spatial information systems on land cover, land emissions, land use and associated trends*". Such systems would be intended to softly reconcile estimates and underlying methodologies, to facilitate dissemination of information, to identify hotspots of land emissions and to prioritize effective and efficient climate action in the land use sector, at the global scale. Tasks of the project included:

- Identifying key gaps and limitations of current land use emission IM approaches;
- Understanding the actual needs of users regarding IM approaches;
- Developing a proof of concept through solving typical IM approach challenges in concrete case studies;
- Drawing conclusions and deriving targeted recommendations for future efforts towards IM approaches.

An online **stakeholder survey** with more than 500 participants was carried out to identify the current level of satisfaction of users with existing information and actual user needs; particularly those of users with limited capacities (see Annexes III.a and III.b). The project analysed land monitoring datasets and portals in a **SWORG analysis**. Strengths, weaknesses, opportunities, risks and gaps of existing datasets were assessed through an assessment framework based on a number of criteria (see Annex II.b and Annexes IV.a and b).

Based on the analysis above we selected, developed and carried out four **case studies** to illustrate possible pathways to overcome the challenges reported by stakeholders and identified in the SWORG analysis (see Annex V). We identified a number of common misunderstandings and **challenges**, ranging from technical data issues, to difficulties regarding data use and interpretation as well as issues of access and capacities (see Chapter 2). Key **elements** that are considered to be essential for the effective use of IM approaches for land use sector MRV were derived from the case studies and further complemented in workshops, also involving external experts (see Chapter 3). In a conceptual model challenges and key elements for overcoming them were analysed regarding their effectiveness to achieve an improved monitoring for more accountability of land use mitigation actions.

Finally we draw conclusions and **recommendations** for specific stakeholder groups, including data producers, users and data-providing institutions (see Chapter 4).

The report aims to provide a better understanding of and explain the challenges and opportunities associated with land sector GHG monitoring and the role for approaches involving independent monitoring information. It does not provide **the** solution to fix data discrepancies and conflicts, nor does it present a comprehensive methodology for all fields of IM approaches. The report rather introduces the problematic aspects, typical IM situations, and indicative ways to reach innovative solutions.

For the purpose of this report, IM approaches refer to the measurements of emission and removals of GHGs from biomass and soils over time (i.e., REDD+ and LULUCF). Yet, other climate-relevant variables are likely to be increasingly required over time: methane or nitrous emissions from agriculture, socio-economic data underpinning the drivers of deforestation and forest degradation, information on the resilience and exposure of terrestrial carbon stocks to climate disturbance such as droughts and fire, including ecosystem integrity and sustainability of forest management.

The report is structured into three main sections:

1) State of play (Chapter 2): We outline the typical situations, and common misunderstandings regarding the use of independent monitoring approaches. We break down their various interpretations by different stakeholders, in order to propose a common definition. A list of 12 challenges is identified.

2) Possible ways forward (Chapter 3): This section synthesizes the results of the four specific case studies, SWORG analysis, stakeholder survey and existing literature. We illustrate to what extent typical gaps or weaknesses in information can be mitigated concretely and whether the approaches chosen have proven to be feasible, efficient and effective. We introduce nine key elements that turned out to be central for effective land use sector MRV. We present a conceptual model to assess the effectiveness of these key elements in overcoming the identified challenges.

3) How to get there (Chapter 4): The findings from the analyses above are then used to identify where priorities should be set to achieve increased transparency and accountability through the increased use of IM approaches.

The report has a number of annexes:

- Annex I including a glossary of terms;
- Annexes II.a – II.b including a list of the analysed datasets and portals;
- Annexes III including detailed results of the survey;
- Annexes IV.a – IV.d including detailed results of the SWORG analysis; and
- Annex V including a detailed description of case studies carried out under the project.

Box 1: Examples for existing datasets, tools and portals and initiatives providing information on land use and land sector emissions (see Annex II for the list of datasets and portals that were analysed in more detail)

- Active Fire Data (NASA) https://earthdata.nasa.gov/data/near-real-time-data/firms/active-fire-data
- Forest Carbon Portal, Consortium of multiple partners (Forest Trends, USAID, UNDP, etc.) http://www.forestcarbonportal.com
- Global Agricultural Monitoring (NASA) http://glam1.gsfc.nasa.gov/
- Global Change Master Directory (NASA) http://gcmd.nasa.gov/records/GCMD_CARPE_smallcomb.html
- Global Emissions Initiative of the IGBP (NASA and consortium of multiple partners) http://www.geiacenter.org/
- Global Forest Change Portal, University of Maryland (UMD) http://earthenginepartners.appspot.com/science-2013-global-forest
- Global Forest Inventory & Analysis Data portal (Global Forest Biodiversity Initiative) http://www.gfbinitiative.org/data
- Global Forest Watch (World Resources Institute) http://www.globalforestwatch.org/
- Global Land Cover Facility, UMD, NASA, GOFC-GOLD http://www.landcover.org/siteMap.shtml
- Global Risk Assessment Services (Germany) https://www.gras-system.org/
- GOFC-GOLD Global Observation of Forest and Land Cover Dynamics http://www.fao.org/gtos/gofc-gold/index.htm
- MAD-MEX: Automatic Wall-to-Wall Land Cover Monitoring for the Mexican REDD-MRV Program Using All Landsat Data (Mexico) http://www.monitoreoforestal.gob.mx/acervo/items/show/22
- MAP BIOMAS (Brazil) http://mapbiomas.org/
- MOABI, Independent monitoring of natural resources (DRC) http://rdc.moabi.org/en/
- Orbiting Carbon Observatory-2 (JPL, NASA) http://oco.jpl.nasa.gov
- PNG REDD+ and Forest Monitoring Web-Portal (Papua New-Guinea) http://178.33.8.126/portal/
- PRODES: Annual estimates of deforestation in the legal Amazon, based on Landsat and CBERS images (Brazil) http://www.obt.inpe.br/prodes/index.php
- Sentinel Land Monitring Thematic Area (ESA) https://sentinels.copernicus.eu/web/sentinel/thematic-areas/land-monitoring
- VEGA-PRO, Satellite based service for vegetation monitoring (Russia) http://pro-vega.ru/eng/
- Web-Enabled Landsat Data (WELD, NASA) https://nex.nasa.gov/nex/projects/1213/

2 STATE OF PLAY: WHAT IS THE PROBLEM?

2.1 Scoping of existing programmes the project aims to support

The Independent Monitoring project aimed at articulating actionable policy-level messages for different policy processes related to climate change mitigation in the land sector and stakeholders involved or interested in independent monitoring. An important recipient of the recommendations are EU institutions and programmes that are managing spatially explicit data sources or acting as data providers. In the following we introduce the INSPIRE Directive, the Copernicus programme with its Sentinel missions, and the planned ESA BIOMASS programme to better understand their technical specifications and objectives.

The **INSPIRE Directive** 2007/2/EC of the European Parliament and of the Council of 14 March 2007, defines the basic legal framework for a European spatial data infrastructure. INSPIRE is designed to simplify the cross-border use of spatial information for the citizen, the administration and the economy in Europe. The European Union wants to support Community environmental policy decisions.

In practice INSPIRE calls for a uniform (interoperable) description and dissemination of spatial data and their deployment in the internet, with services for search (Discovery), visualization (View) and download facilities. The directive has legal obligation for the EU Member States and includes explicit deadlines. Access to spatial data and services constitutes an important basis for environmental policies for all public authorities and is therefore a central aspect of the Infrastructure for spatial information in the European Community.

Since the Community institutions and bodies in most cases have to integrate and assess spatial information from all the EU Member States, INSPIRE recognises the need to be able to gain access to and use spatial data and spatial data services in accordance with an agreed set of harmonised conditions. INSPIRE lays down a number of rights and obligations regarding the sharing of spatial datasets and services between all levels of government (public authorities). Two data schemes are particularly relevant, one on land use[3] (INSPIRE 2013a) and land cover[4] (INSPIRE 2013b).

Copernicus is the European Earth observation programme[5], successor of GMES (Global Monitoring for Environment and Security). It aims at collecting and providing environmental information and services for policymakers and public authorities. ESA is developing a family of missions called Sentinels[6] specifically for the operational needs of the Copernicus programme. These missions carry a range of technologies, such as radar and multi-spectral imaging instruments for land, ocean and atmospheric monitoring. The most relevant for carbon monitoring are:

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[3] http://inspire.ec.europa.eu/id/document/tg/lu

[4] http://inspire.ec.europa.eu/id/document/tg/lc

[5] http://www.copernicus.eu/main/overview

[6] https://sentinel.esa.int/

- Sentinel-1 is a polar-orbiting, all-weather, day-and-night C-band radar mission for land and ocean services. Sentinel-1A was launched in April 2014 and Sentinel-1B in April 2016. Besides other thematic areas, it is used for agriculture, forestry and land cover classification. The advantages are high resolution (~10 m) and frequency (~7 days). The disadvantages are high sensitivity to surface moisture and saturation in high biomass forest. One specific example is forest biomass estimation within the ESA DUE GlobBiomass project.

- Sentinel-2 is a polar-orbiting, multispectral high-resolution imaging mission for land monitoring to provide, for example, imagery of vegetation, soil and water cover, inland waterways and coastal areas. Sentinel-2 can also deliver information for emergency services. Sentinel-2A was launched in June 2015 and Sentinel-2B will follow in 2017. This is an important source of information for land use / land use change monitoring and the following estimation of carbon fluxes.

- Sentinel-3 is a multi-instrument mission to measure sea-surface topography, sea- and land-surface temperature, ocean colour and land colour with high-end accuracy and reliability. The mission will support ocean-forecasting systems, as well as environmental and climate monitoring. Sentinel-3A was launched on 16 February 2016. Sentinel-3 will provide global coverage fire monitoring products (e.g., fire radiated power, burned area, risk maps) which are essential for estimation of carbon fluxes. However, the spatial resolution of thermal channels is 1 km.

Sentinel 1, 2 and 3 are going to contribute a great deal to the independent monitoring of GHG emissions due to free access to the data, high resolution, frequency, and global coverage.

The **ESA Biomass mission** is the seventh ESA Earth Explorer to be launched in 2021[7]. It will be able to estimate forest biomass, canopy height and changes with a P-band synthetic aperture radar (SAR). The advantage of the P-band SAR is its sensitivity to high biomass values (in contrast to any of the existing space-borne instruments). This, together with the ability to penetrate the cloud cover, determine its focus - moist tropics. Another advantage is wall-to-wall coverage, unlike LiDAR. The limitations include rather coarse resolution (200 m for biomass product and 50 m for the changes) and limited coverage (Europe and North America are excluded from the observation). Mission objectives include:

- Improved understanding and quantification of land contribution to the global carbon cycle
- Quantification of flux of carbon from land use change
- Greatly improved modelling of terrestrial carbon cycle
- Gridded high-resolution global estimates of above ground biomass
- Monitoring and quantification of forest disturbance and recovery
- Monitoring and quantification of wetland areas and forest inundation
- Mapping subsurface structures, polar regions

[7] https://earth.esa.int/web/guest/missions/esa-future-missions/biomass

- Mapping subsurface geomorphology in arid zones

The ESA BIOMASS mission will be able to substantially narrow down the uncertainties of estimations of forest biomass and biomass changes, especially in the tropics.

Monitoring Agricultural Resources (MARS) was initially designed to apply emerging space technologies towards providing independent and timely information on crop areas and yields. Since 1993, this activity has contributed towards a more effective and efficient management of the EU's Common Agricultural Policy (CAP) through the provision of a broader range of technical support services to DG Agriculture and Member-State Administrations. Since 2000, the expertise in crop yields has also been applied outside the EU. Services have been developed to support EU aid and assistance policies and provide building blocks for a European capability for global agricultural monitoring and food security assessment.

Land-parcel identification system (LPIS) is an information system based on aerial or satellite photographs recording all agricultural parcels in the EU Member States. It is a key control mechanism under CAP designed to verify eligibility for area-based subsidies. The system also increasingly plays a role in checking compliance with various environmental obligations. In the 28 Member States, there are currently 44 national or regional LPISs in operation, containing over 135 million reference parcels[8]. Models (e.g. EPIC) can absorb the information in order to estimate carbon fluxes.

2.2 What are independent monitoring (IM) approaches? The view of stakeholders

The Paris Agreement stresses the importance of efforts of relevant stakeholders to address and respond to climate change, including those of civil society, the private sector, financial institutions, cities and other sub-national authorities. Thus, land sector information will not only be needed for improving national GHG reporting and global stock tacking but also for guiding local mitigation planning and implementation of land use activities, and the accountability of actions and stakeholders, i.e. for tracking corporate zero deforestation commitments.

We interviewed a large number of **stakeholders**, i.e., experts and practitioners that generate or use information on climate and land use. For this purpose, an online survey was implemented via the tool Survey Monkey and was distributed through various networks and mailing lists. The survey was completed by 594 participants. Survey questions and the summary of responses are documented in Annex III.

> **Stakeholders**: refers to providers and users of Independent Monitoring information including governmental organizations, local stakeholders (incl. indigenous communities), environmentally concerned citizens and NGOs, private sector companies and investors, research institutes and universities.

The background of the survey respondents varied widely. There was coverage of all continents. However, most of the respondents came from Europe (26.8%) and Asia (23.4%). Respondents work at different scales- at the regional/district level (16.3%), the national level (36.7%), in multiple countries (20.4%), at continental scale (4.1%), and at global scale (22.4%). Many of the respondents work at research institutes and universities (31.3%), for governmental organizations (27.57%) and for NGOs (19.37%). Slightly fewer respondents work in the

[8] http://www.eca.europa.eu/Lists/News/NEWS1610_25/SR_LPIS_EN.pdf

private sector (10.28%). Local stakeholders (including indigenous communities) are underrepresented with only 17 respondents (2.53%).

In the survey we asked data providers, users and other stakeholders to prioritize certain aspects of independent monitoring approaches.

Table 1 summarizes the different stakeholder views on what they consider as "independent monitoring". It shows the order of importance by ranking and percentages with regards to the different answering options they could choose from in the stakeholder survey. Aspects such as "*Increased transparency and confidence building*", "*Increasing accuracy, consistency, completeness, comparability of estimates*" and "*Complementary to mandated reporting*" are regarded as most important by stakeholders. However, there are some differences in stakeholder views, and the aspects are evaluated differently.

The many different expectations from IM approaches are as diverse as the stakeholders' perspectives. However, based on the survey results we suggest the essence of IM approaches to be as follows:

Independent monitoring (IM) approaches broaden stakeholder participation and confidence by providing (free and open) information that complements mandatory reporting by national governments. This information must be somehow digested and made available in a user-friendly way, while:

- improving the transparency, accuracy, consistency, completeness and comparability of GHG estimates from land use activities on different scales, the so-called TACCC principles;
- supporting countries in identifying and then filling data and capacity gaps, in a stepwise manner;
- increasing the perceived legitimacy and ownership of data and MRV processes for casual users.

Independent monitoring does not constitute one single system or a one-serves-all approach. Instead, it relies on access to a variety of inter-operable approaches, datasets and initiatives. IM approaches help to detect, anticipate and resolve potential conflicts or discrepancies between datasets.

Box 2: The term "independent monitoring"

Independent monitoring (IM) is not a new idea. In the past IM has been defined as monitoring that employs an independent third party who, by agreement with state authorities, provides an assessment of legal compliance and observation of and guidance on official law enforcement systems. For example, independent forest monitoring has been used in voluntary partnership agreements (VPAs) between the EU and timber-producing developing countries under the Forest Law Enforcement, Governance and Trade (FLEGT) Action Plan to improve forest governance and reduce illegal logging (Brack & Léger 2013).

In the context of the Paris Agreement, IM can take on a much broader and more flexible role as an approach that contributes to a shared understanding of specific mitigation potentials, trust in data and definitions by all stakeholders, and objective information to guide implementation at local, national and landscape scales.

For more information on Independent Monitoring of Forest Law Enforcement and Governance (IM-FLEG) see: http://www.rem.org.uk/independent-monitoring.html.

Table 1: What is independent monitoring? – Views from different stakeholder groups

Independent monitoring...		Simple average of all observations	Government (Annex I)	Government (Non-Annex I)	Intergovern-mental organization	Non-governmental organization	Company (private & state-owned)	Research institute and university	Donor agency	Local stakeholder	Journalism / media	Other
provides information that is increasing transparency, building confidence and broadening participation for multiple stakeholders.	1	55.7%	39.1%	53.7%	54.1%	67.9%	61.0%	53.1%	66.7%	53.8%	42.9%	62.5%
provides information that is accurate, reliable and customizable.	2	54.2%	34.8%	50.0%	67.6%	67.0%	52.5%	52.0%	55.6%	53.8%	42.9%	66.7%
can be defined as methods, data and tools to estimate greenhouse gas emissions from land activities that are additional to mandated monitoring by governments.	3	53.2%	58.0%	55.6%	51.4%	53.8%	49.2%	53.1%	77.8%	61.5%	28.6%	37.5%
provides information that is supporting countries to fill data and capacity gaps.	4	48.6%	42.0%	50.0%	54.1%	57.5%	42.4%	48.0%	44.4%	46.2%	57.1%	37.5%
provides data that can serve the purpose of independent verification by UNFCCC roster of experts for reviewing the annual submissions of greenhouse gas (GHG) inventories.	5	43.4%	49.3%	38.9%	62.2%	39.6%	45.8%	43.0%	22.2%	15.4%	28.6%	50.0%
provides information that is potentially serving as authoritative reference for many kinds of stakeholders.	6	42.7%	37.7%	35.2%	51.4%	52.8%	37.3%	40.8%	33.3%	46.2%	57.1%	41.7%
provides information that is independent from commercial interests.	7	41.7%	33.3%	24.1%	48.6%	51.9%	35.6%	43.6%	33.3%	46.2%	57.1%	45.8%
provides underpinning science to improve data.	8	40.2%	33.3%	37.0%	45.9%	38.7%	25.4%	48.0%	44.4%	38.5%	42.9%	41.7%
ensures that stakeholders, e.g. REDD+ countries, can have ownership and control over datasets and methods and consider them legitimate.	9	37.5%	23.2%	44.4%	40.5%	42.5%	37.3%	38.5%	22.2%	61.5%	28.6%	25.0%
N=		**557**	**69**	**54**	**37**	**106**	**59**	**179**	**9**	**13**	**7**	**24**

Source: own compilation.

2.3 What are current gaps and opportunities of IM approaches identified by stakeholders?

The online survey was used to analyse different stakeholder views and needs on the use, accessibility and usefulness of different existing open data sources associated with forest area and area change data, biomass change and emission factors, and GHG AFOLU emissions.

Survey questions were linked to different criteria and indicators that characterized the stakeholder needs and preferences. The assessment addressed the following aspects: dataset characteristics, applied methodologies, verification, data access, viability and sustainability.

The stakeholder needs assessment indicated that in general all stakeholders would like to have:

1. Data with increased transparency and documentation of data sources, methods, definitions and assumptions
2. Data with increased accuracy, and with associated independent uncertainty estimates for all three datasets types (forest area and area change datasets, forest biomass change and EF datasets, GHG AFOLU emissions datasets)
3. Data on aboveground biomass (AGB) and belowground biomass (BGB) carbon pools with high opportunities and eventually including data on soil organic matter
4. Higher Tier (2 or 3) emission factors and emission estimates
5. GHG AFOLU emissions data, especially for the tropics
6. Region-specific data, and data and uncertainty targeted for users

In the survey, a larger number of datasets were evaluated by the stakeholders. As a next step in the analysis, five key datasets were selected within the category *forest area and area change data,* three key datasets within the category *biomass change and emission factors data*, and three within the category *GHG AFOLU emissions data.* Key datasets (see Annex II) were selected based on user awareness. More than 40% of users that answered these survey questions should be aware of them. The same criteria and indicators as were used to assess the stakeholder needs and preferences were used to evaluate the selected datasets and their use by the different stakeholder groups. This allowed for an evaluation and comparison of the datasets in all relevant aspects from the point of view of data users.

Table 2 gives an overview of the stakeholder satisfaction with the key datasets that were analysed, based on different criteria and indicators.

Per dataset and stakeholder group, a score was calculated for each indicator. The scoring system was based on a comparison of the indicator description for each dataset and the outcome of particular survey questions for a stakeholder group. The score represents the extent to which the indicator outcome matched the dataset description for the same indicator in %.

Annex IV contains the complete tables with the assessment criteria and the indicators, the survey questions and answer options that are associated with these criteria. An aggregate score was calculated for each criterion per dataset, which was the average of all indicator scores for each criterion (Table 2). The scores show to what extent each criterion is met. Furthermore, an overall score for each dataset was calculated from the average of all scores for the criteria. Also, the range per criteria was indicated as a measure of the dispersion among stakeholder groups, calculated by subtracting the minimum average score by the maximum average score from the stakeholder group outcomes.

Most datasets score high on the criteria "viability/sustainability" and "data access", with the exception of the forest biomass change and EF datasets, which are not easily accessible. The score for "methodologies applied" varies between low and good among the datasets. All datasets, except for INPE (PRODES) score low on the criterion verification. "Dataset characteristics" and "legitimacy with stakeholders" received a value between low and intermediate. The range (%) indicates that there was a certain degree of dispersion among stakeholder groups.

The dataset of Hansen et al. (2013) received the highest score (75%) among all datasets and was valued as intermediate on the aggregate scale. All other datasets, on average, were valued as low to limited in quality. Especially, the three forest biomass change and EF datasets received low scores from all stakeholder groups.

Table 3 shows the selected web portals and an aggregate score per criterion for each web portal. This includes an average score (%) for all the stakeholder groups and the range (%). The range is the "max score (%) – min score (%)" of all stakeholder outcomes for one criterion. The range indicates the disagreement among stakeholders with regards to a criterion and the variability in stakeholder needs.

All web portals have a high score for data access, and are freely accessible without registration. Evaluation of dataset characteristics varies among the datasets, ranging from low to very good. In terms of legitimacy with stakeholders, the web portals score relatively low.

Table 2: What are difficulties with existing monitoring data sources? - An evaluation of existing datasets by all stakeholders

	OVERALL SCORE BY CRITERIA: Average (%) and Range (% = "max%-min%" for stakeholder groups)												
DATASETS	**CRITERIA**												
Key author, Year, Name	**Dataset Characteristics**		**Methodologies applied**		**Verification**		**Data access**		**Viability / sustainability**		**Legitimacy with Stakeholders**		**Average by dataset**
Forest area change dataset	Average (%)	Range (%)	Average (%)	Range (%)	Average (%)	Range (%)	Average (%)	Range (%)	Average (%)	Range (%)	Average (%)	Range (%)	Average (%)
Kim et al., 2014. Forest-cover change from 1990 to 2000	59%	3%	79%	7%	25%	35%	100%	0%	50%	1%	44%	18%	60%
Hansen et al., 2013. 21st-Century Forest Cover Change	75%	9%	79%	7%	25%	35%	100%	0%	100%	0%	70%	20%	75%
INPE, 2014. PRODES: Annual estimates of deforestation in the legal Amazon	70%	8%	53%	12%	100.00%	0%	44%	22%	100%	0%	48%	26%	69%
Sexton et al., 2013. Global, 30-m resolution continuous fields of tree cover	64%	3%	85%	7%	25%	35%	100%	0%	50%	0%	41%	10%	61%
Achard et al., 2012. Global Forest Resource Monitoring (TREES-3)	64%	5%	87%	6%	25%	35%	100%	0%	100%	0%	43%	33%	70%
Forest biomass change and EF datasets													
A Baccini et al., WHRC, US, 2012. Estimated CO2 emissions from tropical deforestation	55%	6%	81%	8%	25%	35%	44%	22%	90%	0%	63%	54%	60%
S. Saatchi et al., NASA, 2011. Benchmark map of forest carbon stocks	55%	3%	81%	8%	25%	35%	44%	22%	90%	0%	64%	34%	60%
N. L. Harris et al. Winrock, 2012. Baseline Map of C Emissions from Tropical deforestation	63%	8%	88%	5%	25%	35%	0%	0%	100%	0%	49%	48%	54%
GHG AFOLU datasets													
R. A. Houghton, WHRC, 2008. C Flux to the Atmosphere from Land-Use Changes 1850-2005	53%	5%	45%	14%	25%	35%	100%	0%	60%	12%	49%	20%	55%
FAO, 2012. FAOSTAT Emissions	58%	5%	45%	14%	25%	35%	100%	0%	100%	0%	72%	29%	67%
JRC, 2011. Global emissions EDGAR v 4.2	62%	7%	63%	16%	25%	35%	100%	0%	100%	0%	44%	50%	66%
Average per criterion	62%		71%		32%		76%		85%		54%		

Average score for criteria		
	91-100%	very good
	81-90%	good
	71-80%	intermediate
	61-70%	limited
	</=60%	low

Source: own compilation.

Table 3: What are difficulties with existing monitoring web portals? - An evaluation by all stakeholders

		OVERALL SCORE BY CRITERIA: Average (%) and Range (% = "max%-min%" for stakeholder groups)						
	WEB PORTALS							
No.	Key author/Publisher; Year, Name	Dataset Characteristics		Data access		Legitimacy with Stakeholders		Average by dataset
	Forest area change web portals	Average (%)	Range (%)	Average (%)	Range (%)	Average (%)	Range (%)	Average (%)
1	Hansen, et al., 2013. Global Forest Change	74%	20%	100%	0%	71%	26%	82%
2	GFW, WRI, 2011. Global Forest Watch	84%	13%	100%	0%	64%	35%	83%
3	NASA, NEX, 2012. WELD - Web Enabled Landsat Data	74%	19%	100%	0%	35%	33%	70%
	Forest biomass change and EF web portals							
4	IGES, 2000. IPCC emission factor data base	60%	18%	100%	0%	72%	22%	77%
5	University of Maryland, NASA, GOFC-GOLD, 1997. Global Land	100%	0%	100%	0%	60%	41%	87%
6	Consortium of multiple partners, 2008. Forest Carbon Portal (FCP)	93%	6%	100%	0%	39%	51%	77%
	GHG AFOLU web portals							
7	IGES, 2013. IPCC inventory Software 2.12	81%	18%	100%	0%	53%	28%	78%
8	FAO, 2010. The EX-Ante Carbon-balance Tool (EX-ACT), V.5	81%	18%	100%	0%	38%	49%	73%
9	UK Department of Energy & Climate, 2015. The Global Calculator	29%	17%	100%	0%	19%	18%	49%
	Average per criterion	75%		100%		50%		

Average score for criteria		
(very dark grey)	91-100%	very good
(dark grey)	81-90%	good
(medium grey)	71-80%	intermediate
(light grey)	61-70%	limited
(very light grey)	</=60%	low

Source: own compilation.

2.4 What are common misunderstandings and challenges for IM approaches?

As displayed by the stakeholder survey and the analysis of existing datasets and portals, there are a number of technical challenges but also conceptual misunderstandings that have been reported by stakeholders, data producers and users.

We identified 12 challenges that can be grouped into three fields related to 1) the characteristics of data, 2) the use and interpretation of data, and 3) the access and capacities of people using the data (Table 4). In the following we give concrete examples of these challenges.

2.4.1 Challenges regarding technical constraints

A commonly faced challenge by national inventory and NDC compilers is the question of how to cope with a **lack of data**. One can imagine a situation where a user has a continuous time series of emissions and removals for forests but not for soils, for deforestation but not for degradation. The user would like the estimates to be increasingly comprehensive over time. How can gaps be filled? This requires consistency of data across time that is often lacking due to changes in methods, leaving **data inconsistent**. If appropriate data exist for extrapolation, either geographically or temporally, the question arises, how overall uncertainty can be determined when global data are used for filling regional data gaps.

Another common situation is faced by inventory compilers that need to combine datasets from different authorities into a common reporting framework and face a **lack of data(set) compatibility** (see Box 3). Spatially or sectorally overlapping datasets need to be combined using consistent approaches and definitions in order to correctly assess trade-offs and dynamics across the landscape.

Especially developing countries need to cope with **low data quality** regarding estimates for emissions from land use. This includes too coarse spatial/temporal resolution e.g., of remotely sensed data. Statistics are needed as proxy data to allocate land use emissions to different categories. Low quality statistics are therefore an important bottleneck for more detailed analyses of emission sources at the sub-national level.

An important prerequisite for the implementation of emissions reductions is the **scalability of emission reduction estimates, consistently from local to national levels**. Countries included REDD+ activities at different levels (national and sub-national) in their NDCs. As the REDD+ process develops there will be more and more sub-national initiatives that need to be consistently assessed at the national level. Globally consistent data can help to create a consistent reference.

Many countries rely on reference levels for the assessment of mitigation options. A country that has set a reference level for emissions based on data with a certain quality, methodological bias, definitions and accuracy, would like to compare the reference level with actual emissions that have occurred during an overlapping period. After advancements in terms of improved quality, methodology and accuracy such comparisons are challenging. How can the **significance of differences after methodological advancements be assessed**? How can estimates be kept comparable?

A similar issue emerges for countries when assessing mitigation options across sectors. In July 2016 the European Commission proposed an option for using emission reductions achieved in certain categories of the land use sector for achieving reduction efforts in other non-ETS sectors. This requires a **methodologically consistent comparison of emission reductions across categories** and across EU Member States.

2.4.2 Challenges regarding data use and interpretation

The quantitative evaluation by reviewers of the NDCs is currently challenged by the lack of sufficient documentation of data and other comprehensive information on definitions, assumptions and methods applied by each country, as analyses of the intended NDCs have highlighted (Grassi et al. 2017; Grassi & Dentener 2015). Without transparent documentation of data sources, assumptions and projections, mitigation efforts cannot be assessed or compared reasonably; in this case **documentation of how data was generated is missing**.

In order to track the role of the land sector in achieving the 2°C or 1.5°C target from the Paris Agreement, comparability between scientific studies and national reports needs to be established. As highlighted by Federici et al. (2016) there are a number of technical issues still not resolved regarding the estimation of GHG emissions from the land sector. Such different approaches and this **lack of data comparability** that cannot be reconciled make an aggregation or disaggregation of estimates impossible for potential data users. A concrete example is the controversy around the distinction between "anthropogenic" and "non-anthropogenic" emissions and removals in IPCC Guidelines and IPCC Assessment Reports (see Box 3).

Box 3: An example of data controversies and the need for Independent Monitoring approaches

Land use datasets used for the IPCC Fifth Assessment Report (AR5, Smith et al. 2014) and other available sources (e.g., EDGAR 2012; FAO 2010; Houghton et al. 2012; USEPA 2013) provide comparable estimates among geographies by using the same methodology. However, the data are offered at either too large a scale to navigate mitigation action (e.g.,. country scale from the FAOSTAT database does not inform on the spatial location of the emissions hotspots in the country and is therefore of little use for prioritizing mitigation action and resources) or under intransparent methodological procedures (e.g., EDGAR data) that diminish trust of the data provided. Further, the datasets show a number of inconsistencies such as:

- The variability of the AFOLU emissions at a global level between FAO and EDGAR datasets has been reported to reach up to 25% of their estimates for 2000-2009 (Tubiello et al. 2015) 12.7 vs. 9.9 $PgCO_2e.yr^{-1}$ for EDGAR and FAOSTAT, respectively.
- There are disagreements in the contribution of the AFOLU sector to the total anthropogenic budget in 2010 (e.g.,. 21% and 24% for FAOSTAT vs. EDGAR) (Tubiello et al. 2015).
- There are disagreements in the relative share of the emissions from agriculture versus FOLU since 2010. Thus, while EDGAR implies a relatively equal contribution (IPCC 2014), FAO reports agricultural emissions being larger contributors to the total anthropogenic budget (11.2±0.4%) than forestry and other land uses (10±1.2%) (Tubiello et al. 2015), with a steady growth trend of 1% since 2010.

Another shortcoming is that none of these datasets offers uncertainties of their land sector emissions, which can be useful when navigating the risk of the investments when considering the effectiveness of the mitigation activities. Thus, when the uncertainty equals or overpasses the mean emissions, the effectiveness of the mitigation outputs cannot be guaranteed. No explicit information has been given before, on the assumptions made to aggregate the uncertainties and the effect of selecting different statistical choices to present the uncertainty estimates.

Similar misunderstandings can be observed for other definitions such as gross versus net deforestation, or challenges to differentiate land cover and land use both in modelling (Prestele et al. 2016) and remote sensing communities (Fritz et al. 2011).

If more than one dataset is available, reviewers need to resolve potential **data conflicts**. Using comparable approaches should lead to similar estimates within the uncertainty ranges. If disagreements between estimates cannot be attributed to differences in methods or assumptions, it is impossible to consolidate figures and increase trust in numbers by stakeholders. An agreement on single figures and trust in estimates is especially crucial in the context of a payment agreement between donor and recipient.

2.4.3 Challenges regarding access and capacities

A **lack of access to data** often impedes independent review, which can only be guaranteed with sufficient accessibility to metadata, information on assumptions but also alternative estimates. Accessibility is often inhibited by financial and technical barriers. This includes download or membership fees, cumbersome formatting of data and limited query masks. Free and open data might still be of reduced value for stakeholders with limited **interpretation capacity**. In order to interpret the results of data analyses, statistics and data filtering expert knowledge is needed to e.g., adequately compare the results with other data.

A consequence of these difficulties can be a **lack of participation** of relevant stakeholders. A single factor like the cost to stakeholders to access to the data can exclude large potential user groups. Participation, however, is essential for the legitimacy of processes.

Another result of limited access and capacities can be user **confusion about numbers**. Having more access to data does not necessarily increase the confidence of users in a single dataset. Monitoring observations of the same object, e.g., forest cover, in a country should lead to similar estimates. But inconsistent use of methods and intransparent assumptions leave users puzzled and frustrated.

In fact, data that is incomparable and inconsistent allows for **unchecked self-monitoring**. Incomplete documentation of methods applied might thus be used to avoid the comparison with reference data and benchmarks. Such situations are especially problematic in donor-receiver-relationships.

Table 4 gives an overview of the difficulties and challenges in MRV arising from the Paris Agreement and other reporting obligations. It also illustrates that they presuppose different groups of stakeholders to be involved.

In the following, we give examples of how IM approaches can enable stakeholders to implement mitigation plans and activities that are specific, quantifiable, linked to high-quality reporting, and can be assessed independently. By this means IM approaches can provide supporting information to build trust with donors and the general public for more transparency and accountability in land use mitigation.

Table 4: Summary of identified challenges for different stakeholders

Field	Challenges	Affected stakeholder group	Cases or examples
Technical constraints	Lack of data	NDC compilers, inventory compilers	Missing data on pools (e.g., peat, soil C) Missing data on crops (e.g., oil palm) Missing data on activities (e.g., degradation)
Technical constraints	Data inconsistency	NDC compilers, inventory compilers	Diverging forest definitions Inconsistent time series (start/end points of annual datasets)
Technical constraints	Low data quality	Some countries or indiv. users	Too coarse resolution (spatial/temporal) Low accuracy, lack of information on accuracy
Technical constraints	Lack of data(set) compatibility	NDC compilers, inventory compilers	Scales and resolution Downscaling of global data to national, sub-national level

Field	Challenges	Affected stakeholder group	Cases or examples
Data use and interpretation	Data conflicts	all	Forest maps from different data sources are not congruent
Data use and interpretation	Lack of data comparability	NDC compilers, inventory compilers	Diverging definitions of categories and pools, forest definitions Different accounting rules and frameworks (e.g., reference levels)
Data use and interpretation	Missing documentation of how data was generated	all	Lack of metadata (e.g. non-standardized data base entries)
Data use and interpretation	User confusion about numbers	all	Applying data to wrong scope (over-interpreting data) Misunderstanding of data (e.g., net and gross land cover)
Data use and interpretation	Unchecked self-monitoring	All, watchdog organizations	Zero-deforestation commitments companies have sophisticated monitoring tools but do not disclose fully Countries self-reporting to UNFCCC, e.g. under Paris Agreement, Global Stocktake, or FRA
Access and capacities	Lack of access to data	Some countries or indiv. users	Missing capacity to handle or deal with the data Linked deforestation to company activities
Access and capacities	Lack of interpretation capacity	Some countries or indiv. users	Lack of understanding of definitions and scope of specific datasets Missing understanding or access for non-experts (e.g., forest definition)
Access and capacities	Lack of participation	Indigenous people, some countries, some indiv. users	Knowledge systems Insufficient participation mechanisms

Source: own compilation.

3 POSSIBLE WAYS TO GO: KEY ELEMENTS FOR INDEPENDENT MONITORING APPROACHES

In this section we summarize insights from the stakeholder survey, the case studies, the discussions with stakeholders during the two project workshops, from the SWORG analysis and an additional literature search.

As identified in Chapter 2 above, different stakeholder groups have varying data needs and different challenges in using the data for more transparency and accountability in land use mitigation. Therefore, we developed and carried out case studies that represented specific instances of IM approaches for each group (Table 5). Section 3.1 briefly presents the case studies we undertook in this project, plus a few other instances of "good practices". Annex V (Sections 5.1-5.4) provides detailed information on scope and methods of, and detailed results from the case studies.

In Section 3.2 we then derive nine "key elements", "ways to go" (good practice), or essential principles for an effective implementation, by different users, of transparent monitoring of land cover and GHG emissions from land use. We group them in three problem areas related to the problems that the different stakeholders face (Table 4): the need to overcome technical constraints; improve data use and interpretation; and increase data access and capacities.

Table 5: Relevant stakeholder groups and case studies selected for them

Relevant stakeholder groups	Opportunities to address the gaps and risks and case study
Countries with key data gaps, scientific community	**Case study 1:** Global contribution of AFOLU GHG emissions (2000-2005): patterns, uncertainties and drivers
UNFCCC, European Commission, national MRV institutions, donors	**Case study 2:** Shedding light on forest change, deforestation and degradation datasets in Indonesia and Borneo
National monitoring institutions, donors, research institutions	**Case study 3:** Global forest biomass uncertainties and their integration with national and regional estimation and reporting
EU policy, national experts in non-Annex 1, scientific community	**Case study 4:** Contributing to improved emission factors for forest and agriculture - Using biophysical soil models: challenges and opportunities for Tier 3 approaches

Source: own compilation.

3.1 Lessons learned from case studies and other examples of good practice

This section presents selected examples of good practice that will be used in Section 3.2 to derive the key elements of independent monitoring.

Example 1: Comparing six land use emissions datasets and AFOLU estimates

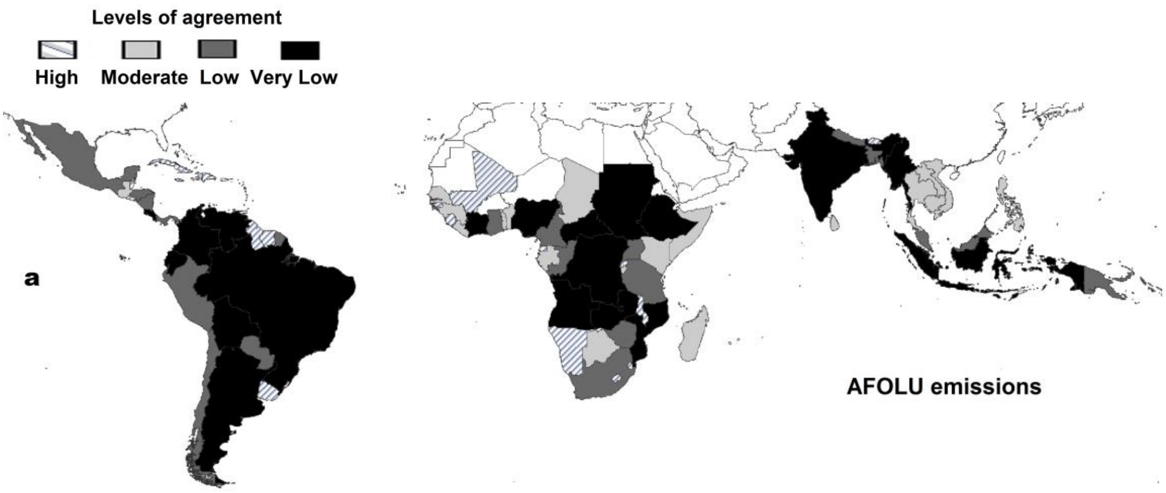
Information on gross fluxes of sources and sinks is important to navigate mitigation implementation effectively through policies and measures to enhance and promote mitigation.

Global AFOLU emission data have shown differences of up to 25% (Tubiello et al. 2015). This high uncertainty hampers the reliable quantification of mitigation options in the AFOLU sector. A comparison of AFOLU emission datasets and estimates in the Fifth Assessment Report for the tropics (2000-2005) provides insight into the sources of these differences (Roman-Cuesta, Herold et al. 2016).

When disaggregating the emissions by sources, the forest sector showed the largest differences, mainly due to estimates from forest degradation and particularly fire. Agricultural emissions were more homogeneous, especially livestock, while cropland emissions were the most diverse. In consequence, CO_2 showed the largest differences in estimates among datasets, while N_2O and CH_4 estimates were more homogenous.

The map shows considerable differences in AFOLU emission estimates at the country level (Figure 1). Identifying countries with low agreement among emission datasets helps for prioritizing where reconciling estimates is most important. The disagreements are partly explained by differences in conceptual frameworks (i.e. definitions), methods and assumptions that call for more complete and transparent documentation for all available datasets. A better dialogue between the carbon (CO_2) and AFOLU (multi-gas) communities is needed to reduce discrepancies between land use estimates.

Global data are not always independent from national information. We calculated livestock and wood harvesting emissions from activity data provided by FAO, which are in turn provided by the countries themselves, and thus, dependent on the national statistics. The original source of data needs to be kept in mind when comparing different pieces of information.



Source: Roman-Cuesta, Rufino et al. 2016.

Figure 1: Country level agreement for AFOLU emissions for the FAOSTAT, EDGAR and 'Hotspots' databases. See Case study 1 in Annex V and Roman-Cuesta, Rufino et al. 2016 for details.

Example 2: Online Atlas distinguishes companies who practiced deforestation from those who avoided it over four decades

The demand for palm oil and wood pulp has significantly modified land covers across Southeast Asia. Conservationists lament the loss of rainforests, and charge oil palm, pulp and paper companies for their destruction. Those on the plantation side argue that planting is done on already deforested degraded land which is a cornerstone of sustainable development and compatible with certification criteria. More transparency is required to distinguish companies who practiced deforestation from those who avoided deforestation, for more effective oversight by certification bodies, to hold companies accountable, and to avoid a bad reputation for those that do not deserve it.

Companies who have pledged zero-deforestation need further data on historical baselines of deforestation and fires to compare against future deforestation trends on land they control (concessions). This user-oriented online atlas[9] provides historical baselines and offers the possibility to distinguish oil palm and pulpwood companies who practiced deforestation from those who avoided it. The current geographic scope is Borneo. Shared by Indonesia and Malaysia, it is one of the world's largest producers of palm oil and globally important producers of pulpwood. The online atlas tracks 42 years of old-growth forest loss and degradation by industrial logging, oil palm and pulpwood expansion. The system is based on assembled Government data of land ownership, with the Hansen et al. (2013) tree cover loss dataset, with Gaveau et al. 2014; Gaveau et al. 2016, and Margono et al. (2014) datasets of 1973 and 2000 forest area cover change maps area, logging roads, and industrial plantations.

For more details and methods, see Case study 2 in Annex V and Gaveau et al. 2014; Gaveau et al. 2016.

Source: www.cifr.org/map/atlas/.

Figure 2: Screenshot of the Kalimantan Deforestation Atlas

[9] www.cifor.org/map/atlas/

Example 3: Biomass Geo-Wiki allows users to compare different biomass products, to improve information about uncertainties and global land cover

To provide a mechanism for users to compare the different biomass products available from a single web portal, the Biomass Geo-Wiki[10] tool has been developed (Schepaschenko et al. 2015). Geo-Wiki is a visualisation, crowdsourcing and validation tool for improving global land cover information (Fritz et al. 2009; Fritz et al. 2012). In addition to the main Geo-Wiki[11] branch which is about land cover, there are many other thematic branches, covering biomass, cropland, forest, human impact, etc.

Geo-Wiki allows different maps to be visualised via Web Map Services (WMS) on top of Google Earth. For example, the major global land cover maps of the GLC-2000 (Fritz et al. 2003), the 2005 MODIS land cover map (Friedl et al. 2010) and GlobCover (Bicheron et al. 2008) can be viewed in the online application. Users can display maps of the spatial disagreement between pairs of land cover maps, along with the overall disagreement in the forest and cropland domains. It is also possible to view a hybrid land cover map, created from existing land cover products and crowdsourced data (See et al. 2015).

Geo-Wiki was designed in such a way that volunteers can zoom into any place on Earth, see the pixels associated with the different land cover types and then view what the land cover type is from different land cover products. Users are then asked to determine what actually appears in those pixels based on what is visible from Google Earth and indicate if each global land cover map characterises the land cover correctly or not. There is also an option to indicate if they were unsure about the quality of a particular land cover product. IIASA runs a number of campaigns based on Geo-Wiki to tackle different regions or specific problem associated with land cover and land cover change. Participants come from a pool of registered Geo-Wiki users from currently 155 countries around the world.

More details are presented in Case study 3 in Annex V.

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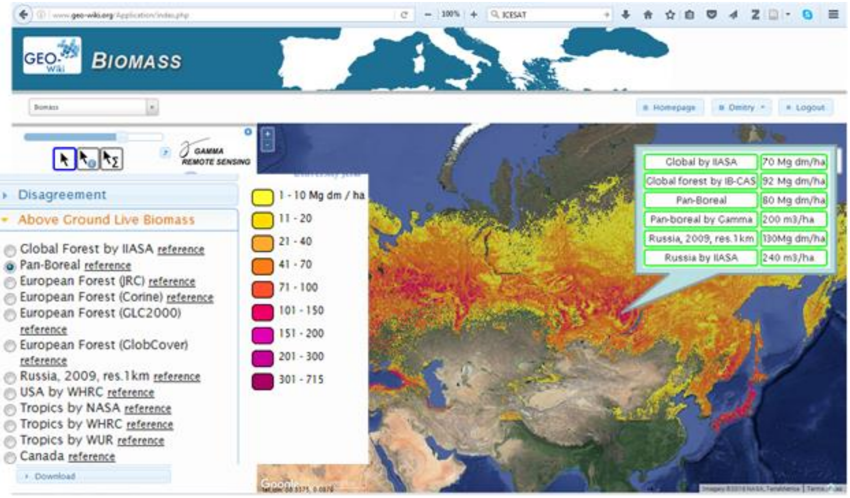
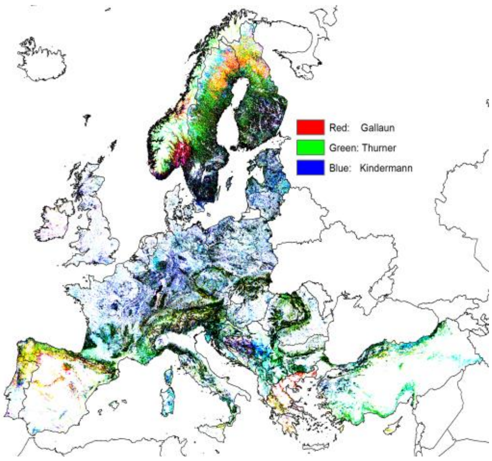
[10] http://biomass.geo-wiki.org

[11] http://www.geo-wiki.org



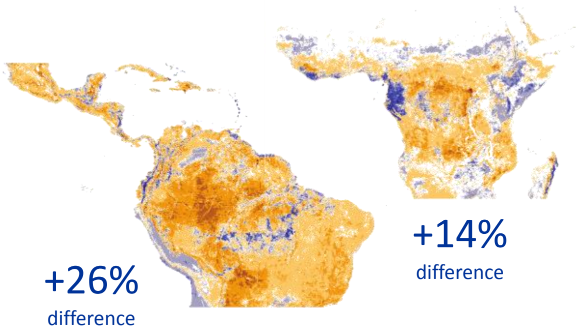
Source: www.cifr.org/map/atlas/.

Figure 3: Screenshot of Biomass Geo-Wiki



Source: own compilation.

Figure 4: Disagreement of three biomass maps for Europe (Gallaun et al. 2010; Kindermann et al. 2008; Thurner et al. 2014). White colour – all map agree on low biomass, black – all agree on high biomass. Other colours represent high biomass on one of the map with the low value on others.



Source: own compilation.

Figure 5: Disagreement of two tropical biomass maps (Baccini et al. 2012; Saatchi et al. 2011). Blue means higher biomass value on the Saatchi map and brown – indicates that the Baccini biomass estimation is higher.

Example 4: Improving soil carbon estimates using models – YASSO as an example

Agricultural and forest soils are an important pool that cannot be neglected in accurate assessments of GHG sources and sinks, and with regard to their potential for mitigation. However, accurately quantifying emissions and their reductions remains a substantial challenge (Paustian et al. 2016; Smith 2012; Smith et al. 2016).

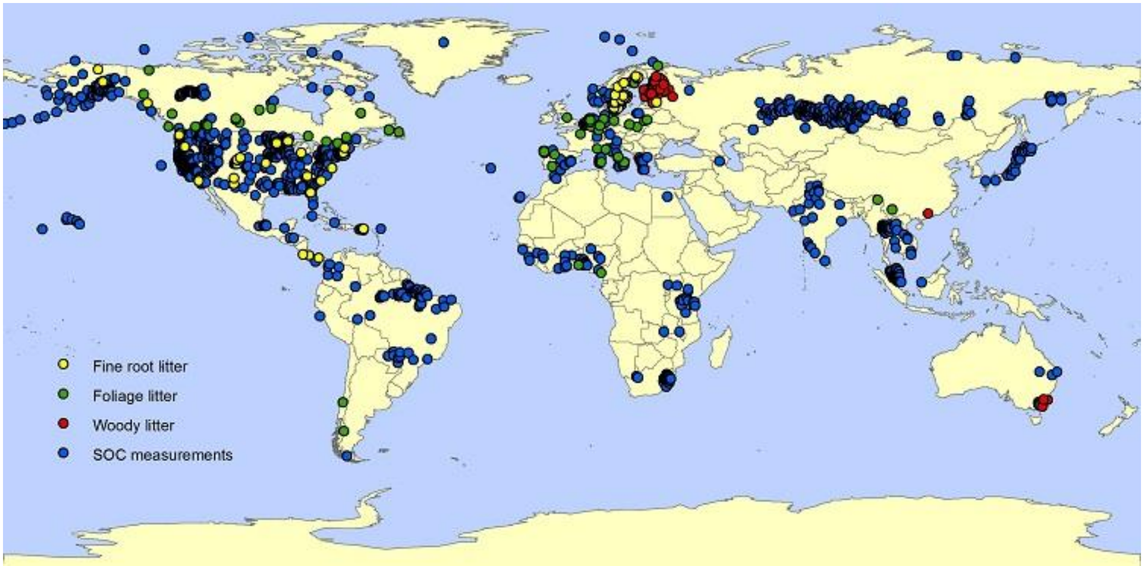
For implementing soil-based GHG mitigation there is a need for the development and implementation of higher tier methodologies that can be applied at fine spatial scales.

It is difficult to apply higher tier (2-3) methodology due to high spatial variability, non-linear dynamics of soil carbon and natural processes. But there is also a lack of data and tools for efficiently estimating soil carbon sequestration potentials, baseline developments and the effect of mitigation measures.

The model Yasso15 describes cycling of organic carbon in soil (Järvenpää et al.). It is based on a large number of measurements (Figure 6). It calculates the stock of soil organic carbon, changes in the stock of soil organic carbon, and heterotrophic soil respiration. Applications of the model include, for example, simulations of land use change, ecosystem management, climate change, greenhouse gas inventories and education. Yasso15 is a relatively simple soil organic carbon model requiring information only on climate and soil carbon input to operate. It is a global-level model meaning that the same parameter values are suitable for all applications for accurate predictions.

The tool is applied in several countries for estimating emissions from mineral soils under forests, including estimates for GHG inventories. The model, parameters and documentation are freely available[12].

For more details see Case study 4 in Annex V.



Source: Jari Liski, personal communication.

Figure 6: Sites of taken measurements in Yasso database. Yasso15 and Yasso07 models are based on about 20,000 measurements of litter decomposition and soil carbon

Example 5: Using high temporal resolution forest cover maps to determine intensity of forest management

EU reporting obligations on land use emissions have increased under the Greenhouse Gas Monitoring Mechanism Regulation (525/2013) and the LULUCF Decision (529/

[12] http://en.ilmatieteenlaitos.fi/yasso-description?doAsUserLanguageId=e

2013). An important reporting category is forest management/managed forest land; indicators and reference levels are needed for management intensity.

The frequency with which national forest inventories (NFIs) are undertaken in EU Member States varies from regular inventories every five years to non-regular ones that depend on available funding. Most inventories use aerial photos to determine if sampling points are forest or non-forest. Satellite-based maps of biomass stock so far had a rather low temporal resolution and do not always agree (cf. Case study 3, Annex V). Satellite data of high temporal resolution have now become available (Landsat 8, Sentinel) but have not yet been used to derive biomass maps.

A promising alternative technique is Light Detection and Ranging (LiDAR). While airborne and ground LiDAR data are typically not openly available and cover limited areas, space-borne LiDAR data until 2009 are openly available from the GLAS sensor on board the IceSAT satellite. Upcoming satellite missions (ESA BIOMASS, GEDI, NISAR) will provide openly available LiDAR data globally and at high spatial and temporal resolution.

Until this becomes available, a good option seems to be to rely on Hansen et al. (2013), with global coverage of annual forest cover change at 25 m resolution. This data set fills an important gap for inter- and extrapolating forest management information from inventories and other national statistics. For example, it can be used to calculate size, regional distribution and frequency of forest clearing patches. This can be a robust and consistent proxy for management intensity across landscapes and national borders. However, users need to be aware of the following shortcomings of the Hansen dataset:

- it provides tree cover change but does not attribute underlying drivers, i.e. any forest loss is recorded, irrespective of whether due to natural change and disturbance (fire, pests, storms) or management
- it has limited accuracy at the local scale, is biased in some regions and may not be sufficiently reliable to assess forest management if not locally calibrated (Tyukavina et al. 2015)

Therefore it needs to be combined with national forest inventory data and other RS products to allow for a much more disaggregated description of current management practices. It could then be used for a number of independent monitoring tasks at MS and EU levels.

- informing reference level setting by defining current management practices
- validation/calibration of forest management models for carbon accounting
- spatial planning and assessment of implementation of mitigation measures

Example 6: Picture Pile: Crowdsourcing the analysis of deforestation with a "serious game"

Deforestation is an ongoing issue in many countries. But deforestation detection in rain forests is a difficult task due to lack of imagery without cloud cover and fast regeneration of green cover after disturbances.

One of the possible ways to collect training data for change detection is visual interpretation of very high and high-resolution satellite imagery. By comparing two images for different time periods we can identify forest cover changes in the images. But collecting large amounts of datasets for this purpose is time consuming and costly. The interests of internet gamers and the power of crowds were brought together to solve this problem.

The Picture Pile game was designed to collect and validate information on deforestation in a number of locations (incl. Tanzania, Indonesia and Madagascar) using high resolution Digital Globe imagery and the power of a large number of people playing the game and working out the data while they do it. The game was launched in October 2015, and since then has collected nearly 4 million validations from more than 1100 unique users through Android, iPhone and desktop applications.

Source: own compilation.

Figure 7: Screenshot of the Picture Pile app

One of the tasks achieved by the game the validation of the global dataset on tree cover change by Hansen et al. (2013). We selected 7854 locations in Indonesia where Hansen et al. report forest losses. The result is that the majority of voting estimation by volunteers agree with the dataset in 61.3% of the cases.

However, disagreement is still high and further analysis is needed. For example, we realised that volunteers sometimes fail to judge blurry images while in some cases Hansen wrongly attributed the year of losses. Nevertheless, the overall experiences with the game are positive. When judiciously managed, such approaches can contribute to faster data sorting as a basis for further analysis. This could be of great importance for countries or CSOs who need to undertake quality control check out of independent monitoring datasets but only have limited resources at their disposal.

Example 7: OpenForis – a free and open toolbox that facilitates data collection, analysis and reporting

OpenForis[13] is a set of free and open-source software tools that facilitates data collection, analysis and reporting. Government, research institutions and NGOs use

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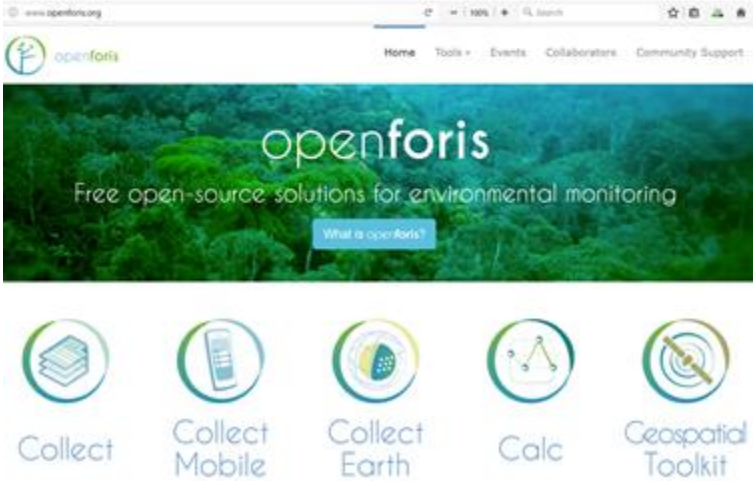
[13] http://www.openforis.org/

these tools for a wide range of their monitoring needs: forest inventories; climate change reporting, socio-economic surveys; biodiversity assessment, land use, land use change and forestry measurement; deforestation monitoring with remote sensing; detecting desertification and trees outside of forest. The tool thus promotes and facilitates independent monitoring.



Source: http://www.openforis.org/.

Figure 8: Landing page of OpenForis

- **OpenForis Collect** is the main entry point for data collected in field-based inventories. It provides a flexible way to set up a survey. It handles multiple data types and complex validation rules, in a multi-language environment
- **Collect Mobile** is an Android app for collecting data in a field-based survey with on-the-fly validation to improve data quality. The handling of large lists of species or other attributes with geo-location through embedded GPS, is possible.
- **Collect Earth** is a tool that enables data collection through Google Earth, Bing Maps and the Google Earth Engine, so that users can analyse high and very high resolution satellite imagery.
- **OpenForis Calc** is a tool for data analysis and results calculation. The input data and metadata come from OpenForis Collect, and Calc provides a way to produce aggregated results which can then be analysed and visualized through the open source software Saiku and R modules.

OpenForis is supported and used by FAO, in particular for the Global Forest Survey[14]. The mission of the GFS is to establish a global network of systematic sampling plots to understand forest ecosystem characteristics and health status at regional/biome level. GFS aims to produce freely available and comparable forest data, in cooperation with governments, technical fora and research organizations worldwide. GFS is an example of independent monitoring of forest resources in contrast to the FAO Forest Recourses Assessment, which fully relies on country reporting.

3.2 Deriving key elements of Independent Monitoring

[14] http://www.fao.org/in-action/global-forest-survey/en/

Here we derive nine "key elements", which are essential principles for an effective implementation of transparent monitoring of land cover and GHG emissions from land use.

3.2.1 Opportunities for IM approaches to overcome technical constraints

The stakeholder survey shows that the satisfaction level with regard to existing AFOLU data is relatively low especially for two groups: countries with key data gaps, and the scientific community. These groups, in the survey, highlighted inconsistencies in definitions and methods throughout the datasets and with the assessment processes (UNFCCC, IPCC). They also identified a need for developing AFOLU GHG emissions datasets for the tropics. The most important requests from AFOLU data stakeholders was that AFOLU emission estimates should be **transparent and clear**, **comparable and interoperable**, **consistent and complete**, and include both assessments of **accuracy** and indicators of **uncertainty**.

Case study 1, aimed at improving the understanding of patterns, uncertainties and drivers in land sector GHG emissions (see Example 1 and Appendix V; cf. also Roman-Cuesta, Herold et al. 2016), provides global data in an independent assessment against which national GHG inventory reports can be contrasted. Such data support the review of NDCs regarding feasibility and ambition levels. They also offer an opportunity to prioritize mitigation action at subnational scales by identifying the areas with higher emissions, higher uncertainties, and the relative contribution of the different emission sources. The case study further demonstrates that information on GHG emissions based on independent monitoring can only be used appropriately if the assumptions of data aggregation are clearly specified and documented (**transparency and clarity**). Not all global information sources are automatically independent from national information (cf. Example 1). A proper analysis of the inconsistencies in definitions and methods between UNFCCC and IPCC is still missing (Federici et al. 2016; Grassi et al. 2017). Finally, the case study mapped **uncertainties** in emissions estimates, an aspect that respondents deemed important in the survey.

In Case study 3 (Biomass Geo-Wiki[15]) we further assessed global forest biomass uncertainties and their integration with national and regional estimation and reporting, as an example of how to achieve the **comparability and interoperability** that was demanded by stakeholders (see Example 3: and Case study 3 in Appendix V). The case study brought together data from **different scales –** "top-down" global biomass maps (i.e. from research in the remote sensing community), and a set of "bottom up" data streams from ground measurements and inventories – in an attempt to derive a best estimate for the purpose of estimation and reporting. Integrating data from different sources illustrates another important principle for independent monitoring: that of **complementarity** of various data sources. Integrating and comparing the different datasets allows for us to fill gaps in data coverage (e.g. from cloud cover in the tropics) and better assess uncertainties of the global maps in areas where reference data are available. The employed methodology of integrating remote sensing data, crowdsourcing and ground truth data collection is applicable across the entire rainforests of the humid tropics (Southeast Asia, Congo and Amazon rainforests) and other regions of the globe.

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[15] http://biomass.geo-wiki.org

Cases studies 1 and 3 also highlight the importance of **reproducibility and adaptability** of independent monitoring approaches. Case study 1 pointed to the need for better dialogue between carbon scientists and AFOLU community to harmonize data and approaches; Case study 2 (Geo-Wiki) points to the importance for independent monitoring approaches to follow a comprehensive validation protocol. The characteristics and quality of biomass ground data vary largely. Biomass data used as reference to validate existing biomass maps need to be selected and screened according to stringent quality criteria to ensure the reliability of the reference data.

The use of the extensive biomass forest inventory data available for Europe for regional map assessment is limited, due to the differences in inventory design and low resolution of some publicly released data sets (for which more high resolution data are available but not disclosed, as is the case for most research field plots). In such cases, direct collaboration with national forestry agencies might provide access, or best guess biomass maps can be produced including information not publicly accessible. Without sharing original data, such kind of information can be used to improve independent estimates of biomass and still allow for wider **access and distribution**.

Key conclusions

In this section we have introduced the following key elements of independent monitoring that will help to overcome technical constraints (listed in the sequence in which they will be discussed in Section 3.3):

- Element 1: Transparency and clarity
- Element 2: Accuracy and uncertainty
- Element 3: Consistency and completeness
- Element 4: Comparability and Interoperability
- Element 5: Complementarity and scale
- Element 6: Reproducibility and adaptability
- Element 7: Access and distribution

3.2.2 Opportunities for IM approaches to improve data use and interpretation

In the survey, stakeholders from the UNFCCC, European Commission, national MRV institutions and donors proved to be only moderately satisfied with existing global datasets on forest area, biomass, and change. While some datasets scored higher (e.g. Hansen dataset), users of all datasets indicated the need for **accuracy and uncertainty** information for maps and datasets. This information can also improve **comparability and interoperability** between products. In addition, users asked for clarification and better guidance on the use of global data at the national level.

Tropical deforestation and degradation datasets were found to leave stakeholders dissatisfied or confused, thus showing a lack of **transparency and clarity**, despite the increasing availability of such products. Until now, no clarity has been offered about validity and uncertainty of datasets about deforestation and degradation, e.g. against a common standard. This leads to user confusion about which dataset to use for which purpose, or how to combined different datasets to yield improved estimates of deforestation and degradation.

Case study 2, for the first time brought together various independent datasets of forest change to assess uncertainties of estimates of forest change, deforestation and degradation in the evergreen closed-canopy forests of the humid tropics in Indonesia and Borneo (see Example 2; Case study 2 in Annex V). The case study compared and validated three existing key forest loss datasets for Indonesia using a common reference and then consolidated estimates of deforestation. The work on this sparked a dialogue among data producers, identified reasons for discrepancies, and revealed the datasets most accurate for a certain purpose.

The case study further shows how independent monitoring can support the assessment of zero-deforestation commitments made by the corporate sector in the palm oil and pulpwood industries. The result of superimposing information on concessions and deforestation and degradation datasets can be used by certification bodies and auditors to verify zero-deforestation pledges. The tool resulting from this case study is now available online[16], and users can track which oil palm and pulpwood companies (names are given) actively caused deforestation of carbon and biodiversity-rich old-growth forest (bad practice) and which companies avoided this by expanding on degraded non-forest lands (good practice). This tool is currently being refined and will later be scaled up to the entire palm oil producing region of the humid tropics.

The survey showed that stakeholders in EU policy, national experts in non-Annex 1 countries, and the scientific community saw soil carbon as an important pool that was not sufficiently considered in global, independent information. Also information on non-CO_2 gases in general was reported as being insufficient and lacking **consistency and completeness**. Case study 4 assessed opportunities for improving and increasing completeness of soil carbon emission factors and trends for forest and agriculture with the help of models (see Example 4 in Section 3.2). Presently, only few countries have nationwide estimates of soil carbon stocks and changes, because the needed nationwide surveys are very costly and field sampling is time-consuming. Costs increase further with increasing variation in soil properties. GHG emissions from soils can also be estimated across a country by combining input data with process-based models, another example of a Tier 3 method.

Models are typically also used to assess mitigation options by running scenarios to prioritize effective and efficient climate action. Soil models of different complexity and coverage exist for estimating GHG emissions. While many are applied for national reporting this does not mean they are ready-to-use tools. With the application of biophysical soil models the necessary input data needs to increase significantly. Data for model validation at the national scale often do not exist. Models increase the degree of complexity and can help countries to better document their activities and assess mitigation efforts. However, their application can reduce the **transparency** of GHG estimates, reduce **access** (because of limited capacity to penetrate the model's limits and underlying assumptions) and increase **uncertainty**.

[16] www.cifor.org/map/atlas

Case study 4 discussed opportunities for using more sophisticated approaches to report on emissions from soils. Moving to higher tiers can make sense for some countries but not for all. The Case study provides guidance on when countries should prioritize moving up in tiers and how they can best reduce uncertainties in soil emission reporting.

Tier 3 methods are typically applied at the national level. However, modelling tools are often developed internationally and for global application. The results of the case study can easily be transferred to other regions and models because it addresses general principles for increasing transparency.

Model application for GHG reporting and the assessment of mitigation efforts does not always fulfil user needs for transparent, yet accurate and easy-to-use tools. Soil maps derived from model runs become increasingly relevant for national reporting. Their usefulness for stakeholders also depends on how well they are documented and how much the data correspond to reporting requirements.

Key conclusions

In this section we have introduced the following key elements of independent monitoring that will improve data use and interpretation:

- Element 1: Transparency and clarity
- Element 2: Accuracy and uncertainty
- Element 3: Consistency and completeness
- Element 4: Comparability and interoperability
- Element 7: Access and distribution

3.2.3 Opportunities for IM approaches to increase data access and capacities

Stakeholders in the survey mostly ranked datasets high on the criteria "viability/sustainability" and "data **access**", with an exception for forest biomass change and emission factor datasets, which were seen as not being easily accessible. Data access was identified as being scale dependent. Access, to global datasets (e.g., Hansen et al. 2013, GFW) is typically easy, while for national and local datasets it is quite often restricted. Moreover, new methodologies and datasets can lead to confusion (e.g. applying the GFW emissions calculator on a local or national scale). A global product cannot be directly implemented at the local/national scale without proper validation. In order to cover the accessibility gap, IIASA created Geo-Wiki.org (Example 3) as a demonstration and crowd-sourcing tool. Another example is OpenForis[17] (Example 7), a tool that facilitates flexible and efficient data collection, analysis and reporting, designed for environmental monitoring from data collection to processing and reporting.

[17] http://www.openforis.org/

While there were no survey questions related to **participation and equity**, we were made aware, e.g. from stakeholder discussions at the workshops, that these pose problems to some users. Participation refers to the participation of users in decision making, and equity can be understood as equal rights to data, both being factors the presence of which increases trust in monitoring systems. On the other side of this coin we find **responsibility and accountability.** These two term pairs often describe an asymmetric situation in which data owners on the one side are made accountable and have responsibilities towards curating the data but also to provide access, allow for participation and make data availability equitable, while the other side is inadequately informed. For example, remote forest communities often lack the technical means, knowledge and capacity to deal adequately with forest cover and biomass data, which creates dependencies and reduces trust.

Key conclusions

In this section we have introduced the following key elements of independent monitoring that will increase data access and capacities:

- Element 7: Access and distribution
- Element 8: Participation and equity
- Element 9: Responsibility and accountability

3.3 Summary of key elements of effective independent monitoring approaches

Based on the stakeholder survey, case studies and other evidence collected from the literature, on available datasets and portals, we have now identified a set of nine key elements of independent monitoring approaches:

- **Element 1: Transparency and clarity**
- **Element 2: Accuracy and uncertainty**
- **Element 3: Consistency and completeness**
- **Element 4: Comparability and interoperability**
- **Element 5: Complementarity and scale**
- **Element 6: Reproducibility and adaptability**
- **Element 7: Access and distribution**
- **Element 8: Participation and equity**
- **Element 9: Responsibility and accountability**

In the following we discuss to what extent these elements can mitigate the identified gaps or weaknesses, what challenges for implementation exist and what ideal cases would look like.

3.3.1 Element 1: Transparency and clarity

What is it? Transparency provides for transparent and consistent information accessible by relevant stakeholders on the data sources, data collected, definitions, assumptions and methodologies used within a jurisdiction, other than confidential business information, to allow for an assessment of the credibility and reliability of data and assumptions (cf. also Sy et al. 2016). Clarity refers to the understandable and unambiguous presentation of the information.

Why is it important? Transparency is among the TACCC criteria of UNFCCC / IPCC referring to assumptions and methodologies clearly explaining how to facilitate replication and assessment of estimates by users of the reported information. It has equal importance for IM approaches. Transparency in data sources, definitions, methodologies and assumptions is a minimum requirement for comparing and understanding differences in AFOLU information, and building trust among countries and stakeholders. The backbone of the Paris Agreement will be the Enhanced Transparency Framework laid out in Article 13. This framework is being developed until 2018 and is expected to contain guidance on information necessary to track progress made in implementing and achieving individual NDCs. According to Article 4, Parties shall also account for their NDCs, inter alia taking into account the TACCC principles. This is a rather central element but can also be considered as general, implying that the other elements below form parts of Element 1. As later analysis will show (cf. Section 3.2, also Figure 9), transparency is central element among the various key elements, as many others elements are limiting or stumbling blocks for transparency to which they refer back.

What are current limitations? Examples for current limitations to transparency and clarity have been outlined in the Examples in Section 3.2 and include missing information and documentation of data, definitions, methods, and assumptions, and ambiguity and lack of clarity about which data sets are most useful for certain cases of use. An example for challenges for increased transparency is the NDC process. Due to the bottom-up nature, NDCs vary in many aspects: level of ambition, types of targets, methods and approaches. There is lack of guidance and uniformed reporting templates, and many stakeholders are not aware or not trained. This is a problem of interoperability (key element 4) but also presents a challenge for transparency and accounting, as data sources are sometimes confidential or not open-source; in particular private and commercial sector data. Another example is in the process for choosing baseline data, and underlying assumptions (e.g. forest definitions), which countries are set to choose individually. Lack of clarity is often seen in improper and insufficient documentation of data sources, underlying assumptions, timelines, units, uncertainties and so forth.

What would be ideal? Many of the examples in Section 3.2 represent attempts to overcome some limits to transparency in the current approaches, e.g. provide for better documentation, comparison and complementarity, all central factors underpinning transparency. Transparent monitoring requires accurate and precise MRV of GHG emissions. For example for implementing the enhanced transparency framework of the Paris Agreement in their NDCs, countries should clearly document data sources, definitions, methodologies and assumptions, to facilitate replication and assessment and to understand the limits of their applicability. The documentation should be complete, up-to-date and easily accessible for all relevant stakeholders. This has, however, to be seen in the context of the independent nature of the contributions. It is likely that the next years will see a convergence of approaches towards a common benchmark. Training efforts, e.g. through GCF or CTCN, would need to address the many shortcomings of national MRV efforts in terms of complete transparency. A set of standards based on these current nine key elements would need to be developed.

3.3.2 Element 2: Accuracy and uncertainty

What is it? Accuracy describes the degree to which an estimate of a quantity is unaffected by bias due to systematic error. For carbon accounting, this specifically refers to repeated measured observations or estimations of a quantity, relevant for quantitative estimates of carbon stocks and flows. An accurate measurement or prediction lacks bias or, equivalently, systematic error. Appropriate methodologies conforming to guidance on good practices should be used to promote accuracy in inventories. Accuracy should be distinguished from precision.

Uncertainty describes the lack of knowledge of the true value of a variable (e.g., reductions in emissions or increases in removals) that can be described as a probability density function characterizing the range and likelihood of possible values. Uncertainty depends on the state of knowledge, which in turn depends on the quality and quantity of applicable data as well as knowledge of underlying processes and inference methods. What is needed in land use and GHG emissions data are clear indications of the uncertainty.

Why is it important? Accuracy is among the TACCC criteria of UNFCCC / IPCC and constitutes a relative measure of the exactness of an emission or removal estimate.

Estimates should be accurate in the sense that they are systematically neither over nor under true emissions or removals, as far as can be judged, and that uncertainties are reduced as far as practicable. Data producers need to provide information about the level of accuracy. An independent assessment of accuracy reduces the potential bias towards "overestimated" accuracy and can increase trust. Appropriate methodologies should be used, i.e. countries are requested to fulfil UNFCCC reporting requirements and following IPCC Good Practice Guidance. They are encouraged to also continuously improve GHG estimates, e.g. by increasing Tier level.

What are current limitations? Despite existing opportunities there are still many uncertainties and gaps in national reporting. The development of NDCs requires investments by countries to improve their GHG inventories (Grassi & Dentener 2015). The consistent integration of IM approaches into national or sub-national datasets is often not straightforward and definitional issues need to be overcome (Federici et al. 2016). National estimates are often incomparable due to different methods and definitions used (and poor documentation). Methods and datasets change over time and this is not always well documented. Different stakeholders are producing their own data and either do not provide uncertainty information or do not generate uncertainty data independently; hence trust in accuracy information requires multi-stakeholder perspectives and engagement.

There is clear need for more expert-consensus guidance and experiences (e.g. through initiatives like GFOI[18]) and training modules to build in-country capacities and approaches to reduce uncertainties (e.g. through GOFC-GOLD[19], FAO OpenForis[20], etc.).

What would be ideal? IM approaches provide an opportunity to increase accuracy of estimates, e.g. by integrating data with high temporal or geographical resolution information. With relatively small investments, the associated uncertainties can be quantified and reported by comparing datasets and harmonizing definitions (see Example 1). This is not only useful at the national level, but can also support technical assessment by UNFCCC experts and provide useful inputs to the global stocktake. There have been previous attempts at harmonizing uncertainty estimates at the IPCC level, and efforts should be undertaken to translate the approach into similar but probably simpler (traffic light indicator systems and similar approaches) and more accessible standards and reporting practice for accuracy and uncertainty for country-level reporting. Donors such as EC can go a long way to help the climate community here, particularly building on existing efforts and experiences with cross-country reporting. Countries need to make greater efforts in building up national research entities (such as universities) that would be able to continuously improve data and tier levels in the national GHG estimates.

3.3.3 Element 3: Consistency and completeness

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[18] http://www.gfoi.org/methods-guidance/

[19] http://www.gofcgold.wur.nl/redd/Training_materials.php

[20] http://www.openforis.org/

What is it? Consistency provides for the use of similar methods to enhance comparisons across jurisdictions, and over time within a jurisdiction. Completeness helps ensure that carbon accounting considers all the relevant information. This includes carbon pools and categories of activities producing emissions or removals of carbon for reporting on the implementation of land use activities.

Why is it important? Consistency in the sense of the TACCC criteria by UNFCCC /IPCC means that inventories should be internally consistent with inventories from other years. Completeness means that an inventory should cover all sources and sinks, as well as all gases included in the IPCC Guidelines and other existing relevant source/sink categories which are specific to individual Parties and may therefore not be included in the IPCC Guidelines. Completeness also means full geographic coverage of sources and sinks of a country. These criteria are central to IM approaches, where consistency of applied definitions and methods across estimates of different sources needs to be addressed.

What are current limitations? The differences in definitions of forest and land use categories required for UNFCCC reporting (IPCC Good Practice Guidance) and regional/global datasets currently inhibit a barrier-free application at the national level. One of our case studies (Case study 2 in Annex V, Example 2) points to different datasets for the same region stemming from differences in forest definition, time periods included in the data (e.g. what is the baseline?) and also the onset of annual periods in different datasets (e.g. whether the year is seen as January-December or May to April may lead to differences in seasonally changing data such as vegetation cover). Consistency over time is often challenged by differences in methodologies to generate time-series data.

What would be ideal? From an accounting point of view, equal definitions of land use categories such as forest definitions in different IM approaches and country reporting consistency and allow completing national datasets using downscaling of global estimates. Global maps would then provide sufficient resolution and consistency with national statistics for countries to use them as consistent sources of information for activity data. Emission factors for land use transitions are available for key categories for countries and provide sufficient geographical disaggregation. It is important to set methodological benchmarks such as the accounting guidelines of the IPCC, but allow for revisions as science progresses.

3.3.4 Element 4: Comparability and interoperability

What is it? Comparability is one of the key qualities which accounting information must possess. Accounting information is comparable when accounting standards and policies are applied consistently from one period to another and from one region to another.[21]

Interoperability denotes the technical “permeability” between datasets, platforms, software and hardware.

Why is it important? Comparability is also one of UNFCCC / IPCC’s TACCC criteria and means that estimates of emissions and removals reported by countries should be

[21] http://accountingexplained.com/financial/principles/comparability

comparable among countries. For this purpose, countries should use the methodologies and formats agreed upon for estimating and reporting inventories. The same applies to IM approaches. A number of other elements form a prerequisite for this criterion, namely Element 1 (Transparency and Clarity) and Element 3 (Consistency and Completeness). Interoperability requires complete information about data interfaces to allow for integration across different data products, components of a monitoring system, different sectors and approaches.

What are current limitations? Many different independent datasets exist today without comparative analysis or good practice advice on how to compare and use them in an interoperable way. Often different stakeholders produce data for their own purposes (self-monitoring) and there is legitimacy in this. But assessing land use mitigation actions comparatively requires more exchange and check of self-monitored data to build trust among stakeholders involved. This feeds back into Element 1 (transparency).

What would be ideal? Functional implementation of Elements 1 (transparency and clarity) and 3 (consistency and completeness) that allows for the comparison and interoperability of various IM approaches is important. Completeness is a "moving target" because better data and data resolution will always move the goalposts. Completeness, however, does not only mean the best wall-to-wall data coverage, as a basis for emissions management. It also refers to being able to attribute emissions to certain sources (drivers), including e.g. land ownership (see Example 2), history of deforestation data (also Example 2), and identifying hotspots that can help guide the prioritization of mitigation efforts (Example 1). It can also mean the improvement of emission reference levels and baseline by including new data on carbon pools that previously have not been informing the emission budgets, such as the inclusion of soil carbon data as in the Yasso example (Example 4).

Achieving consistency is at the heart of many efforts as seen in the examples in Section 3.2 that attempt to analyse and identify disparities between maps and data sets, (e.g. Geo-Wiki, OpenForis).

The ideal situation would be characterized as follows: The considerations and needs of multiple stakeholders/users are considered from the beginning and datasets provide flexibility to respond to different needs. Definitions of land use categories for global data products are chosen that can be compared with national estimates. A combination of global activity data and national emission factors allows also for high accuracy and consistency. Data sets are continuously improving not only in coverage but also in data "depth", and becoming more differentiated to account for different situations, drivers, and allow for effective prioritization.

3.3.5 Element 5: Complementarity and scale

What is it? Complementarity refers to data or tools that have different coverage or characteristics such that the concomitant use of both improves or emphasizes the quality of the resulting product. Scale refers to the spatial scale of information in geographical information systems and maps.

Why is it important? Independent monitoring should be complementary to mandated reporting by countries. The development of NDCs and regular stock taking requires investments by countries to improve their GHG inventories (Grassi & Dentener 2015). In addition to mandated reporting responsibilities, countries need support for their mitigation planning and implementation. Independent monitoring approaches can support, but should not substitute countries' activities in their mitigation planning and implementation and related reporting for the regular stocktaking, in particular in cases where in-country capacities are lacking. Independent monitoring provides an opportunity to integrate independent datasets to fill data gaps in countries and encourage continuous improvements. The engagement of various stakeholders requires information at different scales in addition to national estimation and reporting, such as specific local information for communities, global assessments, and mitigation planning on the landscape scale.

What are current limitations? Integration of independent data is often not straightforward since there may be significant differences between independent studies and national reporting in terms of definitions, scope and methods. Many stakeholders do not have a sufficient understanding of how to use, integrate or compare complementary data and methods. They may not understand at which scale the drawing of which kind of conclusions is safe (e.g. degradation cannot be assessed in very coarse datasets, but high-resolution datasets might be too expensive and detailed for a country-wide assessment). This may also be a problem of missing transparency in data presentation and reporting of methods (Element 1). Particularly, using multi-scale, nested approaches is difficult for many users due to methodological inconsistencies. Users in our stakeholder survey reported different needs with regard to scale. This is not yet fully reflected in how data providers and data users work together.

What would be ideal? Data integration approaches can be used to reduce bias at the local level, by combining (independent) reference data with regional to global datasets (Avitabile et al. 2016). But more general guidance for the use of products providing data at different scales is needed. Proposed methods should be flexible enough to accommodate a diversity of spatial and temporal scales. There is a need for the build-up of national capacities in this regard.

3.3.6 Element 6: Reproducibility and adaptability

What is it? Reproducibility is the ability of an experiment, study or data collection effort to be duplicated, either by the same researcher or by someone else working independently. Adaptability refers to the ability of a system (here: dataset, portal, monitoring system, tool for analysis etc.) to being adapted quickly and easily to changed user needs. Adaptability also includes the ability to learn from experience of users, and being able to improve characteristics of the system relevant for the users.

Why is it important? Reproducibility is a core concept of science and any data collection and analysis efforts. It requires clear documentation of individual methodological steps as well as capacities. Adaptability is a function following reproducibility, if methodological steps can be altered to attain different results stemming e.g. from changed assumptions or input data.

What are current limitations? Reproducibility is often hampered by lack of uniform validation procedures, unclear documentation of a lack of capacities (for example country agencies not having sufficiently trained personnel or lack of resources for spatial data storage and processing (Romijn et al. 2012; Romijn et al. 2015), and lack of e.g. dialogue and exchange between different user communities (e.g. carbon scientists, AFOLU community). These are also challenges to adaptability because systems locked in into the requirements set by a certain dominating user group may make it difficult for them to be adapted to new users and their needs.

What would be ideal? Data, meta-data, assumptions and procedures need to be clearly documented, so that they can be clearly explained for QA/QC, training and continuous improvement; changes in scope and stratification should be anticipated. The documentation should support raising awareness, and the constitution of a critical mass of domestic capacities. It should therefore be based on national systems and definitions, yet translated for external reviewers, and merged with global reference definitions. Examples such as Geo-Wiki and OpenForis are setting standards for how reproducibility can be achieved but will require more investments, coverage and diversification to be useful to a large number of different users.

3.3.7 Element 7: Access and distribution

What is it? Access refers to users having free and open access to the data, and the capacity to understand the data and tools. Distribution in this context refers to the wide availability of the data or tools.

Why is it important? Free and open access, for users, to data, tools or methods with detailed documentation on data processing and creation creates many opportunities to provide better data for various stakeholders. In addition, it makes use of public and private investments in monitoring and new technologies (i.e. remote sensing) to realise higher (cost-) efficiencies. Data can be inaccessible because there is no physical access, or because the person with access cannot properly interpret the data.

What are current limitations?

Not having access to data is a problem for many remote, forest-dependent user communities. As far as this asymmetry is explored for one-sided gains, this impinges on Element 8 (participation and equity). Participatory approaches can go a long way to allow creating ownership of data, but are in budding implementation and are time consuming to implement, report and verify (Hawthorne et al. 2016). They also do not give automatic access, e.g. to the data of the next community, for comparison purposes.

What would be ideal? IM approaches can enhance action and participation of non-state actors, in particular local communities as well as the private sector (see Example 2 in Section 3.1), by increasing awareness, dissemination and interactive acquisition of data via user-friendly, easily accessible and intuitive web portals (Pratihast et al. 2016; FAO OpenForis) or via portable devices. Through such means IM approaches can provide information that can potentially serve as an authoritative reference for many kinds of stakeholder needs. Legitimacy with stakeholders and ease of access are key to successful implementation.

3.3.8 Element 8: Participation and equity

What is it? Participation: association with others in a relationship (as a partnership) or an enterprise usually on a formal basis with specified rights and obligations. Equity refers to a body of legal and procedural rules that protect rights and enforce duties.

Why is it important? Participation is a means for building increasing trust in numbers, bringing together different levels of capacity to get involved and build ownership. This increases empowerment and can improve equity. Equity flows from participation and ownership in the process of land use decisions. It is important that the needs of multiple stakeholders/users are considered from the beginning and datasets provide flexibility to respond to different needs.

What are current limitations?

Procedures to improve participation such as FPIC (Free, Prior and Informed Consent) are in place, e.g. under the safeguards for REDD+, but similar principles are not necessarily available in the MRV context of land use changes and related GHG emissions. Monitoring progress is often driven and assessed by technological developments and not in terms of social participation. Clear indicators and indicator values by which to judge to which degree participation has been implemented fully are also missing. Equity can be understood in different ways and better, understandable and applicable standards need to be provided to policy makers to be able to implement progress in this area more broadly.

What would be ideal? The increased participation of multiple stakeholders (i.e. private sector, local communities, NGOs) in land use mitigation actions, decision making and monitoring is essential to achieve successful climate change mitigation actions. Decision makers have clear guidance in how to truly implement participation, and in an efficient, effective and equitable way. In order respond to trends of reduced interest in monitoring carbon by a vast majority of (local) stakeholders, a greater understanding of the needs and interest of stakeholders through improved communication, trust and dialogue is achieved.

3.3.9 Element 9: Responsibility and accountability

What is it? Responsibility is the state or fact of being responsible, answerable, or accountable for something within one's power, control, or management[22]. In the context of independent monitoring, it means being responsible and answerable for land use decisions that affect emissions. This requires, in turn, being identifiable, a specification that e.g. the Kalimantan Deforestation Atlas (Example 2) implements with great detail.

Accountability refers to the acknowledgment and assumption of responsibility for actions, products, decisions, and policies with regard to emissions deriving from land use change, including the administration, governance, and implementation, as well as the obligation to report, explain and be answerable for resulting consequences[23].

Why is it important? An increased accountability of multiple stakeholders (i.e. private sector, local communities, NGOs) for their land use (and mitigation) actions in decision making and monitoring is essential for achieving successful climate change mitigation actions. Responsibility and accountability refer to the management and governance of monitoring data. Institutions and rules are needed in order to define clear roles and responsibilities regarding the data and how it is used. This means establishing who is accountable for what and the obligation to secure, and report on

[22] http://www.dictionary.com/browse/responsibility

[23] https://en.wikipedia.org/wiki/Accountability

progress regarding many of the elements mentioned previously, e.g. data quality, data access and participation. It includes establishing a system of checks and balances, being answerable for the results and having the ability to sanction. Responsibility and accountability are required to build the overall legitimacy of a monitoring system.

What are current limitations? Weaknesses such as poor quality data, low capacity and confusion over numbers make it more difficult to hold data managers accountable. Also, monitoring is not only a technical process but also has broader, often poorly understood, political, economic and policy implications of great interest to multiple stakeholders, as the experience from Peru shows (Kowler & Larson 2016). But societal implications of monitoring are often not considered. One of the biggest challenges is to establish effective communication among different actors with different interests and goals with regard to monitoring, and between scientists and non-scientists (Kowler & Larson 2016). Some actors may resist clarifying responsibility to avoid accountability.

What would be ideal? Building institutions and processes from the beginning of the process that establish communication across stakeholder groups can build trust and be accompanied by stronger responsibility and accountability. IM approaches need to be truly "barrier-free" to all stakeholders, i.e. open, easily accessible and explained so users can understand and easily use it, with the limitations being known. Participants recognize that technical complexities influence who is involved in monitoring, and that what is being monitored should be made transparent, for what purpose and with what outcome. In an ideal case societal implications of monitoring are also being considered.

Approaches such as the one in Geo-Wiki (Example 3) that actively seek user feedback to increase accuracy, transparency, and with these, responsibility and accountability are widely implemented. Approaches such as the Kalimantan Atlas (Example 2) that link ownership of the history of emissions to the current state of deforestation and degradation, are more widely implemented in a transparent and accountable manner. They increase the accountability and responsibility of the drivers of deforestation of sustainable management by allowing not only "naming and shaming" (which can have great power), but also by protecting countries and companies from a bad reputation. Accountability is thus greatly enhanced by approaches that improve consistency and the completeness of coverage.

3.4 Synthesis

3.4.1 Summary of key elements

The key elements presented above form ingredients for independent monitoring approaches towards increased transparency and accountability. Ideally IM approaches would not have any negative effects on any of these key elements, but in reality, trade-offs will be unavoidable. Accuracy levels might be lower with increased comparability and interoperability, e.g. due to data aggregation or harmonisation.

On the other hand, some of these elements are conditional on each other, or mutually supportive and reinforcing, as we have been exemplifying in the above passages (e.g. accountability depending on the consistency and transparency of data documentation). For example, open access and the wide distribution of data are important elements of transparency, while transparency and clarity are a precondition for reproducibility. In this regard, not all of these elements need to be prioritized at the same time. In

Section 3.4, we will come back to this thought by developing a more hierarchical approach to these nine elements.

To conclude, a summary of the elements, current limitations and challenges and benchmarks of an ideal approach is presented in Table 6.

Table 6: Elements, limitations and benchmarks for independent monitoring opportunities

Elements	Current limitations and challenges	Benchmarks of an ideal approach
Element 1: Transparency and clarity	Incomplete/absent documentation on methods, datasets and assumptions, varying definitions	Data sources, definitions, methodologies and assumptions are clearly described to facilitate replication and assessment and the limits of their applicability.
Element 2: Accuracy and uncertainty	Large or fully missing uncertainty data for land use activities (emissions, AD, EF). Nationally incomparable estimates due to different methods and definitions (and poor documentation). Methods and datasets can change over time (not always well documented)	Provides information that is accurate, reliable and customizable. It allows for the assessment of differences in estimating, allocating and reporting GHG emissions. It promotes the use of similar methods and datasets along time.
Element 3: Consistency and completeness	Lack of consistency and completeness from different inventory approaches and methods Forest and land use categories are defined differently by different stakeholders Temporal inconsistency due to changing data sources, methods and monitoring objectives	Monitoring framework is able to accommodate technological developments and evolving policy objectives in estimation and reporting; including reprocessing of historical estimates as appropriate.
Element 4: Comparability and interoperability	Many different independent datasets exist without comparative analysis nor good practice advice on how to use them in an interoperable way Different stakeholders produce their own data for their purposes	Considerations and needs of multiple stakeholders/users are considered from the beginning and datasets provide flexibility to respond to different needs
Element 5: Complementarity and scale	Not enough understanding on how to use/integrate/compare complementary data and methods.	It expands/complements/ integrates/ improves ongoing monitoring systems. It provides data that can serve the purpose of national

Elements	Current limitations and challenges	Benchmarks of an ideal approach
	Multi-scale (nesting) approaches difficult by methodological inconsistencies.	independent verification by UNFCCC Flexible to accommodate a diversity of spatial and temporal scales
Element 6: Reproducibility and adaptability	There are gaps in data and capacities particularly in the tropics	It expands/complements/ integrates/ improves existing datasets and capacities
Element 7: Access and distribution	Ease of data access is scale dependent (e.g. global datasets easier to publicly access) with national and local scales harder to access freely and openly. New methodologies and datasets can lead to national confusion. Unintuitive data portals limit access and usability to non-technical stakeholder. Technical/human capacity limitations Legitimacy not always recognized	Publicly available data, tools or methods with detailed documentation on data processing and creation Provides information that is potentially serving as authoritative reference for many kinds of stakeholder needs. Legitimacy with stakeholders and ease of access.
Element 8: Participation and equity	Monitoring progress is often driven and assessed by technological developments	All relevant stakeholders (i.e. those involved in achieving land use sector mitigation) are involved and regularly inform and contribute to the monitoring and reporting process
Element 9: Responsibility and accountability	Poor quality data, low capacity and confusion over numbers often impede accountability. Societal implications of monitoring are often not considered.	Different land use sector mitigation stakeholders are and can be made accountable for their activities and actions

Source: own compilation.

3.4.2 Influence model and interdependencies of elements

Basic modelling was applied for analysing the relationship between the elements and challenges identified above. The results propose a prioritisation of independent monitoring approaches. We used interactive software (iMODELER provided by consideo[24]) to build, based on expert knowledge, an exploratory, qualitative influence model.

The resulting model consists of a matrix of links of how these elements and challenges are causally linked to each other. The model explores the relative influence of these many overlapping linkages to generate a so-called "insight matrix" that provides an insight into the relative importance of each of the model elements, based on the number and nature of the linkages (e.g. if these are including positively or negatively reinforcing feedback loops).

When using the "influence matrix" (not shown), Transparency and Clarity (Element 1), Comparability and Interoperability (Element 4) and Consistency and Completeness (Element 3) – one social and two technical factors - show remarkable constancy as the most influential factors for effective IM approaches in the short run (timeline not specified), while in the long run, Accuracy and Uncertainty (Element 2), one of the technical factors, is losing importance to the more social factor Access and Distribution (Element 5). This shows that focusing on the technical aspects of monitoring alone will not provide a complete understanding of the problem and could lead to failure in implementing IM approaches.

The comparison of influences of the various elements towards the overall goal of accountability of mitigation actions emphasizes that Element 1, Transparency and Clarity, is central in many aspects and heavily influences many of the others elements as well as being influenced strongly by them (see Figure 9). This leads us to conclude that transparency and clarity are in many ways essential for independent monitoring. Independent monitoring should be considered an important mechanism for enhancing particularly one high-level goal: transparency in the land-use sector. Stakeholders can engage and benefit from independent monitoring approaches to achieve transparency when starting to implement the Paris Agreement. IM also underpins in crucial ways the Paris Agreement's Transparency Framework, because monitoring achievements, at the heart of the Agreement, requires independent approaches to be effective, efficient and to allow for equity (Sy et al. 2016).

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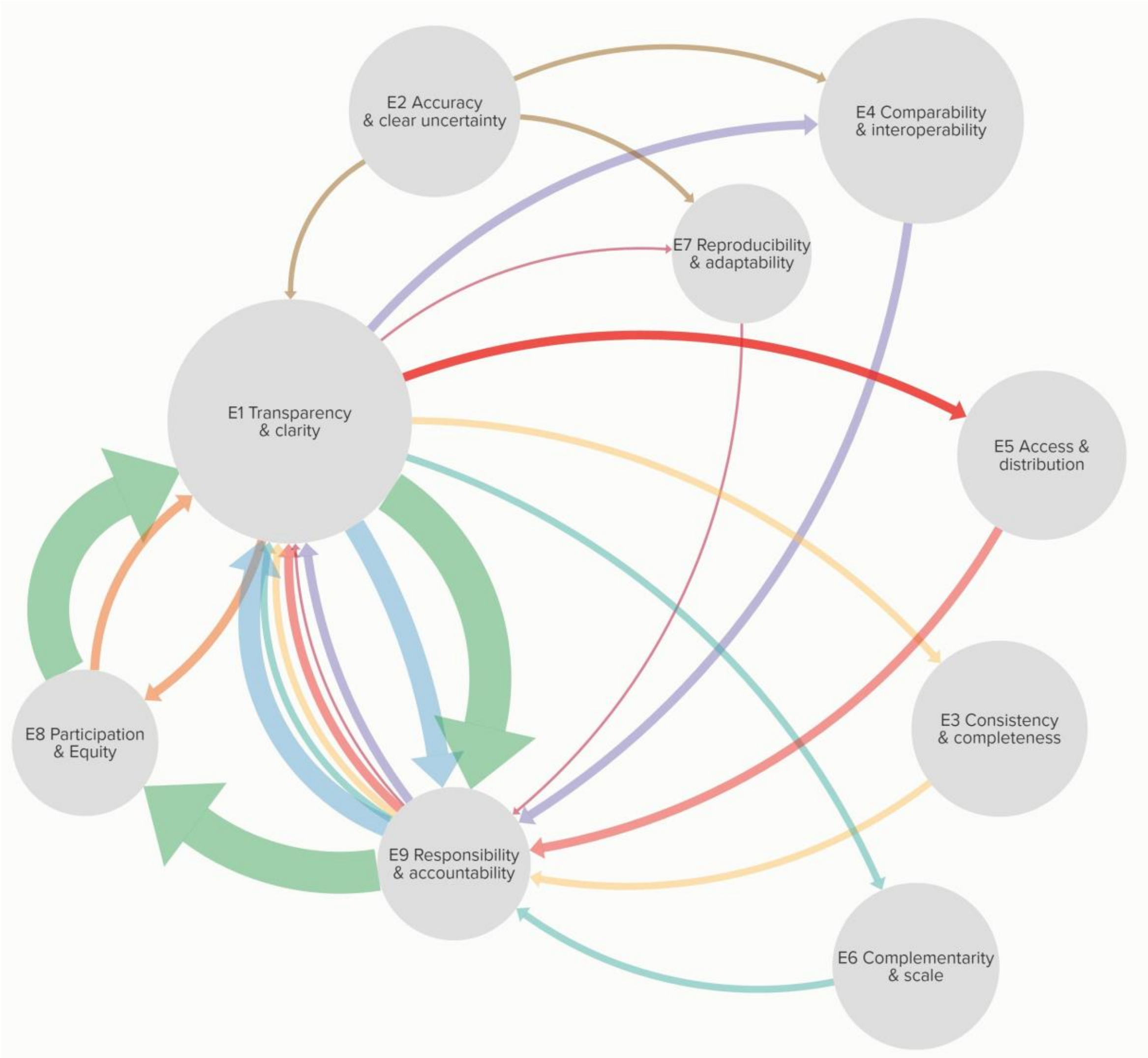
[24] http://www.consideo.com/imodeler24.html



Source: own compilation.

Figure 9: Results of model analysis for setting priorities in IM approach development. Size bubble = influence on monitoring, arrows = positive feedbacks (size = impact of feedback)

4 HOW TO GET THERE: PRIORITIZATION OF INDEPENDENT MONITORING OPPORTUNITIES AND RECOMMENDATIONS

4.1 IM approaches for implementing the Paris agreement

4.1.1 The role of IM approaches for implementation the Enhanced Transparency Framework

With a better understanding of the elements required for independent monitoring approaches, it is clear that such approaches can make an important contribution to the implementation of the Paris Agreement. Box 4 summarizes the challenges in monitoring, reporting and verification arising from several Paris Agreement requirements, the key stakeholders involved, and the contribution independent monitoring can make. Land use sector mitigation under the Paris agreement requires more **transparency** and stakeholder **accountability**, and if these elements are applied, their engagement in monitoring can become an important means to stimulate action and increase confidence. Independent monitoring can enable countries to develop NDCs which are specific, quantifiable, linked to high-quality reporting, and can be assessed independently. It can provide supporting information to build trust with donors and the general public to stimulate and compensate for mitigation actions at the local, national and landscape scales.

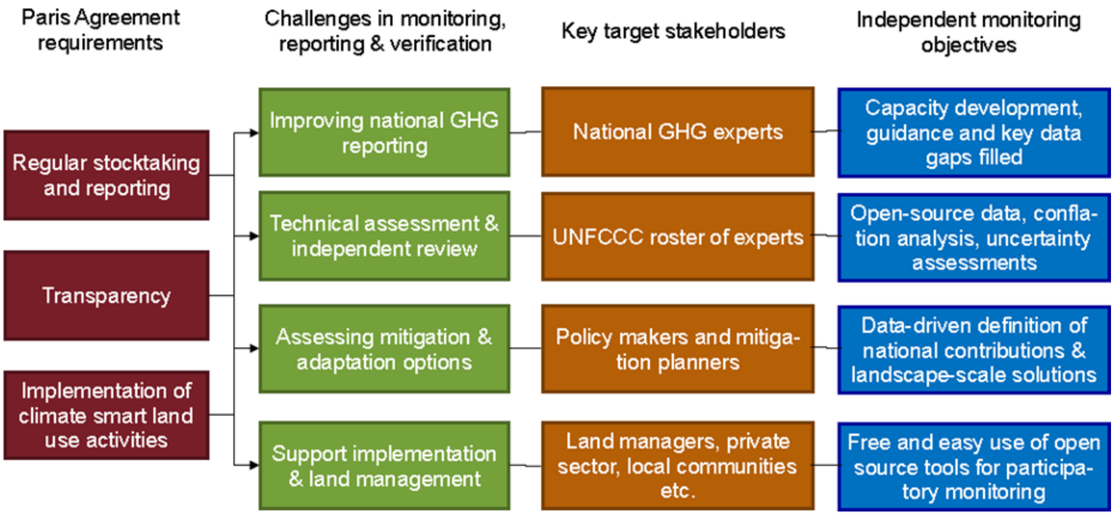
In terms of priorities for the implementation of the Enhanced Transparency Framework recommended independent monitoring approaches should:

1. Provide data and guidance to assist the UNFCCC-coordinated technical assessment processes and upcoming global stock-take(s);
2. Underpin multi-stakeholder processes for streamlining pathways to achieve land use sector mitigation on the national (i.e. NDCs) and landscape scales;
3. Facilitate participatory monitoring for land use mitigation activities tracking and impact assessment involving the private sector engaged in zero-deforestation, civil society and government agencies.

Box 4: What is the role of independent monitoring for implementing the Paris Agreement?

With a number of elements in place, IM approaches can make an important contribution to the implementation of the Paris Agreement. The figure below summarizes the challenges in monitoring, reporting and verification arising from several Paris Agreement requirements, the key stakeholders involved, and the contribution IM can make.

The Paris Agreement requires regular stocktaking and reporting, transparency and implementation of climate smart land use activities. To meet those requirements, certain challenges in MRV have to be overcome and key target stakeholders have to be involved. From these requirements, independent monitoring objectives can be derived. MRV challenges include the improvement of national GHG reporting. This requires the involvement of national GHG experts and has the IM objective of capacity development, guidance and the filling of key data gaps. Technical assessment and independent review addresses the UNFCCC roster of experts. These experts require open source data, conflation analysis and uncertainty assessments that IM approaches can deliver. The assessment of mitigation and adaptation options by policy makers and mitigation planners asks for data-driven definition of national contributions and landscape-scale solutions. Support to implementation and land management addresses land managers, the private sector, local communities and other stakeholders. These stakeholders require IM approaches to deliver free and easy open source tools for participatory monitoring.



Source: de Sy et al. 2016.

Challenges and opportunities for IM approaches in the light of the Paris Agreement

4.1.2 The role of IM approaches in engaging the private sector

Private sector actors committed to deforestation-free commodity supply chains must measure progress towards zero-deforestation from their own plantations, second parties such as contracted outgrowers, and third parties such as independent smallholders. Measuring performance can be difficult given the different forest definitions adopted and the use of different methods to set aside conservation areas (e.g. High Conservation Value, HCV and High Carbon Stock, HCS). This is even more difficult since the different consumer goods companies and those involved in processing and production lack harmonized criteria to assess progress, particularly given the different characteristics of the commitments (e.g. no deforestation, no exploitation, no peat). In addition, there are no clear cut-off dates for establishing baselines. The private sector also faces the challenge of making their assessments of progress in the achievement of their zero-deforestation commitments open to public scrutiny.

Major corporate groups are developing tracking systems to monitor the environmental performance of their supply chains, and thus the impact of their production operations on land use change and carbon emissions. While considering issues of confidentiality of suppliers, and other sensitive information associated with their operations, major corporate groups should adhere to transparency principles by disclosing, for example, the definitions of forest adopted, the sources of information used and methods adopted for determining the forest impacts of their operations, and how much relates to their own plantations or other suppliers. Companies' disclosure of data, methods, and performance outcomes will contribute to increasing the reliability and legitimacy of information on progress made in achieving their zero-deforestation targets, and the implications for their suppliers. In addition, it will be important to verify the accuracy of their self-monitored performance reporting with other sources of information available in the public domain to increase legitimacy. Currently, assessing progress is constrained to a few major corporations. This practice should extend to a large number of third-party suppliers.

The future will most likely see even more diverging methods, data and definitions, creating user confusion, mistrust and lack of confidence in government institutions and their data. Definitions, methods and data sources need to be carefully chosen, and clearly defined, to best correspond to the specific interest or needs of the user, while being kept interoperable for users employing different methods, data and definitions, so that these datasets can be made to converge towards common, broadly accepted values (such as agreements on actual emission reductions to be paid for). Under such circumstances, a perceived independence in monitoring approaches may become a key element of confidence building and legitimacy, which will help to safeguard investments in land use sector mitigation and support stocktaking on local and global levels.

Specifically for Borneo, financing institutions can track deforestation in the plantations they finance, using new approaches datasets mapping deforestation (see Case study 2 in Annex V).

4.1.3 The role of IM approaches in empowering civil society

Civil society, not only NGOs but also interested citizens and particularly those affected by mitigation strategies, should be encouraged to participate in independent monitoring. This requires improved data coherence, increased capacity and relevant tools. Civil society engagement includes not just monitoring but also participation in the design of data and monitoring systems, identifying locally relevant data needs, contributing reliable and accurate data to the system and holding decision makers accountable for decisions made based on the data.

NGOs can play an important role in promoting citizen participation, although this is also a government responsibility. For their part, citizens can identify local needs, seek out and request training opportunities and use their local institutions and organizations to lobby for resources and participation.

Enhancing participation requires building local capacity and an understanding of the standards required for data accuracy and nesting as well as the options available for the design of the data and monitoring system.

With accurate and coherent data and capacity to analyse this data, citizens and NGOs can participate as watchdogs through independent monitoring and established accountability mechanisms.

4.2 General recommendations regarding technical aspects of IM approaches

Many tools that serve IM approaches have an explicit participatory character, in the sense that they allow users to contribute to improving estimates e.g. by uploading data. These tools should take into account different levels of sophistication depending on users' background and level of training. We recommend the development a practice of "data bridging", i.e. not to impose a "one size fits all" system, but rather to simplify and streamline the dialogue between data users and a variety of datasets, without preconception of their intrinsic value.

In order to comply with the technical aspects of IM approaches for increased transparency there are a number of technical requirements to be considered. The first minimum requirement is to open up all datasets that support reporting of GHG emissions in the land use sector and to make them free and openly accessible. Only by making the datasets accessible via the web using standard data formats, it is ensured that other users can verify reported data and get an insight into the quality of the underlying data used in the reporting.

Ideally, in order to be fully transparent all code and land use classification systems and algorithms should be made available on online repositories such as GITHUB. However, there are possibly some obstacles to this such as proprietary software used to produce the relevant datasets. Since land use data is spatially explicit an easy to use web mapping platform with visualization and download functionality is recommended. Additional analysis functionalities for example to derive aggregate statistics are of advantage. There have been major technical advances in the last years with the developments of web services and Application Programming Interfaces (API) allowing third parties to programmatically retrieve the data and integrate it in new applications. A truly transparent and modern monitoring system will use such web services and provide an API in order to easily access underlying spatial databases.

Independent and transparent monitoring is not a specific tool, one single system or a one-serves-all approach. Different stakeholders have different views on what independent monitoring means for them and this needs to be acknowledged when developing datasets, tools and services.

Independently of the dataset and application the following set of recommendations is fundamental to all providers and must be considered when providing data for enhancing transparent monitoring:

1. All data need to be transparent including the original data sources. Definitions, methodologies and assumptions should be clearly described to facilitate

replication and assessment. All datasets need to include accuracy assessments and uncertainties;

2. Methods for data production need to be publicly available and preferably published in peer-reviewed papers;
3. Data systems require regular update data and consistent estimates over time; including long-term sustainability of production;
4. The institutional background of the data producer should be known and understood by all stakeholders involved.

4.3 Specific recommendations

This project has aimed to articulate actionable policy-level messages for different policy processes related to climate change mitigation in the land sector and stakeholders involved or interested in independent monitoring. Based on the analyses above, the SWORG analysis, the stakeholder survey, and the case studies the following key messages to specific stakeholders can be concluded:

4.3.1 Recommendations to EU Copernicus

There are many opportunities for EU Copernicus to provide targeted services and datasets which can serve stakeholders on local, national and global scales. Copernicus has largely focused on providing services with a European scope and the current Global Land Monitoring Service is mostly targeting biophysical variables that only marginally support the monitoring and assessment of land use mitigation activities. With the Paris Agreement in place and the needs of stakeholders in such mitigation being now more clear and concrete, Copernicus should take immediate action to expand the service portfolio in that direction. The free and open availability of the Sentinel (1+2+3) satellite assets offer a unique opportunity here and we recommend utilizing them to underpin the development of three particular services:

- Copernicus service for national REDD+ and AFOLU reporting,
- Copernicus global AFOLU transparency data system,
- Copernicus land use mitigation tracker service.

Copernicus service for national REDD+ and AFOLU reporting

The stakeholder survey and case studies have highlighted important gaps in the transparency consistency and completeness, comparability and reproducibility of national GHG inventory data that are attributed to the lack of data and capacities within countries. Building upon the Sentinel satellites as foundations, we recommend to provide data, tools, capacities and expert guidance targeted for national GHG experts to enhance transparency and fill key data gaps, in particular for developing countries implementing REDD+ and AFOLU as part of their commitments to the Paris climate agreement. Table 7 summarizes the more detailed specifications and recommendations for using the Copernicus assets for that purpose and highlights that the Copernicus assets are not only suited for the estimation of activity data for forest area changes but rather should also be used to assess land change trajectories and land management, and expand to include the estimation of biomass from space in combination with ground data (i.e. ESA BIOMASS, see recommendations for biomass mapping from space).

Table 7: Specifications for Copernicus services on national REDD+ and AFOLU reporting (Source of recommendations: project stakeholder survey, project stakeholder workshop, Case study 2, Paris Climate Agreement)

Specifications	Recommendations for activity data	Recommendations for biomass and emission factors	Recommendations for AFOLU emission data
Observations required	• Regular, long-term global coverage by Sentinel 1+2 and Landsat, wall to wall pre-processed and available for country-level assessments • Samples of very-high resolution data to provide reference data (sample might vary by country)	• Combination of in-situ carbon observations from national inventories and ground surveys and satellite observations (Sentinels, ESA-BIOMASS, Landsat, ALOS-PALSAR, GEDI)	• Combination of in-situ observations from national inventories and ground surveys and satellite observations for biomass burning, wetlands and land management (Sentinels/Landsat)
Thematic detail and definitions	• Map products with forests and other land use classes (agriculture, grassland, cropland, settlements, wetlands, etc.) and specific classes with forest land sub-divided into different forest types, degraded forest, plantations, mangroves and peatlands etc. are required. • Forest and land definitions should be based on country preferences	• Aboveground biomass, belowground biomass and soil carbon to estimate emission factors on IPCC Tier 2 or Tier 3 • Important to be able harmonize biomass estimates with that of national definitions (i.e. definition of biomass and forests) • Data for dead wood, litter and harvested wood products are also in demand but of lower importance	• Emission data from biomass burning, grassland management, and estimating direct and indirect N_2O emissions from managed soils • Emissions from peatlands and mangroves • Priority GHG are: CO_2, CH_4, N_2O; of less demand are data on NOx, CO, NVMOC, SO_2. on • IPCC Tier 2 or Tier 3
Spatial resolution (satellite data)	• 10-30 m, wall to wall coverage, <5m for high resolution sampling	• 10-30 m, wall to wall coverage to match with activity data estimation	• 10-30 m, wall to wall coverage, <5m for high resolution sampling
Temporal resolution (satellite data)	• Data analysis need to lead to annual, unbiased estimation of IPCC activity data for forest and land use area changes incl. confidence intervals.	• Data analysis for annual, unbiased estimation of emission factors	• Dense-time series (few days/weeks) required to track fire/biomass burning, wetland dynamics, and land use and land management activities.
Tools and guidance	Data analysis methods and results should be open source and published, and follow the guidance provided by the IPCC good practice guidelines and the Global Forest Observations Initiative (GFOI) / GOFC-GOLD		
Transparency	All data and estimates produced should be publicly shared and available to serve other stakeholders needs		

Source: own compilation.

These recommendations are generic for all countries but gaps and needs will vary for various national circumstances based on their current capacities and land use mitigation commitments (i.e. NDCs). It is important that such services become part of coordinated capacity development with country experts as a key audience and in partnership with other EU/EC (i.e. REDD facility, JRC, DevCO) and global initiatives (i.e. UN-REDD, Worldbank FCPF).

Based on the results of this study, it is further recommended to also put emphasis on other elements for enhancing transparent monitoring:

- Reproducibility and access: use the quality data and estimates that can be produced from Copernicus assets to spawn an environment of open sharing of data and methods using web-based interfaces and interactive data systems. Making them available and useful to serve other stakeholder needs in terms of awareness and exchange of data for their purposes is the basis for broad legitimacy and acceptance.

- Participation and accountability: national data should become an authoritative reference for the reporting of land use mitigation progress from multiple stakeholders and across various levels of governance and climate mitigation policy objectives. These partners (often non-technical experts) need to be engaged in the design and implementation of the monitoring system to make use of the data information not only for estimation and reporting but also to underpin the accountability of various stakeholders.

Copernicus global AFOLU transparency data system

The UNFCCC enhancing transparency process, and the required UNFCCC technical assessments and global stocktake(s) are new high-level political requirements and provide an opportunity to address key gaps that we have also identified in our project’s stakeholder interactions: limited transparency, lack of uncertainty information, comparability, access and low-levels of acceptance and participation of stakeholders including dealing with the various forms of unchecked self-monitoring and reporting. We therefore recommend for the EC and Copernicus to develop a global data system to support the UNFCCC’s technical assessments and stocktake(s) with independent and comparative information and analysis for AFOLU experts and reviewers.

This data system should provide national, continental and global estimates on AFOLU GHG emissions and removals based on a comparison and harmonization of multiple data sources (i.e. AFOLU datasets, country reports, scientific studies, GFW etc.), related uncertainty analysis, and a regular, at least annually update based on various data inputs including Copernicus satellite data. The data system should facilitate the comparison and contrasting of AFOLU GHG reporting provided by countries (as part of their commitments to the Paris Agreement) with those of independent data sources. It should further support the estimation of the regional and global GHG impact and performance of land use mitigation activities reported by countries as a contribution to the UNFCCC global stocktake.

Table 8: Specifications for Copernicus contribution to a global AFOLU transparency data system (Source of recommendations: project stakeholder survey, Case study 1, 3, 4)

Specifications	Recommendations for forest and land use change emissions and removals	Recommendations for biomass burning	Recommendations for land management and wetlands emissions
Observations required	• Regular, long-term global coverage by Sentinel 1+2 and Landsat • Combination of in-situ carbon observations and satellite observations (Sentinels, ESA-BIOMASS, Landsat, ALOS-PALSAR, GEDI) • Samples of very-high resolution data to provide reference data	Combination of ground and satellite observations for fire and biomass burning (Sentinel1,2,3/Landsat)	Combination of ground and satellite observations for land management and wetlands and (Sentinels 1+2/Landsat)
Thematic detail and definitions	• Flexibility to address multiple forest definitions (FAO, land cover/GFW, UNFCCC, countries) and include at least IPCC land use classes (agriculture, grassland, cropland, settlements, wetlands, etc.) and, if possible specific classes with forest land sub-divided into different forest types, degraded forest, plantations • Aboveground biomass, belowground biomass and soil emissions (flexibility to harmonize biomass estimates with national definitions of biomass and forests) • Estimation of annual gross and net emissions	• Emission data from biomass burning consistent with various forest and land use definitions • Aboveground biomass, belowground biomass and soil emissions	• Grassland management, and estimating direct and indirect N_2O emissions from managed soils • Emissions from peatlands and mangroves • GHG gases: CO_2, CH_4, N_2O
Spatial resolution (satellite data)	• 10-30 m, wall to wall coverage, <5m for high resolution sampling	• 10-30 m, wall to wall coverage	• 10-30 m, wall to wall coverage
Temporal resolution (satellite data)	• Data analysis need to lead to annual, unbiased estimation of IPCC activity data and emission factors for forest and land use area changes incl. confidence intervals.	• Data analysis for annual, unbiased estimation biomass burning emissions	• Dense-time series (few days/weeks) required to track wetland dynamics, and land use and land management activities
Tools and guidance	Data analysis methods and results should be open source and published, and follow the guidance provided by the IPCC good practice guidelines and the Global Forest Observations Initiative (GFOI) / GOFC-GOLD		
Transparency	All data and estimates produced should be publicly shared and available to serve other stakeholders needs		

Source: own compilation.

The need for global and regional comparison between country reported data, remote sensing datasets (i.e. from GFW), and results from global vegetation and earth system modelling (i.e. as used in previous IPCC reports) as part of the global stocktake is fundamental and the IPCC is essential partner here (see Section 4.3.3, Recommendations to the IPCC). Copernicus satellite assets are particularly needed for the regular annual and global updating for the duration of the Paris Climate Agreement with specifications recommended in Table 8.

The development of such a data system can both inform the ongoing negotiations of how transparency can be best achieved as part of Paris Climate agreement (see recommendations in Section 4.3.3) but most importantly should be implementing any UNFCCC decisions and processes in the years to come including the modalities for enhancing transparency, the UNFCCC global stocktake and technical assessments, and the IPCC (see recommendations to the IPCC)

Copernicus land use mitigation tracker service

We recommend a targeted service to particularly address the lack of limited capacities of local stakeholders and the private sector for their participation and accountability in land use mitigation actions. This gap can be addressed when they are involved, regularly inform and contribute to the monitoring and reporting process, share progress in a transparent manner and in return can be made accountable for their mitigation activities and actions (see Case study 2 in Annex V). The global Copernicus satellite assets provide a unique data source to support the open and transparent monitoring and tracking of land use sector mitigation actions, including assessing relevant land use change, forest and agriculture activities, areas and drivers of deforestation, reforestation, and restauration, environmental safeguards; including near-real time monitoring of activities for enforcements. The provision of such data and information should underpin an open and transparent sharing of information among the key stakeholders involved in local implementation of mitigation activities (i.e. private sector zero deforestation, local communities, farmers, forest and land managers) for participatory implementation and monitoring (Table 9).

The EU Copernicus free and open data policy is fundamental for the successful implementation and should evolve towards a barrier-free uptake of data and information. This requires working equally with stakeholders of different technical capacities and background and any technical progress and implementation.

The three recommended Copernicus services address different stakeholder groups and in this sense can evolve as separate processes. However, it is important that all datasets and services remain compatible with definitions and standards used in IPCC GHG accounting and the related intergovernmental process. All uncertainties should be independently quantified and help the interoperability of datasets and harmonizing definitions. It is further recommended to actively engage in the development of expert community-consensus guidance and training materials (i.e. through IPCC TSU or GFOI) to make best use of available sources increases opportunities not only for participation but also transparency and stakeholders’ capacity to understand, compare and reconcile each other’s processed data.

Table 9: Specifications for Copernicus contribution to land use mitigation tracker service (Source of recommendations: Case study 2, project stakeholder survey)

Specifications	Recommendations for near real time alerting	Recommendations for monitoring for environmental safeguards	Recommendation for interactive monitoring for participation and enforcements
Observations required	• Regular, long-term global coverage by Sentinel 1+2 and Landsat in high temporal detail • Samples of very-high resolution data to provide reference data	Combination of ground and satellite observations (Sentinel1,2,3/Landsat)	Combination of participatory local monitoring/crowd sourcing and satellite observations (Sentinels 1+2/Landsat)
Thematic detail and definitions	• Alerts for forest and land changes according to national definitions • Context data to better characterize alerts such as Carbon stocks, forest and land use types, land ownership, concessions etc.	• Ecosystem characterization for carbon and biodiversity • Consistent with REDD+ safeguards	• Use distributed alerts to support participatory monitoring and independent assessment by stakeholders and assessment of critical changes/drivers and enforcements • Identification of causes of changes, responsibilities and impacts • Transparent data system that facilitates moderation of conflicts among different stakeholders
Spatial resolution (satellite data)	• 10-30 m, wall to wall coverage, <5m for high resolution sampling	• 10-30 m, wall to wall coverage	• 10-30 m (alerts) to target local interactive monitoring
Temporal resolution (satellite data)	• Daily coverage	• Annual updates	• Daily coverage required to track critical changes and support enforcements
Stakeholder engagement	System needs to facilitates access to alerts to all relevant stakeholders (incl. those with low capacities)		
Tools	Data analysis methods should be open source and published		
Transparency	All data and estimates produced should be publicly shared and available to serve other stakeholders needs		

Source: own compilation.

Main recommendations

1. We recommend the development and long-term operation of three dedicated Copernicus services to address the needs from different stakeholder groups: (1) improving national REDD+ and AFOLU reporting, (2) a Copernicus global AFOLU transparency data system, and (3) Copernicus land use mitigation tracker service.
2. We recommend using the capabilities of Sentinels 1 and 2 to expand global monitoring for forest area change to include land use change (incl. drivers of forest change), land management, biomass burning, wetlands and peatlands, and for near-real time alerting.
3. We recommend enhancing participation and accountability of stakeholders through improved monitoring to fulfil the requirements from the Paris Climate agreement, in addition to meeting the known UNFCCC / IPCC TACCC criteria for estimation and reporting.

4.3.2 Recommendation to biomass mapping from space

The continental-scale biomass map and data comparisons highlight substantial disagreement in the amounts and spatial distribution of biomass density among existing maps for the study area of Europe, similarly to the differences found in the pan-tropical maps (see Case study 3 in Annex V). The sources of these differences could not be fully assessed due to the lack of uncertainty estimates for some maps and the use of different forest definitions, limiting the comparability of the maps among each other and with national forest inventory data and, thus do not allow for large area comparison. The advent of satellite biomass missions (i.e. ESA-BIOMASS, NASA-GEDI) provides the opportunity to significantly improve spatially explicit and timely provision of biomass data. We recommend to space agencies (ESA, national space agencies) and other donors to further support research aimed at a better understanding of biomass distribution and uncertainty, including the acquisition of ground reference data as well as airborne and terrestrial LiDAR measurements to better calibrate and validate space-borne measurements.

We recommend to biomass map producers (incl. those for the ESA-BIOMASS mission and supporting projects):

- to increase the quality and consistency by producing biomass maps at higher spatial (10-100m) and temporal (≤ 5 years, ideally annual) resolutions to better integrate them with NFIs, interlinkage and integration with activity data, and to support the needs of local users;
- to increase comparability and complementarity by providing wall-to-wall biomass maps without applying a-priori forest masks, to allow the users to apply the mask that best correspond to their forest definition;
- to provide the uncertainty associated to the biomass values in form of a spatial layer (i.e., pixel based uncertainty layer) and summary statistics including all main sources of error that affect the biomass estimates;

- to estimate and reduce bias of the biomass maps and estimations using reference data that are fully independent, quality screened, representative of the range of biomass existing in the study area, and spatially and temporally compatible with the map units.

There are three satellite missions planned to estimate biomass (ESA-BIOMASS, NASA-GEDI, NISAR). Our study strongly suggests to get away from the "one sensor/one map" approach and rather focus on combining the strength; a charge to the international technical community to ensure that (i.e. CEOS, GOFC-GOLD, GFOI). Any biomass mapping from needs to be underpinned by adequate ground reference data for calibration and validation.

All of the upcoming space-borne biomass mapping efforts are planned as one-off research missions. We encourage ESA and the EC to take steps to operationalize biomass mapping from space (i.e. through developing a dedicated Sentinel-Biomass mission) building upon the experiences and progress made. We recommend ensuring seamless continuity and consistency of biomass mapping from space after the ESA-BIOMASS mission ends.

International research and UN organizations (such as IPCC, JRC, FAO, GFOI, GOFC-GOLD) are encouraged to provide guidance and data to harmonize biomass estimates based on national definitions, and to convert estimates of growing stock volume (the variable most often provided by the NFIs) to aboveground biomass, and to better link spatially-explicit biomass estimations with activity data to estimate emission factors. This requires a better dialog collaboration between the remote sensing community and the national forest inventory institutions, which is essential to combine, integrate and reconcile biomass estimates obtained with different approaches (i.e., sample-based vs. mapping approach) and data (mainly driven by ground data or remote sensing data). National Forest Agencies should develop protocols/agreement to allow access to ground plot data with precise geolocation to the research communities, as sub-national statistics or approximated geolocation of small (0.1 ha) plots at 1km resolution (100 ha) are not usable for integration with remote sensing data and spatial analysis.

Main recommendations

4. Research and pre-operational demonstrations are required to improve the quality, consistency and complementarity of satellite-derived biomass map products before they can be useful for land use sector climate change mitigation assessments. Efforts should capitalize on the new dedicated satellite missions and aim for "best estimates" synergizing from the variety of space and ground-based data sources.
5. We recommend to the EC to ensure seamless continuity and consistency of biomass mapping from space after the ESA BIOMASS mission ends.
6. International research and UN organizations (such as IPCC, JRC, FAO, GFOI/GOFC-GOLD) are encouraged to provide demonstrations and community-consensus guidance to better harmonize space-based and NFI-based biomass estimations, and their integration with activity data to improve emission factors.

Table 10: Recommendations to ESA BIOMASS

Element	Current limitations and challenges	Opportunities for ESA BIOMASS mission
Transparency and Clarity	• Incomplete/absent documentation on methods, datasets and assumptions, varying definitions	• Needs to comply with standards as implemented by Copernicus; the definition of biomass still needs to be clearly defined and accepted by the scientific community, other stakeholders and policy makers
Accuracy and uncertainty	• Large or fully missing uncertainty data for land use activities (emissions, AD, EF). • Nationally incomparable estimates due to different methods and definitions (and poor documentation). • Methods and datasets can change over time (not always well documented)	• The BIOMASS mission aims to produce a Benchmark/Reference dataset for tropical biomass estimates with consistency across national borders. To reach and prove the target accuracy (biomass estimation with 20% uncertainty at 4 ha), we recommend to invest in the collection of calibration and validation data
Consistency and completeness	• Lack of consistency and completeness from different inventory approaches and methods • Forest and land use categories are defined differently by different stakeholders • Temporal inconsistency due to changing data sources, methods and monitoring objectives	• Consistent, repeated biomass estimation with same instrument (P-band radar) over 5 years, after 2021
Comparability and interoperability	• Many different independent datasets exist without comparative analysis nor good practice advice on how to use them in an interoperable way	• We recommend to extrapolate data into the past based on (1) BIOMASS mission estimation of regional ranges of biomass in connection with disturbances regime and ecological conditions; (2) records on forest cover dynamics from other remote sensing instruments available for the time before the BIOMASS mission
Complementarity and scale	• Not enough understanding on how to use/integrate/compare complementary data and methods.	• We recommend comparative analysis, especially with LiDAR observations (airborne and NASA GEDI mission) and forest inventory
Reproducibility and adaptability	• There are gaps in data and capacities particularly in the tropics	• The BIOMASS mission product can be used for the stratification of forest inventory sampling
Access and distribution	• Ease of data access is scale dependent (e.g. global datasets easier to publicly access) with national and local scales harder to freely and openly access. • New methodologies and datasets can lead to national confusion. • Unintuitive data portals limit access and usability to non-technical stakeholder.	• The BIOMASS mission (P-band radar) should be considered as complementary to other missions, current or in preparation: ESA Sentinel (C-band radar and optical), ESA SAOCOM-CS (L-band radar) NASA GEDI (LiDAR), JAXA PALSAR (L-band radar), etc. However, extended validation/calibration efforts are needed
Participation and equity	• Monitoring progress is often driven and assessed by technological developments	• BIOMASS mission especially designed for high biomass forest, in particular, tropics
Responsibility and	• Poor quality data, low	• ESA declares an open data policy.

Element	Current limitations and challenges	Opportunities for ESA BIOMASS mission
accountability	capacity and confusion over numbers often impede accountability. • Societal implications of monitoring are often not considered.	Efforts are needed, however, to make data available and useful for different stakeholder groups – an issue not specific to the BIOMASS mission, but to all remote sensing data. Initiatives to address this include: Global Forest Watch, Geo-Wiki, Eurogeoss-broker, etc.

Source: own compilation.

4.3.3 Recommendations for extended guidance provided by IPCC and UNFCCC

Approaches and elements of independent monitoring can play an important role in enhancing transparency and accountability in the land use sector. Modalities, procedures and guidelines to be developed under the Paris Agreement for enhancing transparency should acknowledge:

- the abundance of available data sources and tools and set out basic principles for using such data sources for reconciliation and validation. Good practice guidelines need to be updated to reflect the availability of global information that can be used to complement national and local monitoring efforts for mitigation purposes;
- that stakeholders involved in land use sector mitigation have different perspectives, needs and expectations for monitoring and accountability.

The implementation of the Enhanced Transparency Framework is a great opportunity to build confidence and legitimacy. This process can cause (initial) frustration but will enhance quality in the long-term.

Transparency requires capacities. Circumstances and capabilities of countries and stakeholders vary, and flexibility is required to allow for step-wise improvements.

We recommend to developers of good practice guidance to:

- provide guidance for integrating/combining global data with national inventory information, reconciling the different definitions (e.g.) of forest and biomass by developing (e.g.) ad-hoc correction and conversion factors, and considering different temporal resolutions (see Case study 3 in Annex V);
- refine future guidelines on Tier 3 methods for soil carbon reporting involving free and independent datasets and modelling tools with case study examples studies based on practice examples of countries that have developed such methods with model-based assessments (see Case study 4 in Annex V);
- develop guidance for applying advanced Tier 2 methods that involve readily available larger scale model simulations, e.g. soil carbon baseline maps (see Case study 4 in Annex V);
- develop guiding principles on how to assess Tier 3 level uncertainties. This could mean incorporating methods, practice examples and decision trees on how to deal with stratification, spatial variability, regional upscaling, propagation of

uncertainty, sensitivity analyses, etc. when using models (see Case study 4 in Annex V);

- give an indication of acceptable levels of uncertainty for advanced methods involving IM approaches and modelling and typical ranges of uncertainty from practice examples. This should involve methods on how to use uncertainty to improve the inventory, e.g. through identifying emission hotspots, focusing effort parameters with high uncertainty or reducing model complexity) (see Case study 4 in Annex V).

Main recommendations

7. We recommend providing guidance for integrating/combining global data with national inventory information for higher tier level reporting.
8. We recommend developing guiding principles for assessing uncertainties associated with these approaches and how to reduce them.

4.3.4 Recommendations to global modelling and carbon science community

Models of GHG cycling are important tools for independent monitoring. They are also indispensable for the global stock-take required by the Paris Agreement. However, a number of misunderstandings and misconcepts exist that need to be overcome through a dialogue between the communities (see Recommendations for a dialogue between IPCC science and GHG reporting communities).

According to IPCC guidance, verification of GHG inventories is key to improve scientific understanding and to build confidence on GHG estimates and their trends. The global modelling and carbon science community can help in building confidence in land use emission estimates by providing independent references for GHG inventories. This will increase transparency, accuracy, consistency, completeness and comparability, especially in countries with limited own capacities.

Meaningful verification requires improving mutual understanding and cooperation between the scientific community and compilers of national GHG inventories. A successful partnership between results from global models of GHG cycling and requirements for MRV and policy needs a clear formulation of the technical requirements for reporting purposes to be addressed by models. Such guidance does not exist in a way that it would allow model developers to build models that are consistent with reporting requirements (see Case study 4 in Annex V). Neither do current guidelines provide practice examples for inventory compilers on using existing larger scale modelling results or even running adapted soil carbon models directly for reporting purposes (see recommendations for developers of good practice guidance).

In most cases models have been developed for other purposes than GHG reporting and need to be adapted.

- We recommend to modellers to consider reporting purposes as an application of models and to make model parameters and output variables consistent with current IPCC guidelines to allow for more models being used for national level reporting.
- Model applications for reporting purposes require free access to model, parameters and documentation. We recommend to model developers and

model users establishing an infrastructure that allows for models to be parametrized, calibrated, run, and evaluated. Such infrastructures would not only increase transparency of model application but also allow for continuous improvement of model and data by users.

- We recommend to the scientific community to help advancing IPCC guidance and contributing to improved emission factors e.g. through submission to the IPCC EFDB. Here a combination of ground and space-data can be used to provide better estimates globally that in case of country gaps can be used as key data sources.

Main recommendations

9. We recommend considering reporting purposes much more as an application of models and to make models more consistent with current IPCC guidelines and country GHG reporting.
10. We recommend to model developers and model users establishing an infrastructure that allows for models to be independently parametrized, calibrated, run, and evaluated. Such infrastructures would not only increase transparency of model application but also allow for continuous improvement of model and data by users.
11. We recommend to the scientific community to help advancing IPCC guidance and contributing to improved emission factors.

4.3.5 Recommendations for a dialogue between IPCC science and GHG reporting communities

Our harmonization and comparison of available land use emission databases (see Case study 1) has explained how differences in conceptual frameworks (e.g. carbon-only vs multi-gas assessments, definitions, land use versus land cover, etc.), in methods (Tiers, scales, compliance with IPCC GPG (legacies, etc.) and in assumptions (e.g. carbon neutrality of certain emissions, instantaneous emissions release, etc.) call for more complete and transparent documentation, and subsequent improvement for all the available datasets.

There is an urgent need to reconcile the large differences between the land use emission databases, scientific studies (as reflected in IPCC reports) and the country reported data (Grassi et al. 2017). The communities that have been producing these various datasets had different scopes and objectives that have spurred the observed differences in data and approaches today. We recommend:

- entering in a dialogue and develop consensus among the various monitoring communities (i.e. country GHG inventory experts, earth system and impact assessment modelling, land use modelling, remote sensing etc.) to reconcile current estimates towards a logical framework for comparison, a joint synthesis for land use sector mitigation options, and to prepare for consistency in the upcoming global stocktake(s) under Paris Agreement.
- for the IPCC to take a leading role in facilitating this dialog, and use the results and outcomes to:

  - ensure that AFOLU estimations in the following scientific assessment reports are also consistent and comparable with those provide by countries and independent remote sensing and modelling studies;
  - incorporate the findings in the methodological update of the IPCC GPG;

- improving data sources and approaches underpinning a complete, comparative, timely, consistent and reproducible assessment of AFOLU flux estimations; including making use of Copernicus assets for that purpose (see recommendations for Copernicus);
- using better data and methods and increase transparency for independent AFOLU databases. Improving their transparency requires clear definitions, methods, approaches, assumptions, Tiers, on the data used and provided (EF, AD and GHG). This should include complete emissions by including all C pools (incl. peats, fire, drainage, soil removal), and key forest degradation emissions such as wood harvesting. The provision of uncertainty for AFOLU emissions and of its trends is essential.

Main recommendations

12. We recommend a joint effort to reconcile the large differences between the AFOLU databases, scientific studies (as reflected in IPCC reports) and the country reported data. The IPCC should facilitate such a dialogue and develop consensus to ensure that AFOLU estimations in the following scientific assessment reports are also consistent and comparable with those provide by countries and independent remote sensing and modelling studies, and incorporate the findings in the methodological update of the IPCC GPG.
13. We recommend improving data sources and approaches underpinning a complete, comparative, timely, consistent and reproducible assessment of AFOLU flux estimations; including the use of Copernicus assets.

4.3.6 Recommendations to government agencies, national inventory experts and reviewers

The availability of open and ready-to-use data and tools for independent monitoring increases opportunities for GHG reporting, planning and implementation of land-based mitigation policies. But such approaches might also be subject to misuse or misinterpretation. Using, assessing and interpreting data and tools require skilled professionals. For example, different temporal resolutions and definitions need to be considered to make datasets comparable (see e.g. Case study 1 in Annex V). There are no ready-to-use datasets for national level comparisons, and the most frequently used data is not always the most suitable for a specific country situation.

Independent monitoring opportunities for inventory compilers and reviewers, especially in developing countries, emerge from freely accessible tools for remote sensing analysis, such as the stratification of sampling for national forest inventories, data processing and modelling etc. (e.g., OpenForis). Global datasets with high resolution information on land cover change can serve as a reference for national experts. However, due to inconsistencies in definitions such datasets are not readily usable.

National experts need to be aware of the limitations of global datasets to be able to integrate them appropriately into national inventory work. Provided that global datasets are scalable and compatible with national data (see e.g. recommendations to biomass mapping from space), such information can be used for filling data gaps at temporal and geographical scales, leading to more complete and consistent reporting.

- We recommend that countries build and maintain institutional capacity capable of using independent monitoring approaches, i.e. analysing and interpreting independent data as reference or input for national estimations instead of focusing investments on data purchase or external consultancies. This might also facilitate later inclusion of non-carbon monitoring (e.g. for livelihoods, biodiversity objectives).

- Countries should facilitate subnational and broad-based participation in the design of national institutional frameworks for data and monitoring, to increase legitimacy and ownership of the system at multiple levels. This means establishing clear responsibilities and accountability mechanisms, understanding that different actors have different perspectives and data needs, and facilitating the inclusion of compatible local data and opportunities for nesting data. Attention to these concerns early in the design process will lead to greater acceptance of mitigation measures and less conflict in the medium and long term.

- We recommend that national experts are trained not only in identifying global data that can be used but also in tailoring them to national definitions.

- We recommend that data and tools and related documentation used in producing GHG inventory become open source as much as possible. Information underpinning national GHG inventories are also essential to assess the options and priorities for stimulating land use sector mitigation on national and local levels.

- At national level we recommend institutions involved GHG reporting to assess how independent monitoring approaches and especially global data sources and open source tools can be used for GHG inventory compilation and its internal QA/QC.

Main recommendations

14. We recommend that countries build and maintain institutional capacity capable of using independent monitoring approaches.
15. We recommend that data and tools and related documentation used in producing GHG inventory become open source as much as possible.

4.3.7 Role of INSPIRE to support IM approaches

The INSPIRE implementation represents a significant investment from all Member States. More than 300 thousand datasets have been made available via the inspire data discovery portal. The main INSPIRE portal allows users to search for datasets from across the EU from a single interface, and allows individual filters.

However one limitation of the INSPIRE portal is that it only displays metadata for each dataset and does not allow users a direct access to any of the datasets. Nevertheless, each metadata resource contains a link to the data source, which may be a file, service or web application. The Directive requires that common implementing rules are adopted in five main specific areas: metadata, data specifications, network services, data and service sharing and monitoring and reporting.

We present in Table 11 opportunities for INSPIRE to support IM approaches in the area of land use GHG emission assessment.

Main recommendation

16. We recommend to extend INSPIRE specifications to additional metrics describing accuracy and sources of uncertainty relevant for land use and AFOLU GHG emission reporting, including to expand INSPIRE requirements to algorithms and models as data sources.

Table 11: Opportunities for INSPIRE to support independent monitoring approaches

Element	Current limitations and challenges	What does INSPIRE recommend for overcoming the limitations	What is currently missing in INSPIRE to support IM approaches
Transparency and Clarity	• Incomplete/absent documentation on methods, datasets and assumptions, varying definitions	• Once INSPIRE is fully implemented all public spatial data will be fully free and openly available, metadata will be attached and in the abstract on the metadata there is information on what definitions were used	
Accuracy and uncertainty	• Large or fully missing uncertainty data for land use activities (emissions, AD, EF) • Nationally incomparable estimates due to different methods and definitions (and poor documentation) • Methods and datasets can change over time (not always well documented)	• Inspire asked for information on positional accuracy and thematic accuracy and uses the error rate as the basic measure	The specification could be extended to a confusion matrix and other metrics which describe accuracy. Only land use and land cover is covered, other sources of error in the field of GHG reporting such as conversion factors etc. are not covered
Consistency and completeness	• Lack of consistency and completeness from different inventory approaches and methods • Forest and land use categories are defined differently by different stakeholders • Temporal	• Inspire stresses the need for completeness. Different definitions are taken care of in the metadata fields.	There might be additional requirements to describe land-cover and land-use change. GHG reporting is not considered in the Inspire themes

Element	Current limitations and challenges	What does INSPIRE recommend for overcoming the limitations	What is currently missing in INSPIRE to support IM approaches
	inconsistency due to changing data sources, methods and monitoring objectives		
Comparability and interoperability	• Many different independent datasets exist without comparative analysis nor good practice advice on how to use them in an interoperable way • Different stakeholders produce their own data for their purposes	• The Inspire model could serve as an orientation on what processes are needed to facilitate a truly comparable and interoperable system on for GHG emission reporting in the land-use sector globally	Additional data specifications would be needed to standardize GHG emission reporting
Complementarity and scale	• Not enough understanding on how to use/integrate/compare complementary data and methods • Multi-scale (nesting) approaches difficult by methodological inconsistencies		
Reproducibility and adaptability	• There are gaps in data and capacities particularly in the tropics	• INPIRE contributes to reproducibility of the data though	INPRIRE requires access to and sharing of spatial data but does not require full transparency on the detailed algorithms used to produce the data and does not require free and open models on how to derive the datasets and does not require to make algorithms free and openly available (e.g. on GITHUB). Full reproducibility and adaptability of the datasets can only be achieved by having all tools and algorithm open access
Access and distribution	• Ease of data access is scale dependent (e.g. global datasets easier to publicly access) with national and local scales harder to freely and	• The inspire data portal is an interesting starting point to be considered in order to understand and find existing datasets on land use, land-use change and	The inspire portal just focusses on metadata but does not have visualization and analytical functionalities of the spatial datasets

Element	Current limitations and challenges	What does INSPIRE recommend for overcoming the limitations	What is currently missing in INSPIRE to support IM approaches
	openly access • New methodologies and datasets can lead to national confusion • Unintuitive data portals limit access and usability to non-technical stakeholder	GHG reporting in the land use sector[25]	
Participation and equity	• Monitoring progress is often driven and assessed by technological developments		
Responsibility and accountability	• Poor quality data, low capacity and confusion over numbers often impede accountability • Societal implications of monitoring are often not considered	• INPRIRE standards contribute to a clearer understanding of the numbers	

Source: own compilation.

4.4 Feasibility and cost-effectiveness of main recommendations

The recommendations derived from the evidence found by the Independent Monitoring project from SWORG analysis, stakeholder survey, case studies and the literature and listed above address different stakeholders. However, they imply different levels of implementation or feasibility. While there might be sufficient data already there for implementation of one recommendation and it is more about training of people, building capacities, developing guidance, while in another case substantial costs might be involved for generating new data, or, on the contrary, large co-benefits e.g., regarding the assessment of other environmental services than climate.

In order to qualify the main recommendations and provide some prioritization of recommended actions we provide more concrete suggestions for implementation (Table 12). We give an indication of the time horizon needed (from short (1-2 years), to medium (3-5 years), and long (5-10 years)). We also give an indication of costs. Low costs means there are multiple benefits, use cases for other purposes, international coordination processes, guidance developments etc. of recommended activities. Medium costs occur for demonstration and collaboration projects, such as H2020 or Cost Actions. High costs are expected if significant investments are needed or long-term operation of services and new space assets are required.

25

Table 12: Feasibility, time horizon and indicative costs related to main specific recommendations

Recommendation	Feasibility/Implementation	Time horizon	Indicative costs
Copernicus			
1. Long-term operation of three dedicated Copernicus services	Copernicus assets in space, develop pre-operational services now for (1) improving national REDD+ and AFOLU reporting, (2) a Copernicus global AFOLU transparency data system, and (3) Copernicus land use mitigation tracker service. Align with modalities for UNFCCC enhancing transparency framework. Services need to be operational for global stocktake in 2023	Short with long term operations	High
2. Sentinels 1 and 2 for global monitoring of forest area change	Sentinel (1+2) satellites operational , invest in H2020 global demonstration project, ideally to align with FRA2020 and provide input to new Copernicus services (see above)	Short-Medium	Medium
3. Participation and accountability of stakeholders	Demonstrate IM practices for various stakeholder groups in the Copernicus context to increase their accountability for land use sector mitigation actions; in coordination with capacity development activities (i.e. DG DevCo, JRC, etc.)	Short-Medium	Medium
Biomass mapping from space			
4. Improve quality, consistency and complementarity of satellite-derived biomass map products	Synthesize results from ESA-GLOBBIOMASS and related projects project and global and regional biomass comparisons and aim for dedicated H2020 research activity together international partners (i.e. CEOS WGCV LPV, GOFC-GOLD)	Short	Medium
5. Ensure seamless continuity and consistency of biomass mapping from space	Work with ESA and include biomass mission (including both a space and in-situ component) as part of the next space assets plan for Copernicus to deliver operational global biomass mapping data for the duration of the Paris Climate Agreement	Medium	High
6. Provide guidance to harmonize space-based	Support a dedicated coordination mechanism with international research and UN organizations (such as IPCC, JRC, FAO, GFOI, GOFC-GOLD) to develop such guidance,	Medium	Low

Recommendation	Feasibility/Implementation	Time horizon	Indicative costs
and NFI-based biomass estimations	suggested lead: GFOI/FAO		
Guidance provided by IPCC and UNFCCC			
7. Provide guidance for integrating/combining global data with national inventory information	Engage with IPCC TSU, nominated country experts, expert communities and support synthesis for refinement of IPCC GPG to address more the inclusion of IM methods and approaches in any updated methodologies	Short	Low
8. Develop guiding principles for assessing uncertainties of IM approaches	Foster more inclusion of IM approaches based on guidelines for assessing uncertainties to be developed by expert communities (i.e. GFOI, JRC, FAO). Stimulate all AFOLU estimation activities to include independent accuracy estimation	Short	Low
Modelling community			
9. Consider models being used for reporting and consistency with guidelines	COST Actions on developing and consolidation Carbon and Earth System Modelling for GHG reporting	Medium	Medium
10. Develop infrastructure for model parametrization, calibration, evaluation	Foster all GHG modelling data and approaches (in particular those funded by EC) to become free and openly available (open source), seek opportunities with JRC and IPCC to develop an infrastructure that host such open-source tools and data and be made available for independent use and assessment	Medium	Medium
11. Help advancing IPCC guidance and contributing to improved emission factors	Stimulate a collaboration (H2020 or cost action) that systematically synthesizes available data and scientific studies to deliver new land use sector emission factors data to IPCC EFDB (incl. uncertainties) and with particular focus on the tropics	Medium	Medium
Scientific and GHG reporting community dialogue			
12. Joint effort to reconcile large	Work and support IPCC and key European partners (i.e. JRC, science partners) to develop	Short	Medium

Recommendation	Feasibility/Implementation	Time horizon	Indicative costs
differences scientific studies and the country reported data.	consensus for AFOLU estimations in the following scientific assessment reports are also consistent and comparable with those provide by countries (i.e. through collaborative H2020 project)		
13. Comprehensive assessment of AFOLU flux estimations; including the use of Copernicus assets.	Make sure that effort under recommendation 1, 2 and 12 are well linked and integrated	Medium	Medium
Government agencies and national experts			
14. Build and maintain institutional capacity capable of using independent monitoring approaches	Support EC (and other) country capacity development activities to expand their efforts to include IM approaches	Medium-Long	Medium
15. Data and tools for GHG inventory become open source	Stimulate countries to make their data tools openly available and integrate with activities for recommendation 10	Medium-Long	Low
INSPIRE			
16. Extend INSPIRE for needs of transparent AFOLU reporting	Foster a collaboration mechanism led by INSPIRE to include Paris Climate Agreement needs for AFOLU GHG reporting and those for related IM in the INSPIRE framework	Medium-Long	Medium

Source: own compilation.

5 LITERATURE

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ANNEX I: GLOSSARY AND ACRONYMS

Access: Refers to users having free and open admission to information and data. It can also include the capacity to understand data and tools.

Accountability: Refers to the acknowledgment and assumption of responsibility for actions, products, decisions, and policies including the administration, governance, and implementation, as the obligation to report, explain and be answerable for resulting consequences[26].

Accuracy: Describes the degree to which an estimate of a quantity is unaffected by bias due to systematic error. Here, the term specifically refers to repeatedly measured observations or estimations of a quantity of carbon stocks and flows. An accurate measurement or prediction lacks bias or, equivalently, systematic error. Accuracy should be distinguished from precision.

Activity data: Data on the magnitude of human activity resulting in emissions or removals taking place during a given period of time[27]. Here the term refers usually to area data on land use and land use changes related to forests expressed in ha.

Adaptability: Refers to the ability of a system (here: dataset, portal, monitoring system, tool for analysis etc.) to being adapted efficiently and fast to changed user needs. Adaptability also includes the ability to learn from experience of users, and improve the characteristics of the system relevant for the users.

Afforestation: Planting of new forests on lands that historically have not contained forests (IPCC 2003).

AFOLU: Refers to activities aiming at reducing GHG emissions from Agriculture, Forest and Other Land Uses. AFOLU can also be referred to as the land (use) sector.

Annex I countries: Includes the industrialized countries listed in Annex I to the Convention. They include the 24 original OECD members, the European Union, and 14 countries with economies in transition. (Croatia, Liechtenstein, Monaco, and Slovenia joined Annex 1 at COP-3, and the Czech Republic and Slovakia replaced Czechoslovakia.)

Approaches: Refers in a general way to methods applying data, tools, and guidelines.

Bias: Refers to the difference between the true, but usually unknown, value of a quantity being measured, and the mean observed value as would be estimated by the sample mean of an infinite set of observations. It is a synonym for systematic error. Bias can occur because of failure to capture all relevant processes involved or because the available data are not representative of all real-world situations, or because of instrument error (IPCC 2003).

Biomass: Refers to organic material both aboveground and belowground, and both living and dead, e.g., trees, crops, grasses, roots etc. Tree litter is usually

[26] https://en.wikipedia.org/wiki/Accountability

[27] http://unfccc.int/ghg_data/online_help/definitions/items/3817.php

accounted for as a soil component. Biomass includes the pool definition for above- and belowground biomass. Biomass is usually measured in units of mass of dry matter or carbon per unit ground area.

Biomass Expansion Factor (BEF): Forms a multiplication factor that expands growing stock volume, or commercial round-wood harvest volume, or growing stock volume increment data, to account for different biomass components such as biomass of stems, branches, foliage, roots and (mostly in tropical forests) biomass of non-commercial trees (IPCC 2003).

Canopy cover: Refers to the proportion of the forest floor covered by vertical projections of tree crowns. Canopy cover of a forest stand is the aggregation of the crown projection areas of tree individuals (without double-counting overlapping crown projection areas) divided by the stand area. There are several remote sensing sensors that are used in forest inventory, including visible and infrared scanner systems (satellite and airborne), laser systems, imaging spectrometry and imaging radar systems. In fully stocked forests these sensors measure canopy cover, although for tree species with a significant transparency of the crowns (e.g., larch forests, particularly in high latitudes) some methods (e.g., shortwave SAR) measure canopy closure.

Canopy closure: Refers to the proportion of the sky hemisphere obscured by vegetation when viewed by a single point. It should not be confused with canopy cover as it may generate unrecognized biases in attribution of forest land and assessment of aboveground live biomass.

Carbon pool: Refers to components of the climate system where carbon is stored, i.e., reservoirs of carbon. Here, carbon pools include above ground biomass, below ground biomass, dead wood, litter, soil organic carbon.

Carbon stock: The average amount of carbon in carbon pools (during a reference period) expressed in tonnes C.

Carbon stock change: The carbon stock in a pool can change due to the difference between additions of carbon and losses of carbon. When the losses are larger than the additions, the carbon stock becomes smaller, and thus the pool acts as a carbon source to the atmosphere; when the losses are smaller than the additions, the pools acts as a carbon sink to the atmosphere (IPCC 2003).

Clarity: Refers to the understandable and unambiguous presentation of information.

Comparability: Refers to key qualities that accounting information must possess. Data is comparable when accounting standards and policies are applied consistently from one period to another and from one region to another[28]. For this purpose, common methodologies, definitions and formats for estimating and reporting inventories should be used or robust bridge functions be developed.

Complementarity: Refers to data or tools that have different coverage or characteristics so that the concomitant use of both improves or emphasizes the quality of the resulting product.

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[28] http://accountingexplained.com/financial/principles/comparability

Completeness: Refers to the quality of being whole or perfect and having nothing missing. In context of GHG monitoring completeness helps assure that reporting and accounting considers all the relevant information. This includes carbon pools and categories of activities producing emissions or removals.

Confidence interval: Refers to the true value of the quantity for which the interval is to be estimated is a fixed but unknown constant, such as the annual total emissions in a given year for a given country. The confidence interval is a range that encloses the true value of an unknown fixed quantity with a specified confidence (probability)

Consistency: Provides for use of similar methods to enhance comparisons across time, space, and categories.

Criteria: Refer to the content level of a standard. They set out the conditions which need to be met in order to deliver a principle. It can be possible to verify criteria directly but they can also be further elaborated through indicators.

Cropland: Land that is regularly cultivated. This category includes arable and tillage land, and agro-forestry systems where vegetation falls below the threshold used for the forest land category. The vegetation usually is agricultural crop but coppices grown for energy proposes and trees for fruit production may exist on cropland as well. Cropland also includes managed olive groves, vineyards, and fast-growing tree plantations (poplars, willows etc.) in agricultural area.

Crown cover: Synonymous for canopy cover.

Data: Refers to raw, unorganized facts that need to be processed (e.g. satellite data on crown cover).

Deforestation: Refers to the direct human-induced conversion of forested land to non-forested land (IPCC 2003).

Degradation: Refers to a reduction in the capacity of land to produce ecosystem services such as carbon storage and products as a result of anthropogenic and environmental changes.

Distribution: Refers to an action of sharing something out among a number of recipients. In the context of this report it describes the way of how information and data is made available for specific stakeholders (users).

Emission Factor (EF): Describes a coefficient that quantifies the emissions or removals of a gas per unit of activity (ha, tonnes, m^3, etc.). Emission factors are often based on a sample of measurement data, averaged to develop a representative rate of emission for a given level of land use (change) related to land under a given set of operating conditions.

Emissions: Refers to the release of GHGs into the atmosphere over a specified area and period of time. It is measured in units of CO_2 equivalents in the sense of the amount of CO_2 that would have the same global warming potential.

Enhanced Transparency Framework: The agreement of an enhanced transparency framework was a key outcome of the Paris Agreement. It will play an important role in tracking progress towards individual and collective goals, and in understanding achievement of nationally determined contributions (NDCs) under the Agreement.

Equity: Refers to a body of legal and procedural rules that protect rights and enforce duties. Here, we refer to equality and fairness in relationships between people. Information should be accessible for all stakeholders in an equal way. Equity can be understood in different ways and better, understandable and applicable standards need to be provided to policy makers to be able to implement progress in this area more broadly.

FPIC (Free, Prior and Informed Consent): Refers to the principle that a community has the right to give or withhold its consent to proposed projects that may affect the lands they customarily own, occupy or otherwise use.[29] Monitoring progress is often driven and assessed by technological developments and not in terms of social participation. There are also missing clear indicators and indicator values by which to judge to which degree participation has been implemented fully.

FLEGT (Forest Law Enforcement, Governance and Trade) Refers to an EU Action Plan that was established in 2003 aiming to reduce illegal logging by strengthening sustainable and legal forest management, improving governance and promoting trade in legally produced timber[30].

Forest: FAO defines forest as land spanning more than 0.5 ha, with trees higher than 5 m of a canopy cover of more than 10%, or trees able to reach these thresholds in situ. The definition excludes areas fulfilling the thresholds specified above but with maximum width of less than 20m (linear formation) and land predominantly under agricultural or urban use, as fruit plantations, agroforestry systems, trees in urban parks and gardens. Includes: temporary unstocked forest land (like un-regenerated cut areas, burnt forests etc.), forest nurseries and seed orchards that constitute an integral part of the forest; forest roads, firebreaks and other small open areas; forest in national parks, nature reserves and other protected areas such as those of specific scientific, historical, cultural or spiritual interest; windbreaks and shelterbelts of trees with an area of more than 0.5 ha and width of more than 20 m; plantations primarily used for forestry purposes, including rubberwood plantations and cork oak stands (FAO 2010; Tomppo 2010).

The FAO definition of forest is a land use definition and is not directly applicable for remote sensing application because includes temporary unstocked forest land usually presented by burnt areas, un-regenerated clear cuts, barrens, grassy glades, etc. National definitions of forests are substantially different, mostly using minimum relative stocking (or canopy closure) as a proxy threshold ranging from 20 to 60%. Such difference should be taken into account when comparing global or regional products with national forest inventories data[31].

Forest management: Refers to the formal or informal process of planning and implementing practices aimed at fulfilling relevant environmental, economic, social and cultural functions of the forest.

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[29] http://www.forestpeoples.org/guiding-principles/free-prior-and-informed-consent-fpic

[30] http://www.euflegt.efi.int/about-flegt

[31] http://globbiomass.org/biomass/

GIS (Geographic Information System): Refers to a system designed to capture, store, manipulate, analyse, manage, and present all types of geographical data.

GFW: Global Forest Watch

GHG (Greenhouse Gases): Are gases in the atmosphere that absorb and emit radiation within the thermal infrared range quantity is usually expressed in tCO_2e (stands for "Tonnes of CO_2 equivalent").

Good Practice: Refers to a set of procedures intended to ensure that criteria are fulfilled and information on indicators is produced in adequate fashion.

Grasslands: Includes rangelands and pasture land that are not considered as cropland. It is land used for grazing or unmanaged land covered predominantly with perennial grasses/ herbs. Grasslands are either managed or unmanaged.

Guidance: Refers to a set of documents and tools that detail and explain how to apply good practice.

IM (Independent monitoring): Refers to the use of authoritative, unbiased templates and sources of information that broaden stakeholder participation and confidence by providing (free and open) data that complements mandatory reporting by national governments.

Implementation: Refers to actions (legislation or regulations, judicial decrees, or other actions) that governments take to translate international accords into domestic law and policy. Here, the term also describes actions by non-governmental stakeholders.

Indicator: Refers to quantitative or qualitative parameters which can be achieved and verified in relation to a criterion. It is generally accepted that a good indicator should be Specific, Measurable, Attainable, Relevant and Time-bound (SMART).

Information: Refers to processed, organized, structured data presented in a given context so as to make it useful to stakeholders (e.g. deforestation map based on crown cover data applying a national definition of forest based on crown cover).

INDC (Intended Nationally Determined Contribution): see NDC.

Interoperability: Denotes the technical permeability between data sets, platforms, software and hardware.

IPCC: Intergovernmental Panel on Climate Change

Kyoto Protocol: Is an international agreement linked to the United Nations Framework Convention on Climate Change, which commits its Parties by setting internationally binding emission reduction targets.

Land cover: Refers to the observed (bio)physical cover on the earth's surface.

Land sector: Refers to the activities Agriculture, Forestry and Other Land Use (AFOLU), including Reduced Emissions from Deforestation and Degradation (REDD+) and Land Use, Land Use Change and Forestry (LULUCF).

Land use: is characterized by the arrangements, activities and inputs people undertake in a certain land cover type to produce, change or maintain it.

Legitimacy: Refers to the right and acceptance of an authority, i.e. a governing law or government system.

LULUCF: Land Use, Land Use Change and Forestry

Measurement: Refers to the assignment of numbers to objects. All measurements consist of three parts: magnitude, dimensions (units) and uncertainty.

Monitoring: Refers to repeated measurements, collection, compilation and recording of all relevant data necessary for estimating emissions and for conducting verification in accordance with relevant standards. Monitoring is performed in a systematic (using standard operating procedures) and consistent (using the same or comparable operational procedures) fashion.

MRV (Monitoring, Reporting and Verification): Refers to a process/concept that potentially supports greater transparency in the climate change regime[32].

NFI: National Forest Inventory

NDC (Nationally Determined Contribution): Refers to documentation submitted by Parties under the UNFCCC Paris Agreement that contains different information on the national target for 2030 (or 2025); many also included information about the land sector.

Participation: Refers to association with others in a relationship (as a partnership) or an enterprise usually on a formal basis with specified rights and obligations. Here, the term describes the degree to which stakeholders are involved in development and application of datasets and portals.

Precision: Refers to an agreement among repeated measurements of the same variable. Better precision means less random error. Precision is independent of accuracy.

Quality Assurance (QA): Refers to a planned system of review procedures conducted to verify that data quality objectives were met, ensure that the inventory represents the best possible estimate of emissions and sinks given the current state of scientific knowledge and data available, and support the effectiveness of the quality control programme.

Quality Control (QC): Refers to a system of routine technical activities, to measure and control the quality of the inventory as it is being developed. The QC system is designed to: i. provide routine and consistent checks to ensure data integrity, correctness, and completeness; ii. identify and address errors and omissions; iii. document and archive inventory material and record all QC activities.

Random errors: Refer to unpredicted variation above or below a true value. Random error is inversely proportional to precision. Usually, the random error is quantified with respect to a true value, and the mean is the best estimate of the true value. Thus, random error is a distinct concept compared to systematic error.

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[32] http://unfccc.int/essential_background/glossary/items/3666.php

REDD+ Activities: Refers to activities listed in UNFCCC Decision 1/CP.16, para 70 as follows: Reducing emissions from deforestation, Reducing emissions from forest degradation, Enhancement of forest carbon stocks, Conservation of carbon stocks, Sustainable management of forest.

Reference Level: Refers to the amount (expressed in tonnes of carbon dioxide equivalent per year) that is a benchmark for assessing each country's performance in implementing certain mitigation activities under LULUCF and REDD+.

Reference period: Refers to the time period for which historical emissions and removals from carbon stocks changes from land are estimated to establish the reference level.

Removals: Describes removal of carbon dioxide (CO2) from the atmosphere by a sink.

Reproducibility: Refers to the ability of an experiment, study or data collection effort to be duplicated, either by the same researcher or by someone else working independently. Reproducibility is one of the main principles of the scientific method. One should not that reproducibility remains academic unless data are actually reproduced, which very often is not the case due to limits to costs and resources available to scientific institutions (Grassi, 2017, personal communication).

Responsibility: Refers to the state or fact of being responsible, answerable, or accountable for something within one's power, control, or management[33].

Scale: Refers to the spatial scale of information in geographical information systems and maps.

Sink: Refers to any process, activity or mechanism which removes a greenhouse gas, an aerosol, or a precursor of a greenhouse gas from the atmosphere (from UNFCCC Article 1.8).

Soil Organic Matter: Includes organic carbon of litter and top 1 m layer of mineral soil.

Source: Refers to any process or activity which releases a greenhouse gas, an aerosol or a precursor of a greenhouse gas into the atmosphere (from UNFCCC Article 1.9).

Spatially explicit data: Refers to characteristics of objects in geographical space.

Stakeholders: Refers to providers and users of Independent Monitoring information including governmental organizations, local stakeholders (incl. indigenous communities), environmental concerned citizens and NGOs, private sector companies and investors, research institutes and universities.

Systematic error: see Bias.

TACCC Principles: Transparency, Accuracy, Completeness, Comparability and Consistency.

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[33] www.dictionary.com/browse/responsibility

Transparency: Provides for transparent and consistent information accessible by relevant stakeholders on the assumptions, data collected, and methods used within a jurisdiction, other than confidential business information, to allow assessment of the credibility and reliability of data and assumptions.

Uncertainty: Describes the lack of knowledge of the true value of a variable (e.g., reductions in emissions or increases in removals) that can be described as a probability density function characterizing the range and likelihood of possible values. Uncertainty depends on the state of knowledge, which in turn depends on the quality and quantity of applicable data as well as knowledge of underlying processes and inference methods.

UNFCCC: United Nations Framework Convention on Climate Change.

Verification: Refers to methods that are external to a system used for reviewing, inspecting or testing, in order to establish and document that a product, service or system meets regulatory or technical standards. Here, we refer to methods for assessing the inventory and apply independent data, including comparisons with inventory estimates made by other bodies or through alternative methods. Verification activities may be constituents of both QA and QC.

Wetland: Includes land covered or saturated by water for all or part of the year (e.g. peatland) and does not fall into the Forest land, Cropland, Grassland or Settlements categories (IPCC, 2003). Temporary flooding is not sufficient for assigning land to this category.

ANNEX II.A: LIST OF ANALYSED DATASETS AND PORTALS

Table 13: Analysed datasets

No.	Topic	Name	Key Author / PI	Year
1	Forest Area and Area Change	Global, Landsat-based forest-cover change from 1990 to 2000	Kim et al.	2014
2	Forest Area and Area Change	Four decades of forest persistence, clearance and logging on Borneo	Gaveau et al.	2014
3	Forest Area and Area Change	Primary forest cover loss in Indonesia over 2000-2012	Margono et al.	2014
4	Forest Area and Area Change	PRODES: Annual estimates of deforestation in the legal Amazon, based on Landsat and CBERS images	INPE, Brazilian National Institute for Space Research	2014
5	Forest Area and Area Change	High-Resolution Global Maps of 21st-Century Forest Cover Change	Hansen et al.	2013
6	Forest Area and Area Change	Integrating global land cover products for improved forest cover characterization: an application in North America	Song et al.	2013
7	Forest Area and Area Change	Global Forest Resource Monitoring	Achard et al.	2012
8	Forest Biomass Change and Emission Factors	The Amazon Forest Inventory Network (Rainfor)	University of Leeds	2015
9	Forest Biomass Change and Emission Factors	The Center for Tropical Forest Science - Forest Global Earth Observatories (CTFS-ForestGEO)	Smithsonian Tropical Research Institute (STRI)	2015
10	Forest Biomass Change and Emission Factors	The African Tropical Rainforest Observation Network	University of Leeds	2015
11	Forest Biomass Change and Emission Factors	Estimated carbon dioxide emissions from tropical deforestation improved by carbon-density maps	Baccini et al.	2012
12	Forest Biomass Change and Emission Factors	Baseline Map of Carbon Emissions from Deforestation in Tropical Regions	Harris et al.	2012
13	Forest Biomass Change and Emission Factors	Retrieval of growing stock volume in boreal forest using hyper-temporal series of Envisat ASAR ScanSAR backscatter measurements	Santoro et al.	2011
14	Forest Biomass Change and Emission Factors	Benchmark map of forest carbon stocks	Saatchi et al.	2011

No.	Topic	Name	Key Author / PI	Year
15	Forest Biomass Change and Emission Factors	EU-wide maps of growing stock and AGB in forests based on remote sensing and field measurements	Gallaun et al.	2010
16	Forest Biomass Change and Emission Factors	A new hybrid land cover dataset for Russia: a methodology for integrating statistics, remote sensing and in situ information	Schepaschenko et al.	2011
17	Forest Biomass Change and Emission Factors	A first map of tropical Africa's above-ground biomass derived from satellite imagery	Baccini et al.	2008
18	Forest Biomass Change and Emission Factors	A Global Forest Biomass Map	Kindermann et al.	2008
19	GHG AFOLU Emissions	MAD-MEX: Automatic Wall-to-Wall Land Cover Monitoring for the Mexican REDD-MRV Program Using All Landsat Data	Gebhardt et al.	2014
20	GHG AFOLU Emissions	FAOSTAT Emissions	FAO	2012
21	GHG AFOLU Emissions	Global emissions EDGAR v 4.2	JRC	2011
22	GHG AFOLU Emissions	Carbon Flux to the Atmosphere from Land-Use Changes 1850-2005	Houghton (Houghtonetal.É	2008
23	GHG AFOLU Emissions	Full carbon account for Russian forest	Shvidenko et al.	2009

Table 14: Analysed web portals and tools

No.	Topic	Name	Institute, Organisation	Year
1	Forest Area and Area Change Global	GOFC-GOLD Sourcebook	Wageningen and Boston Universities / ESA	2014
2	Forest Area and Area Change Global	GFOI	GEO / FAO / CEOS	2014
3	Forest Area and Area Change Global	Global Forest Change	University of Maryland	2013
4	Forest Area and Area Change Global	WELD - Web Enabled Landsat Data	NASA, NEX	2012
5	Forest Area and Area Change Global	Active Fire Data, FIRMS	NASA, EOSDIS	2011
6	Forest Area and Area Change Global	Global Forest Watch	GFW in partnership with WRI	2011
7	Forest Area and Area Change Global	Geo-Wiki	IIASA	2009
8	Forest Area and Area Change Global	GOFC-GOLD Global Observation of Forest and Land Cover Dynamics	FAO	2007
9	Forest Area and Area Change Global	Forest Carbon Portal	Consortium of multiple partners (Forest Trends, UKAID, USAID, UNDP, GEF)	2008
10	Forest Area and Area Change Global	Global Land Cover Facility (GLCF)	University of Maryland, NASA, GOFC-GOLD	1997
11	Forest Area and Area Change Regional	Moabi DRC	Moabi DRC	2014
12	Forest Area and Area Change Regional	INPE	Terra Amazon	2005-2014
13	Forest Area and Area Change Regional	Borneo Database showing four decades of deforestation logging and plantation development	CIFOR	2014
14	Forest Area and Area Change Regional	Land-cover changes resulting from human activities in near real-time	CIAT	2014
15	Forest Area and Area Change Regional	Sumatra Database showing several decades of forest loss and plantation development	Eyes on the Forest	2012
16	Forest Area and Area Change Regional	Baseline Map of Carbon Emissions from Deforestation in Tropical Regions	Applied GeoSolutions and WI	2000

No.	Topic	Name	Institute, Organisation	Year
17	GHG AFOLU Emissions	The Global Calculator V23	UK Department of Energy & Climate	2015
18	GHG AFOLU Emissions	FAOSTAT Emissions Database	FAO	2015
19	GHG AFOLU Emissions	IGES IPCC GPG Emission Factor Database	IPCC	2015
20	GHG AFOLU Emissions	FAOSTAT Emissions	FAO	2012
21	GHG AFOLU Emissions	Global emissions EDGAR v 4.2	JRC	2011
22	GHG AFOLU Emissions	Global Agricultural Monitoring (GLAM)	Collaboration between NASA/GSFC, USDA/FAS, SSAI, and UMD Department of Geography	2010
23	GHG AFOLU Emissions	The EX-Ante Carbon-balance Tool (EX-ACT), V.5	FAO	2010
24	Forest Biomass Change and Emission Factors	Orbiting Carbon Observatory-2	JPL, NASA	2014
25	Forest Biomass Change and Emission Factors	Geo-Wiki	IIASA	2009
26	Forest Biomass Change and Emission Factors	Forest Carbon Portal	Consortium of multiple partners (Forest Trends, UKAID, USAID, UNDP, GEF)	2008
27	Forest Biomass Change and Emission Factors	Vegetation Map of Central Africa from AVHRR LAC and GAC Images used in CARPE Map	University of Maryland	2008
28	Forest Biomass Change and Emission Factors	IGES emission factor data base	EFDB	2000
29	Forest Biomass Change and Emission Factors	Global Land Cover Facility (GLCF)	University of Maryland, NASA, GOFC-GOLD	1997
30	Forest Biomass Change and Emission Factors	GEIA: Global Emissions InitiAtive	IGAC, iLEAPS, AIMES, NASA	1990

ANNEX II.B - KEY DATASETS AND THEIR CHARACTERISTICS

ANNEX III: STAKEHOLDER SURVEY QUESTIONS AND RESULTS

ANNEX IV.A: SWORG ANALYSIS: METHODOLOGY AND RESULTS

ANNEX IV.B: SWORG ANALYSIS: CRITERIA AND INDICATORS

ANNEX V: CASE STUDY REPORT

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