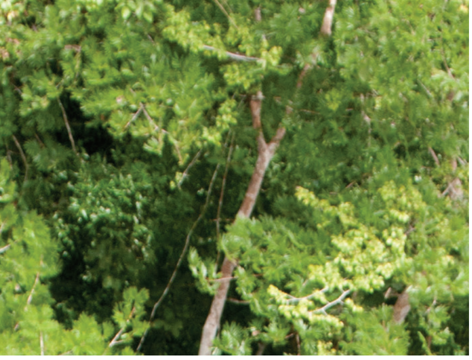

Modelling Land Use Changes in Cameroon

2000–2030

A Report by the REDD-PAC project

Supported by:

Federal Ministry for the Environment, Nature Conservation, Building and Nuclear Safety

based on a decision of the German Bundestag

CREDITS

THE REDD-PAC PROJECT TEAM

COMIFAC: Martin Tadoum, Chouaibou Nchoutpouen, Peguy Tonga, Adeline Makoudjou, Didier Bokelo Bile, Roland Gyscard Ndinga, Eustache Awono†

IIASA: Aline Mosnier, Michael Obersteiner, Florian Kraxner, Johannes Pirker, Géraldine Bocqueho, Petr Havlík

UNEP-WCMC: Rebecca Mant, Blaise Bodin, Andy Arnell, Valerie Kapos, Paulus Maukonen

PARTNER INSTITUTIONS

COMIFAC: Central African Forest Commission

IIASA: International Institute for Applied Systems Analysis

UNEP-WCMC: United Nations Environment Programme, World Conservation Monitoring Centre

Financial support

The REDD-PAC project is part of the International Climate Initiative (IKI). The Federal Ministry for the Environment, Nature Conservation, Building and Nuclear Safety (BMUB) supports this initiative on the basis of a decision adopted by the German Bundestag.

Citation

Mosnier A, Mant R, Pirker J, Makoudjou A, Awono E†, Bodin B, Tonga P, Havlík P, Bocqueho G, Maukonen P, Obersteiner, M, Kapos V, Tadoum M (2016): Modelling Land Use Changes in Cameroon 2000–2030. A report by the REDD-PAC project. Available online: www.redd-pac.org

Acknowledgements

The authors thank the participants of the various workshops held in the framework of the REDD-PAC project in Doula and Yaoundé in particular Collins Mboufak and Emmanuel Ngom.. A special thanks to René Siwe, the head of the technical REDD+ secretariat, the team of the national REDD+ coordination

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First edition, June 2016

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AGB	Above-ground Biomass
BGB	Below-ground Biomass
CBD	Convention on Biological Biodiversity
CIFOR	Center for International Forestry Research
COMIFAC	Central African Forest Commission
ECAM3	The third Cameroon households survey
EPIC	Environmental Policy Integrated Model
FAO	Food and Agriculture Organisation
FLEGT	Forest Law Enforcement, Governance and Trade
FPIC	Free Prior and Informed Consent
FRA	Global Forest Resources Assessment
FSVA	Food Security Vulnerability Atlas
GDP	Gross Domestic Product
GLC	Global Land Cover
GLOBIOM	GLOBal Biosphere Management Model
GOFC-GOLD	Global Observatory for Forest and Land Cover Dynamics
HRU	Homogeneous Response Units
IGBP	International Programme for the Geosphere-Biosphere
IIASA	International Institute for Applied Systems Analysis
ILRI	International Livestock Research Institute
IPCC	Intergovernmental Panel on Climate Change
IUCN	International Union for Conservation of Nature
JRC	Joint Research Centre (Joint Research Centre of the UE), Joint Research Center
LTBI	Industrie de Transformation des Bois de la Likouala
Mha	Millions of Hectares
MINADER	Ministry of Agriculture and Rural Development
MINEP	Ministry of Environment, Nature Protection and Sustainable Development
MINEPIA	Ministry of Livestock, Fisheries and Animal Industries
NASA	National Space Agency
NTFP	Non-timber forest product
RIL	Reduced Impact Logging
ROC	Republic of the Congo
SSP	Shared Socioeconomic Pathways
tC/ha	tons of carbon per hectare
UNEP-WCMC	United Nations Environment Programme, World Conservation Monitoring Centre
UNFCCC	United Nations Framework Convention on Climate Change
WFP	World Food Programme
WHRC	Wood Hole Research Center

Executive Summary

Land use is a crucial factor for economic development and the environment. As dedicating land to agriculture enables regular production, it is beneficial for satisfying surrounding population's food needs and the economy as a whole. Conversely, agricultural land has a much lower carbon content than forest land and is generally poor in biodiversity. Land can be used in different ways to meet different objectives and it can potentially be difficult to satisfy all objectives at the same time; leading to difficult choices when designing policies.

Often called "Africa in miniature", Cameroon benefits from a rich geographical and climatic diversity, which favours at a time the production of a wide range of agricultural commodities and the presence of a wealth of animal and plant diversity. The country is covered by ca. 35 Million hectares of forest, of which 19 Million hectares are dense humid forests. Almost one third of dense humid forests are under managed, making Cameroon the second biggest producer of tropical wood in the region. Despite the strong potential of the agricultural sector, 20 % of the rural population do not have satisfactory food consumption and farmers' living conditions showed a worsening tendency since the 90s.

Cameroon is involved in the REDD+ process since 2005 notably at the sub-regional level in cooperation with COMIFAC and more than 30 REDD+ projects are currently on track in the country. This study aims at identifying the zones which will face the pressure on land cover in the future and its consequences in terms of agricultural production, greenhouse gas emissions and risk of biodiversity loss. The core objective of the REDD-PAC project is to accompany the institutions involved in REDD+ in Cameroon as well as in strategies and action plans for biodiversity protection in Cameroon.

In order to explore the consequence of future changes within a simplified framework, the REDD-PAC project adapted the GLOBIOM model (GLOBal Biosphere Management Model) to the context of the Congo Basin. The GLOBIOM model is a global economic model which represents the competition for land use between the forestry sector and the bio-energy sector. The total simulation period is 2000–2030. The first 2000–2010 period allows to test the capacity of the model to reproduce past trends ("validation period"). The national model covers Cameroon as part of the Congo Basin region of the model which includes all the COMIFAC countries. As such, Cameroon can trade with the other COMIFAC countries and with the other regions of the World. Agricultural production and changes in land use are represented at the level of 239 spatial units.

Deforestation is modelled from changes in production and consumption, and for all countries of the world at the same time. Thus, it is easy to check the validity and consistency of the estimates. It is also possible to avoid estimating reference levels that over-estimating future deforestation, unrelated to change in demand. The spatially explicit nature of the results ensures the consistency of the deforestation calculated at the sub-national level with the total deforestation at the national level. They also enable the heterogeneity in the distribution of carbon and biodiversity to be taken into account.

It is very important for the modelling work to have a good representation of the initial situation. Cameroon is the one COMIFAC-country disposing of the best statistical service, including the agriculture sector. A hybrid land cover map was created through the combination of the best land cover maps and agricultural statistics available after consultation with local experts.

According to moderate projections, 28 million people are expected to live in Cameroon in 2030, 62 % of which in cities. Moreover, the average GDP per head is set to almost double between 2010 and 2030. A larger and richer population leads to an increase in local consumption of agricultural products which translates into an increase in cultivated land. Our results show an average annual increase in deforestation from ca. 37,000 hectares between 2000 and 2010 to 58,000 hectares between 2010 and 2020 and yet another increase to 113,000 ha p.a. in the period 2020–2030, causing the emission of 1.8 Gt CO_2 over the 2010–2030 period. Two thirds of the projected deforestation is caused by the expansion of cassava, corn and groundnut and related fallow land, and 12 % from the expansion of oil palm.

Habitat loss constitutes one of the main drivers of biodiversity loss. Cameroon is home to two species of Great Apes which are heavily dependent upon the presence of natural forests for their habitat: the Western Lowland Gorilla and the chimpanzee. These are also species which represent an important potential for the development of ecotourism in Cameroon. The model predicts a loss of habitat for the great apes in the regions South-West, Center and East. Apart from the direct loss of habitat, the expansion of agricultural areas will also lead to an increase in contact, and consequently conflicts, between the Great Apes and humans.

Cumulative deforestation over the period 2010–2030 varies between 1.4 and 2.2 Million hectares (Mha) depending on the scenario compared to 2 Mha in the base scenario. Predicted future deforestation is lower when there is an increase in agricultural yields, an expansion of protected areas and a lower demographic and economic growth. On the contrary, converging to targets of expansion of oil palm plantations, the uncontrolled expansion of agriculture in protected areas or forest concessions, and a strong increase in the population and in GDP increases deforestation in relation to the base scenario.

Agricultural yields in Cameroon are often higher than in other countries of the sub-region and the country disposes of an agro-ecological diversity which allows for the production of a large variety of agricultural products. It is the only net exporting country of food and in the sub-region and in our simulations agricultural exports to the neighbouring countries increase strongly over the period 2010–2030. Owing to its status as agricultural exporter country, a reduction of the demand and/or an improvement of the production conditions in the other countries of the sub-region are simulated to reduce the agricultural production. This link is the reason for the observed reduction of both deforestation and exports while demographic and economic growth continues in the scenario which simulates a strong increase of agricultural yields in the COMIFAC countries.

Hence, if agricultural yields do not improve rapidly in Cameroon, the pressure on forests due to the population growth could be exacerbated by the increase in demand for agricultural products from the neighbouring countries. A good share of funds mobilized through the REDD+ mechanism should therefore be invested in the improvement of agricultural productivity while minimizing the impact of agricultural production on forests. To that end, accompanying urban elites who are more and more interested in investing in agriculture in Cameroon could also be an important factor contributing to sustainable intensification in the coming years.

The non-respect of the permanent forest area entails a degradation of all indicators. Thus, the results of this study show the prime importance of an effective management of the currently designated permanent forest area. The lack of funding for the management of existing protected areas poses a great risk to the persistence of the habitat of numerous species. Further, our results underline the important potential role of logging concession in halting deforestation. Many efforts were undertaken in many logging concessions in Cameroon to transition to reduced impact logging. These activities should be pursuit as should be efforts to combat poaching inside logging concessions such that these can contribute to effective biodiversity protection.

1 Introduction

The emissions linked to the conversion of tropical forests are estimated at close to 1 Pg of carbon per year over the period 2000–2010, which represents about 12 % of total Greenhouse Gas (GHG) emissions over the period (Hansen *et al.,* 2008). Forest protection can therefore be an effective way to combat climate change. The reducing of emissions linked to deforestation and forest degradation has been discussed since 2005 as part of the international climate negotiations. Developing countries are particularly encouraged to contribute to the reduction of emissions from the forestry sector in accordance with the capacities of the country and the domestic circumstances, through five activities: a) reducing emissions from deforestation, b) reducing emissions from forest degradation, c) conserving of forest carbon stocks, d) sustainable management of forests and e) enhancement of forest carbon stocks. The REDD+ acronym is often used to refer to these five activities.

Since the start of discussions, the countries of the Congo basin have expressed great interest in REDD+. They support the establishment of a reference level which takes future social and economic development policies of the sub-region into account within the framework of the international climate negotiations. The countries of the Central African Forests Commission (COMIFAC) have also reaffirmed the role of REDD+ in promoting non-carbon benefits, including socio-economic benefits, poverty reduction, benefits linked to biodiversity and ecosystem resilience, as well as strengthening of the links with the adaptation to climate change. Several specific aspects of the Congo Basin underpin this position: i) deforestation and forest degradation in the Congo Basin are historically low and it is difficult to decrease them and ii) forest planning fulfils a triple role of conservation, economic growth and fighting poverty which it absolutely must support (Kasulu *et al.,* 2008).

Often called "Africa in miniature", Cameroon benefits from a rich geographical and climatic diversity, which favours at a time the production of a wide range of agricultural commodities and the presence of a wealth of animal and plant diversity. The country is covered by ca. 35 Million hectares of forest, of which 19 Million hectares are dense humid forests. Almost one third of dense humid forests are under concession, making Cameroon the second biggest producer of tropical wood in the region. Despite the strong potential of the agricultural sector, 20 % of the rural population do not have satisfactory food consumption and farmers' living conditions showed a worsening tendency since the 90s. The economy of Cameroon mainly relies on the tertiary sector, notably trade, telecommunication and transport; however, the primary sector still employs more than 60 % of the total workforce in the country underlining the importance of an intervention in the sector.

Cameroon is engaged in the REDD+ process since 2005, notably at the sub-regional level with COMIFAC. The REDD+ process has effectively started in 2008 in Cameroon with the submission of the R-PIN (Readiness Plan Idea Note) and in June 2011 with the submission of the R-PP (Readiness Preparation Proposal) which has been finally accepted in February 2013. In November 2013 the government of Cameroon (GoC) received a 3.6 Million US$ grant from the Forest Carbon Partnership Facility (FCPF) of the World Bank for the elaboration of a REDD+ strategy. Further, more than 30 REDD+ projects are being operated in Cameroon.

The preparation for the REDD+ implies the development of certain key elements. The use of models can inform the development of several of the elements required by the United Nations Framework Convention on Climate Change (UNFCCC) within the framework of REDD+:

a. A national strategy or an action plan: by making it possible to explore the impact of different factors on land use and identify the areas subject to the strongest conversion pressures, the models can assist in the development and implementation of strategies to avoid or reduce deforestation and forest degradation. The modelling can also make it possible to test the potential impact of different policies. This evaluation can be made simultaneously in terms of emissions, agricultural protection and biodiversity, thereby enabling better integration of these different problems in the planning and preparation of policies.

b. A national forest reference emission level and/or forest reference level: by assisting under-standing of the extent to which changes in land use would occur if REDD+ was not applied, the models can also potentially feed the development of a national forest reference emissions levels/ forest reference levels. This possibility is explored in more detail in the following sections.

c. A robust and transparent national forest monitoring system for the monitoring and reporting of the [REDD+] activities, bearing in mind the national situation: the models will probably have a more limited role in the development of a national forest monitoring system.

d. A system to provide information on how REDD+ safeguards are being addressed and respected: understanding the potential impacts of different policy options for implementing REDD+, including on biodiversity, can help with identifying what measures may need to be put in place to ensure that the REDD+ safeguards are addressed and respected.

Changes in land use not only contribute to global greenhouse gas emissions but also the loss or fragmentation of natural habitats for different species. Cameroon is party to the Convention on Biological Diversity (CDB), ratified in 1996. Its main objectives are the conservation of biological diversity, the sustainable use of its components, and the fair and equitable sharing of the benefits arising out of the utilization of genetic resources. The 2011–2020 Strategic Plan, adopted by the parties at the CDB in October 2010, breaks down these three large areas into five strategic goals and 20 Targets – hereinafter referred to as the "Aichi Targets". These are global objectives but they are mainly implemented at the National, sub-national and local levels.

The objectives are mainly adapted to the national level through National Biodiversity Strategy and Action Plans (NBSAPs) prepared by the Parties to the CDB. A revision process of the NBSAP of Cameroon has started in 2010 with the aim to streamline the document with the Aichi Strategic plan for Biodiversity 2011–2020. The COMIFAC Convergence Plan, to which Cameroon belongs, also promotes the adoption of sustainable forest management policies in the sub-region.

REDD+ presents numerous potential opportunities for providing benefits for biodiversity, ecosystem services and the green economy. For example, REDD+ activities seeking to reduce deforestation obviously contribute to Aichi Target 5 on reducing the "loss of all natural habitats, including forests", and vice versa. However, REDD+ also potentially involves risks for biodiversity. For example, limiting the conversion of forests into agricultural land without dealing with the factors responsible for the conversion, may simply displace these pressures to other ecosystems which are important for biodiversity, such as the natural savannah. The potential risks and benefits of REDD+ have been recognised by the UNFCCC through seven safeguards adopted during the Cancun Conference of the Parties in 2010, which the countries are requested to promote and support in their implementation of REDD+.

While Cameroon is in the process of developing its National REDD+ Strategy, there is an opportunity to integrate considerations of the multiple benefits of REDD+ with the objectives of the CBD. Such an integration would reinforce the country's different environmental agendas.

The REDD-PAC (REDD+ Policy Assessment Centre) project seeks to provide understanding around the factors driving change in forest cover and biodiversity in the coming decades in the Congo basin and Brazil, and the impact of policies on these changes. Within the framework of this study, the GLOBIOM economic land use change model has been enriched and adapted to the contexts of these two regions in order to study potential deforestation trajectories under different hypotheses and conditions, and related impacts on GHG emissions, agriculture and biodiversity. This report presents the methodology and results of the REDD-PAC project for Cameroon. We hope that these results may help countries in establishing their reference levels and planning for REDD+, as well as more broadly in their land use related planning.

2 The land use model

2.1 The GLOBIOM model

The GLOBIOM land use model (www.globiom.org) has been developed at IIASA (in Austria) since 2007 and has been/is used within the framework of numerous projects, notably for estimating the evolution of emissions resulting from change in land use and agriculture at the global level, but also for Europe and the United States (Havlik *et al.,* 2011; Mosnier *et al.,* 2013). For the REDD-PAC project, this model has been adapted for Brazil and the Congo basin. More specifically it has been adapted for Cameroon as one of the projects pilot countries in the COMIFAC region. The main advantages of using GLOBIOM to inform planning of the REDD+ Strategy and preparation of the reference level are that:

- **Deforestation in the model is the result of changes in production and consumption** which makes it easier to check the validity and consistency of the estimates and avoid over-estimating future deforestation, without any relationship to change in demand. There may be non-productive reasons for deforestation such as urban sprawl or land speculation but the influence of these factors is generally a lot less. Productive land potential which is an important determinant of total demand for agricultural land is calculated on the basis of biophysical characteristics which can vary a lot from one region to another in a country.
- **Deforestation calculated at the sub-national level is perfectly consistent with deforestation at the National level** since the latter is calculated as the sum of deforestation in each of the country's geographic units. Deforestation calculated at the sub-national level depends on the interacting of the factors which occur at different levels. For example, at the local level, current land use, climate, soil type and distance to the nearest town are factors which will influence the model's results. Whereas at the national level, population growth, GDP and the change in competitiveness with other regions of the world will be factors which influence the level of demand for local products. Moreover, the level of deforestation in the region also depends on what is happening in the other countries of the region.

- **The spatially explicit nature of the results is important for calculating total emissions and the impact on biodiversity.** The emissions linked to deforestation depend on the local carbon content of the forest which is destroyed. Carbon content varies a lot between a dry forest and a rain forest, for example. Similarly, the impact on biodiversity will be different according to the area affected by the future land use changes. Finally, the spatially explicit nature of the results can guide the land planning strategies, particularly by identifying the areas requiring priority action in order to limit deforestation while pursuing economic development.

- **The modelling makes it possible to better understand the complex mechanisms** underlying deforestation and forest degradation, sometimes with counter-intuitive but valid results due to interactions between several factors.

The model uses a global database which has been enriched with national data (see www.redd-pac.org for a description of the database). In the model, changes in land use are caused by an increase (or decrease) in local and global needs for food, wood and bio-energy based on population and economic growth projections which have been made by other institutions (e.g. the United Nations). Additional needs can be met by increasing the land used (e.g. deforestation), by an increase in the productivity of the land used (e.g. increase in yield) or by importing products. Changes in land use leads to a change in the land carbon content (emissions of carbon into the atmosphere) and to a change in habitat for certain species which can lead to a loss of biodiversity in some areas at the national level (Figure 1).

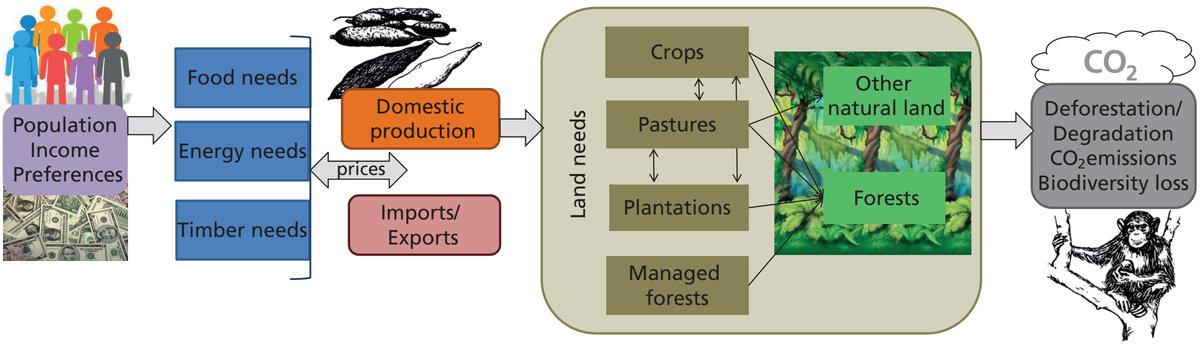

Figure 1. Future deforestation depends on future needs in terms of food, wood and energy in the GLOBIOM-Cameroon model

The main characteristics of the GLOBIOM model are the following.

- **Market balance model:** Price adjustments contribute to equality between consumption and productions less exports plus imports for each product and each region. GLOBIOM is built on the hypothetical principles of the neoclassical economic theory: agents take decisions which give them the biggest utility, the increasing of utility becomes less as agents buy and sell more, and there is a unique balance, namely agents have no interest in modifying their actions once the balance is attained.
- **Optimisation model:** The aim of the optimisation problem is to maximise the sum of the consumers and producers surplus[1] under a certain number of constraints, notably the market equilibrium constraint. A constraint which is very important is the constraint on land availability: in each spatial unit the total amount of land is fixed. Therefore, in order to increase the area used it is either necessary to decrease another use or convert natural land into productive land if there is any still available. Some constraints can also make it possible to include agents' non-economic objectives such as satisfying food needs at the local level (self-consumption).
- **Partial Equilibrium model:** Contrary to a general balanced model which encompasses all the sectors of the economy, GLOBIOM focuses on some sectors of which land is the main production factor: crops, breeding, livestock, and bio-energies. These sectors compete in land use.

1 A surplus of consumers is a monetary evaluation of the satisfaction they derive from their consumption. The surplus of producers is the sum of their profits.

- **Spatial balance model:** This is a specific category of the partial balanced model where goods are considered homogeneous: if two traders sell peanuts at different prices in the market, the consumer will always buy the peanuts which are cheaper (no differentiation according to quality). This will lead to an equaling out of the prices in the market regardless of the origin of the product: if the product is imported, then the production costs in the country of origin plus the transport costs and the tariffs must be equal to the local production costs. Therefore, the exporting countries must always have lower production costs than the importing countries, and even more so where the transport and/or tariffs are high.
- **Recursive dynamic model:** GLOBIOM has been carried out for each 10-year period since the year 2000 (base year). Contrary to fully dynamic models, profits or losses which may occur after 10 years are not anticipated by the agents. The optimal decision at period t only depends on the decisions taken during the previous periods. Therefore, in GLOBIOM, at the start of each simulation period (2010, 2020 and 2030), land use is updated taking account of the changes which have taken place in the previous period whereas the demand is adjusted to take account of increasing needs due to population growth and the GDP for the following period.

The originality of GLOBIOM comes from the representation of land use change drivers at two different geographical levels: all the variables linked to the land, in other words the change to land use, the cultivated areas, wood production and the number of heads of livestock are represented by pixels, but the final demand, the transformed quantities, the prices and trade are calculated at the regional level. This means that in GLOBIOM, **regional factors influence land use at the local level, and local constraints also influence the result of the variables defined at the regional level** whereas coherence is assured by the market equilibrium constraint and at the local level by the land availability constraint (Figure 2).

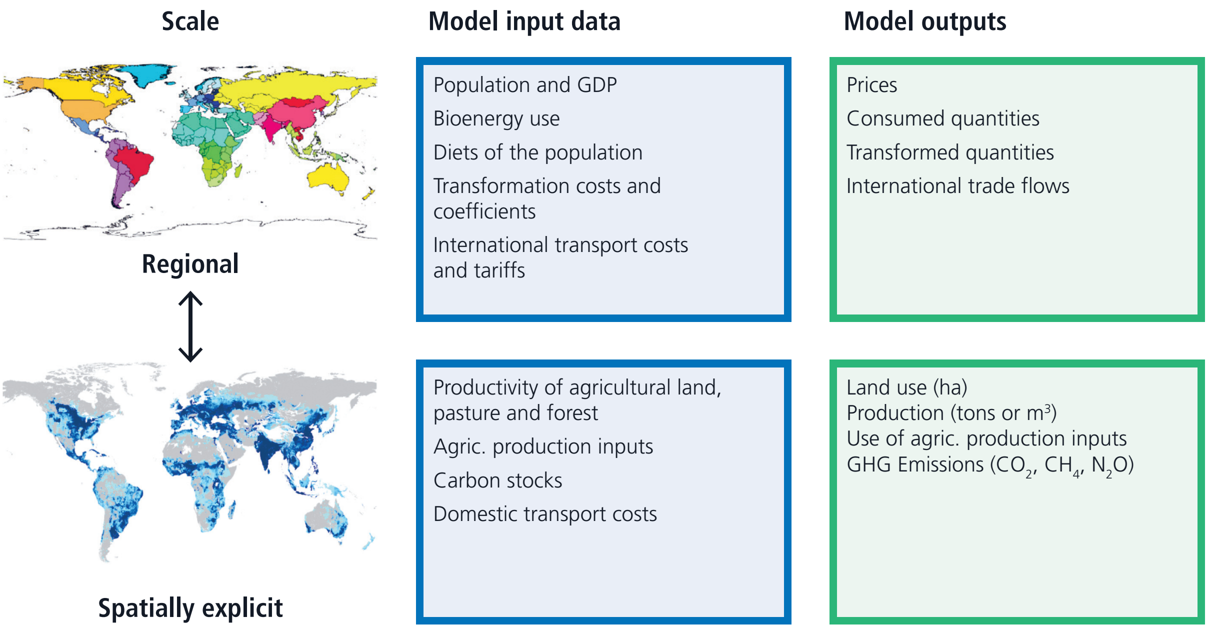

Figure 2. Main input and output data of the GLOBIOM model at different resolution levels

In GLOBIOM all the entry spatial data is available at the simulation unit level. Figure 3 shows how the simulation units have been constructed. The simulation units are defined by the combination of pixels whose size is ~10 x 10 km which are in the same country (dashed line), a same pixel whose size is ~50 x 50 km (blue grid), and a similar homogeneous response unit (HRU – Homogeneous Response Units) (there are 4 HRUs in the figure on the left represented by orange, violet, green and yellow surfaces). The

Homogeneous Response Units (HRU) are defined by biophysical characteristics which are stable over time and over which producers have little influence: altitude (5 classes), incline (7 classes), and soil type (5 classes). The simulation unit is used as the basis for the Environmental Policy Integrated Model (EPIC)[2] which calculates the productivity potential for 17 crops used as input data for the GLOBIOM economic model. In total there are 217,707 simulation units globally whose size varies between 10 x 10 km and 50 x 30 km (in the example below, 27 simulation units are represented with each having a different colour in the image to the right).

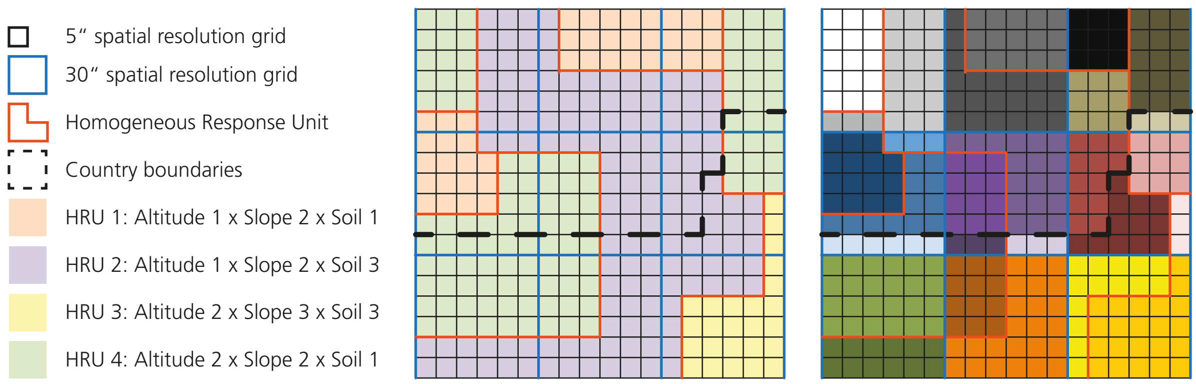

Figure 3. The elements used to delimit simulation units.

GLOBIOM directly represents production on the basis of four types of land use -cultivated land, grazing land, managed forests and short rotation tree plantations – by Leontieff production functions[3]. Productivity and production costs vary according to biophysical potential and management type (Herrero *et al.,* 2008; Sere and Steinfeld, 1996). Currently 18 crops, five forest products and six livestock products (4 types of meat, eggs and milk) are included in the model.

2.2 The CongoBIOM model

GLOBIOM had already been adapted to the context of the countries of the Congo Basin (CongoBIOM) in 2010 to explore the evolution of emissions from deforestation and forest degradation until 2030 (Megevand *et al.,* 2013; Mosnier *et al.,* 2014). It was a regional model covering 6 countries: Cameroon, Republic of the Congo, Central African Republic, the Democratic Republic of the Congo, Gabon and Equatorial Guinea, and connected to other parts of the model by trade.

The results would have a strong development impact of roads on deforestation which was three times higher after the completion of roads planned in 2030. Contrary to the expected result, improving agricultural productivity also increased deforestation in the Congo Basin. This result was linked to a strong increase in consumption after the fall in prices caused by the introduction of the technical progress. Therefore, part of this additional demand should be satisfied by an increase in cultivated land. Increased worldwide demand for biofuels or increasing meat consumption also resulted in increased deforestation in the Congo Basin because this drove up global prices of agricultural products. When import prices are more expensive, local production increased through the expansion of agricultural land in order to be able to offset a reduction in food imports.

2 See http://www.iiasa.ac.at/epic
3 The Leontieff type production function is a production function where the entrants are perfectly complementary. This means that the share of each entrant for the production of a product unit is fixed.

Finally, the introduction of a limit on emissions from deforestation globally showed a strong reduction of deforestation in the first place in the Congo Basin, where the opportunity cost of the land was lower than in the other tropical regions. However, without additional measures to stimulate agricultural production, this caused an increase in food prices in the region and an increase in food imports. Where an emission control policy was introduced in other countries but not in the Congo Basin, the results showed a significant risk of emissions flight ("leakage") to the Congo Basin where deforestation increased.

The main limitations of the study which were highlighted by the participants of the study during the 2010 feedback workshop were:

- "In reality political decisions are taken by countries and not by the COMIFAC region and it would be desirable to develop national models to inform the REDD+ process" (consult section 2.3.).
- "Livestock breeding extends to non-forest areas and pushes crops into the forest. Livestock breeding activities needs to be included in the model." Livestock breeding is now explicitly represented (Havlík *et al.,* 2014; consult section 4.3).
- "Governments in the region are looking to develop mines which might become a factor of deforestation in the future". We have tried to collect data about the mining sector in the Congo Basin. However, it remains difficult to make projections on the future development of mining on the basis of the exploration licenses which have been issued.
- "There is a need to strengthen capacities in the Congo Basin about the REDD+ issues.". Several workshops and sessions by the "REDD-PAC school" have been held at the national and regional levels both to present the results and discuss the model hypotheses but also to improve the understanding about the mechanisms of deforestation and forest degradation and their quantification in the modelling approach (consult section 3).

2.3 The GLOBIOM model adapted to Cameroon

For the REDD-PAC project it has been decided to enlarge the sub-regional model to all COMIFAC countries (the six countries named above plus Rwanda, Burundi, and Chad[4]) and to develop national models for three pilot countries: DRC, the Republic of the Congo (ROC) and Cameroon. The COMIFAC region is linked to the other regions of GLOBIOM whereas Cameroon can also trade with the other sub-regions of the COMIFAC space: the Republic of the Congo, the Democratic Republic of the Congo, the West, which includes Gabon and Equatorial Guinea, the North which includes Chad and the Central African Republic and the East which includes Rwanda and Burundi (see Figure 4).

4 Sao Tome and Principe fare also part of the COMIFAC space but are not included in GLOBIOM at the present time.

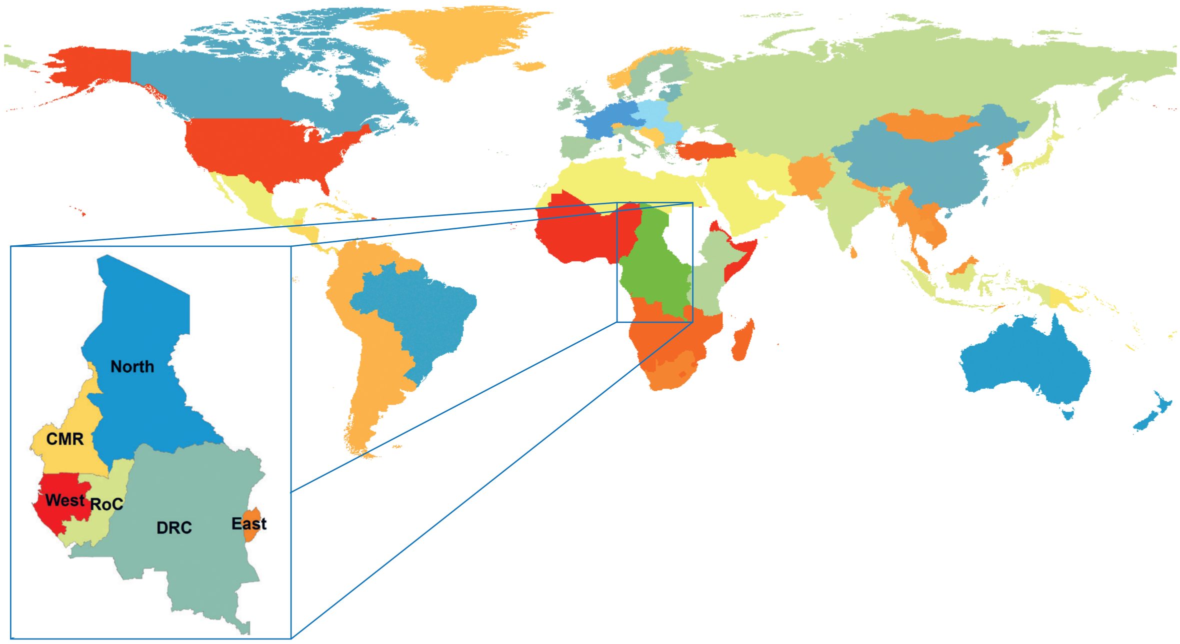

Figure 4. Cameroon is a sub-region of the COMIFAC zone (left) which is linked to the 29 other regions of the global model (top)

In total, Cameroon includes 1,337 simulation units whose size vary between ~50,000 and 300,000 hectares (Figure 5a). All of the model's spatial entry data is integrated at the level of the simulation unit. Some production statistics are available from the first (region) and second (department) administrative level of Cameroon (Figure 5c). One of the first tasks has been to calculate the intersection of each simulation unit with each department. The resolution level of the model's final grid during the optimisation process is ~50x50km, which results in 239 spatial units (Figure 5b). As a comparison, in the other GLOBIOM regions outside the COMIFAC the spatial resolution during the simulations was four times coarser.

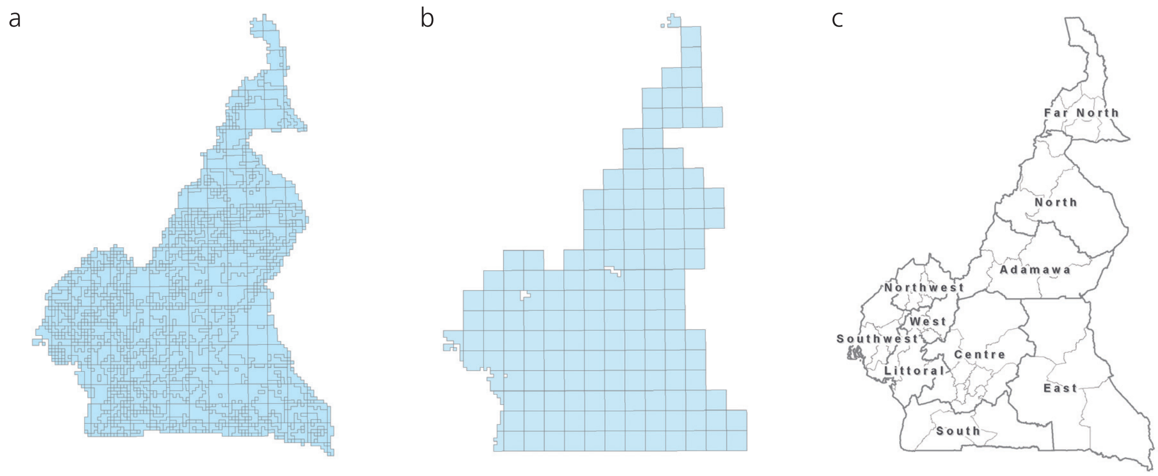

Figure 5. The simulation units (a), the 30 ArcMin grid (b) and the and the regions (c) in Cameroon

It is very important for the modelling work to have a good representation of the initial situation. For GLOBIOM this corresponds to the year 2000 whereas the model's projections for 2010 allows us to evaluate the model's performance, in other words if the model's results are closer to what happened in reality. A lot of effort has gone into the collection of data specific to Cameroon in order to replace and refine the information coming from global databases, including a national land use map, sub-regional agricultural and forestry statistics and the national policies governing forest use.

The land cover map forms the first layer of model information. Land cover maps are produced by analysing satellite data, but the strong presence of cloud cover in the Congo Basin complicates the analysis of this data. The map which is used by default in GLOBIOM is the map of Global Land Cover (GLC) produced by the Joint Research Institute (JRC) for the year 2000. Land cover maps are generally built by analysing satellite imagery, yet the analysis of these data is complicated by the presence of both permanent cloud cover in the Congo Basin and the small field size of agricultural plots.

Special attention has also been paid to improving the representation of the deforestation drivers and of the forest degradation in Cameroon. The causality diagrams of deforestation and forest degradation by sector have been established during a workshop held in Yaoundé with representatives of the different ministries and of the CN-REDD (section 3.4).

The exhaustive list of the changes made in the model for this study is presented in the annex.

2.4 The main drivers of the deforestation in Cameroon and their representation in the GLOBIOM model

A preliminary analysis of the drivers of deforestation and forest degradation had been presented in the R-PP document and consequently been supplemented by a sample-based detailed study of the causes of deforestation and forest degradation in 2013 (Carodenuto *et al.,* 2015). Moreover, in the framework of the REDD-PAC project, participants from different ministries who participated to the stakeholder workshop in Yaoundé on 21 and 22 may 2015 elaborated the causality diagrams displaying different types of consumption needs and their impact on the forest cover. In a first step, for each type of consumption need, the causality chain up to planned and unplanned deforestation and forest degradation is described. Then, we explain how this is represented in GLOBIOM.

2.5 Deforestation drivers according to the R-PP of Cameroon

According to the R-PP, the direct drivers of deforestation are the expansion of agricultural areas, fire wood consumption, the non-respect of management plans of logging concessions, illegal wood timber harvest, mining in forest areas and the development of infrastructures.

- **The agriculture sector:** Cameroon is a country disposing of a strong potential for agriculture. The agriculture sector employs more labour than any other sector in the country (EESI survey, 2010). The area of arable land and pasture are in the range of 9.2 Mha (R-PP, 2013). Slash-and-burn agriculture for subsistence production is often cited as the main cause for deforestation. Cash crops – mainly cocoa and coffee – which are often cultivated in the forested area also contribute to both deforestation and forest degradation. For 2007 the area covered by coffee and cocoa was estimated at 914,609 ha (Ministry of Environment, Nature Protection and Sustainable Development (MINEP) and Food and Agriculture Organisation (FAO, 2007). In certain regions of the country – notably in the Centre, South-West and Littoral regions – the scale of forest conversion stimulated by agro-industrial plantations gained non-negligible dimensions (Biki *et al.,* 2000). Oil palms, for instance, covered 136,180 ha of previously forested areas in 2008 (Lebailly et Tentchou, 2008)

- **Wood continues to be the main source** domestically used energy source for both urban and rural households in Cameroon who mainly use wood energy for cooking. It is estimated that close to 53 % of the population of Cameroon uses solid fuels (SIE, 2010; UNDP, 2008). According to an estimate of the FAO (2009) fire wood in the range of 9.8 Mm^3, three quarters of which in evergreen forest areas, are collected annually in Cameroon (Topa *et al.,* 2010). This heavy dependence from fuel wood as energy source can be mainly explained by the difficult access to alternative sources of energy (electricity, natural gas etc.) due to the prices of these which generally exceed the financial possibilities of the mainly poor households: in 2007, the third Cameroon households survey (ECAM3 in French acronyms) estimated that close to 40 % of the population of Cameroon lived under the poverty line (Nat. Statistics Institute, 2007). Moreover, the better part of the country's land area is still not covered by an electricity network.
- **The development of infrastructure** is both a direct and indirect cause of deforestation and forest degradation. At the same time, Cameroon is pursuing a path of economic development with the aim to attain the status of an emerging country by 2035. The realisation of this vision is routed – amongst other factors – in an accelerated development of road infrastructures and a strong support of the social and economic development. Both the sectoral strategy and the strategic plan developed to that end aim for a doubling of the share of paved roads among the total road network from currently 10 % to 19 % by 2020. Moreover, an expansion of the railway network is envisaged.
- **Logging,** both legal and illegal also constitute a main driver of forest degradation in Cameroon. Forest management plans, put in place to assure sustainable management and permanent availability of the resource should limit forest degradation; however, there is evidence that these plans are not always respected in practice. Close to 3 million m^3 are extracted per year of which 25 to 30 % illegally, mainly to supply the domestic market (Topa *et al.,* 2010). A CIFOR study conducted in the cities Yaoundé, Douala, Bertoua, Bafoussam, Kumba and Limbe from July 2008 to June 2009 estimated the volume extracted informally to 755,000 m^3 (Cerutti *et al.,* 2011).
- Appart from petrol which is currently exploited off the shore only, **mineral prospection** for gold, iron, uranium and others did not yet result in the issuance of exploitation permits of a significantly great magnitude to have entailed major consequences in terms of deforestation and forest degradation. However, numerous explorations are on track and could lead to a steep increase in mining of in particular iron, nickel/cobalt and gold. Mineral prospections are little disturbing but mining exploitation could have strong direct adverse effects on forests and other ecosystems such as the surface need of open-cast mines, pollution with mercury, pollution of water and soils etc. and indirct effects through the settlement of population in the forest zone.

2.6 The main drivers of the deforestation in Cameroon and their representation in the GLOBIOM model

This section is based on the causality diagrams between different types of needs and their final impact on the forest cover prepared by the representatives of different Ministries who have taken part in the REDD-PAC workshop in Yaoundé on 21 and 22 May 2015. For each type of need, the causality chain up to planned deforestation, non-planned deforestation, planned degradation or the non-planned degradation is first of all described. Then, the representation of the causality chain in GLOBIOM is discussed.

2.6.1 Food needs

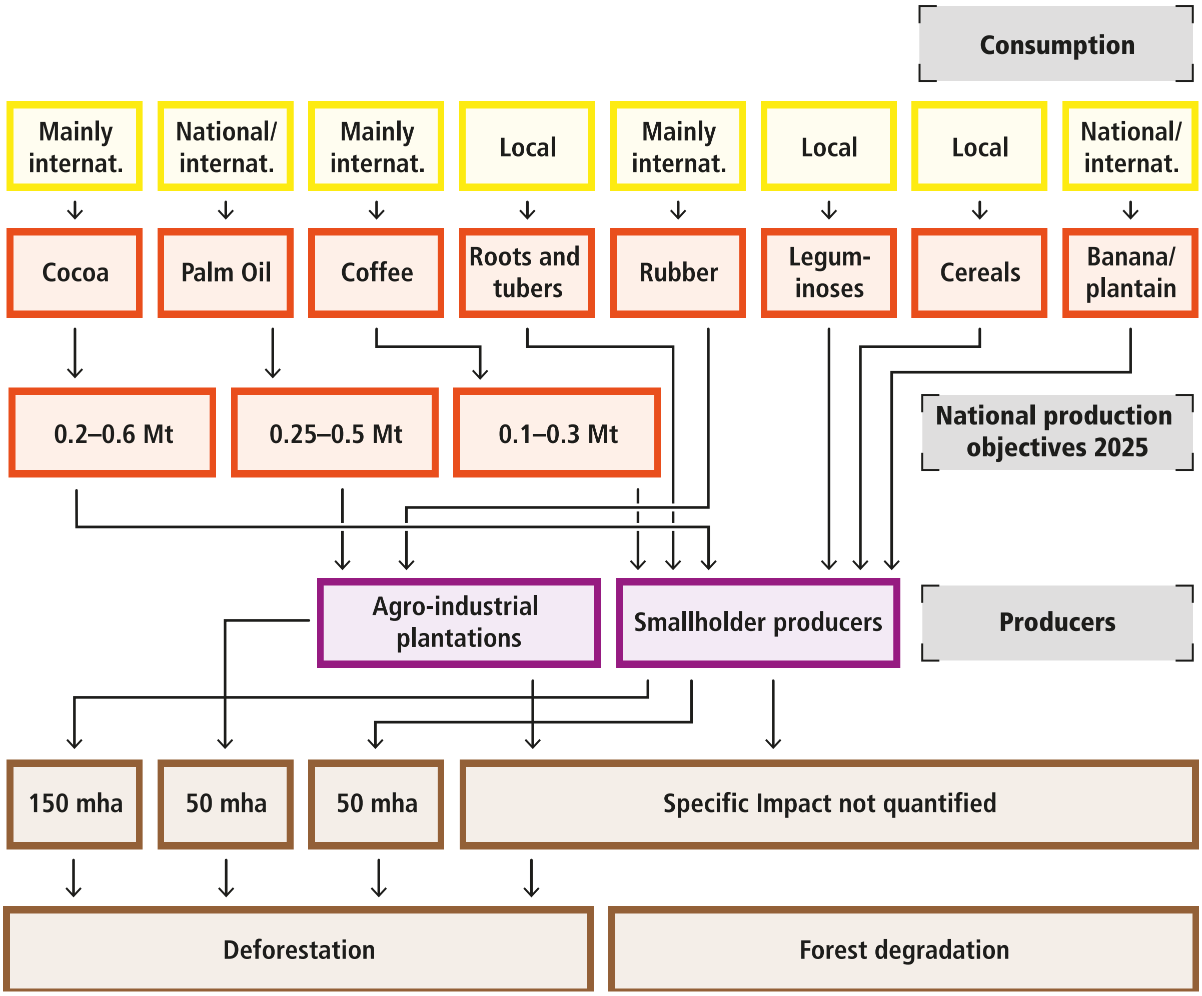

Figure 6. The impact of food needs on forest degradation and deforestation. Diagram established during the group work.

Description of the causal diagramme: The participants binned different crops into groups: cash crops among which are cocoa, coffee, rubber and oil palm; the roots and tubers group which contains cassava and macabo *(Xanthosoma sagittifolium);* vegetables (ground nuts and bananas); and bananas. (Figure 6). With the exception of the oil palm, cash crops aim at the export to foreign markets. The majority of the agricultural production is performed by smallholders and a few agro-industrial plantations of oil palm and rubber. For some key cash crops production targets for the year 2025 have been set on the national level by the Ministry of agriculture. Such production targets were established for cocoa (600,000 tons), coffee (300,000 tons) and the oil palm (500,000 tons). The participants estimate that ca. 250,000 ha of future deforestation will be attributable to these three cash crops. The other crops are mainly targeting the local market and the expansion of their crop surfaces might also result in additional deforestation.

Representation in the model: In the model, the change in the need for agricultural land is the main driver of changes in the use of land. Agricultural land includes crop-land related fallows as mentioned above, but also pasture for livestock. The demand for food is determined by population increases but also increases in income. An increase in income leads to an increase in total food consumption and particularly in meat consumption. Different consumption elasticities relating to income make it possible to represent these changes (Alexandratos and Bruinsma, 2012). The model also distinguishes the food demand of the urban population (definition: towns >300,000 inhabitants), which can be satisfied either through local production or through food imports depending on what costs the least, and the rural population which must produce an important part of its food consumption. The fertility of the soil is taken into account through crop productivity (in tonnes per hectare) as estimated by the EPIC model. This productivity varies inside the country depending on the climatic conditions, the topography and the soil types. The development of infrastructure reduces the cost of transport from the place of production to consumption centres which encourages both consumers to increase their consumption because products are cheaper and producers to increase their production because they can obtain more attractive prices.

2.6.2 Energy needs

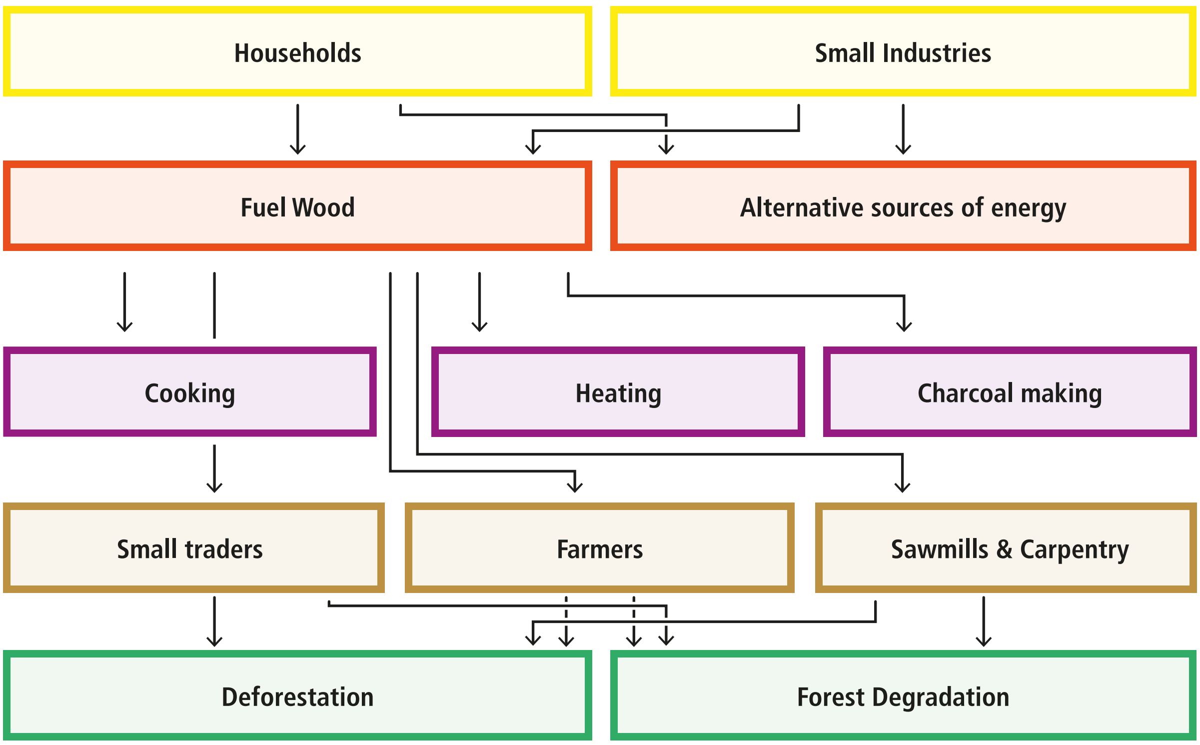

Figure 7. The impact of energy needs on forest degradation and deforestation – Diagram made during group work at the workshop in Yaoundé

Description of the causal diagramme: The workshop participants identified two principal groups of fire wood consumers in Cameroon: households and small industries, mainly for cooking, heating and drying. In the cities charcoal is used more frequently than fuel wood. There are alternatives to fire wood and in cities a growing share of houdsholds uses natural gaz or electricity. The types of producers of fuel wood are identified: Small fuel wood traders, farmers and saw mills or carpenters. Fuel wood consumption impacts both deforestation and forest degradation because the associated wood harvests are usually not organised sustainably or with a long-term productivity in view. Fuel wood collection is particularly worrying in fragile ecosystems such as the mangroves of the Littoral region and the arid North region and the zone around Yaoundé. In the forest area fuel wood is mainly sources from deadwood and wood cut during the clearing process linked to shifting agriculture.

Representation in the model: In the model the fuel wood demand depends on the evolution of the total population as well as the split between urban and rural populations. This is because charcoal is preferably consumed by urban housholds due to easier handling for transport and storage and also because its relative energy content is double of that for fuel wood, whereas in rural areas fuel wood dominates the marked due to its easy availability. In the model, by default the hypothesis is made that 70 % of the urban households in Cameroon use charcoal for cooking and whereas the rural population uses exclusively fuel wood. Since charcoal and fuel wood have different energetic yields[5] (Figure 8), we use the estimates of the UN concerning the future evolution of rural versus urban populations to calculate the average energy yield for cooking on the national level over all scenarios. The growing urbanisation of the population will entail an increase in energy sourced from wood. This is because we make the assumption that the charcoal production technology and the cook stoves remain the same as they are today but the increased use of charcoal linked to the growing urbanisation results in a doubling of the wood consumption compared to the traditional cooking methods in rural areas.

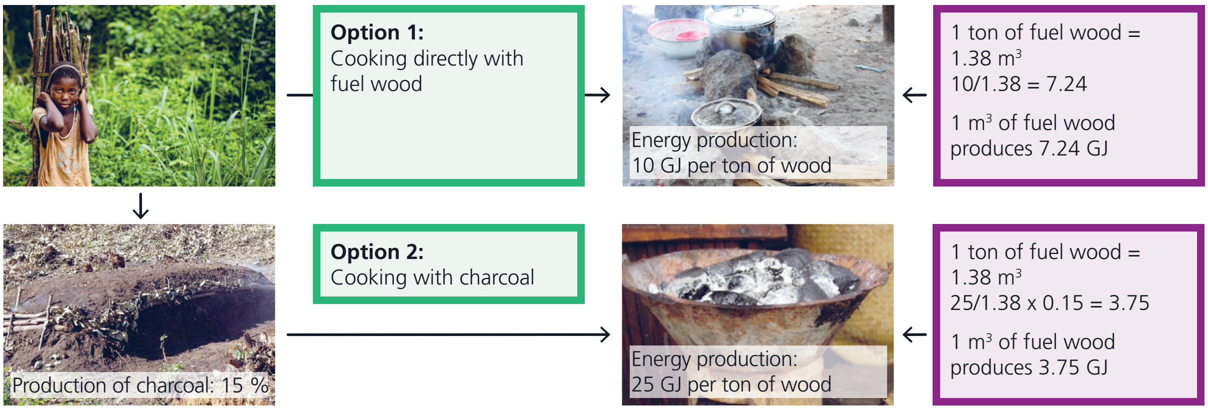

Figure 8. Conversion of fuel wood and charcoal into energy for cooking

To calculate the energy demand for cooking in the base year of the model, we use the average energy consumption per inhabitant in 2000 in fuel wood (equalling fuel wood production as reported by FAO) adjusted with population growth and the changing energy efficiency linked to a stronger use of charcoal which is related to growing urbanization. Fuel wood collection can be associated to the clearing of fallows under the subsistence agriculture regime or it can occur informally in unmanaged forests.

5 Using charcoal as cooking material requires a first conversion of wood to carbon before it is burned and the energy is released. The assumption is made that carbonisation is mainly done in traditional kilns where average energy yields are estimated at 15 % of the energy stored in the wood. Moreover, metal braziers for charcoal burning are more and more common means of cooking in cities.

2.6.3 Demand for lumber

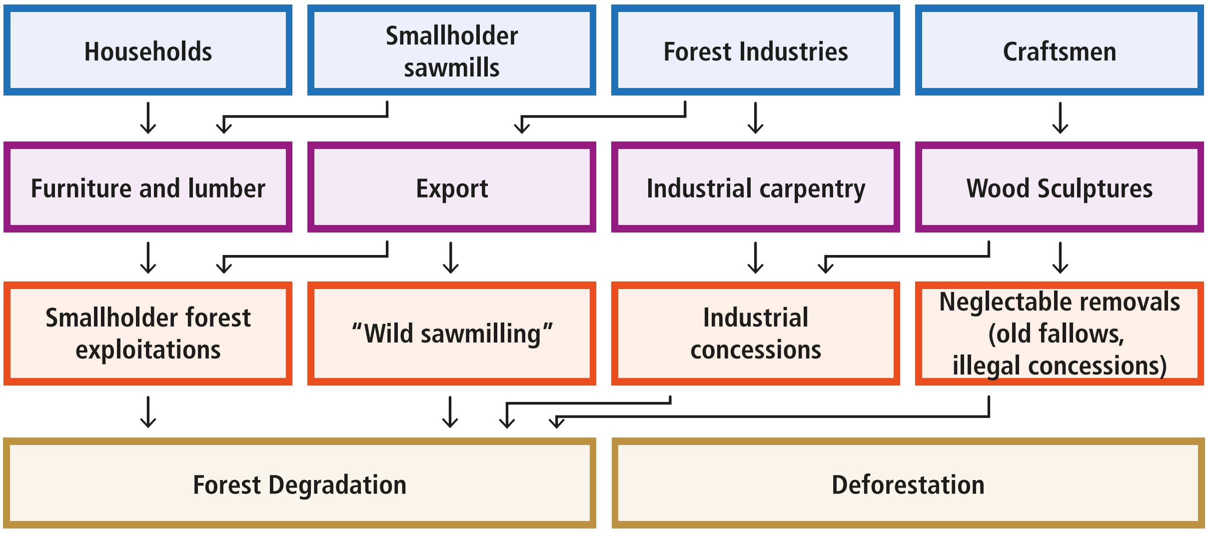

Figure 9. The impacts of the demand in lumber on forest degradation and deforestation – Diagram established during group work with stakeholders.

Description of the causal diagramme: The participants identified four main groups of lumber users: households, craftsmen, wood industries and artisanal loggers. In fact, here it is considered that the households are the end user of lumber and in particular of transformed wood products which are produced by craftsmen. Those source the lumber from artisanal loggers who harvest logs on old fallows, communal or community forests or in other, unmanaged forests (Figure 9). There is also demand from outside, mainly from China and Europe for sawn wood and veneer which is sourced from industrial logging concessionaires. Hence, there are two distinct production sectors which supply very different markets: artisanal logging for the domestic market and industrial logging for the export. Communal and community forests were established with the aim to supply the local market but in reality communities often partner with industrial logging companies which subsequently bring the harvest to the export. Regardless the actor, logging contributes stronger to forest degradation than deforestation.

Representation in the model: The model generally takes into account all the elements of the chart. Artisanal logging is represented in a simplified manner by omitting the difference between the formal and illegal activities. In addition to the elements identified during the workshop, the model also takes the country's economic development into account measured by the gross domestic product (GDP) as well as the demand for lumber in other countries of the world. In its current configuration, the model only allows for degradation – not deforestation – linked to the lumber logging activities. Forests located in protected areas where there are currently no concessions are classified as not available for logging.

2.6.4 Mining needs

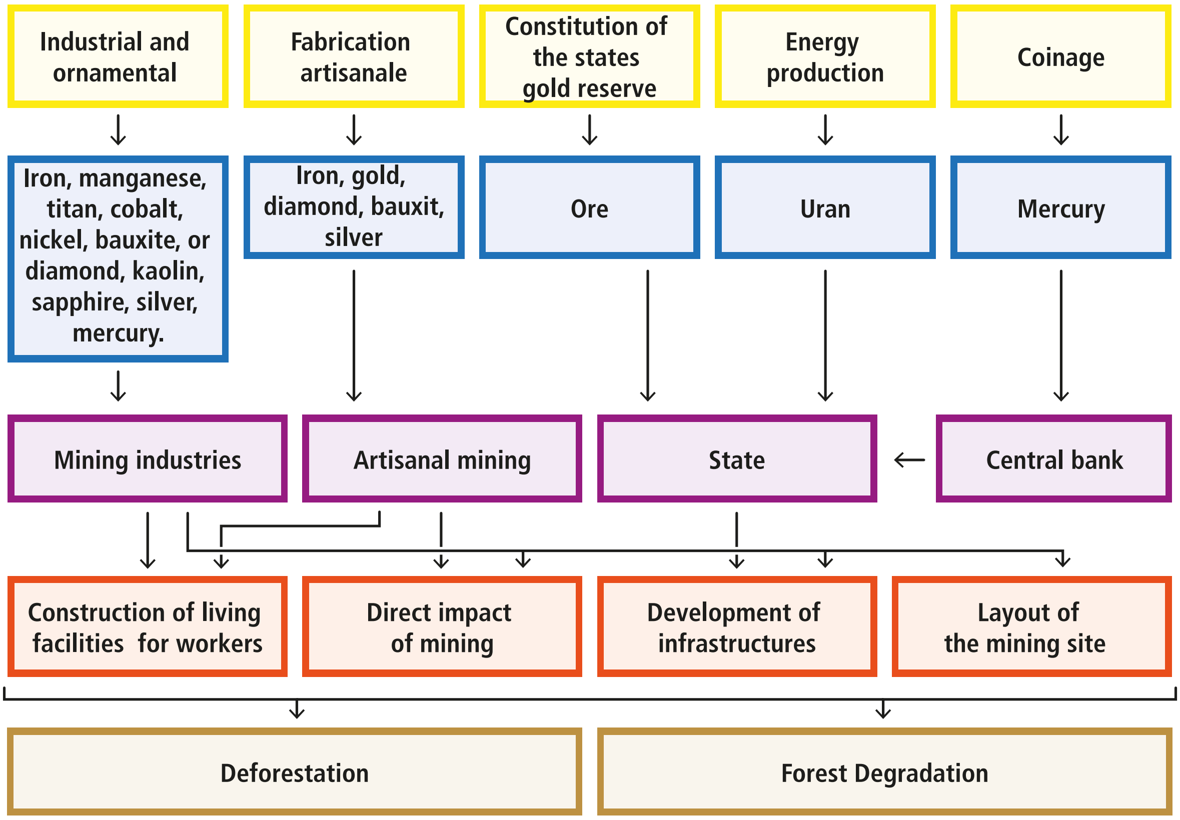

Figure 10. The impacts of mineral demands on forest degradation and deforestation – Diagram established during group work with stakeholders.

Description of the causal diagramme: Needs for minerals mainly arise from external demand. The workshop participants identified different uses and user groups for minerals in Cameroon: industrial or ornamental use, artisanal mineral use, the federal gold reserve of Cameroon, energy production and coinage. For these different uses four major agent groups can be distinguished, notably industries, craftsmen, the state and the central bank. In many cases mineral mining can exercise a direct adverse effect on ecosystems. However, the main impact on ecosystem comes from indirect effects related to the installation of facilitites which give the access of the mining site, hence indirectly leading to deforestation and forest degradation. Among these facilities were named transport infrastructures (roads etc.), housing facilities for workers of the mine and their families and the construction of the actual mining site (Figure 10).

Representation in the model: The "mines" module of the model is in the process of being developed. Once the spatial data concerning these mining activities is available, the envisaged modelling approach is to estimate the direct impact in terms of the mine size and type of mineral mined and indirect impact according to the number of workers multiplied by the average size of a household in Cameroon. This will give rise to the emergence of a new local demand for food and energy which can be satisfied according to the mechanisms described above. The infrastructure planned within the framework of the mining can also be included in the calculation of the reduction of the transport costs.

3 Land cover maps

3.1 Global Land Cover (GLC)

The Global Land Cover 2000 map was produced by the Joint Research Centre[6] using the satellite images of the SPOT 4 VEGETATION 1 programme between November 1999 and December 2000[7] and the FAO vegetation classification system (Di Gregorio and Jansen, 2000). In all, 22 classification classes have been mapped. Regional maps have initially been prepared (consult Mayaux *et al.,* 2004 for Africa) and then merged to create a global map at a spatial resolution of 1 km at the Equator.

3.2 GlobCover

The GlobCover project started in 2005 at the initiative of the European Spatial Agency in collaboration with the Joint Research Centre, the FAO, UNEP, the GOFC-GOLD initiative and the International Programme for the Geosphere-Biosphere (IGBP). The high resolution ENVISAT-MERIS satellite images acquired between December 2004 and June 2006 have been used to produce a 300 m spatial resolution global vegetation map (Defourny *et al.* 2006). As in the GLC2000, the classification is based on the FAO (22 classes) but is extended to 51 classes.

3.3 MODIS collection 5

The MODIS vegetation map was built by the American Space Agency (NASA) on the basis of MODIS satellite images. The global vegetation maps have been produced for each year between 2000 and 2010 at a spatial resolution of 500m. As the base year of the GLOBIOM model is 2000 we here use the MODIS map for 2000. 17 classes are mapped according to the classification proposed by IGBP.

3.4 UCL

This map includes the eight countries of the Congo Basin – Cameroon, Republic of Congo, Central African Republic, the Democratic Republic of the Congo, Gabon, Equatorial Guinea, Burundi and Rwanda-using satellite data from ENVISAT-MERIS with a spatial resolution of 300 m collected between December 2004 and June 2006, and SPOT VEGETATION images collected between 2000 et 2007 at a spatial resolution of 1 km (Verhegghen *et al.,* 2012). 20 classes have been identified on the same basis as the FAO typology.

3.5 Comparison

The four maps described above were analyzed and compared for Cameroon (GLC2000, Globcover, MODIS and UCL). In order to better understand the existing maps a first step has been to aggregate them into the same land cover classes (consult www.geo-wiki.org for the display). The following land cover classes are distinguished: crop-land, grasslands, humid forests, dry forests, swamp forests, other flooded zones and other natural lands.

There are great uncertainties concerning the land use in Cameroon, in particular for crop-land (see Figure 11 and Figure 12). The total crop-land area varies between 5.7 and 8.2 million hectares (Mha) between

6 The Joint Research Centre, also commonly called the JRC fort Research Centre in English is the European Union scientific and technical research laboratory.
7 See http://www.cnes.fr/web/1468-vegetation.php

the four land cover maps in question. Total crop-land maps are relatively close between the GLC, UCL and GLOBCOVER maps whereas MODIS tends to estimate a smaller crop-land area. While all maps consistently estimate a strong presence of crop-land in the Far North region, there are big differences for the other regions. The GLC map identifies crop-land mainly in the South-West region whereas UCL and GLOBCOVER identify relatively vast crop-land areas in the Center, West and Littoral region. According to MODIS crop-land is more concentrated around Yaoundé and in the Western part of the country.

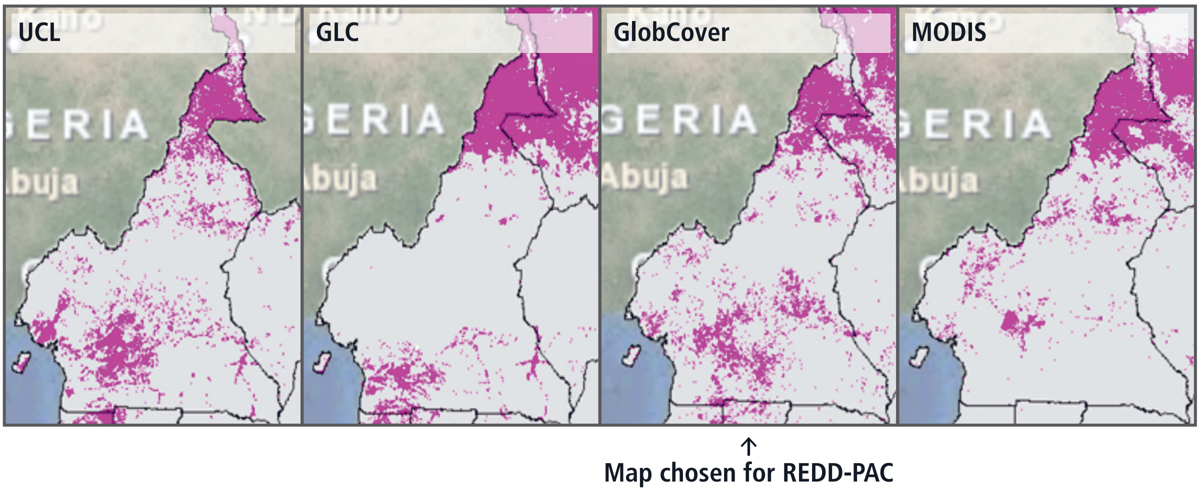

Figure 11. Location of crop-land in Cameroon according to different sources

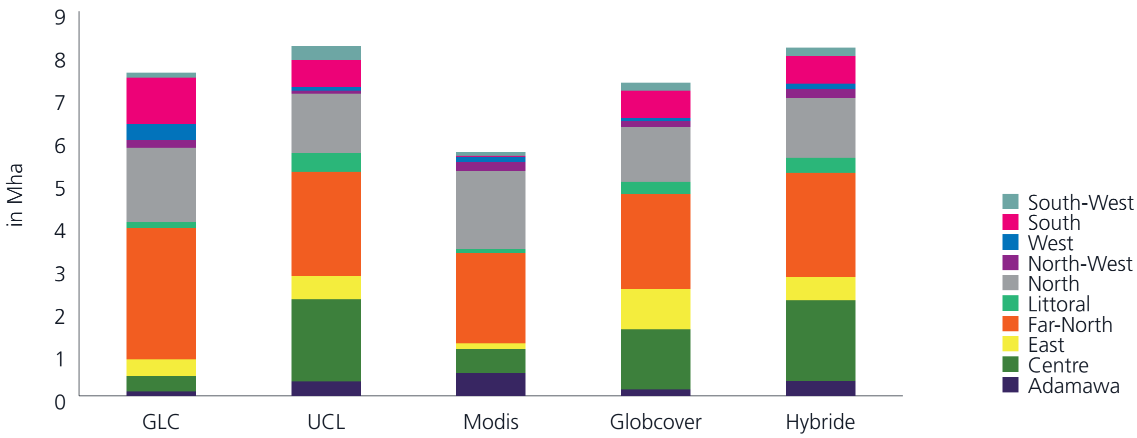

Figure 12. Distribution of crop-land over regions according to different vegetation maps

For forests the total area varies among the land cover maps from 20.2 to 35.9 Mha (Figure 13). The major differences, however, could be explained by varying thresholds for criteria which define what constitutes a forest, which is particularly true for dry forests covering about half of the country (mainly the regions Adamaoua, North and Extreme-North) whereas estimated areas for humid forests are relatively consistent among the different maps.

In July 2015 Cameroon submitted a national forest definition to the UNFCCC, where the minimal forest cover is 10 %, the minimum tree heigth of mature forest is 3 m and the minimum forest area is 0.5 ha. These thresholds constitute a wide definition of what is a forest and therefore comprises dry forests and the majority of woody savannah's.

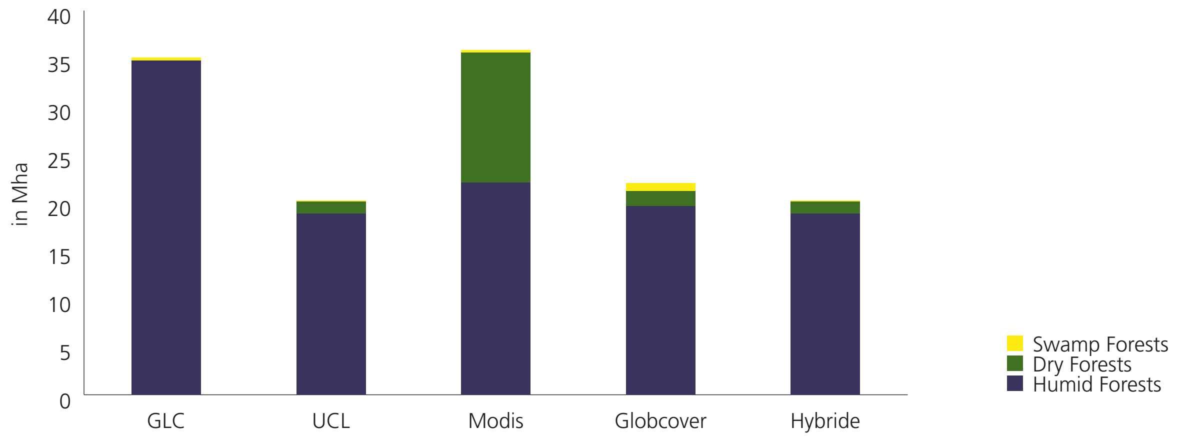

Figure 13. Breakdown of forest by forest type according to different sources

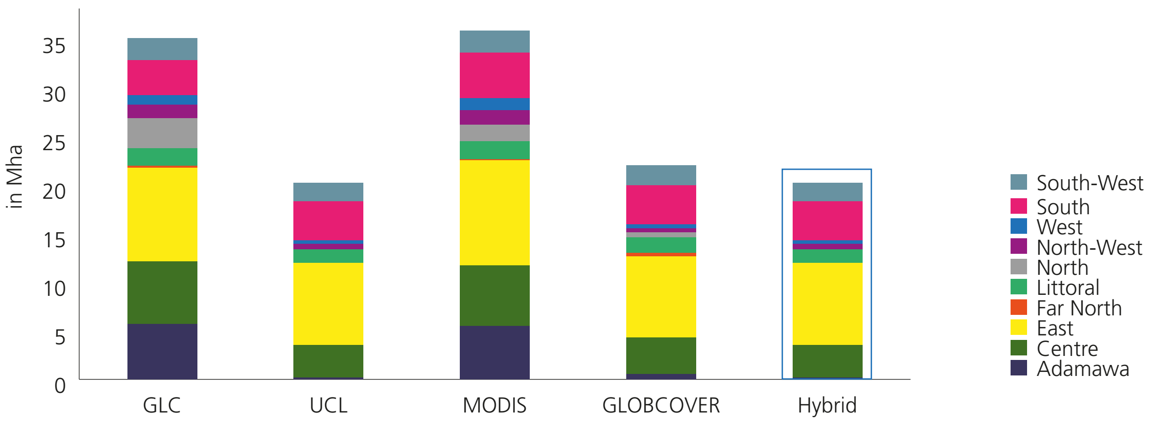

Figure 14. Distribution of forest land according to different land cover maps

3.6 The hybrid land cover map for Cameroon

Owing to the great uncertaintites encountered, it was decided to construct a hybrid land cover map where features from the four maps could be blended in in order to reach a good representation of any given land cover class or region (Figure 14). Based on discussions with national experts, the UCL map was generally considered to be the most reliable map with the exception of crop-land in the South-West region where GLOBCOVER was considered to the better choice. The land cover map used in the further land use modelling exercise therefore corresponds to the "Hybrid" map as presented in Figure 15.

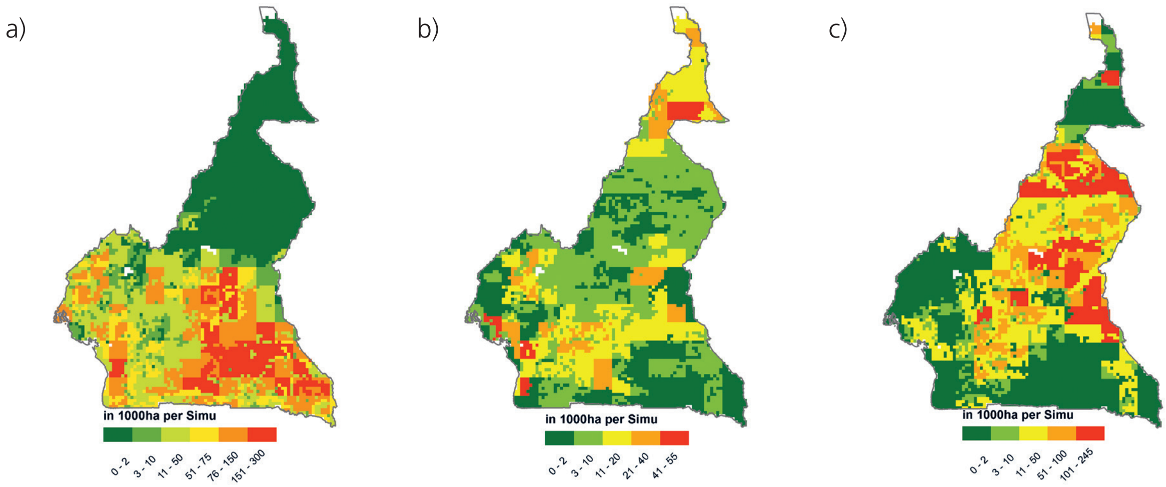

Figure 15. Hybrid land cover map for Cameroon: share of simulation units covered by a) dense humid forests, b) cropland and c) other natural lands such as savannahs.

4 Harmonizing land cover and land use

In a second step, the maps of protected areas, forest concessions, and the agricultural statistics were used to break down the different types land cover to different uses. Crop-land is broken down by crop, grasslands are differentiated depending on whether it is used for livestock (pasture) or not (other natural land), and logged forests are separated from unmanaged forests.

4.1 Logging concessions and protected areas

The maps of forest concessions and protected areas used in the model for the base year 2000 was sourced from the WRI Interactive Forest Atlas of the Republic of the Congo which represents the data for approximately the year 2008. The area under active forest concessions was 6.5 Mha and protected areas covered about 3.5 Mha (Figure 16).

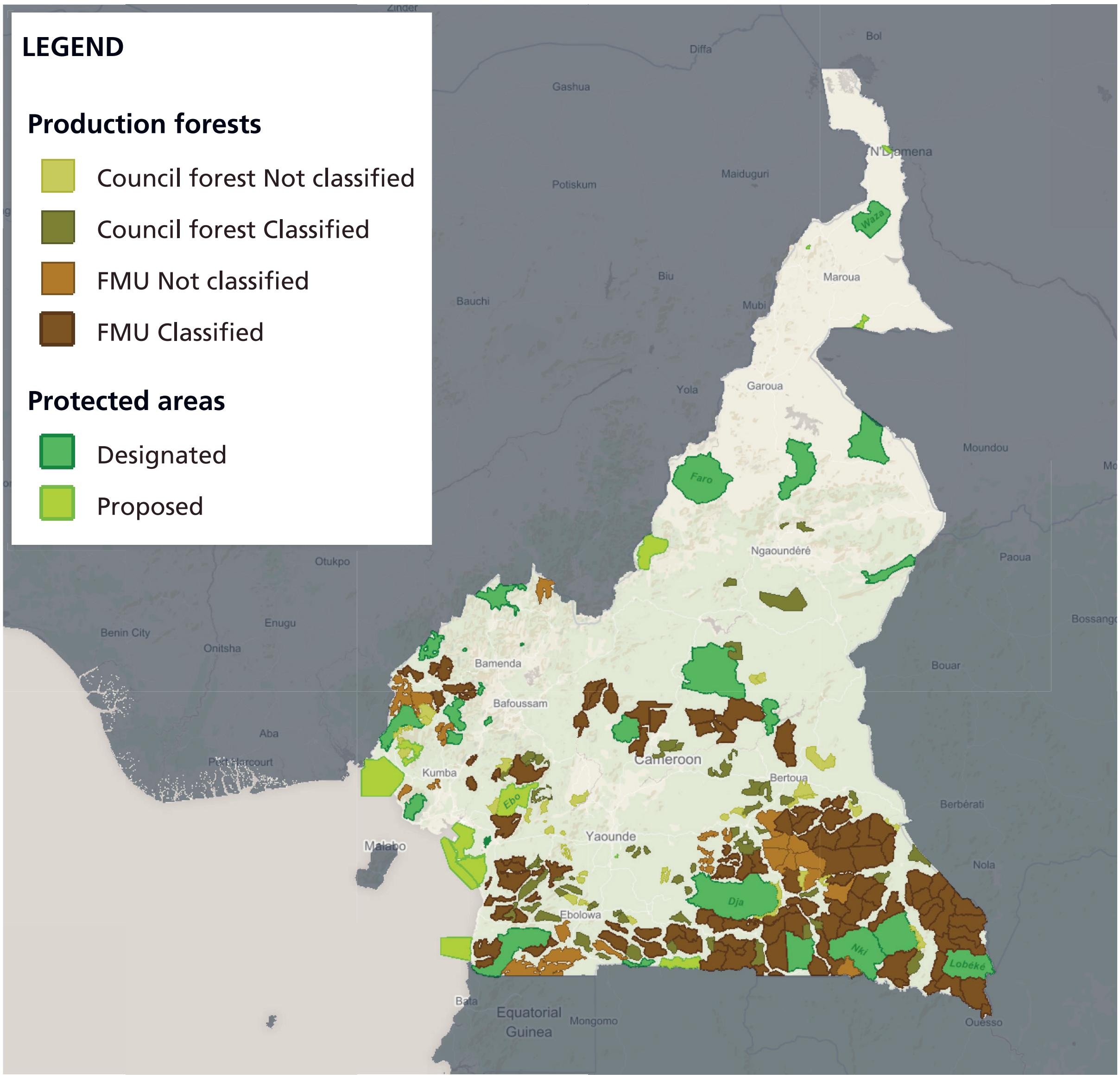

Figure 16. Forest concessions and protected areas listed for 2008 in Cameroon by WRI

We sometimes observe an overlapping of forest concessions and protected areas in Cameroon. To ensure the same total surface area per spatial unit, where the area under the under concession area plus the protected area exceed the total area of the simulation unit, we assume that the forest area within the protected area is operated by the forest licensee and the surface is subtracted from the initial surface of the protected area (Figure 17). This explains why the protected areas in the model can be less that the official surface area (Table 1).

For Cameroon this reduced the total surface of protected areas by 3.2 %. Protected areas are then divided by land cover class: in the model, 76 % of the surface of protected areas is included in the forests class of which 72 % is in the "dense humid forests" class.

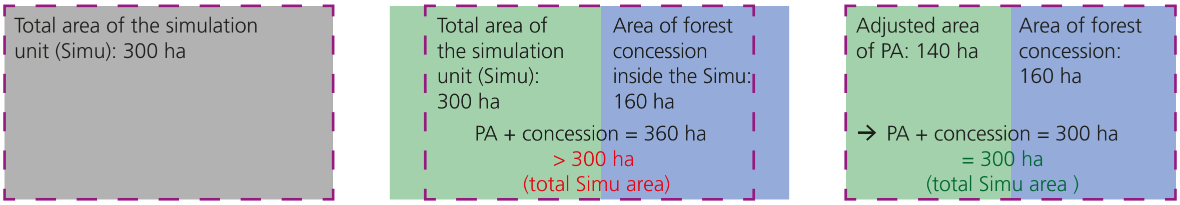

Figure 17. Procedure for adjusting the protected areas (PA's) if there is an overlap of land uses

It should be noted that the forest management in the model corresponds to sustainably maanaged forests, i.e. extraction rates are applied which ensure constant availability of the resource in the future. This mode of operation is becoming widespread in the Congo Basin, with the development of management plans. We only consider the rainforests within industrial logging concessions. The base area in the "managed forests" class can therefore be less than the total area under forest concessions if the concessions also include other types of vegetation such as flooded forest areas (Table 1). Unallocated forest concessions are included in the "unmanaged forests" class.

Table 1. Comparison between the initial total area and the area included in the model for the managed forests and the protected areas in Cameroon (in Mha)

	Initial data	Total in the model	Of which humid forests	Of which swamp forests	Of which dry forests	Of which other natural lands
Protected areas	5,2	5,05	3,6	0,12	0,12	1,2
Managed Forests	6,5	6,4	6,4	0	0	0

In total, there are therefore almost 12 Mha of forests that cannot be converted for other uses in 2010 thanks to forest concessions and protected areas, which represents more than half of the total forest area in Cameroon.

4.2 Agricultural areas

4.2.1 Family-based agriculture

Availability of statistics about the agriculture sector in Cameroon is the best among all the COMIFAC countries in terms of the degree of detail of the data but further efforts remain to be made concerning the frequency of the update of the data. For this study the statistical yearbooks of the Ministry of Agriculture and Rural Development (MINADER) constituted the starting point for the collection of agricultural statistics. These statistics provide region-specific information about quantities produced, cultivated areas and the number of harvests or cropping cycles per year between 2000 and 2010. The 20 crops covered are sweet banana, plantains, cassava, macabo, yam ("igname"), beans, black-eyed peas ("niébé"), tomatoe, onion, ananas, corn, ground nut, potatoe, sweet potatoe, rice, soy bean, sorghum, coffee, cocoa and palm oil. For coffee and cocoa, however, statistics are available at the national level only for production quantitites and at the region level for cultivated areas.

Several "ruptures" of the statistical time series between 2000 and 2010 are noted. The first is the decline of both cultivated areas and production for all crops in the year 2005 which could be due to a change in the method used to establish the statistics as there is also a change in the reporting format from the year 2005 onwards: the number of cropping cycles is not mentioned any more. Another change occurs in the year 2009 where statistics stop to be reported at the department level but only continue at the region level instead.

Not all the crops reported by the statistical yearbooks could be integrated in GLOBIOM. Hence, in order to make best use of the wealth of statistical information, a number of aggregations and modifications were made to the statistical database underlying the model:

- Add statistics for regionally important tubers macabo and yam to the dominant tuber cassava
- Coffee and cocoa were added as new and separate crops to the database
- The category "Other crops" was added which accomodates banana, plantains, rubber and tea

In terms of spatial distribution, it becomes evident that ground nut and corn are the most present crops across the territory of Cameroon (in Table 2). By contrast, there are great climate-related differences for other crops. Sorghum is a very important in the dry zones of Northern Cameroon, in the North and Far North regions whereas cassava, banana and macabo are mainly cultivated in the more humid zones of the country. Beans and black-eyed peas are of local importance in the West and Far North regions. According to a study of the World Food Programme (WFP, 2007), an important part (40 %) of rural households inb Cameroon do grow cash crops for the market as opposed to pure subsistence farming. The choice of the cash crop also strongly depends on the agro-ecological zone which a farmer inhabits, with cotton being the main cash crop in the north of the country, cocoa in the dense humid forest areas and palm oil in the moist Littoral and South-West regions.

Table 2. Preferences for crops cultivation of household in each region of Cameroon

	Ground nuts	Banana	Vegetables & Fruits	Beans/Black-eyed bean	Yam	Macabo	Corn	Cassava	Millet/ Sorghum
Adamawa	+	+	+	+		+	+++	+++	
Centre	+++	+++	+		+	+++	++	+++	
East	+++	+++				++	++	+++	
Far North	++			++			++		+++
Littoral	++	+++		+	+	+++	+++	+++	
North	+++			+			+++		+++
North-West	++	+	+	+++	+	++	+++	++	
West	++	+	+	+++		+	+++	+	
South	+++	++				++	+++	+++	
South-West	+	+++	+		+	+++	+++	+++	
Total	++	+	+	++	+	++	+++	++	++
Rural Households	32 %	19 %	4 %	23 %	5 %	20 %	55 %	29 %	30 %

Legend: + >4 % and <20 %,
++ >20 %,
+++ >50 %;
Source: WFP, FSVA 2007

In addition to the cultivated areas, fallow lands need to be considered to obtain a robust estimate for the total area of arable land. To calculate areas of fallow it is assumed that the fallow period varies with the population density, i.e. fallows times are shorter in densely populated areas (Raintree and Warner, 1986). Based on consultations with local experts, we consider three classes of fallow periods[8]

- for a population density below 20 inhabitants per km^2, two years of crops cultivation are followed by seven years of fallow period (the land multiplier coefficient of cultivated land is equal to 4.5),
- for a population density between 20 and 30 inhabitants per km^2, two years of crops cultivation are followed by 5 years of fallow period (the land multiplier coefficient of cultivated land is equal to 3.5),
- for a population density above 30 inhabitants per km^2, two years of growing crops are followed by three years of fallow period (the land multiplier coefficient of cultivated land is equal to 2.5).

The fallow time also varies as a function of the agro-ecological zones. The technique of restoring soil fertility by leaving areas fallow for a longer period is particularly widespread in the dense humid forest areas whereas fallow periods are generally shorter in the savannah areas. Hence, the assumption is made that in dry temperate zones the fallow period is generally two years only. No fallow is assumed for perennial crops (oil palm, coffee, banana).

In certain cases the area of crop-specific cultivated land as reported by department-level statistics plus fallow area calculated with the method described above exceeds the area of arable land obtained from the hybrid land cover map. This may be the results of errors of either of the three factors in the equation, agricultural statistics, the hybrid land cover map or the land area multiplier used to calculate fallow areas. The problem occurs in the regions West, South-West and North-West and for the departments Haut-Nyong, Sanaga Maritime, and Lebialem. In these cases the fallow period was reduced, hence making the assumption of a more intense agricultural production system. Figure 18 shows the resulting heterogenity of the fallow coefficient for agricultural areas when taking into account the different fallow practices across the country and the correction described above.

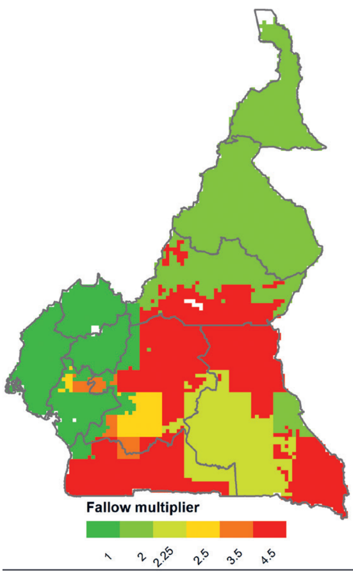

Figure 18. Land multiplier coefficient for arable land corresponding to the varying fallow times

8 Apart from the regions Adamawa, South and East, population density is always greater than 25 inhabitants per km^2 (the average population density in Cameroon is 35 inhabitants per km^2).

4.2.2 Agro-industrial concessions

Best available concession maps were used to estimate the area of agro-industrial concessions per crop (Figure 19). The oil palm is the main crop but there are also two big concessions planted with in the South region and one major sugar cane plantation in the Centre region. No fallow is assumed to be practiced in agro-industrial plantations.

Areas of agro-industrial concessions (in 1000 ha)					
	Sugar cane	Rubber	Oil Palm	Other	TOTAL
Centre	64.7	2.3	9.9	0.2	77.1
East	31.3	1.8			33.1
Littoral		3.9	50.5	9.0	63.4
North-West				2.9	2.9
West				0.9	0.9
South		99.2	22.5	3.2	125.0
South-West		4.1	58.7	10.9	73.7
TOTAL	**96.0**	**111.3**	**141.6**	**27.2**	**376.0**

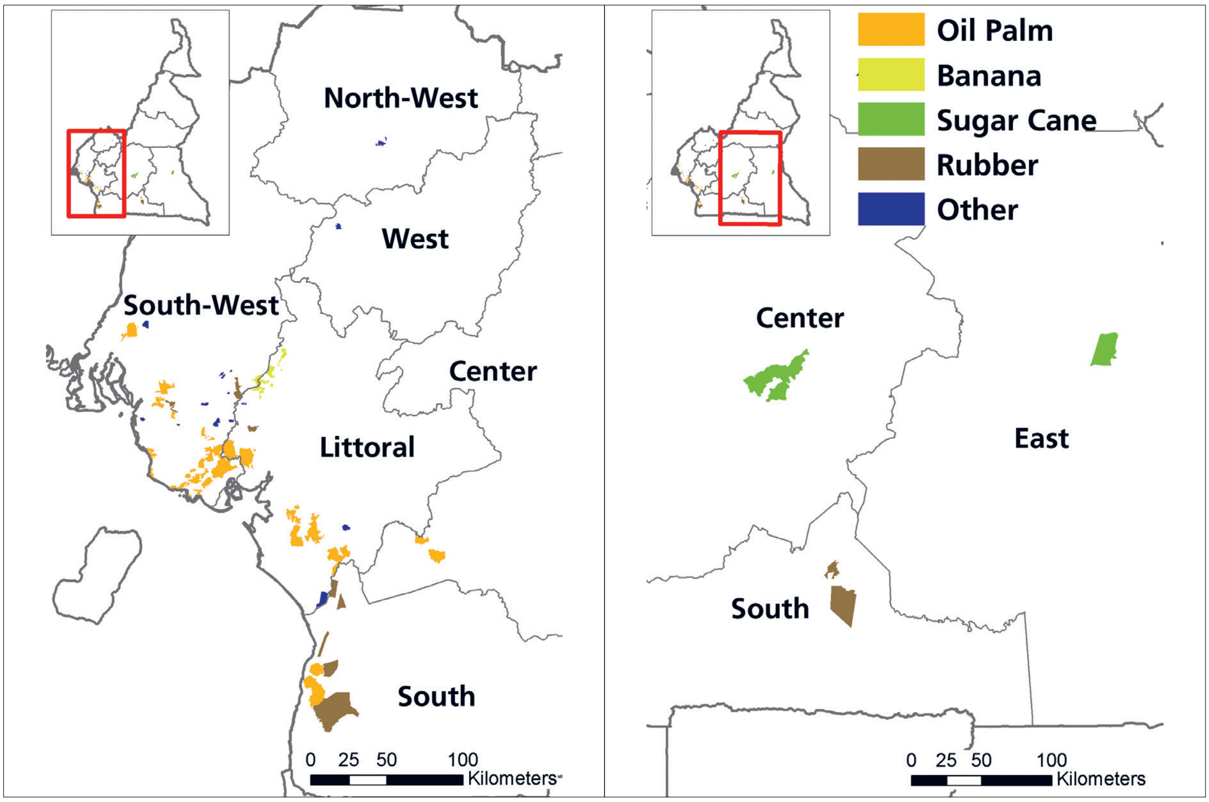

Figure 19. Location of agro-industrial concessions near the coast (bottom left) and in the hinterland (bottom right) and corresponding areas in 1000 hectars (top). Source: Nkongho *et al.* (2015)

4.3 The livestock sector

Data used by default in GLOBIOM are sourced from FAO and the International Livestock Research Institute (ILRI). Statistics for the livestock sector in Cameroon were collected from the Ministry of Livestock, Fisheries and Animal Industries (MINEPIA). The number of heads of bovines, goats, pigs and sheeps is available for the years 2005, 2008, 2009 and 2010 at the national level and only for the year 2010 at the regional level. At the national level MINEPIA data are relatively close to FAO/ILRI statistics (Figure 20). For bovines and small ruminants (sheeps and goats), national statistics report greater numbers than FAO/ILRI whereas FAO/ILRI report greater herd sizes for pigs than national statistics do. However, since it is not possible to compare the exact same year, it is difficult say wheter the difference is due to the evolution of the herd size between 2000 and 2005

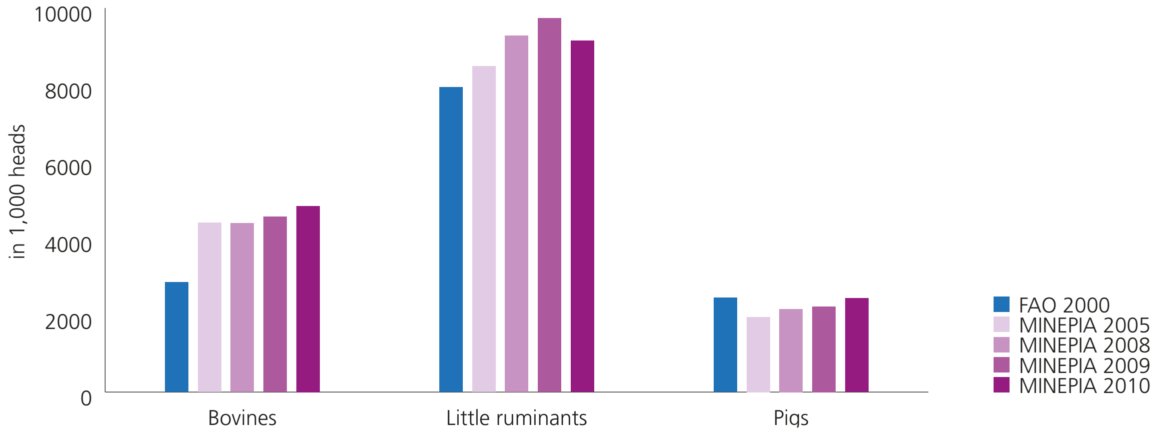

Figure 20. Comparison of herd size per species according to the sources

In terms of spatial distribution of livestock across the territory of Cameroon there are strong differences between the two sources for the regions South-West and North-West as well as Adamawa (Figure 21). Whereas according to FAO/ILRI the regions Adamawa and Far North comprise 34 % and 23 % of the national bovines herd, they only represent 18 % each according to national statistics. For sheeps and goats big differences can be observed between FAO/ILRI and national statistics. According to national statistics, half of the small ruminants are breeded in the regions Far North and North while FAO/ILRI allocates a significant part of small ruminants to the East and Centre regions. According to national livestock experts, national statistics better reflect the reality than the FAO/ILRI statistics do. Consequently, it was decided to keep the herd size reported by FAO/ILRI at the national level for the year 2000 but to distribute them across the national territory according to the shares reported for each region according to national statistics.

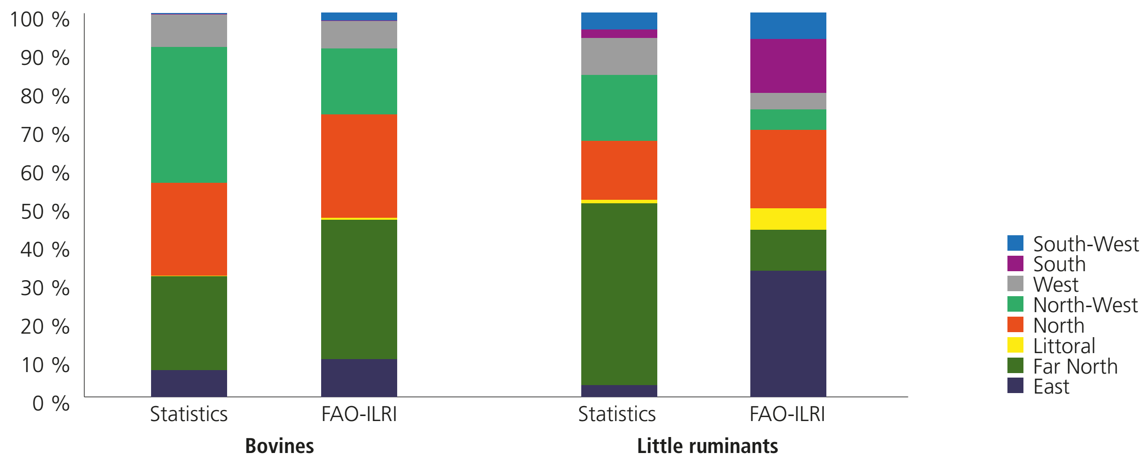

Figure 21. The herd size of cattle and small ruminants by source and region.

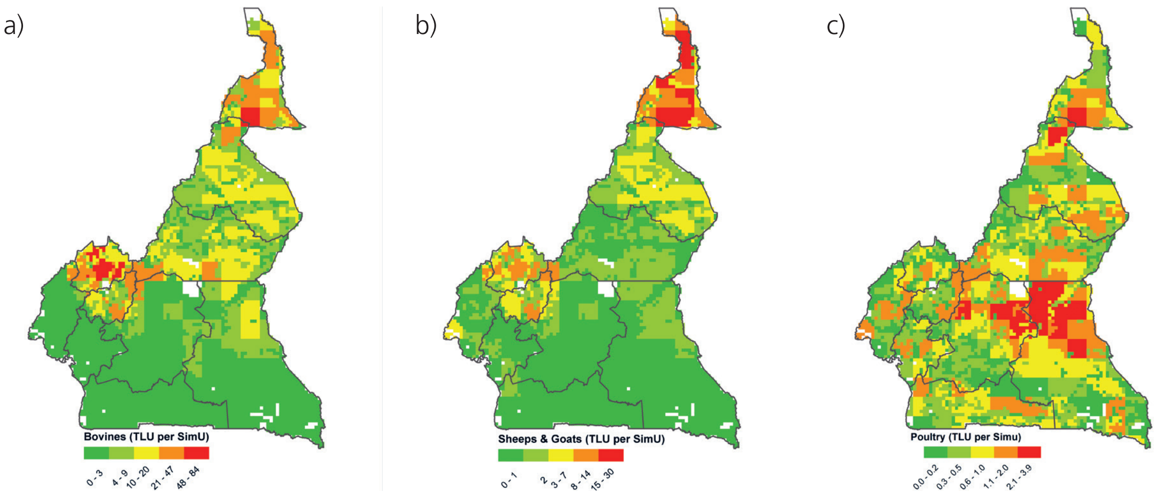

Figure 22. Map of the distribution of a) bovines, b) sheeps and goats and c) poultry across the country (in thousands of TLU per simulation unit)

4.4 Estimating the productivity of the land

4.4.1 The oil palm

In order to improve the representation and the possible expansion of the growing of oil palm in the model, we created a global map of the potential for the cultivation of oil palm on the basis of the biophysical constraints (Pirker *et al.,* 2015). We conducted a literature review in order to establish the optimum, maximum and minimum thresholds for each criterion. The global indicator is then obtained according to the law of the minimum: it takes the value of the most constraining factor of all factors considered.[9] As many natural constraints to cultivation may be lifted with certain cultivation techniques, we calculated the production potential of oil palm in two cases: the first reflects the case of agro-industrial plantations where we assume that adequate management techniques can be applied ("best management"), and the second case rather reflects the small producers who do not have the means to invest the capital required to develop best-standard plantations and who therefore remain limited by the natural constraints ("minimal management"). The bio-physical criteria that are taken into account are listed below.

- **Climate.** Four climatic factors are particularly important for oil palm: the average annual temperature, the average temperature during the coldest months of the year, annual rainfall and the number of months that receive less than 100 mm of rainfall.
- **Soil type.** Several types of soils can be problematic for the growing of oil palm: soil which is naturally poor in nutrients (ferralsols and acrisols), saline soils, very sandy soils with low capacity for water retention (podzols), rocky soils that prevent a good grip of the roots, peat soils, and frequently flooded wetlands.
- **Topography.** Steepness of lands increases the costs and efforts of maintenance and harvesting of plantations and also present a risk of erosion. Elevated areas are also less suitable due to lower temperatures.

9 The document showing the methodology for establishing the potential production areas of oil palm in greater detail can be downloaded from the following link: http://www.iiasa.ac.at/publication/more_IR-15-006.php.

Our results show that Cameroon has a total of 31.15 million hectares of land suitable for the industrial cultivation of palm oil, corresponding to 66 % of the national land area (Figure 19). Most of the land suitable for oil palm cultivation is in suitability class 3 out of 5, which corresponds to an average potential productivity level. With the exception of the coastal area, the biophysical conditions necessary for having a very high potential for oil palm cultivation are not met in the Cameroon. Notably in those regions where the dry season is longer than 2–3 months, the potential for oil palm cultivation is expected to be lowered.

From a climate-topography-soil perspective the Littoral, South and Centre regions are most favorable for oil palm cultivation. The regions of Adamawa, North and Far North are only marginally suitable and in part totally unsuitable for oil palm cultivation (Figure 23).

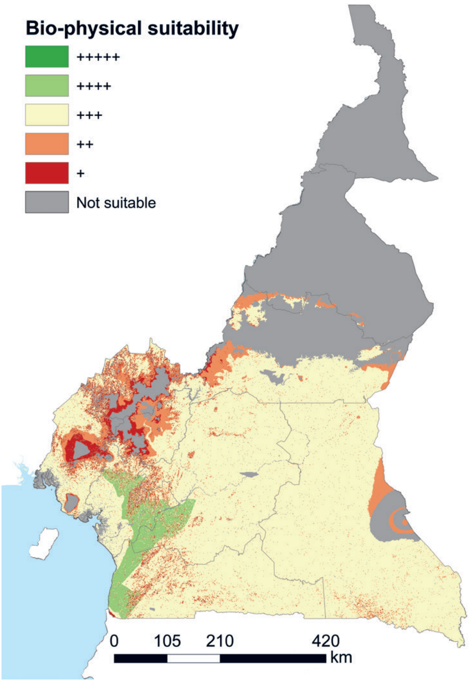

Figure 23. Map of biophysical potential of oil palm in Cameroon and in the Congo basin where green means very high potential, red corresponds to low potential and dark grey shows areas which are not suitable according to Pirker and Mosnier (2015).

4.4.2 Other crops

Crop-specific agricultural yields are estimated based on region-level average yields of national statistics in 2000, the base year of the model. For some crops and regions (indcated in red in the figure), regional yields were replaced by the average national yield as reported by the FAO (Figure 24).

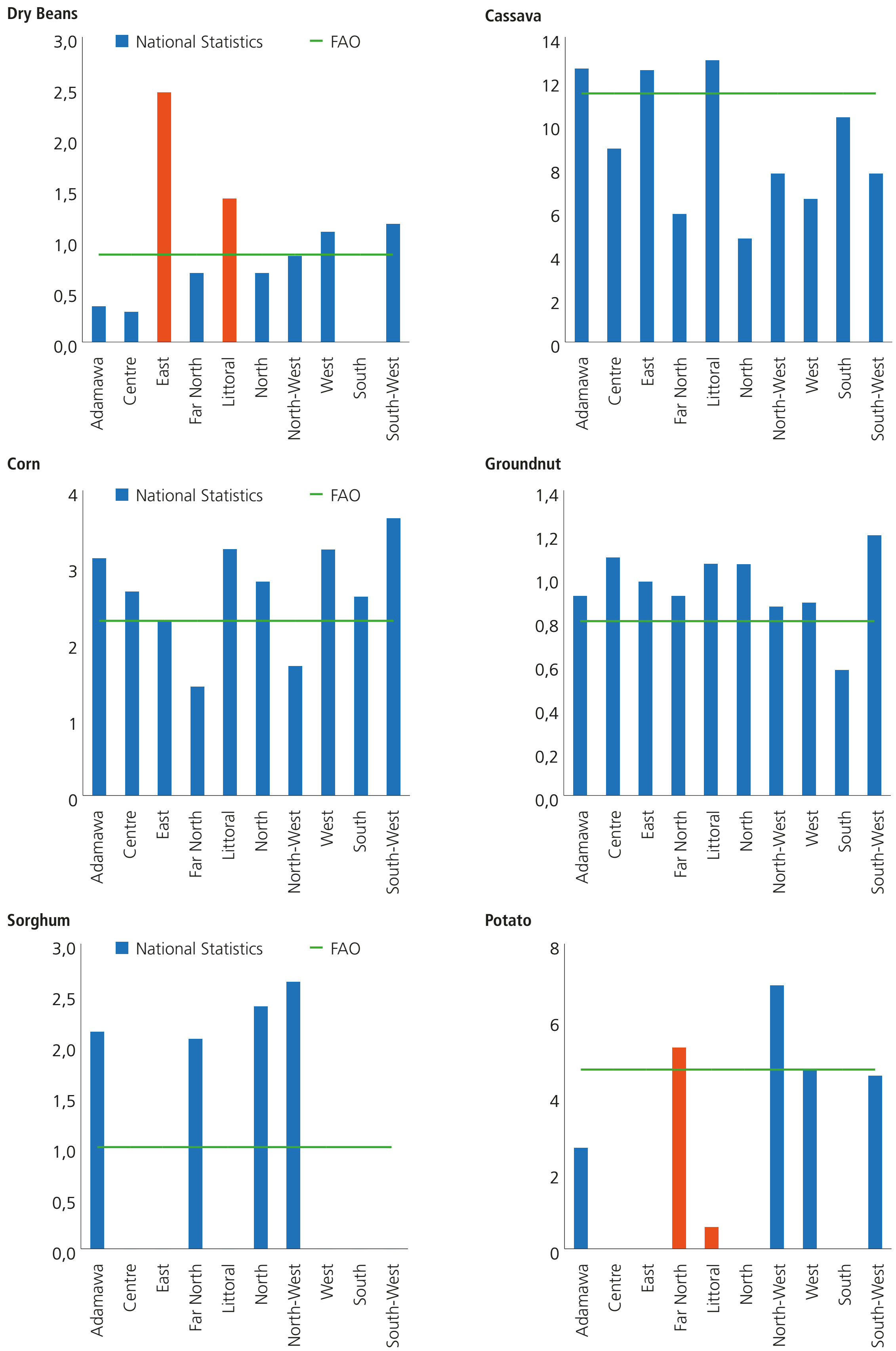

Figure 24. Yields (in tons/ha) for selected crops in the year 2000 per region (blue bars) and national average as reported by FAO (green line). (Source: Ministry of Agriculture; FAOStat)

4.5 Harmonisation of land cover and land use

4.5.1 Allocation of crop-land statistics to simulation units in the base year (2000)

Both cultivated and fallow areas are allocated to simulation units using a "cross-entropy" method where the maps on transportation costs to the nearest town, potential productivity and population density are used to det ermine the most likely location of the agricultural activities. Transport costs were calculated on the basis of existing infrastructure (Mosnier *et al.,* 2012) and productivity potential was estimated using the EPIC crop model, except for oil palm. Two additional constraints are important: 1) the sum of cultivated land per crop plus fallow remains less than or equal to the area of arable land of the original map in each simulation unit and 2) the amount of cultivated land in the simulation units must be equal to the initial area per administration. The actor-group specific cropland areas to be downscaled are presented in Table 25.

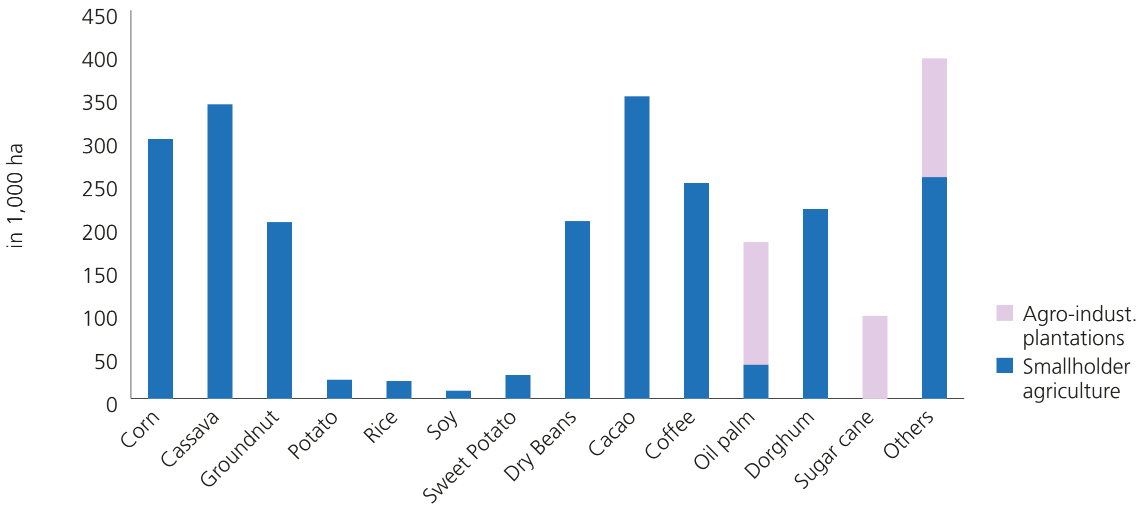

Figure 25. Area of agricultural land per crop in 2000 per actor group.

We obtain a total arable land area of 4.2 Mha in 2000 for Cameroon, of which one third is composed of fallow[10]. The difference between the agricultural land class of the original land cover map and the agricultural land thus calculated is 3.9 Mha which are consequently reassigned to the "other natural lands" class. The geographical distribution of thus calculated arable land remains very close to the original map, but with a more homogeneous distribution across the country (Figure 26 a). We particularly see on the map that in the majority of the simulation units the cultivated land area is in the range of 3 and 15 % the total area of the simulation units.

4.5.2 The Livestock Sector

Pasture areas[11] are derived from the numbers and type of ruminants and estimated grass productivity of pastures. Pasture productivity is estimated using the EPIC model taking into accound climate and other bio-physical conditions. Pasture areas are removed from the "Other natural lands" land cover class. According to these estimates pastures cover areas in the range of 500,000 ha in Cameroon (Figure 26 b).

10 For comparison, FAO reports 5.9 Mha of arable land and 1.2 Mha of perennial crops.

11 "Pasture" is defined as areas of grass vegetation which are regularly used for grazing to support animal husbandry as opposed to natural grasslands which are not used by animal husbandry.

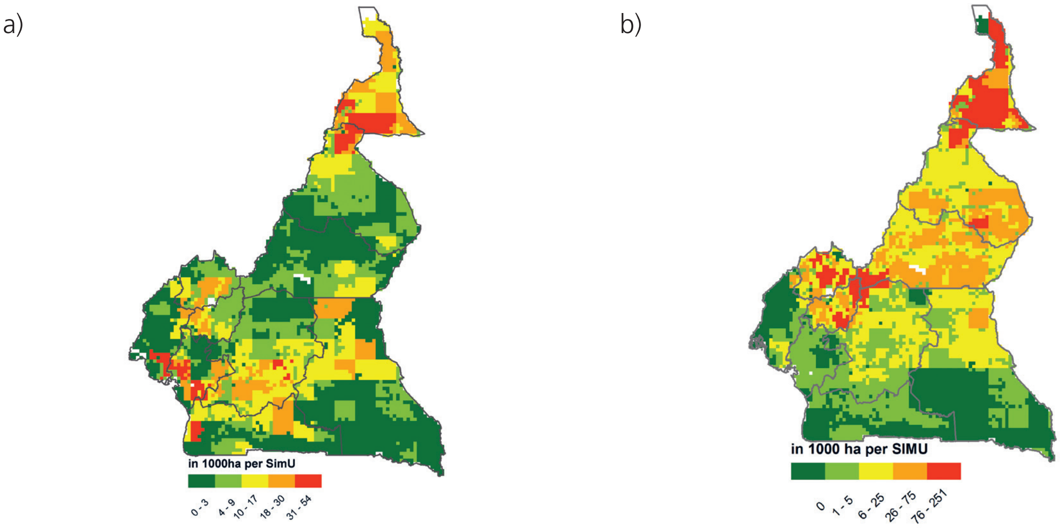

Figure 26. Maps of a) arable land and b) pasture area in the year 2000.

4.5.3 Final land cover distribution for the base year in the model

Based on the data and methodology described the previous chapters, the cover-land use map for Cameroon for the base year 2000 is estimated as presented in Table 3.

Table 3. Land cover and land use allocation in Cameroon in the year 2000 (in millions of hectares)

	Mha
Arable land	4.16
Unmanaged forests	9.93
Forest Concessions	6.37
Forests inside protected areas	3.75
Short rotation forest plantations	5
Pastures	0.5
Other natural lands	19.6
Other natural lands inside protected areas	1.18
Flooded areas	0.25
Not relevant	0.5
Total	**51.24**

5 Methodology for calculating GHG emmissions and impacts on biodiversity

5.1 Calculation of greenhouse gas emmissions

5.1.1 Greenhous gas emissions linked to land use change

The calculation of greenhouse gas emmissions (GHG) linked to land use change is based on the carbon balance for each land cover type. Estimates of carbon stored in the living forest biomass above and below the ground sourface based on estimates by Kindermann *et al.* (2008) information on forest biomass is available from a mixture of sources, including in-situ measurements, national forest inventories, administrative-level statistics, model outputs and regional satellite products. These data tend to be regional or national, based on different methodologies and not easily accessible. One of the few maps available is the Global Forest Resources Assessment (FRA are used per default in GLOBIOM. These estimates include an adjustment such that they correspond to the carbon inventory carried out by FAO's Global Forest Resources Assessment (FRA) for each country. For carbon stored in forest plantations (e.g. eucalypt, populus and pine plantations) the carbon stock is based on on estimates of the plantations' potential productivity. For carbon stocks in other natural lands the biomass map by Ruesch and Gibbs (2008) is used. Using this approach allows to introduce a variability in carbon stock both among land cover types and spatially explicit simulation units. CO_2 emissions (or sequestration) are calculated as the the difference between the carbon stock before and after a land use change. For example, for deforestation due to expanding crop-land remaining carbon is assumed to be zero, therefore the emissions equal the carbon stock contained in the biomass above (AGB) and below (BGB) the surface in a given fraction of a simulation unit. Other carbon pools than those in the living biomass are not taken into account such as dead wood, litter and the soil.

Given the importance of emissions calculations in the framework of REDD+ several alternative biomass maps were used and compared in calculating emissions from deforestation. Two maps assessing AGB across the tropics were added to the existing database of biomass maps: Baccini *et al.,* (2012) from the Wood Hole Research Center (WHRC) and Saatchi *et al., (*2011) from the NASA. Both use similar input data concerning tree height and canopy structure obtained from LiDAR but they use different spatial modelling methods and field data for the calibration of their models Mitchard *et al.,* (2013).These methodological differences result in differences in AGB estimates, in particular for the Congo Basin[12].The AGB estimates tend to converge at the national level but since emissions from deforestation strongly depend on the location of deforestation in a country, the choice of the one or the other map can significantly affect national emissions from deforestation.

The maps from the WHRC and NASA only account for above-ground biomass. We estimate the biomass living below the soil on the basis of the biomass living underground by taking into account the coefficients estimated by Mokany *et al.,* (2006): for the dense humid forests with more than 125 tC/ha, the median value of the biomass below the ground is 23.5 % of the AGB. For comparison purposes, the IPCC provides confidence intervall for the AGB-to-BGB-ratio of 6 % to 33 %.

12 The biomass maps can be compared on the Geo-Wiki platform: http://biomass.geo-wiki.org/

5.1.2 Emissions linked to forest degradation

We distinguish three types of activities leading to forest degradation in GLOBIOM: formal and informal logging for lumber production and the informal gathering of firewood. Formal logging is in the model only possible inside the previously identified forest concessions.

Several studies provide information concerning the direct impact of industrial logging on forest carbon stocks. According to Pearson *et al.,* (2014) who carried out measurements in a forest concession of the Sangha in the north of the Republic of the Congo in 2004, the average wood extraction rate was 9 m^3/ha. Total emissions related to logging are broken down into three factors: 0.25 tC/m^3 for the volume of wood extracted, 0.50 tC/m^3 for damage to the residual stand and logging waste and 0.24 tC/m^3 for emissions linked to infrastructure construction[13]. This amounts to 0.99 tonnes of carbon per m^3 extracted. Compared to emissions from logging in the five other tropical countries of their study, emissions from industrial logging concession in the Republic of the Congo are by far the lowest per unit extracted from wood. In terms of emissions per hectare exploited, the Republic of the Congo remains in the lower range of the sample of countries considered with 8.9 tonnes of carbon loss per hectare logged, but it is quite comparable with Brazil and Bolivia. A FAO study found very similar results in the logging site of the company "Industrie de Transformation des Bois de la Likouala" (LTBI) with 10.2 tonnes of carbon lost per hectare logged (Boundzanga & Bouta, 2003).

Durrieu de Madron *et al.* (2011) have calculated the impact of different logging practices on carbon stocks based on forest management data sourced from multiple concessions in the Congo Basin and from the relevant literature. They make the assumption that Reduced Impact Logging entails: i) the establishment of a "serie de protection" in which no removals occur, ii) an increase in the minimum diameters of harvestable trees, iii) a reduction of the areas occupied by wood hauling tracks and iv) a reduction of the surface needed for creating logging roads and log yards. According to their estimates, reduced impact logging (RIL) would reduce emissions by 9–10 % compared to conventional logging. The increase in minimum diameters for harvestable trees is the main source of emission reduction.

The emission factors used in this study are presented in the table below. The estimates provided by Pearson *et al.* are associated with the formal logging under the management plan. The emissions related to the conventional formal logging are calculated by increasing the emission factors for the damage caused by the logging of 10 % as recommended by Durrieu of Madron *et al.*

Table 4. Emission factors by impact specific per forest exploitation schemes Total emission factors and by type of impact for different types of forest logging

Forest exploitation scheme	tC in the extracted wood	tC for damages to the remaining stand	tC for damages linked to logging infrastructures	TOTAL EF in tC per m^3 of extracted wood
Formal exploitation under management plan	0.25	0.5	0.24	0.99
Formal conventional exploitation	0.25	0.50 x 1.1= 0.55	0.24 x 1.1 = 0.26	1.06

13 The central hypothesis of these calculations is that emissions all take place during the operation although in reality the collected wood can be used to produce goods that might store carbon for decades.

5.1.3 Emissions from agriculture

Emissions linked to agriculture include the emissions linked to livestock and the emissions linked to the cultivation of crops. The emissions linked to livestock are methane (CH_4) which is emitted through enteric fermentation (during the ruminants' digestion) and nitrogen (N_2O) from manure. Accounting of emissions corresponds to the IPCC's Tier 2 approach as it is specific per livestock species, production system and production region (Herrero *et al.,* 2013; van Wijk *et al.,* 2014). For crops, the emission sources that are considered are nitrogen (N_2O) from the application of chemical and organic fertilizers, and methane (CH_4) from paddy rice cropping.

5.2 Assessment of impacts on biodiversity

One of the objectives of the REDD-PAC analysis is to assess the links between land use policies and their potential impacts on biodiversity, ecosystem services, and the achievement of the Aichi Biodiversity Targets. Land use change is one of the main determinants for biodiversity loss globally. The conversion of natural ecosystems can cause the destruction of the biodiversity which they contain and the ecosystem services which they provide, and results in a loss or fragmentation of species habitats. These impacts depend on the location, the total area, and the type of land use following the conversion of initial land cover.

In this section, we present the methods used in assessing impacts on biodiversity in more detail. Depending on the aspect considered, many variables are potentially relevant for assessing the impacts on biodiversity and the spatial planning of the implementation of the Aichi Targets. Information about potential land use changes and deforestation can be used to target certain areas to combat the decline in natural habitats (Aichi Target 5). Overlaying information about the spatial distribution of biodiversity, ecosystem services and sustainable use of biodiversity with information on land use can inform action planning in support of the Aichi Targets 12 and 14 (avoidance of the extinction of endangered species and safeguarding and restoring the services provided by ecosystems)[14]. The lack of data available in the Congo Basin region is a commonly known problem; however, several relevant data sets have been identified during this project.

14 Aichi Target 12: "By 2020 the extinction of known threatened species has been prevented and their conservation status, particularly for those that are most in decline, has been improved and sustained. "
Aichi Target 14 "By 2020, ecosystems that provide essential services, particularly water and contribute to health, livelihoods and well-being, are restored and safeguarded, taking into account the needs of women, indigenous and local communities, and the poor and vulnerable. "

5.2.1 Impact on ecosystems

The territory of Cameroon is composed of a number of eco-regions with unique ecological characteristics. Using this information, the impact of changes in land use on eco-regions can be evaluated and thereby, a first assessment of impacts on different components of biodiversity can be performed. Within the framework of this study we use the eco-regions identified by WWF presented in Figure 27 (Olson *et al.,* 2001).

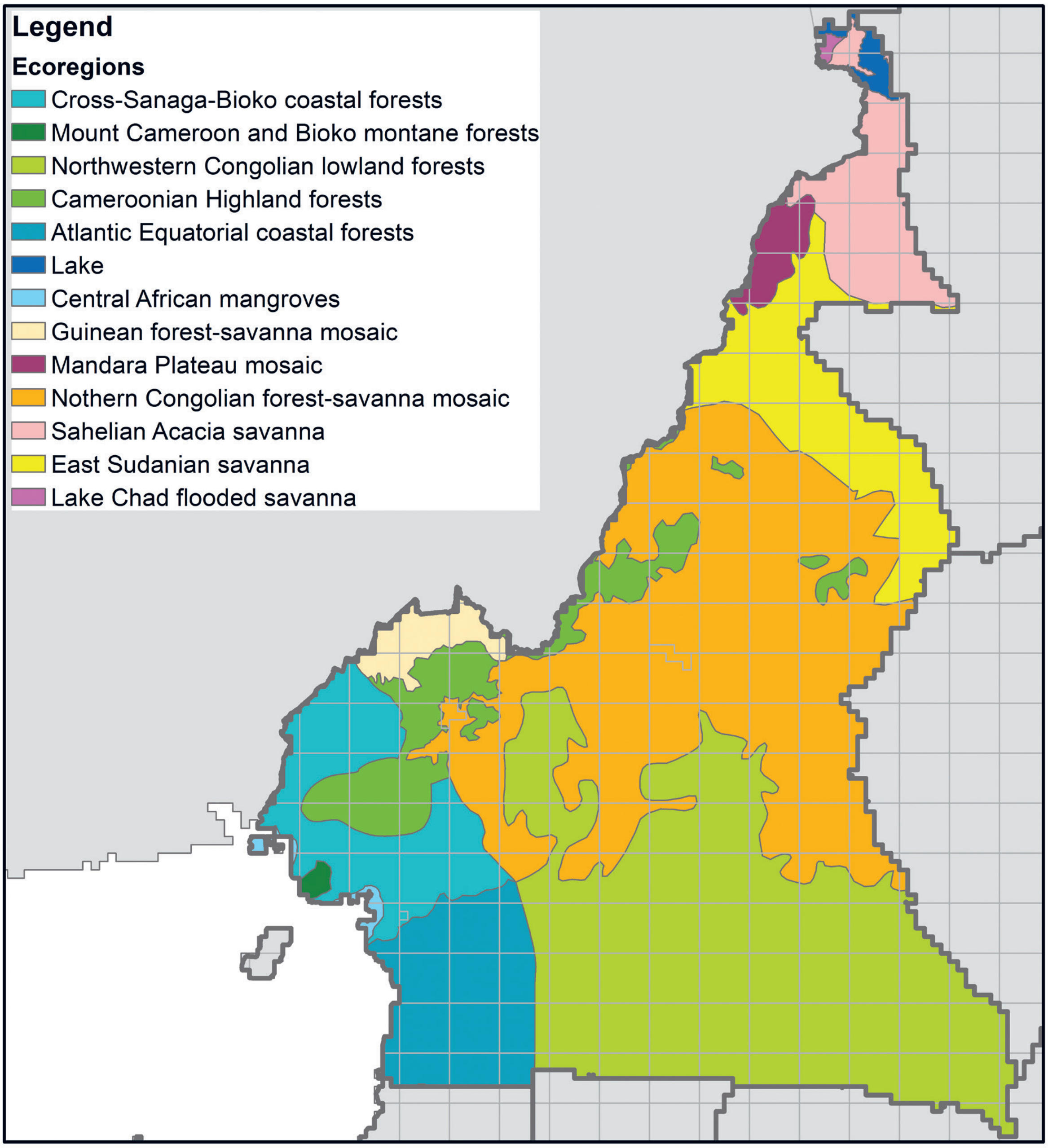

Figure 27. Map of the ecoregions of Cameroon (Source: Olson *et al.*, 2001)

5.2.2 Impact on species

The loss of natural vegetation (including forests and other natural vegetation types) has an impact on the species present within these areas and the potential values they can provide. A range of different species and groups of species may be of interest, for example because of the special benefits they can provide, or because of specific policy objectives or both. For example, Cameroon is home to two endangered species of great apes, which have the potential to support the development of ecotourism activities, a key ecosystem service. Cameroon is also a signatory to the Kinshasa Declaration on protecting Great Apes dating from the year 2005.

The distribution of species richness may differ depending on the species group concerned and thus the selection of species of particular interest can influence the findings of the evaluations. The assessment of impacts in relation to all species potentially present would enable a comprehensive assessment to be made of the impact on species diversity. However, it is impossible to obtain data on the precise location or habitat requirements for all species, and moreover, many species are yet to be discovered (Pimm *et al.,* 2010).

Assessing the impact on endangered species is relevant to the Aichi Target 12 (prevention of species extinction). It is also important that the groups of species analysesd are those considered to be most relevant on the national level, so that the spatial analysis can inform decision making and policy development. At the regional level, the COMIFAC Convergence Plan takes up the targets of the CBD and puts the focus on enhancement of the effectiveness of protected areas and conservation of large mammals. Some of these large mammals are also the subject of special attention through additional regional instruments such as the Kinshasa Declaration on the Protection of the Great Apes or the various action plans for the prohibition of trade in ivory and poaching of forest elephants which has been on the rise in recent years (Nellemann *et al.,* 2014). At the national level, it is possible to refer to the legislation in order to identify which species are partially or fully protected.

Therefore, the REDD-PAC project focuses on assessing the impacts on great apes and species identified as endangered by the International Union for Conservation of Nature (IUCN) species whose protection was identified as sub-regional and national policy priority. The impacts are also assessed for species protected by law, and for all species for which information was available concerning their potential distribution. In the absence of national data on potential distribution of species, the project used data collected by IUCN for most mammals, birds and amphibians in the context of the global assessment for the Red List[15]. Mammals, birds and amphibians are the groups for which the IUCN data is the most comprehensive.

To assess the individual impact of land use change on species, one of the first factors to consider is the habitat needs for the different species, which determines the likely impacts of changes in land use. For example, for species that depend on forests, deforestation will probably lead to the local extinction of these species in the cleared area, whereas it will probably have a lesser impact on species can also survive on pasture. The species habitat requirements are also included in the database of the IUCN Red List. The impact on individual species can be measured by calculating the percentage of potential habitat that would be lost according to the model projections. On this basis, it is possible to assess the combined impact of land use change for a given group of species by adding the individual impacts on species of this group.

In order to understand the spatial distribution of the relative impact of land use change on species, an aggregate index was developed; the index is higher the greater the area of habitat loss, the more this

15 See http://www.iucnredlist.org/

habitat is shared by many species, and the more this represents a large proportion of a species' habitat in the country (endemism level). Figure 28 presents the methodology used to calculate this composite index of "combined species habitat change":

a. **We start from maps of species range.**
b. **We calculate the habitat distribution for each species taking into account their degree of endemism in each cell (i.e. calculating the proportion of the potential area cell represents and so giving a higher score to species with small range, shown here in darker grey).**
c. **We use future land use projection calculated by the GLOBIOM model, which shows where potentially suitable vegetation for each species is destroyed.**

d. **Combing the species range data and land use change data we calculate where each species loses (or wins) potential habitat and the proportion of their habitat it represents (represented here by various shades of red)**
e. **The sum is made of the loss (or gain) in potential habitat for all species.**

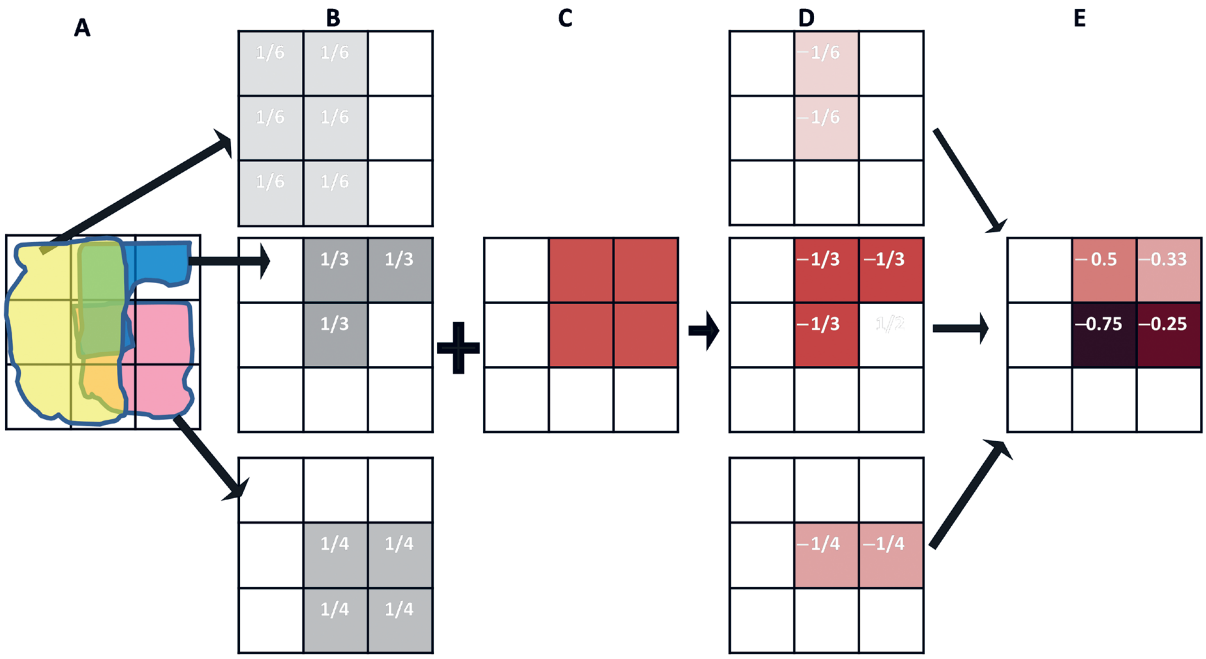

Figure 28. Method of calculation of the composite index of combined species habitat change.

5.2.3 Impact on non-timber forest products

Forest are not only important for the intrinsic value of the biodiversity that they harbor bus also for the services that they offer to local people and more generally to the economy of countries with a high forest cover like Cameroon.For example, non-timber forest products (NTFP's), fuel wood or construction wood contribute significantly to local subsistence and national economies in the Congo Basin (Ingram, 2012). Recent studies confirm the importance of the revenues that local populations obtain from forest products (Angelsen *et al.,* 2014). However, data on ecosystem services in general and data to quantify the spatial variation of NTFP's in particular are very scarce in the region.

Recent information could be identified for certain species such as *Prunus africana* ("Red stinkwood"), a tree whose bark is widely used as a medicinal plant and whose likely distribution range is known (Vinceti *et al.,* 2013). In an ideal case, the identification of priority zones for NTFP's should be complemented by information about the actual use of these resources by local populations. However, combining information about suitable areas for harvesting *Prunus africana* products with information about the likely location of future forest cover loss allows to determine the scale of the impact of different scenarios on the potential provision of the ecosystem service and the zones where forest cover loss might exercise the biggest influence on the provision of these services.

Information on *Prunus africana* is available in terms of the probability that the species might be found in different zones. This information is detailed into areas where it is *highly probable* that *P. africana* is present (probability of presence >50 %) and zones where it is possible to find the species (probability from 50 to 13 %). Given the fact that GLOBIOM runs at a spatial resolution of 30' x 30' (ca. 50 x 50 km) as described in previous sections, a number of hypotheses must be made to fusion both datasets, *P. africana* potential distribution ranges and GLOBIOM outputs. Taking the example of a simulation unit which is fully overed by forest and where *P. africana* can potentially occur on 50 % of the area. If the model predicts a loss of 25 % forest cover, it is necessary to know whether this land cover change occurs inside or outside of the potential distribution range of *P. africana,* which a priori is not possible, i.e. it is not known where a change occurs inside a simulation unit. To that end, we assume that the land cover changes are distributed uniformly over the simulation unit, independent from the likely distribution of *P. africana.*

6 Description of the scenarios

The time frame chosen for this study is 2030. To explore the change of deforestation in the future, we first present the population and GDP projections that are used to determine the demand for the different products that are represented in the model. Then we present the specific assumptions to changes in the use of bio-energy and particularly wood energy. This baseline scenario (BAU) can be seen as what would happen with moderate growth of global population and wealth and in the absence of new government policies in Cameroon (Figure 29).

BAU	Other Scenarios		
	Socio-economic context in Cameroon	**Permanent forest domain**	**Agricultural Development**
Macro ▪ 28.7 million inhabitants in 2030 ▪ GDP: $ 53.8 billions in 2030 **Permanent forest domain** ▪ No expansion of agriculture into protected areas ▪ No expansion of agriculture into forest concessions **Agriculture** ▪ No increase of agricultural yields	**Macro +** + 2.4million inhabitants in 2030 + $ 3.3 billions of GDP in 2030	**NoPA** Expansion of agriculture into protected areas possible	**Yields +** Increase of future agricultural yields
	Macro – – 2 million inhabitants – $ 9.5 billions of GDP in 2030	**NoFC** Expansion of agriculture into forest concessions possible	**Palm +** Objective of 250,000 ha of oil palm in Congo-Brazzaville and 300,000 ha in Cameroon in 2030
		PA + Protection and expansion of protected areas to 17 % of territory	

Figure 29. The base scenario hypotheses are presented to the left whereas the changes introduced in each scenario are described on the right (one scenario for each white box)

6.1 Socio-economic context

Changes in population and GDP trends depend on factors that are not represented in the model. Future population depends on birth rates, death rates and migration, and policies can have impacts on all three. For example, they can encourage the birth rate to rise through subsidies or curb it through penalties, as was done, for example, through the one-child policy in China. Most population projections reach far into the future and the uncertainty associated with them is large. For GDP, the uncertainty is even greater because it depends on the evolution of a complex set of factors that are not all under the control country, but also may be influenced by its neighbours.

As part of the preparation for the fifth assessment report of the Intergovernmental Panel on Climate Change (IPCC), an international group of sociologists and economists developed scenarios with various socio-economic developments characteristics and adaptation and mitigation strategies for climate change.

Five families of scenarios, called the SSP's (Shared Socio-economic Pathways), were defined (Figure 30)[16]. For each scenario, population and GDP projections were carried out for each country, resulting in different average per capita levels of GDP.

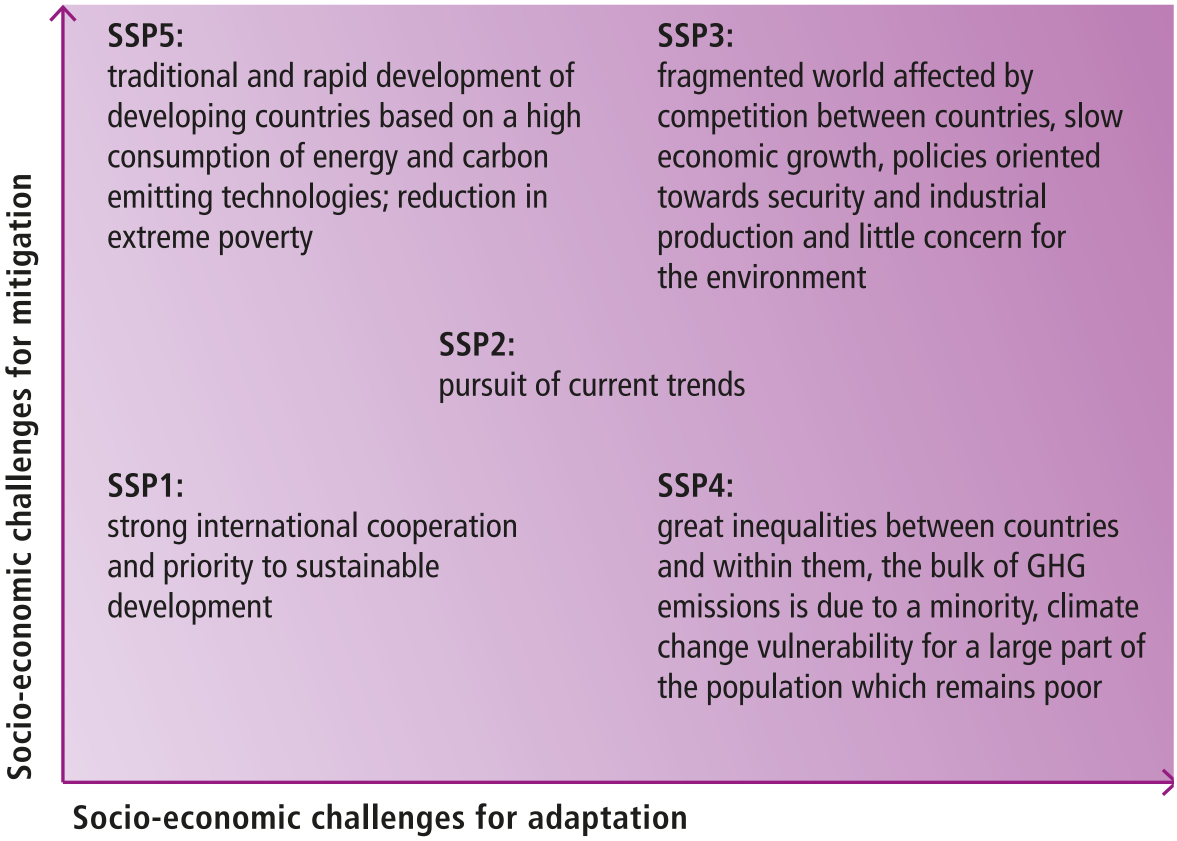

Figure 30. Socio-economic development trajectories prepared within the framework of the IPCC (O'Neill *et al.*, 2013)

In the baseline scenario, we use the SSP2 scenario that reflects "the continuation of past trends". The SSP2 is considered an intermediate scenario with a moderate growth in GDP and populations worldwide: Under this scenario, world population will increase by 20 % and average per capita GDP should increase by 50 % by 2030. We note, however, that the anticipated socio-economic change for Cameroon in the SSP2 is generally much greater than the world average: By 2030 Cameroon's population is expected to almost double and GDP is expected to be four timed higher compared to the year 2000.

"Macro–" and "Macro+"scenarios: As alternative scenarios to explore the role of the population and of the economic context of future deforestation, we test two scenarios that combine different SSPs scenarios. These scenarios were desired by participants at the sub-regional workshop on the presentation of the project results in Douala in September 2015. "Macro +" is the combination of the most optimistic GDP projection (SSP1, +) and the highest population projection (SSP3) while "Macro-" is the combination, from the first three SSPs, of the most pessimistic GDP projection (SSP3) and the lowest population projection (SSP1). Both scenarios lead to average nominal GDP projection in 2030 for Cameroon of 2,000 and 1,700 USD$ per capita, respectively. These alternative scenarios will influence future deforestation through changing food consumption and demand for lumber and and fuel wood (see section 3.4.1; Valin *et al.*, 2014).

16 This work was done in parallel and is consistent with current knowledge of future climate conditions and the impacts of climate change on different scenarios regarding changes in concentrations of greenhouse gases (GHG), ozone and aerosol precursors for the twenty-first century worldwide.

The diet plan in Cameroon is mainly based on the consumption of tubers and cereals. This is similar to other Central African countries but it is not so common in other parts of the world. The average consumption of meat and dairy products is very low in Cameroon and although the anticipated increase is relatively large, meat and dairy products will continue to represent a small part of the daily intake of calories in 2030 only. The average per capita consumption of eggs, beans, cereals, oil and sugar is generally expected to rise sharply in the coming decades, and this is especially true under the SSP1 scenario where the average level of GDP per capita is high.

The majority of rural households in Cameroon as in other African countries run agricultural production mainly to satisfy their own consumption. Therefore, a constraint was introduced in the model in order to represent this phenomenon: for each region the local production of tubers and cereals must be sufficiently high to satisf the food needs of the local populations. Surplus production can be used to supply the capitals Yaoundé and Douala or they might be exported to other countries.

6.2 The permanent forest areas

Per default, conversion of forests to other uses is not possible in protected areas and forest concessions. In fact, the permanent forest area ("Le domaine forestier permanent" in French) encompassess a wider range of forest types such as communal forests but in our simulation these do not benefit from the same protection status and can be converted to other land uses.

6.2.1 Alternative scenarios for protected areas

Owing to a lack of financial means, numerous protected areas in Cameroon are currently not fully effective and we therefore developed scenarios to simulate changes in the protected areas regime.

"No PA" Scenario: We explore the consequences of non-compliance with protected areas on deforestation. This is an extreme situation that does not reflect reality but this scenario can help us identify: 1) the protected areas that may be threatened by the expansion of agriculture in the coming decades and where enhanced protection could be considered and 2) the potential contribution of protected areas in the fight against deforestation.

Two scenarios have been developed to to explore the potential impact of an expansion of the area of protected areas to 17 % of the national territory. Although the main objective of protected areas is the conservation of biodiversity, their location coula also depend from other associated ecosystemic benefits, including the reduction of greenhouse gas emissions.

Decisions concerning the location of new protected areas are likely to take into account many other criteria including the representativeness of protected areas and their connectivity, opportunity and implementation costs as well as the consent of local peoples. However, these simplified scenarios can illustrate the potential impacts of protected areas and the trade-offs that exist in the pursuit of several objectives (carbon and biodiversity) through the implementation of a policy (the expansion of the protected areas).

"PA+ Biod" Scenario: the new protected areas are located in areas that are subjected to the highest biodiversity loss threats in the two decades according to the 2030 baseline scenario (as calculated by the "combined species habitat change " composite index, see section 5.2.2) and in the eco-regions that are currently under-represented in the protected areas existing network.

"PA+ Carb" Scenario: new protected areas are located in areas that have the highest emissions in the baseline scenario by 2030.

6.2.2 Forest concessions

In the past forest concessionaires only interested in short term gains left the concessions before the end of the recommended rotation time after having intensively logged their concession for a few years. The fate of forests in these retroceded concessions may be particularly fragile, especially with a possible conversion of forest concession titles to agricultural concession in logged-over concessions. With the obligation to submitting long-term management for forest concessions, this risk should now be lower; however, the appropriate management of forest concessions is costly and challenges their long-term profitability.

"No FC" scenario: In this scenario, we assume the change of the legal status of existing forest concessions from the permanent to the non-permanent forest area, resulting in a possible conversion of all these forests to other uses after 2010. Obviously this is an extreme scenario that is not realistic. However, there is a risk of certain forest concessions being returned in the Republic of the Congo. Moreover, this scenario allows us to quantify the role of forest concessions in the fight against deforestation in addition to their economic role.

6.3 Agricultural developement

6.3.1 Evolution of agricultural yields

By default in the model, changes in agricultural yields (in tonnes per hectare) are linked to the change in GDP (see section 6.1.1): It is assumed that greater economic growth allows greater technological progress, resulting in higher yields (Valin *et al.,* 2010). However, in the absence of reliable statistics on changes in agricultural yields in the Congo, the feeling is rather that there is a stagnation in agricultural yields because of low investment in agriculture over the last decade (FAO Statistics Division, 2015).

Thus, in the baseline case, we assume that there is no technical progress allowing for an exogenous improvement to yields in Cameroon in the coming decades, that is to say that the only possibility to increase crop yields in the model is through the use of fertilizers, which are expensive.

YIELD+ scenario: To simulate the expected modernisation of the agricultural sector we use an alternative hypothesis which is a diffusion of technical progress with the distribution of improved seeds, for example, which results in an increase in annual fixed yields (Table 5).

Table 5. Development of agricultural yields in the YIELD+ scenario

	Yield growth over the period 2011–2030
Beans	12 %
Cassava	26 %
Corn	41 %
Cotton	74 %
Ground nuts	34 %
Millet	113 %
Oil Palm	12 %
Potatoes	33 %
Rice	18 %
Soy	34 %
Sorghum	48 %
Sugar cane	65 %
Sweet potatoe	8 %
Wheat	20 %

6.3.2 Oil palm planting objectives

Cameroon is the biggest palm oil producer in the subregions. The production comes from both smallholder farmers and agro-industries. Agro-industries contribute about 80 % of the national production brought to the formal market and their plantations cover close to 60,000 ha which are mainly located in the regions Littoral and South-West. However, the national demand for palm oil remains unsatisfied: Annual palm oil production in Cameroon ranges between 235,000 and 270,000 tons whereas the national demand is officially estimated at 385,000 tons. For the moment the deficit is covered by imports mainly from Asia but the government of Cameroon has ambitious targets to end the imports of palm oil to satisfy the national demand. Against this backdrop, the strategic document for the development of the rural sector sets out a production target of 450,000 tons of palm oil for the year 2020, corresponding to an area of 250,000 ha.

PALM+ Scenario: In this scenario the model is set to reach an oil palm planting area of 300,000 ha in 2030. In the model this objective is formulated on the national level, meaning that the model allocates plantations to certain departments with the objective of maximizing the expected profit under consideration of land suitability and availability.

7 Validation of the model for the period 2000–2010

The base year of the GLOBIOM model is 2000 and the model provides estimates for each subsequent 10-year period. The first period for which GLOBIOM provides estimates is 2010. More and more statistics are now available for 2010 both for estimates of deforestation and changes in production or cultivated areas. First, we compare the historical deforestation in Cameroon according to the different sources available and we compare our results with the observations to see if the model is able to satisfactorily reproduce the trends in 2000–2010.

7.1 Comparison of historical deforestation according to different sources

Three historical forest cover change maps issued from remote sensing studies were found useful for Cameroon: The Hansen map of tree loss (covering the period 2001–2010), the land use change map of GAF (2000–2010) and the Airbus map (1990–2010). Hansen covers the full territory, AIRBUS covers the regions Adamawa, South-West, North-West, West, East, South and Littoral whereas the GAF map is limited to the Centre region. Given that the North and Far North regions harbor little forest, the combination of the Airbus and GAF maps allow to monitor deforestation at the national scale.

Hansen reports historical deforestation in Cameroon from 2001–2010 to be 352,000 ha whereas AIRBUS-GAF estimate 422,000 ha over the period 2000–2010. GLOBIOM simulations yield an estimate of 582,000 ha, meaning that the model tends to overestimate historical deforestation in Cameroon.

In terms of spatial distribution of the modelled deforestation, the Center region is the deforestation hotspot whereas due to the scarcity of forests in the northern half of the country, deforestation is low in the regions North and Far North. For the regions Adamawa, Center, Littoral, South and South-West the modelled area of deforestation is close to the one observed by the remote sensing products. In the regions East, West and North-West, however, the model clearly overshoots observed deforestation (Figure 31).

Deforestation is causes by an expansion of agricultural land in the model. Hence, if we overestimate historical deforestation in Cameroon, this means that we overestimate the expansion of agricultural lands compared to what happened in reality or that this expansion of agricultural land took place in non-forested areas, rather, such as savannah's. The next section will be dedicated to tracing these uncertainties.

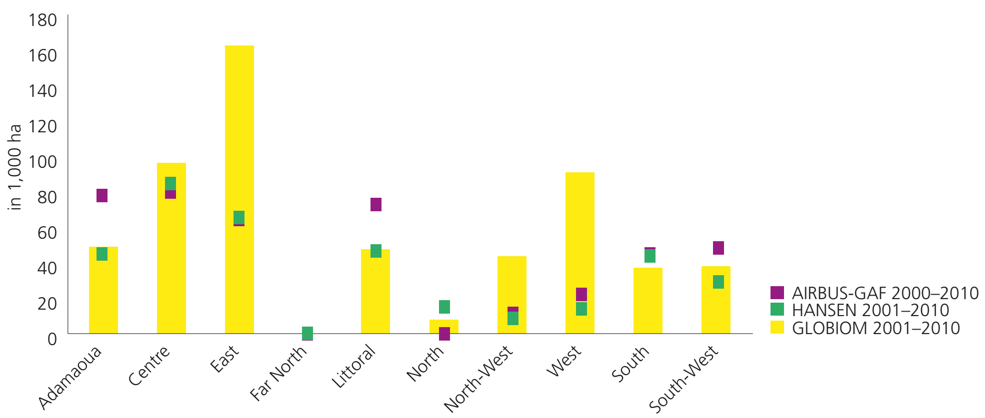

Figure 31. Comparison of GLOBIOM modelled deforestation over the period 2001–2010 and remotely sensed deforestation according to Hansen and AIRBUS-GAF.

7.2 Evolution of crop-land area

According to our results the cultivated area evolves from 2.7 Mha in 2000 to 3.1. Mha in 2010, corresponding to an increass of 14 %. Yet, the FAO reports a much stronger increase of cultivated area from 2.6 Mha to 4.5 Mha or 71 % over the period 2000–2010. As shown in Figure 32, the differences are particularly strong for four crops: sorghum, corn, cocoa and rice.

According to national statistiques, the expansion of sorghum acreage is even stronger than the FAO estimates would suggest, with an increase of more than one Mha of agricultural land in the period 2000–2010. Since sorghum is mainly cropped in the regions North and Far North, it is not surprising to see that the biggest differences between model estimations and statistiques appear for these two regions. This should, however, not have a strong impact on deforestation results since due to the scarcity of forests in these aride regions deforestation remains low.

Comparing cultivated areas estimated by the model with national statistiques in terms of both cultivated areas and production, a tendency to underestimate cultivated areas for some crops becomes apparent. This is particularly true for the crops corn, Sorghum and cocoa (Section 7.1, Figure 32).

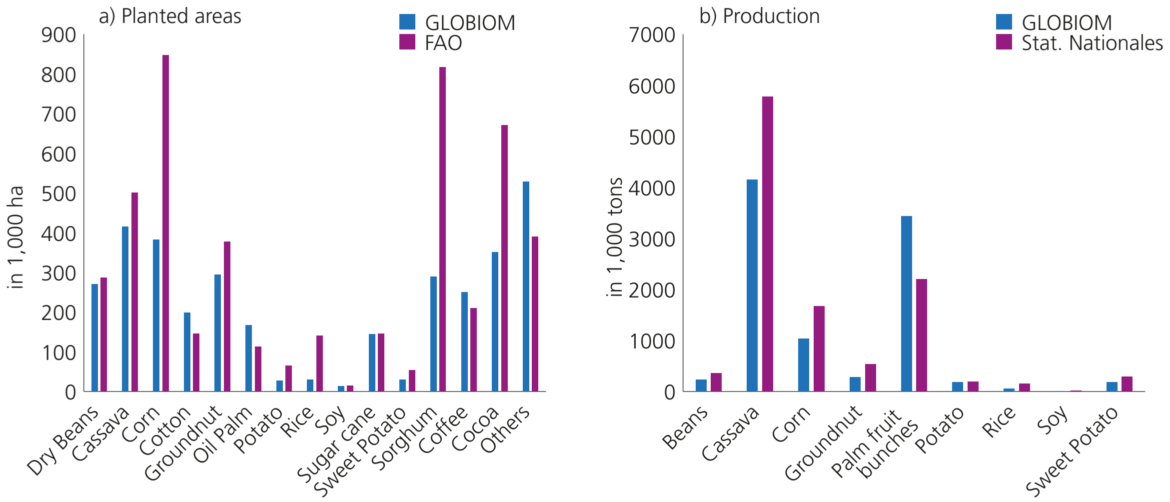

Figure 32. Comparison between model estimates (blue bar) and agricultural statistics in terms of cultivated areas (a) and agricultural production (b) for the year 2010.

Confronting agricultural statistiques with historical deforestation obersved by Airbus and GAF reveals that country-wide less than 20 % of the expansion of agricultural areas came at the expense of forests. Even taking into account the variability between the regions, it is surprising that that in the regions Center and East only 30 % of the expansion of agricultural lands replaced forests. Moreover, taking into account agricultural fallows, the gap between the need for new land for agriculture and the observed reductions of forests widens even further.

One possible explication is an error in agricultural statistiques owing to erroneous assessment of agricultural lands, where harvested area is reported rather than planted area. Since several zones in Cameroon enjoy a hot and humid climate throughout the year, allowing for several harvests per year and thus resulting in harvested areas exceeding planted areas. In that case, the agricultural areas reported by the statistiques need to be divided by the number of harvests occurring on these per year to surfaces in order to obtain corrected estimates for agricultural areas.

Another possible source of error is the definition of agricultural land in the Airbus/GAF analysis. According to the FAO, there were about 7 Mha of arable lands in the year 2000, including agriculture areas (both crops and pasture) and fallow land. According to the Airbus-GAF study, however, less than one Mha are classified as agricultural lands in 2010. While true that the regions North and Far North are not covered by this study, the absence of these two regions alone does not explain the difference of 6 Mha. Another explication for the considerably lower estimates of agirultural lands in the remote sensing products which should be verified with the authors of the Airbus-GAF study is the omission of agricultural fallows and/or the omission of agricultural lands with a field size smaller than 0.5 ha which are common in Cameroon (Gillet *et al.* 2016).

The duration of fallow is one parameter which lacks data to assess the validity of our estimates. According to our results fallow areas represent 43 % of the total agricultural land, meaning that for an expansion of agricultural land by 682,000 ha between 2000 and 2010, fallow area increased by 291,000 ha.

According to national statistiques the expansion of corn was very significative in all the regions of Cameroon in the period 2000–2010 (Figure 33). This dynamic has not been well captured by the model and we try to elucidate the reasons for this in the next sections.

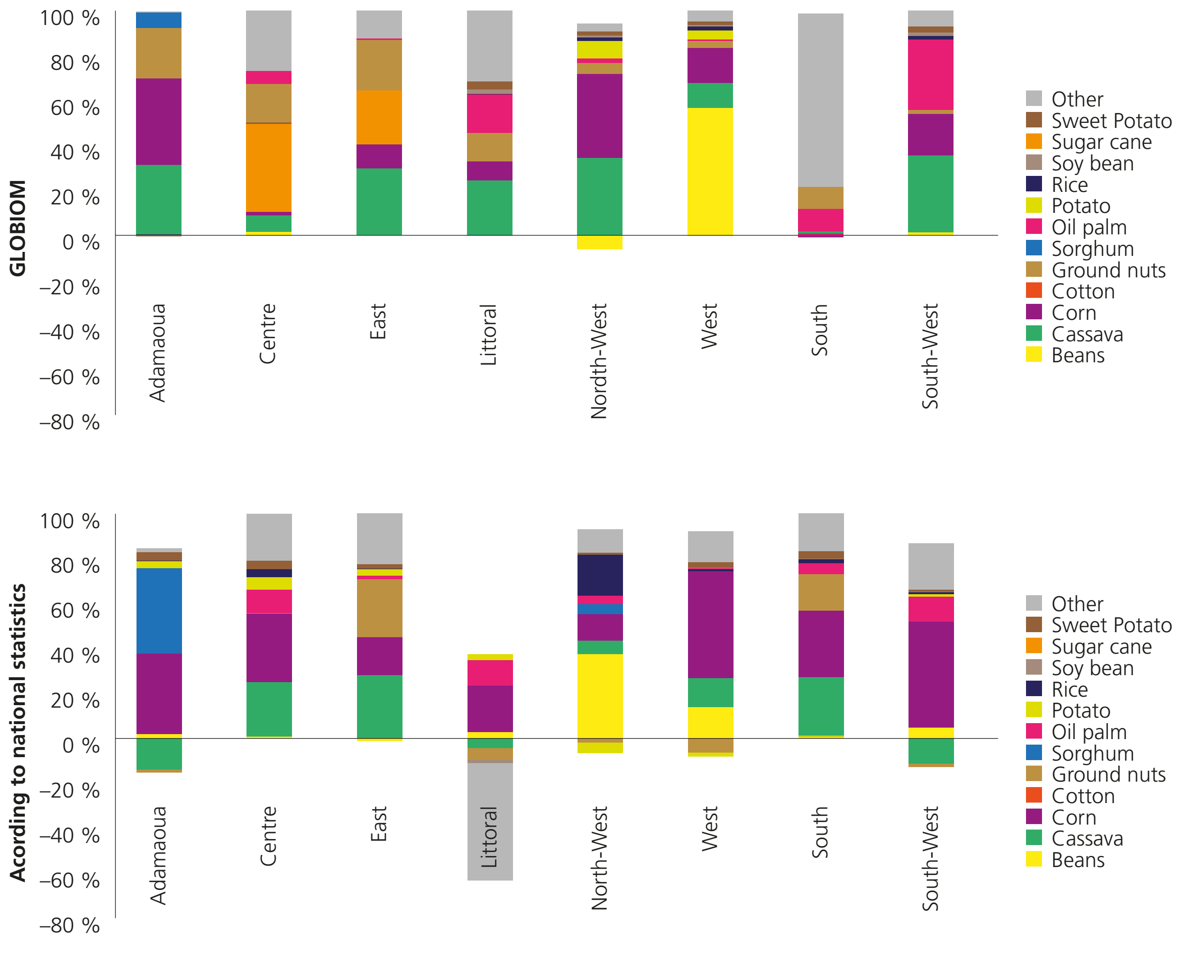

Figure 33. Comparison of the share of different crops in the total expansion of agricultural land per region in the period 2000–2010 according to GLOBIOM and agricultural statistics.

7.3 Evolution of production and consumption of agricultural products

As shown in Figure 34, for most products the model tends to underestimate the increase in consumption in the period 2000–2010 in Cameroon; this fact might explain the underestimation of the production and the associated expansion of respective crops area. There are only three crops for which the model overestimates the increase in demand: corn, palm oil and sugar cane. For sugar cane and oil palm the demand projections in global clearly need a revision. At the same time it is surprising that according to FAO statistiques there has not been an increase of sugar consumption in Cameroon during the last decade despite the significant population growth and urbanization trends. As described in the last section, the model underestimates largely the expansion of cultivated areas for corn and sorghum. By contrast, the estimates for the increase in food consumption are not very far from those provided by the FAO.

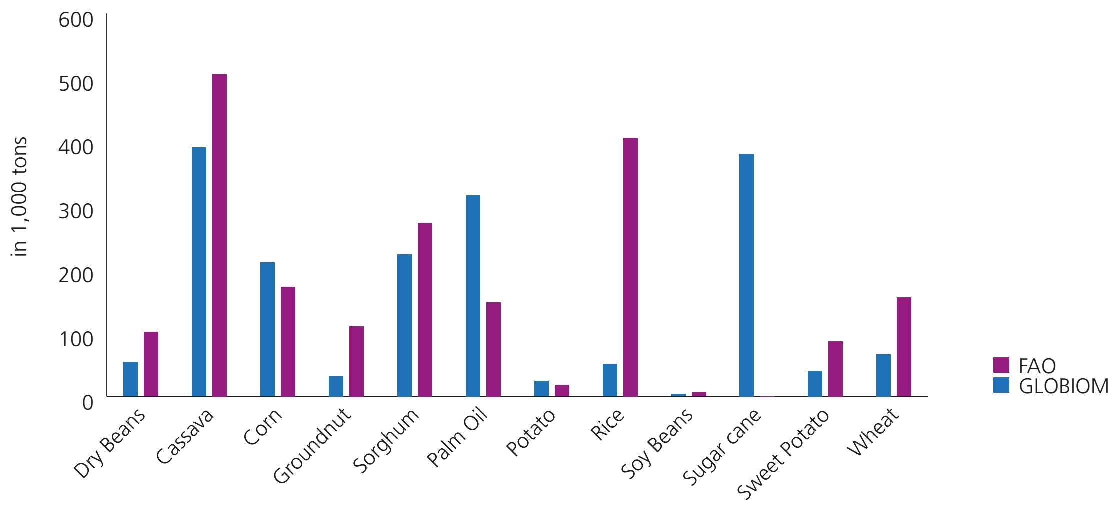

Figure 34. Differences between 2000 and 2010 in terms of consumed quantities per product in Cameroon according to GLOBIOM (blue bars) and FAO (purple bars).

Human food consumption is not the only possible use of the agricultural production, it can also serve for feeding livestock of being exported to foreign markets. It appears that a strong increase of the use of corn and sorghum for animal feed occurred (Figure 35), in particular for raising chicken. Whereas the consumption of sheep meat and beef only increased by 14 % over the period 2000–2010, the consumption of chicken almost doubled (+92 %) and pork consumption more than doubled (+120 %). Since imports of mostly frozen chicken decreased in the same time, the increase in consumption of chicken and pork must have translated to a strong increase of local production though the development of chicken and pork farming in Cameroon, presumably with major impacts on agricultural areas and eventually land use change in Cameroon. At current, the model does not well reproduce these dynamics. Improvements in the representation of the livestock sector in Cameroon will be the focus of a future study.

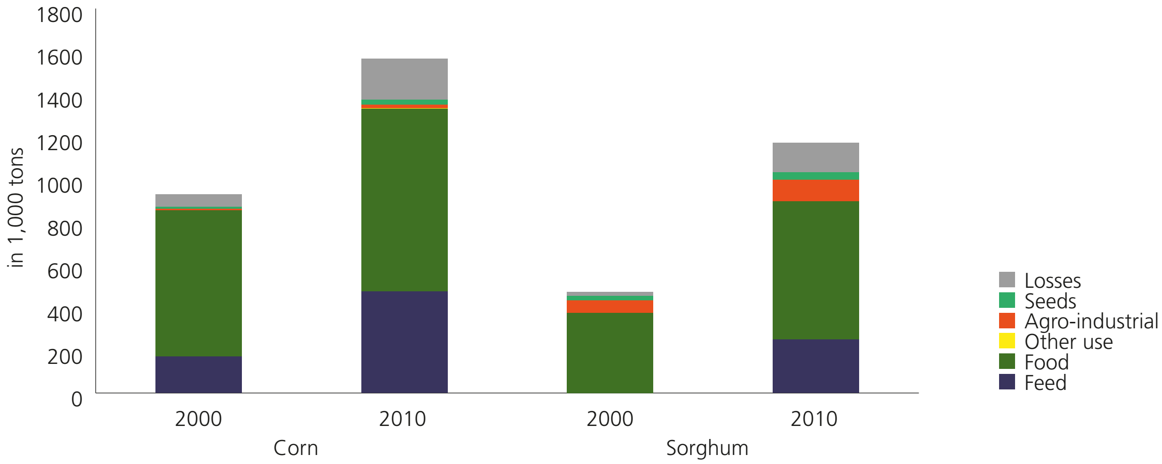

Figure 35. Evolution of corn and sorghum use between 2000 and 2010 by sector according to the FAO.

8 Model projections for the period 2010–2030 in the base scenario

8.1 Deforestation and other land use changes

In the base scenario deforestation evolves from 582,000 ha in the period 2001–2010 to 1.1 Mha in the period 2021–2030, corresponding to an increase by 94 %. Deforestation is mainly caused by the expansion of agricultural land and to a smaller extent by the expansion of pasture. The model also projects a strong increase of the conversion of other natural lands to agricultural land: about half of the expansion of agricultural land took place in savannah's in the period 2021–2030 (Figure 36).

Figure 36. Conversion or expansion of different land uses for each simulation period.

More in detail, we estimate that 64 % of the projected deforestation between 2011 and 2030 comes from the expansion of cassava and ground nut and their associated fallows. The area of ground nut increases and the associated deforested area are in the range of 128,000 ha per annum in average (Figure 37). Whereas the cultivation of oil palm has a relatively small impact on forest cover with induced deforestation of 20,000 ha, this changes considerably in the later periods when it induces deforestation of 140,000 in the period 2011–2020 and 100,000 ha in the period 2021–2030, respectively.

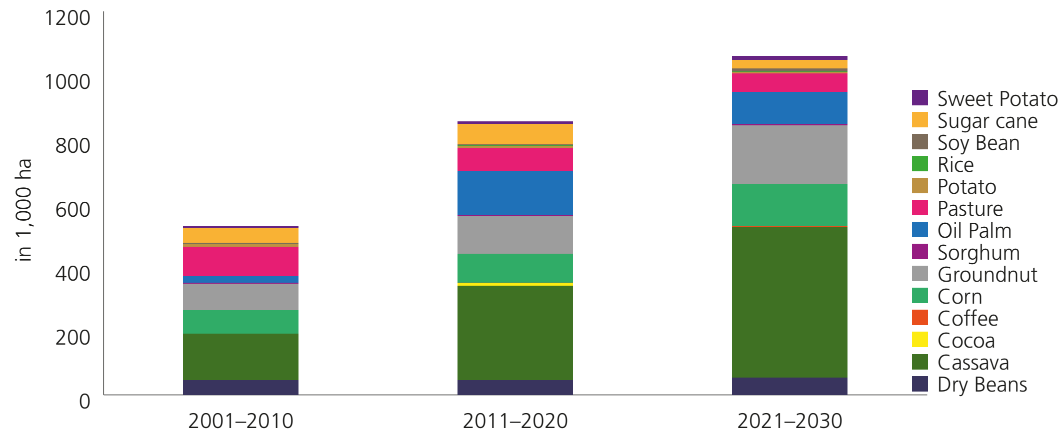

Figure 37. Evolution of deforestation per crop and per 10 years period in Cameroon from 2001 to 2030.

In terms of spatial allocation of this deforestation 43 % of the deforestation projected by the model over the period 2011–2030 is located in the East region where it is mainly driven by the expansion of cassava, ground nut and pasture. The regions Center and North-West follow with a deforestation of 200,000 and 400,000 ha, respectively, over the period 2011–2030. It is interesting to note that 80 % of the deforestation in the Center and South regions is associated to the expansion of cassava, ground nut and corn, whereas in the South-West the expansion of oil palms causes 75 % of the deforestation (Figure 38).

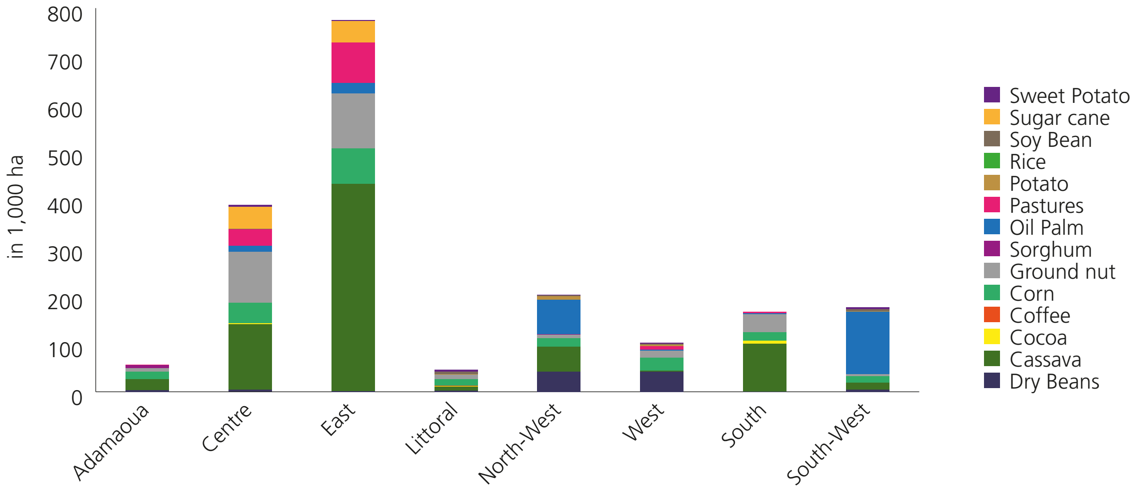

Figure 38. Contribution of each crop to cumulative modelled deforestation over the period 2010–2030 per region in Cameroon.

8.2 Agricultural production and consumption

The average per capita calorie consumption in Cameroon is projected to increase by 24% between 2010 and 2030. The vegetal calorie production (i.e. calories sourced from crops) continues to exceed the national consumption in the period 2011–2030, meaning that Cameroon will keep its status as net exporter of vegetable calories. More precisely, Cameroon is projected to export significant amounts of fruits and vegetables to it neighbouring countries but at the same time the imports of cereals, notably rice and wheat increase by 70 % between 2011 and 2030. According to our results, the increase of the animal calories (meat, fish and milk) is mainly satisfied through an increase of imports. However, these results should be taken with caution because our estimates tend to underestimate the growth of livestock production, notably chicken in Cameroon.

8.3 Forest management

Since in our simulations we fixed the areas under forest concessions to the current area under concessions and we only take into account humid non-swampy forests inside concessions, we obtain 6.4 Mha of managed forests in Cameroon in the year 2030. (see section 4.4.1). For that reason the log production remains similar to the current level of 2 million m^3. The annual fuel wood production increases from 11 to 18 million m^3 per year between 2010 and 2030 in order to satisfy the energy demand of the local population. In our simulations fuel wood is sourced from fallows as well as unmanaged forests located in proximity to urban centers. At current, forest degradation associated to fuel wood collection is not taken into account in the model (see Section 10.2).

8.4 Emissions

We us five alternative biomass maps to calculate emissions associated to deforestation in Cameroon: Saatchi *et al.* (2011), Baccini *et al.* (Baccini *et al.*, 2012), FRA 2010 (Kindermann *et al.*, 2008), Mermoz *et al.* (2014) and Avitabile *et al.* (2016). Our results show that emissions from deforestation vary between 702 and 1785 million tons (Mt) CO_2 over the period 2011–2030, depending on the biomass map used. The choice of the biomass map hence leads to a difference in accumulated emissions from deforestation over the 2011–2030 period of 154 %. As shown in Figure 39, the differences of emissions between the different maps used tend to increase over time when comparing the three ten-year simulation periods. The average carbon stock (or emission factor per hectare) varies between 94 and 239 tC/ha over the period 2011–2030, depending on the biomass map used (Table 6).

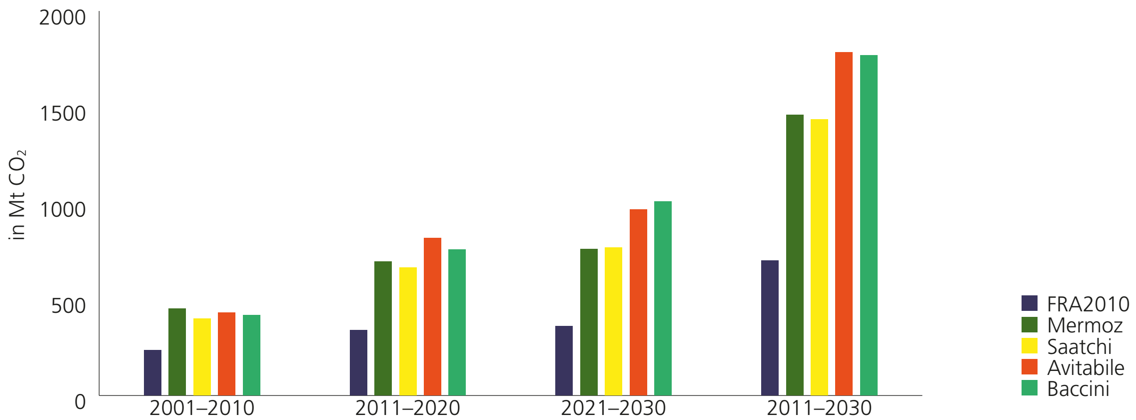

Figure 39. Emissions from deforestation per 10 year period and cumulated over the period 2010–2030 using different biomass maps.

Table 6. Evolution of emission factors for deforestation per simulation period according to the biomass maps used.

Unit		2001–2010	2011–2020	2021–2030	2011–2030
in tCO_2/ha	FRA2010	405	376	321	345
	Mermoz	777	768	676	717
	Saatchi	686	734	683	706
	Avitabile	742	902	857	877
	Baccini	718	836	895	869
in tC/ha	FRA2010	110	102	87	94
	Mermoz	212	209	184	196
	Saatchi	187	200	186	192
	Avitabile	202	246	234	239
	Baccini	196	228	244	237

Besides land use change, there are two other main sources of emissions associated to land use in Cameroon: selective logging of forests and the conversion of other natural lands, mainly savannah's to agriculture. The agriculture sector uses almost no external input factors and the livestock sector continues to be relatively weak in our sector, hence very little emissions (less than ten Mt CO_2 over the period 2010–2030).

Looking at the forestry sector, using the emission factor for conventional formalized logging inside concession, the simulations show that activities in this sector result in 155 Mt CO_2 over the period 2011–2030. This represents 9 % of the emissions from deforestation. Further, our projections also reveal that the conversion of other natural lands causes emissions of 261 Mt CO_2 or 15 % of emissions from deforestation (Figure 40). Total emissions from land use change (including forests and other natural lands, agriculture and forest logging inside concessions) is in the magnitude of 2.2 gigatons CO_2 over the period 2011–2030.

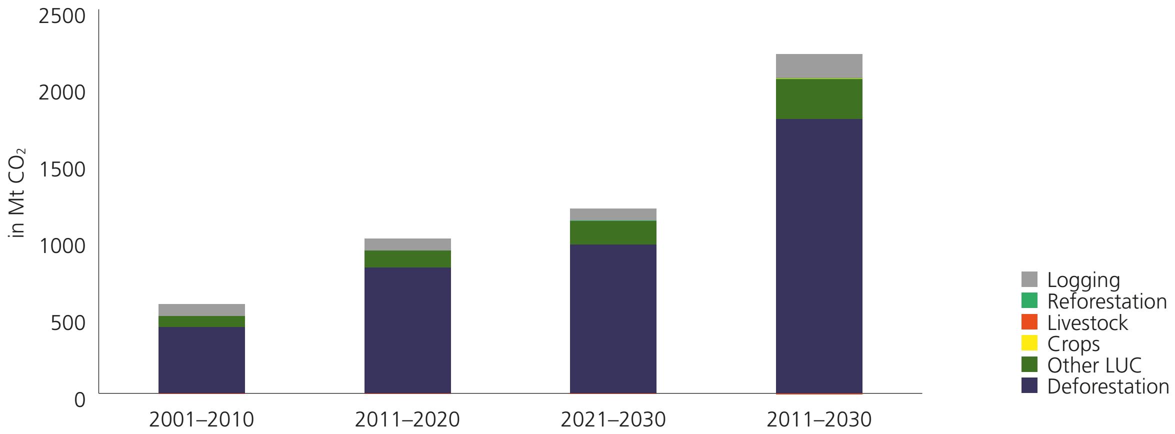

Figure 40. Emissions form the land-based sectors per source and per 10 years period and cumulative over the period 2010–2030 in Cameroon. Emissions from livestock, cropping and reforestation are barely visible due to relatively small emissions associated to these.

8.5 Potential impacts on biodiversity

The decrease in area of both forests and other natural lands in the base scenario constitutes a threat to biodiversity in the sites where it is currently present and to the services that these nature areas can provide to people. However, the projected land use change and the associated threats to biodiversity are not uniformly distributed across the different ecosystems in Cameroon (Figure 41), nor are the main driver of land use change the same across the ecoregions.

In the majority of the ecoregions agriculture is the main driver of land use change but in the mangrove forests of Central Africa and the Cross-Sanaga-Bioko coastal forests degradation is also very important. The impact of conversion of degraded forests will depend on the degree of degradation observed. An important future expansion of pastures can be observed in the East Sudanese Savannah, livestock grazin has a weaker impact in the savannah zones than the conversion of these zones in agricultural land, depending on the density of the grazing regime.

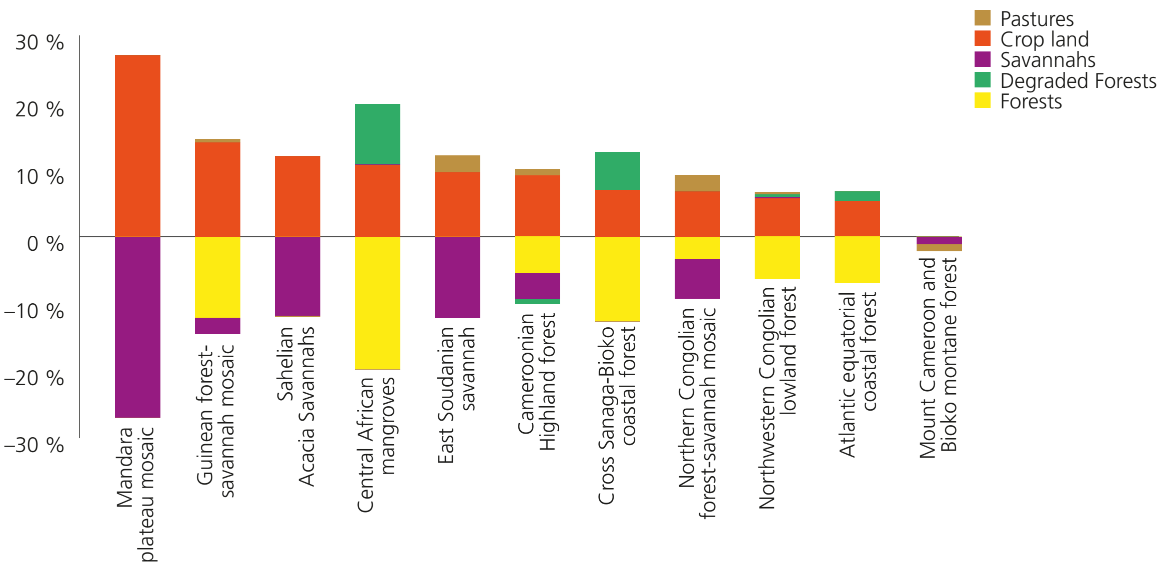

Figure 41. Land use changes over the period 2010–2030 in the eco-regions of Cameroon.

The combination of information about forest loss in the base scenario between 2010 and 2030 with information about the potential habitat of Great Apes points to the threat of habitat loss on a great share of their potential habitat in the country. (Figure 42). The model projects important habitat loss in particular in the regions South-West, Centre and East. The total loss exceeds 10 % of their habitat in the country and there is a risqué that this loss will increase the fragmentation of their habitat.

Furthermore, the extent of the habitat loss means that there are many zones in which the potential services that great apes provide, including their role in the development of eco-tourism activities, will face substantial risks in the future.

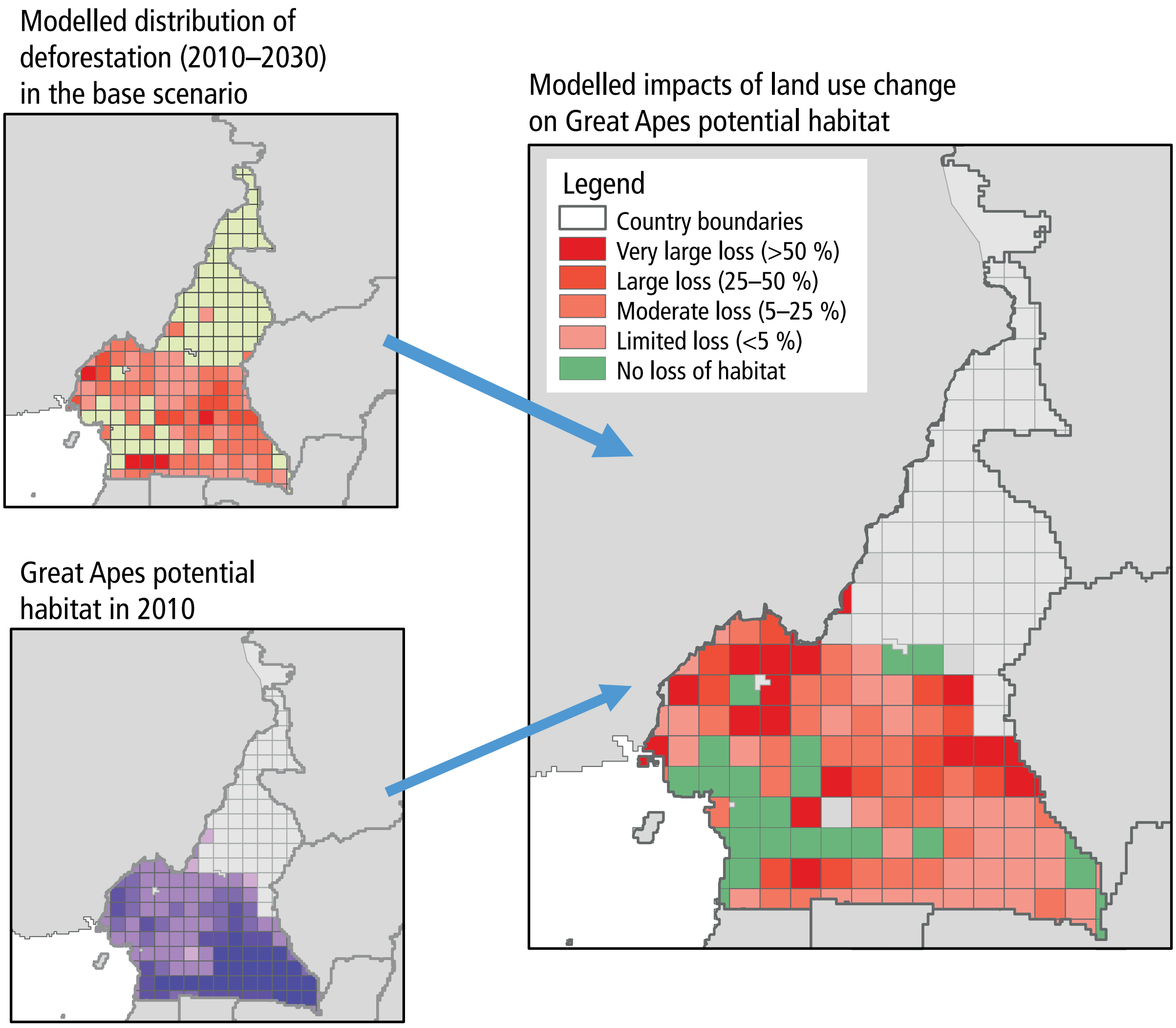

Figure 42. Impact on the potential habitat of Great Apes.

The estimated loss of natural vegetation will not only have an impact on great apes but on all species present in these zones and the potential values that they can offer. Combining information about land use changes in the base scenario (including the loss of forests and other natural land projected by the model with information about the distribution of species and their requirements to potential habitats reveals that 675 out of the 1367 species assessed will suffer a loss of more than 10 % of their potential habitat in the country of which 76 species are projected to lose even more than 20 %. Of these 675 species estimated to lose more than 10 % of their potential habitat, 43 are considered globally threatened by the IUCN and 104 are protected by national law. The combination of information about the proportion of habitat loss for each species in a zone produces an index that represents the total potential habitat loss in the different zones (Figure 43); this index, will be highest in zones where both species abundance and conversion of forests and other natural land are greatest.

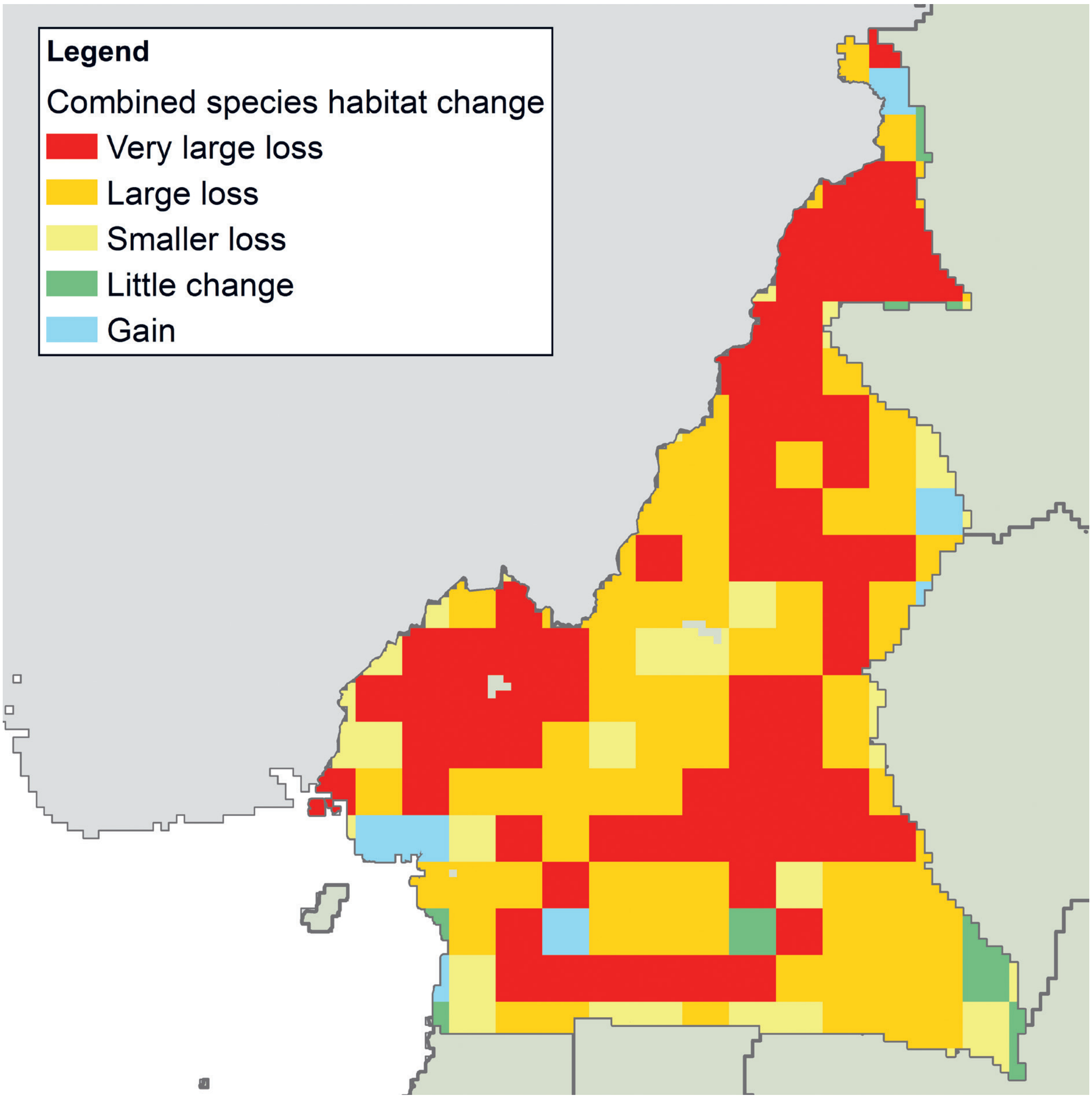

Figure 43. Map of the combined loss of habitat over the period 2010–2030 for all species assessed weighted by the relative endemism for each species.

It is difficult to assess the impact of the lost of natural habitat on ecosystem services provided in these zones due to the scarce data availability about the spatial distribution of these services. However, combining the information about land use with information about the spatial distribution of *Prunus Africana* shows that deforestation is likely to occur on 36 % of the area where *P. Africana* has a high probability to be reproducing and 12 % of the areas where it can potentially reproduce.

9 Results for alternative scenarios

9.1 Deforestation and other land use changes

Total deforestation in Cameroon over the period 2010–2030 varies between 1.366 and 2.210 Mha, corresponding to a reduction of 33 % and an increase of 9 %, respectively, relative to the base scenario (Figure 44).

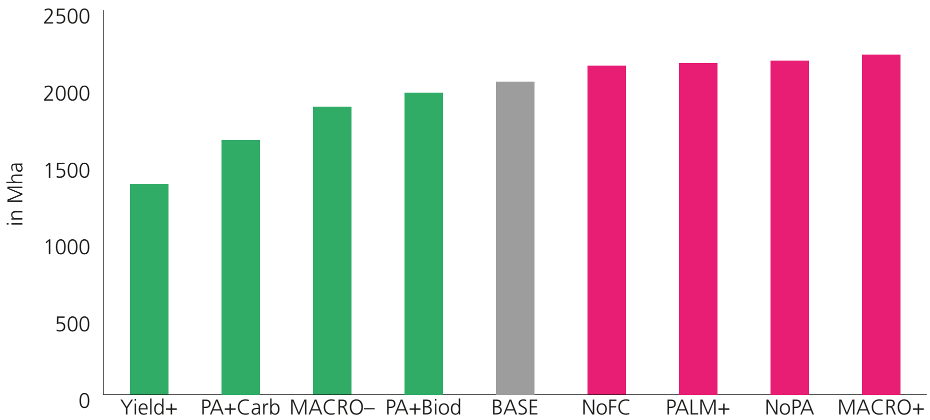

Figure 44. Cumulative deforestation over the period 2010–2030 according to the different scenarios: scenarios represented by green bars reduce deforestation compared to the base scenario (in grey) whereas scenarios in pink increase future deforestation.

The most pessimistic scenarios is the one with the strongest underlying growth of population and GDP (MACRO+). The other scenarios which lead to an increase of pressures on forest in Cameroon are: a retro-cession of logging concessions in the permanent forest area (NO FC), the implementation of oil palm development (Palm+) and the non-respect of protected areas (No PA).

On the other hand, the adoption of techniques leading to a stronger performance of agricultural production (Yield+) is projected to have the strongest mitigating impact on future deforestation in the next decades, as compared to the base scenario. The expansion of protected areas to 17 % of the country's territory (PA+) would also contribute to reducing deforestation relative to the base scenario. As mentioned before, in this scenario the location of the new protected areas occurs into zones where demographic pressure is particularly strong in the future. A less pronounced demographic and economic growth (Macro-) would also reduce deforestation as compared to the base scenario, but only by 8 %. However, deforestation could be reduced by almost the same percentage without reducing growth of the economy and population but by investing in the creation of protected areas in zones which will face the strongest losses of biodiversity (PA+Biod).

Looking at the full land use change over the period 2011–2030 in Cameroon, we observe simultaneously the greatest conversion of natural lands and the greatest deforestation in the scenario where both population and GDP growth are elevated (Macro+). This scenario leads to the strongest increase of agricultural land. However, if logging concessions and protected areas are well respected, i.e. no deforestation occurs within their boundaries, close to 80 % of the expansion of agricultural lands occurs in savannah's (Figure 45). By contrast, in case that the agricultural sector decides to rely on techniques favouring a stronger performing agricultural production (Yield+), this would lead to reduced land use change across land use types.

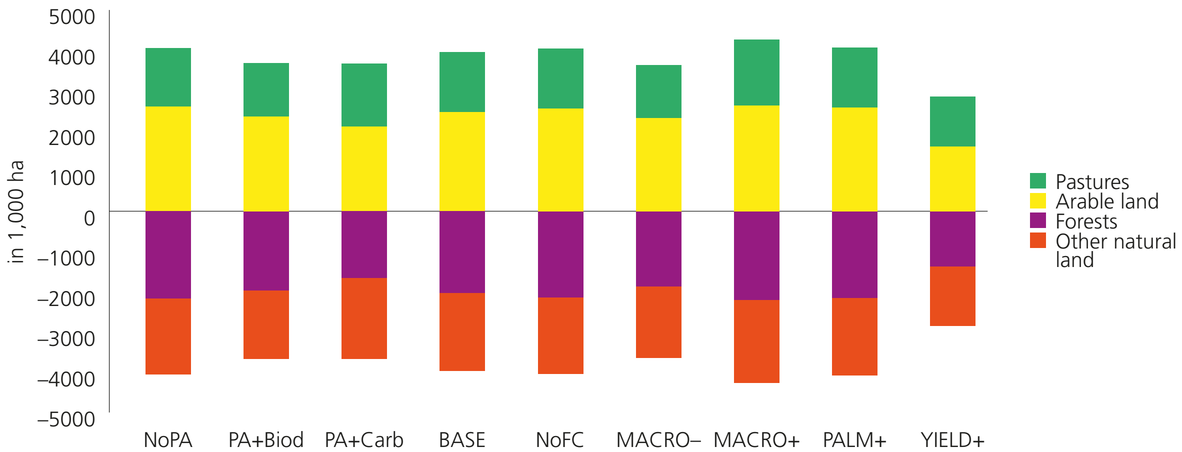

Figure 45. Conversion or expansion of different land use types between 2010 and 2030 for each scenario.

9.2 Agricultural production and consumption

Any strong variation of population and GDP – both relative increases as well as decreases (Macro+ and Macro–) bring about a reduction of the per capita production of calories. Whereas a strong increase of population and GDP entail a decrease of the production of the different sources of calories, including a weaker decrease of the production of animal calories (by –7 % as compared to the base scenario), a strong negative development of both indicators (Macro-) leads to a decrease of the production of calories from dairy and vegetable products and rather an increase of the production of all animal products by 4 % compared to the base scenario. The scenarios which presume the expansion of protected areas just as those simulating the non-respect of logging concessions and protected areas lead to a very weak impact on calories production compared to the base scenario. The improvement of agricultural yields also increases the production of animal calories per inhabitant while the production of calories per capita from vegetable origin decreases. The expansion of oil palm plantations leads to an increase of vegetable calories production but this increase is not very strong as compared to the base scenario (Figure 46).

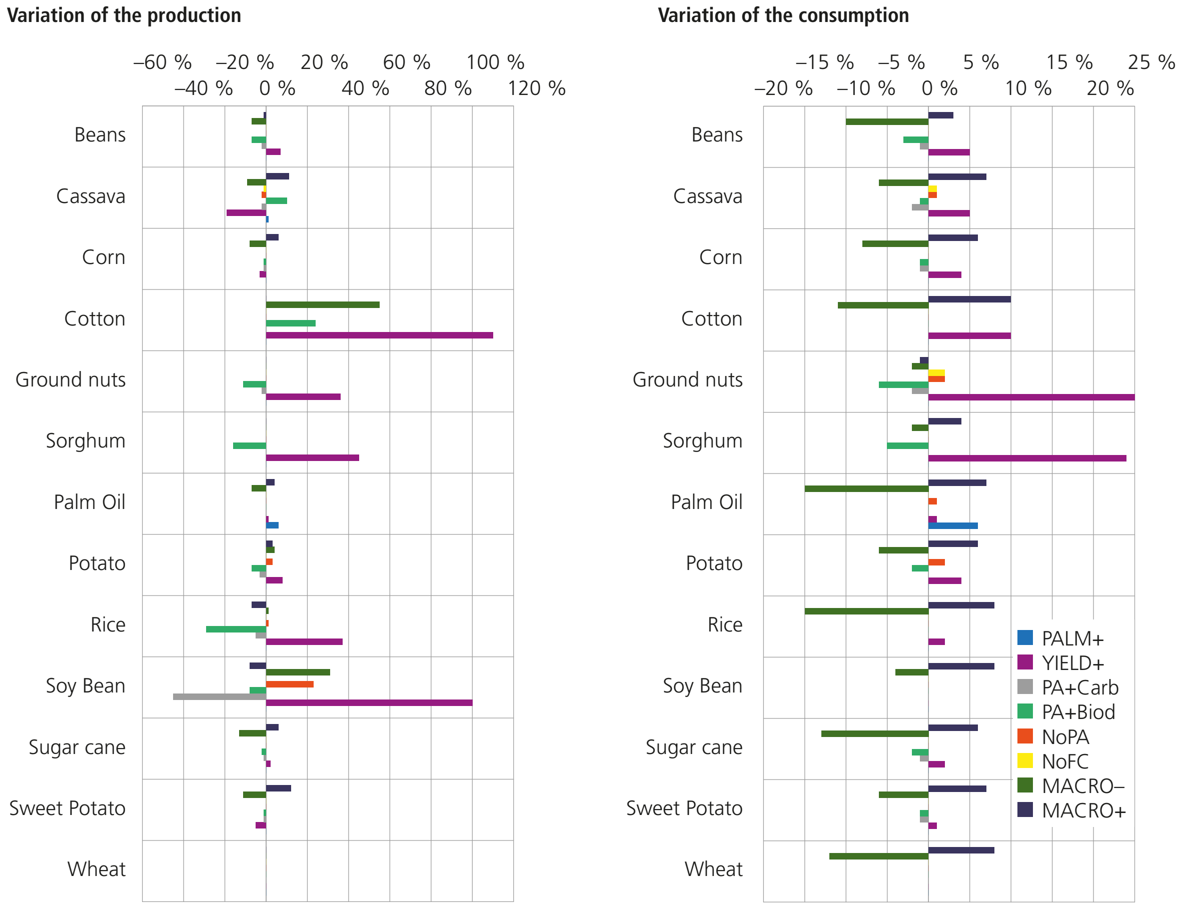

Figure 46. Variation of production (left) and consumption per crop in 2030 compared to the BAU scenario.

9.3 Emissions

Emissions form deforestation over the period 2011–2030 vary between 517 and 1954 $MtCO_2$, corresponding to a variation between –26 % and +9 % as compared to the base scenario (Figure 47). It is noted that emissions from deforestation in Cameroon increase proportionally with the deforested areas in the various scenarios. If the other sources of emissions represented in the model are taken into account total emissions vary between –35 % and +9 % compared to the base scenario. It it noted that the emissions from the conversion of other natural lands tends to increase in the scenario where the protected areas expand. This effect can be explained by the enforcement of the protection of those areas where the yields are highest, or more in forest areas which could lead to an increase of the needs for other natural lands.

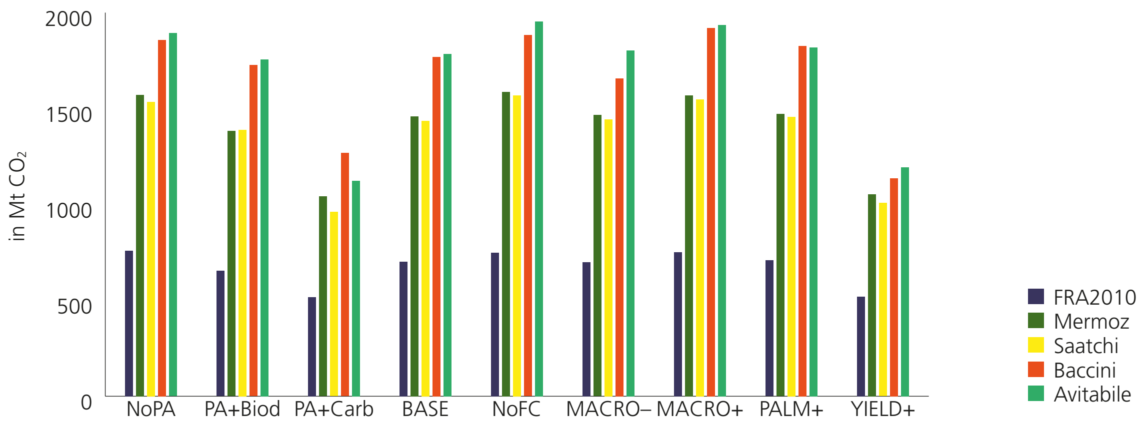

Figure 47. Variation of emissions from deforestation in Cameroon over the period 2011–2030 according to the different scenarios and biomass maps used.

9.4 Impacts on biodiversity

The impact on biodiversity vary significantly between the different scenarios. Figure 48 shows the total impact on the habitat of the Western Lowland Gorilla *(Gorilla gorilla)* and of the chimpanzee *(Pan troglodytes)*. Where deforestation leads to a loss of areas which represent a habitat for both species this zones is effectively represented twice. Consequently, the scenarios where each species loses habitat at different places have the same impact equivalent to the scenarios where both species lose their habitat at the same places. In those areas where both species occur the total habitat loss can hence be higher than the total deforestation. The non-respect of protected areas and the abolition of forest concessions lead to an increase of the habitat of great apes as compared to the base scenario. This underlines the importance of assuring that protected areas and logging concessions will be effectively maintained and enforced.

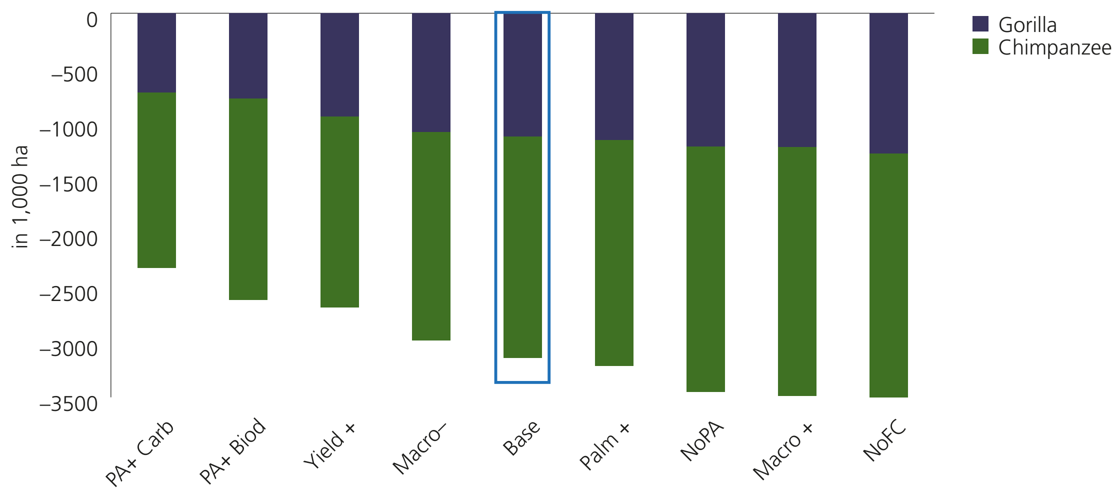

Figure 48. Variation of loss of potential habitat for great apes across different scenarios over the period 2011–2030

When looking at the assessment across all species under the scenario which assumes the non-respect of protected areas and the abolition of forest concessions the loss of habitat of the greatest number of species is projected. In these scenarios it is estimated that just less than 800 of the 1367 species assessed will lose more than 10 % of their habitat (Figure 49), and more than 100 species are projected to lose more than 20 % of their habitat. In the scenario of non-respect of protected areas, out of the 797 species projected to lose more than 10 % of their habitat 119 are protected by Cameroonian law and 53 are considered threatened by the IUCN. In the scenario of non-respect of protected areas. In the scenario of the abolition of logging concessions, out of the 785 species projected to lose more than 10 % of their habitat, 118 are protected by law.

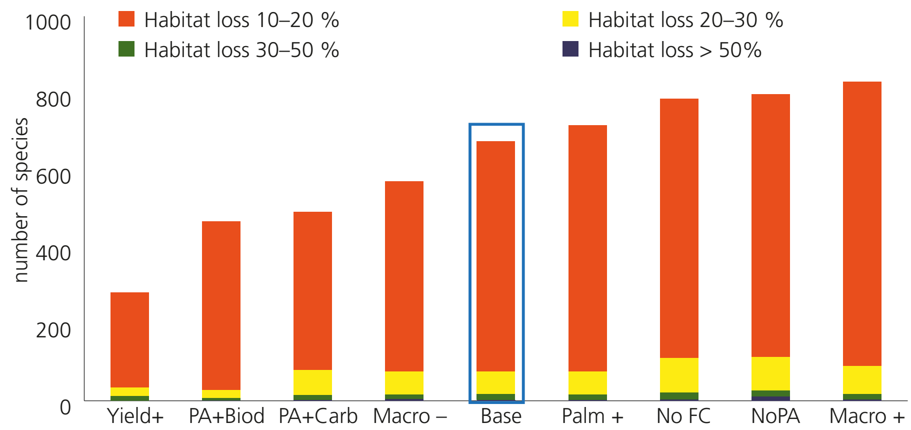

Figure 49. Number of species of which a certain part of their potential habitat is converted to other uses over the period 2010–2030.

In terms of impacts on ecosystem services the scenario where the non-respect of protected areas is assumed (No PA) projects the highest amounts of deforestation in areas where the presence of *P. Africana* is likely. Although the spatial distribution of other ecosystem services (including other NTFP's) could be different from that of *P. Africana,* these results show the considerable role which the protected areas can play in the protection of ecosystems. The relatively large error bars in Figure 50 show that the impact on ecosystems will vary depending on the location of land use changes as compared to the locations of important zones of ecosystem services. The loss of *P. Africana* could vary considerably depending on whether deforestation is more or less likely to occur in the zones where *P. Africana* is more likely to be present as compared to the neighbouring forests within the same simulation unit.

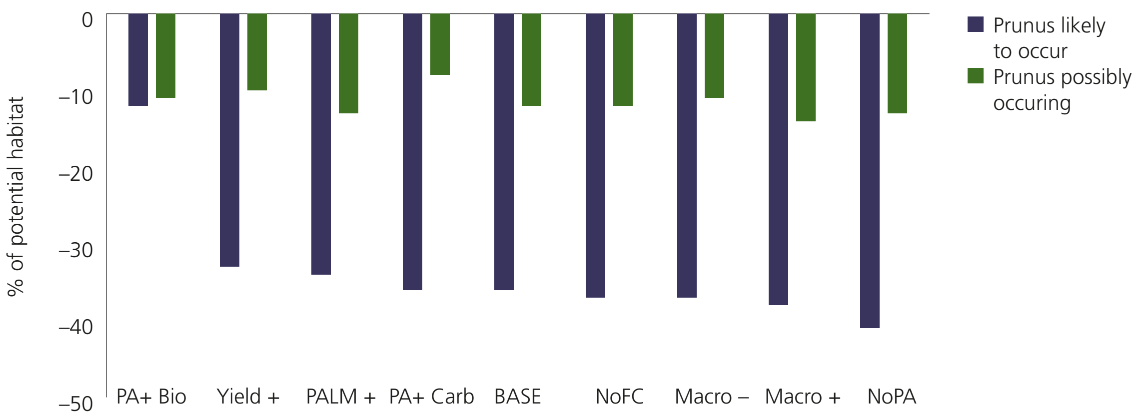

Figure 50. Variation across scenarios of potential habitat loss of *P. africana* due to deforestation.

The scenarios which project less habitat change across all species and where loss of habitat of great apes is lowest are those which assume an expansion of protected areas, which highlights the important role of which protected areas play in the protection of ecosystem services and biodiversity such as eco-tourism linked to the presence of great apes. In reality, protected areas are created based on a number of criteria, including the level at which biodiversity, specific species and ecosystemare or ecosystem services are threatened as well as the viewpoint of local stakeholders and the feasibility of creating and managing a protected area on the ground.

9.5 Which factors scan reconciles several objectives?

Decision maker are often confronted with situations where several objectives are to be fulfilled with limited resources. Identifying policies which can allow for the realisation of several objectives at a time is therefore of particular interesting for decision makers (Table 7).

Here we compare the impact of each scenario on three types of objectives: economic development, the fight against climate change and the protection of biodiversity. For each of these objectives we identified two indicators which can be quantified using the results of the GLOBIOM model. Most of these indicators have been presented in the analysis of results in the previous sections. For economic development and food security the indicators a) average per capita production of calories from vegetable origin in the year 2030 and b) the value of net agricultural imports from vegetable origin in 2030. For the fight against climate change the c) emissions from the agriculture sector and land use change between 2010–2030 and d) the emissions from deforestation only between 2010 and 2030 are considered as indicators whereas e) the loss of potential habitat of great apes and f) the number of species losing more than 2 % of their potential habitat in Cameroon between 2010 and 2030 are indicators to represent the overall objective of biodiversity conservation and sustainable use of biodiversity.

Table 7. Comparison of scenarios in terms of their contribution to multiple objectives. Cells highlighted in green indicate an approximation to the realisation of an objective whereas red indicates an increasing distance to an objective.

	Economic development and food security		Climate change mitigation		Conservation and sustainable use of biodiversity	
	Calories produced per inhabitant[a]	Net food exports[b]	Total emissions[c]	Emissions from deforestation[d]	Loss of great apes' habitat[e]	Number of species losing >10 % of their habitat[f]
BASE	2303	266	2444	1785.0	10.9 %	675
MACRO+	–2.2 %	15.2 %	9.3 %	8.4 %	11.1 %	23.0 %
MACRO–	–0.5 %	–21.6 %	–5.8 %	1.0 %	–5.1 %	–5.4 %
NoPA	–0.6 %	–14.0 %	5.1 %	6.0 %	10.0 %	18.1 %
NoFC	–0.4 %	–8.5 %	8.0 %	9.4 %	11.5 %	16.3 %
PA + Biod	1.3 %	–16.9 %	5.0 %	–1.7 %	–18.0 %	–41.9 %
YIELD+	–-2.2 %	–60.0 %	–36.7 %	–33.2 %	–14.7 %	–58.2 %
PALM+	1.4 %	–3.1 %	5.6 %	1.9 %	2.3 %	6.2 %

a) production of calories in kcal per inhabitant per annum in 2030 on the basis of the crops represented in the model,
b) value of imports of agricultural products in 1000 USD in 2030 on the basis of the crops represented in the model,
c) total emissions from the agricultural sector and changes in land uses in Megatons CO_2 between 2010 and 2030,
d) total emissions from deforestation in Megatons CO_2 between 2010 and 2030,
e) proportion of the area of the potential habitat of large primates converted to other uses between 2010 and 2030,
f) number of species considered that lose more than 10 % of their potential habitat within the country between 2010 and 2030

There is not one single scenario for which an improvement of all objectives at a time can be observed (Table 7). The improvement of agricultural yields (YIELD+) allows an improvement of the score of environmental indicators, be it the reduction of GHG emissions or a weaker impact on the habitat of fauna. However, this scenario leads to a reduction of exports of agricultural goods and a reduction of the production of calories per inhabitant. This its due to the sub-regional dimension of the definition of these scenarios, i.e. the measures of the scenarios are implemented for all COMIFAC countries at the same time. In reality and in the base scenario of the model, Cameroon is a net exporter of agricultural products to other countries in the region. Therefore, if the countries of the entire sub-region manage to improve their productivity (YIELD+) or they experience a reduction of their populations consumption (Macro-), the model shows that as a side effect exports and thus agricultural production in Cameroon will decrease. A future study will isolate the impact of purely domestic changes in the rest of the sub-region.

10 Discussion of the results

10.1 Agriculture

Two aspects of our results merit commenting on and directing the focus of a future study on:

- Evolution of the livestock sector: the chicken and pork farming sector in Cameroon has seen a strong increase between 2000 and 2010. This trend is currently not well captured by the model. The underestimation of the evolution of this sector also leads to an underestimation of the expansion of crop-land destined for feeding animals, notably corn and sorghum. An improvement of the evolution of the livestock sector will be in the focus of future studies.
- Fallows: The overestimation of deforestation in the East region could be linked to an overestimation of fallow periods in this region.

Several scientific papers showed that an increase of agricultural yields is in many cases accompanied by a surge of deforestation (Byerlee *et al.,* 2014; Hertel *et al.,* 2014; Rudel *et al.,* 2009). The underlying economic mechanism is that an increase of agricultural productivity tends to making production costs per unit decrease and thus also the price for agricultural input factors. The lowered prices stimulate the consumption of agricultural products which in turn increases the demand for crop-land; hence, improved yields can provide incentives to produce more and expand crop-land potentially at the expense of forests at both, the production and the consumption side. On the production side it is therefore crucial to know which technologies can be used, their costs and their impact on productivity whereas on the demand side a good characterization of the price elasticity is important, i.e. how the consumption reacts vis-a-vis price changes

It is important to comprehend the main constraints of farmers in order to increase the chances of adoption of new production techniques (investment in workforce, costs of farm inputs, investment security etc.). In the framework of a project for the World Bank where the CongoBIOM model was used for the first time, we also found that an improvement of agricultural yields entails an increase of deforestation (Mosnier *et al.,* 2012).In the meantime the model has undergone major changes (see Annex) which can explain the different results to this study. In a follow-up of this study we will carry out a thorough sensibility analysis to analyse in detail under which conditions the improvement of agricultural yields does or does not lead to a reduction of deforestation in the Congo Basin using GLOBIOM.

In the model, expansion of agriculture leads to the complete disappearance of forest to the same extent as agriculture expands. In reality, the slash-and-burn system, which is still the most practiced agricultural system in the forest zones of the Cameroon, often maintains at least few high-value trees during the cultivation phase. Further, two to three years of cropping are generally followed by several years of fallow which allows the forest to regenerate on the abandoned sites (Makana and Thomas, 2006; Russell *et al.,* 2011). The regrowth of carbon stocks is particularly fast during the first 20 years after abandonment of agriculture. This can lead to a carbon sequestration of 3 to 9 t Carbon per year on one hectare, depending on site conditions such as soil fertility and the fallow duration (Palm *et al.,* 2000).

Even if certain zones have shorter fallow durations and less fertile soils which might reduce the capacity for forest regeneration, agricultural fallow in forest areas could represent a considerable sequestration factor in the national carbon accounting framework budget. The contribution of the traditional agricultural system to carbon sequestration in the Congo Basin will be in the focus of a future study.

An important share of the expansion of oil palm in the model is projected to occur in the forest zone. In reality, almost all palm plantations in the past came at the expense of forests. One possible explication of this results is the fact the many forest areas which are suitable for oil palm plantations and which have not already been attributed to logging concessions or protected areas are more difficult to access than other zones with a lower potential put which are located closer to existing transport infrastructures. It is possible that in the future agro-industrial investors are ready to construct transport infrastructure to access remote but suitable areas but this effort would come at a supplementary cost and transport costs and infrastructure are currently not subject automatic adaptation in the model.

Another explication for this difference is that palm oil yields are not differentiated inside a simulation cell (~50 x 50 km). This is, for the areas located at the frontier between forest and non-forest, the model does not see the difference in terms of potential for oil palm planting whereas in reality there can be a difference. One final explication is the fact the monetary benefits linked to the clearing of the forest during the installation of industrial plantations are not taken into account whereas investors often do take the value of the "conversion wood" into account to calculate the long-term profitability and in particular the possibility of covering installation costs early up. Also these points will be explored more in detail in a future study.

10.2 Forest management

Despite our efforts to collect data, modelling the co-existence of informal and formal logging of forests merits further efforts. In the model the two types of forest exploitation are in direct competition on the market where the price for logs is the same for everybody whereas in reality export markets which are reserved for concession holders and the local markets, the latter exercising less scrutiny as to the origin of the wood and using many different species are quite well differentiated (Bayol *et al.,* 2014).

There is also a difference of requirements in terms of sustainability and traceability of the forest exploitation depending on the destination county. This study relies on the hypothesis that forest management plans are fully respected. The Forest Law Enforcement, Governance and Trade (FLEGT) Action Plan which should ban imports of illegal wood to Europe should facilitate the implementation of forest management plans but there is a risk of "leakages", i.e. the export of illegal wood to Asian markets which are currently little vigilant with respect to the provenance of their raw materials. For the formal exploitation we are still lacking information about the availability of the resource wood, its exact location of forest exploitation and the long-term impact of forest management on the forest stands. Despite many studies highlighting the importance of the informal sector in the countries of the Congo Basin with wood quantities of extracted wood being close to those in the formal sector (Lescuyer and Cerutti, 2013; Ondele-Kanga, 2012), it has not been possible to represent forest degradation and its associated emissions in the framework of this study.

10.3 The expansion of protected areas

In two scenarios the zones of expansion of protected areas have been identified based on one single criterion each: habitat loss in the PA+Biod scenario and carbon content in the PA+Carb scenario. As a consequence these scenarios are likely to represent the maximal possible impact of the expansion of protected areas to 17 % of the national territory on the indicators habitat and carbon loss, respectively. In reality the expansion of protected areas will depend on a wide range of criteria, including a certain number of different aspects linked to biodiversity and it should ideally be developed as part of a process of systematic conservation planning (Worboys *et al.* 2015). The systematic conservation planning comprises the identification of national conservation priorities (e.g. identification of certain target species, certain types of vegetation elements), an assessment of the extent to which the existing conservation network corresponds to these objectives and to the selection of supplementary zones to fill the gaps identified. The scenario PA+ is based on the global threat to all mammals, amphibians and birds for which data is available and it does not take into account the gaps that exist in species coverage nor the fact that protected areas could be developed with the objective to protect specific species, for example particularly charismatic ones.

The connectivity between protected areas and the protection of intact landscapes are also two important elements for the planning of protected areas (Worboys et al 2015) which are not among the criteria considered for the possible location for protected areas to expand under the PA+ scenario. In the PA+ scenario the areas which are the richest in biodiversity or where carbon loss is greatest in the base scenario, respectively, have been selected for the expansion of protected areas, even if these areas are isolated from the existing network of protected areas. The protection of greater stretches of natural habitat can reduce the pressure linked to the fragmentation and enhance the resilience of these areas and this scenario could concentrate the location of protected areas and hence their impact on land use in comparison to the modelled scenarios. Further, areas rich in biodiversity or in carbon stock which are more likely to undergo land use change (i.e., the selected zones for expansion of PAs in the PA+ scenario) could also be zones where opportunity costs for developing protected areas and limit the land use change, which would make the practical implementation of these protected areas more difficult.

Even though the PA+ scenarios generally do not represent the complete reality of the zones where the expansion of protected areas is likely to take place – the location of new protected areas is a political decision demanding the Free Prior and Informed Consent (FPIC) of the local population, the scenarios show the protected areas can support the conservation of biodiversity and carbon stocks stored in the forest biomass in Cameroon.

11 Conclusion

According to moderate projections, 28.7 million people will live in Cameroon in 2030, more than 70 % in cities and the average GDP per capita is predicted to be 2.3 times higher than in 2010. A larger and richer population leads to an increase in local consumption of agricultural products, which translates into an increase in agricultural land. Our results show an average annual increase in deforestation from ca. 37,000 hectares between 2000 and 2010 to 110,000 hectares between 2020 and 2030, causing emissions of between 702 and 1,768 million tCO_2 between 2010 and 2030, depending on the carbon map used. Two thirds of the deforestation observed between 2010 and 2030 comes from the expansion of cassava, groundnut and related fallow land, and 6 % from the expansion of oil palm. The model also predicts increasing deforestation due to the expansion of grazing land.

Accrued deforestation over the period 2010–2030 varies between 1.36 and 2.2 Million hectares depending on the scenario, compared to 2.0 Million hectares in the base scenario. Improving agricultural yields, expanding protected areas and lower population and GDP growth reduce future deforestation. However, oil palm expansion targets, uncontrolled expansion of agriculture in protected areas or in forest concessions, as well as a strong increase in population and GDP would increase deforestation in relation to the base scenario. The scenario in which agriculture expands into the existing forest concessions increases future deforestation the most.

Habitat loss constitutes one of the main drivers of biodiversity loss. Cameroon is home to two species of great apes, the Chimpanzee and the Western Lowlands Gorilla, which are heavily dependent on the presence of natural forests for their habitat. These are also species which represent an important potential for the development of eco-tourism. The model predicts important habitat losses for great apes in the regions South-West, Centre and East. Apart from the direct loss of habitat, the expansion of agricultural areas may lead to an increase in contact and consequently conflicts between great apes and humans. Our results emphasis the role that the protected areas can play in reducing changes in land use, on the basis of the hypothesis that the protected areas are supposed to prevent any change in land use. Observational studies show that the presence of protected areas reduces land conversion, but that some changes nonetheless occur inside protected areas (Céline *et al.* 2013, Butsic *et al.* 2015), at a proportion which varies according to the type and effectiveness of the management (Nelson and Chomitz 2011). The lack of funding for protected areas in Central African countries already makes the effective management of the existing protected areas difficult (Wilkie *et al.,* 2001).

By comparing the results of several scenarios in terms of agricultural production, emissions from land-use change, and the conservation and sustainable usage of biodiversity, trade-offs are observed for all tested policies. However, an increase in agricultural productivity would lead to significant gains for climate change mitigation and biodiversity conservation. Conversely, combining stronger economic and population growth would result in a degradation of all the indicators. For example, under the oil palm expansion and agricultural expansion into forest concessions scenarios there is a small gain for agricultural development but losses for the environment. Conversely, under the protected areas expansion scenario there are gains for climate and biodiversity but losses for agricultural development.

In order to minimise the impact on the forests and ensure the viability of a long-term extensive palm oil planting programme, the government should as a first step identify the areas which are most suitable for plantation development. According to our results, an objective of 300,000 hectares of oil palm would translate into an increase in deforestation of 240,000 hectares between 2010 and 2030. Moreover, our results show that the forest concessions can be an important brake on deforestation. The efforts which have been made to move to sustainable logging in Cameroon must be pursued and combined with more efficient use of wood products to ensure the long-term profitability of the operation. The contribution of forest concessions to biodiversity conservation can also be supported by the widespread use of low-impact logging practices and fighting poaching in forest concessions, including through certification.

Cameroon clearly disposes of the best statistics in the sub-region notably in the sectors agriculture and forestry. This should put the country in a good position to measure progress towards the achievement of various development goals, reduction of greenhouse gas emissions and biodiversity conservation but further efforts should be made as to the continued and coherent collection of data in the future. Particular focus should be put on the choice of consistent, country-wide land cover and carbon stock information as the choice of one or the other carbon map induced largest uncertainties in estimating emissions from land use change.

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Annexes

Improvement	Implementation in the CongoBIOM model in 2010	Implementation in the GLOBIOM Cameroon model in 2010
Introduction of the the permanent forest areas	Protected areas, forest concessions and other forest pertaining to the permanent forest area in Cameroon cannot be converted to other uses.	Update of forest concessions and protected areas over the period 2010–2020 by integrating the data available in the year 2015. Creation of alternative scenarios where conversion is possible.
Adjustment of wood extraction rates in managed forests	Taking into account the concentration of wood removals to only selected commercial species (selective logging) based on a literature review.	Adjustment of extraction rates per forest type (e.g.: dense humid forest, dry forest …).
Estimation of emissions from forest degradation linked to the management of forests under concession	Utilisation of emission facors from Durrieu de Madron *et al.* (2010).	No change as compared to 2010.
Making the demand for fuel wood and forest degradation linked to fuelwood collection spatially explicit	Demand for fuel wood established per simulation unit. Introduction of a new class «degraded forests» associated to fuel wood collection.	Demand for fuel wood established at the national level but the intensity of fuelwood removals depends on the population density which is spatially explicit represented in the model. Fuel wood can also be sourced from agricultural fallows.
Wood transformation	Wood transformation coefficient for sawn wood in the Congo Basin lowered to to 0.38 (instead of 0.59)	A wider range of forest products taken into account.
Introduction of coffee and cocoa as new crops in the model for the Congo Basin.	Utilisation of SPAM maps to allocate coffee and cocoa per simultion unit and to estimate productivity levels.	Errors detected in SPAM data. Hence use of national statistics and spatial downscaling process to allocate crop areas for cocoa and coffee.
Calculation and introduction of internal transport costs	Collection of data about existing and planned infrastructure and transport. Calcultion of transport costs to the closest city with more than 300,000 inhabitants.	No update of planned infrastructure. Transport costs on the basis of planned infrastructure are now integrated in all scenarios including the base scenario.

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CREDITS

THE REDD-PAC PROJECT TEAM

COMIFAC: Martin Tadoum, Chouaibou Nchoutpouen, Peguy Tonga, Adeline Makoudjou, Didier Bokelo Bile, Roland Gyscard Ndinga, Eustache Awono†

IIASA: Aline Mosnier, Michael Obersteiner, Florian Kraxner, Johannes Pirker, Géraldine Bocqueho, Petr Havlík

UNEP-WCMC: Rebecca Mant, Blaise Bodin, Andy Arnell, Valerie Kapos, Paulus Maukonen

PARTNER INSTITUTIONS

COMIFAC: Central African Forest Commission

IIASA: International Institute for Applied Systems Analysis

UNEP-WCMC: United Nations Environment Programme, World Conservation Monitoring Centre

FINANCIAL SUPPORT

The REDD-PAC project is part of the International Climate Initiative (IKI). The Federal Ministry for the Environment, Nature Conservation, Building and Nuclear Safety (BMUB) supports this initiative on the basis of a decision adopted by the German Bundestag.

Supported by:

Federal Ministry for the Environment, Nature Conservation, Building and Nuclear Safety

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