Modelling Land Use Changes in the Republic of the Congo

2000–2030

A report by the REDD-PAC project

COMIFAC
IIASA
UNEP WCMC

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THE REDD-PAC PROJECT TEAM

COMIFAC: Martin Tadoum, Chouaibou Nchoutpouen,

Peguy Tonga, Adeline Makoudjou, Didier Bokelo Bile,

Roland Gyscard Ndinga

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

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List of abbreviations

CDB	Convention on Biological Diversity
COMIFAC	Central African Forests Commission
DGE	Direction Generale de l'Economie
EF	Emission Factor
FACET	Central African forests assessed by remote sensing – Forêts d'Afrique Centrale Évaluées par Télédétection
FCPF	Forestry Carbon Partnership Fund
FLEGT	Forest Law Enforcement, Governance and Trade
FREL/FRL	Reference Emission Levels for Forests and/or Forest Reference Levels
GDP	Gross Domestic Product
GHG	Greenhouse Gas
GLC	Global Land Cover
GLOBIOM	GLOBal BIosphere Management Model
HRU	Homogenous response units
IGBP	International Programme for the Geosphere-Biosphere
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
LiDAR	Light detection and ranging
MAE	Ministry of Agriculture and Livestock
MDG	Millennium Development Goal
NASA	the American Space Agency
NBSAP	National Biodiversity Action Strategy and Action Plan
NFI	National Forest Inventory
PCI-REDD	REDD+ Principles, Criteria and Indicators
PFDE	Forest and Economic Diversification Project (Projet Forêt et Diversification Economique in French)
PPP	Purchasing Power Parity
ProNAR	National Programme of Afforestation and Reforestation; "Programme National d'Afforestation et de Reboisement" in French
REDD-PAC	REDD+ Policy Assessment Centre
RIL	Reduced Impact Logging
ROC	Republic of the Congo
R-PP	Readiness Preparation Proposal
SDG	Sustainable Development Goal
SPAM	Spatial Production Allocation Model
SSP	Shared Socioeconomic Pathways
TLU	Tropical Livestock Unit
UNFCCC	United Nations Framework Convention on Climate Change
WHRC	Wood Hole Research Centre

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 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.

The Republic of the Congo is 65 % covered by forest including 21 million hectares of dense humid forests. At present, three quarters of the Republic of the Congo's dense humid forests are within forestry concessions. With a low population density and a predominantly urban population, only a small proportion of land is currently cultivated. The Congolese economy is mainly based on timber and oil exploitation, while imports cover 90 % of the country's cereal needs. The REDD+ process was official launched by the government of the Republic of the Congo in January 2010, followed three years later by the implementation of the REDD+ preparation plan.

This study seeks to identify the areas subject to the largest conversion pressures in the future and the consequences in terms of agricultural production, Greenhouse Gas (GHG) emissions and risks to biodiversity. The aim of the REDD-PAC project is to support the institutions involved in the REDD+ as well as in the planning of the National Biodiversity Strategy and Action Plan in the Republic of the Congo.

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 makes it possible to test the capacity of the model to reproduce past trends. The national model covers the Republic of the Congo as part of the Congo Basin region of the model which includes all the COMIFAC countries. The Republic of the Congo 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 218 spatial units.

Deforestation is modelled from changes in production and consumption, and for all countries at the same time. Thus, it is easy to check the validity and consistency of the estimates. It is also possible to avoid the 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. The location of cultivated land varies greatly from one vegetation map to another, and agricultural statistics are almost non-existent for the Republic of the Congo. To overcome these problems, a hybrid map was created by combining several existing vegetation maps in consultation with local experts. In the absence of sub-regional agricultural statistics, local production was derived from local consumption and trade assumptions for major cities.

According to weighted projections, 6 million people are expected to live in the Republic of the Congo in 2030, 72 % in cities. Moreover, the average GDP per head is set to 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 15,000 hectares between 2000 and 2010 to 25,000 hectares between 2020 and 2030, causing the emission of 238 million tCO_2 over the 2010–2030 period. 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 pasture.

Habitat loss constitutes one of the main drivers of biodiversity loss. The Republic of the Congo is home to two species of Great Apes which are heavily dependent upon the presence of natural forests for their habitat: the Western gorilla and the chimpanzee. These are also species which represent an important potential for the development of ecotourism. The model predicts a loss of habitat for the great apes in Bouenza, East Cuvette and South Likouala. 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.

Accrued deforestation over the period 2010–2030 varies between 425,000 and 697,000 hectares according to the scenarios, compared to 449,000 hectares in the basic scenario. Predicted future deforestation is lower when there is an increase in agricultural yields, an expansion of protected areas and a lower growth in population and GDP. On the contrary, the oil palm plantation expansion targets, 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 basic scenario. The possibility of expanding agriculture into the existing forest concessions is the scenario which increases future deforestation the most.

Several scenarios are compared in terms of agricultural production, emissions from land use change, and impacts on conservation and the sustainable usage of biodiversity. An increase in agricultural productivity, as well as lower economic and demographic growth, is projected to lead to significant gains for agricultural development, climate change mitigation and biodiversity conservation. Conversely, the combining of stronger economic growth and stronger growth in population is projected to result in degradation of all the indicators. For the other policies that are tested trade-offs are observed, such as a gain for agricultural development but losses for the environment as in the palm oil expansion target and agricultural expansion into forest concessions scenarios, or gains for climate and biodiversity but losses for agricultural development as in the protected area expansion scenario.

According to our results, an objective of 250,000 hectares of oil palm would translate into an increase in deforestation of 140,000 hectares between 2010 and 2030. In order to minimise the impact on forests and ensure the long-term viability of the plantations, the areas most conducive to the development of the plantations should be identified at the outset. The programmes targeting an increase in the plantation yields should be continued and extended. Moreover, our results show that the forest concessions can be an important brake on deforestation. The efforts which have been made to move to low impact logging in the Republic of the Congo must be pursued and go hand in hand with a better enhancing of wood products so as to ensure the long-term operation. Moreover, it is necessary to combat poaching inside the forest concessions so that these can also participate in conserving biodiversity.

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).

The Republic of the Congo is 65 % covered in forest including 21 million hectares of dense humid forests. At present, three quarters of the Republic of the Congo's dense humid forest are within forestry concessions. With a low population density and a predominantly urban population, only a small proportion of land is currently cultivated. The Congolese economy is mainly based on timber and oil exploitation, while imports cover 90 % of the country's cereal needs. The REDD+ process was official launched by the Government of the Republic of the Congo in January 2010 with the drafting of the Readiness Preparation Proposal (R-PP). Phase 1 of the REDD+ process started in January 2013 through the Forest Carbon Partnership Facility (FCPF) of the World Bank and the UN-REDD Programme. Within this framework 8 million dollars have been provided for the implementation of the R-PP in the Republic of the Congo.

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 understanding 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 activities [REDD +], 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. The Republic of the Congo 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. The Republic of the Congo has published a NBSAP in 2015 which incorporates the Aichi Targets. The COMIFAC Convergence Plan , to which the Republic of the Congo belongs, also promotes the adoption of sustainable management policies for forests in the sub-region.

REDD+ presents numerous potential opportunities for 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 the Republic of the Congo 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 the Republic of the Congo. 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 Current status of REDD+ in the Republic of the Congo

The Republic of the Congo has been involved in the REDD+ process since 2008 and has shown significant progress in relation to the elements of the preparatory phase of the mechanism. The Republic of the Congo's REDD+ National Strategy is based on three major objectives: (i) contributing to the fight against climate change, (ii) fighting against poverty and (iii) effectively setting the bases for a green economy, one of the country's sustainable development tools. A particular focus is placed on: (i) the mobilisation of funds which meet the National vision and ambitions in terms of REDD+, (ii) the improvement of the National macroeconomic framework and country's economic growth, (iii) the improvement of people's living conditions and fighting poverty. The REDD+ National Strategy is being finalised and structured on the basis of four strategic intervention objectives (strategic options). Moreover the Republic of the Congo has developed a series of REDD+ Principles, Criteria and Indicators in response to the UNFCCC requirements outlined in the Cancun safeguards.

2.1 Study on deforestation drivers

A preliminary analysis of the drivers of deforestation and forest degradation has been carried out for the drafting of the R-PP and was then supplemented by an in-depth study of the causes of deforestation and forest degradation in 2013. The main causes of deforestation, according to this study, were agriculture and infrastructure development, whereas the main causes of forest degradation are wood for burning and industrial logging. In concrete terms:

- The agricultural sector is the main cause, both now and in the past, of deforestation and degradation, particularly as a result of family or traditional agriculture which is what is most practised in the Republic of the Congo. In this type of production, set-aside land is traditionally used. Set-aside tenders to increase land needs for agriculture but in the absence of fertiliser, it is the main way to restore fertility to the soil after farming cultivation.

- Wood remains the main source of rural and urban domestic energy in the Republic of the Congo. The unsustainable use of forests to meet energy needs is frequently observed in the Republic of the Congo, particularly in natural forests located close to major urban centres and gallery forests in savannah areas. Alternative wood energy is too expensive for most households.

- Urban sprawl is a direct cause of deforestation and forest degradation. This urban sprawl is accompanied by an increase in logging, often illegal, in order to supply the market in large towns with fire wood and timber.

- The industrial logging practised in the Republic of the Congo is very selective with on average 11 m^3 of wood per hectare. Industrial exploitation may result in increased deforestation through the creation of infrastructure for the removal of the wood that facilitates access to the forest for the local population. However, deforestation in forest concessions is currently limited due to the low population density in these areas.

- Apart from oil, currently operated offshore, mining surveys (gold, iron, diamonds, potash, etc.) have not yet resulted in a mining permit of a large enough scale to have major consequences for deforestation and degradation. Numerous explorations are underway and may lead to iron, gold and oil being extracted on land. Exploration is somewhat disruptive, but the operation could lead to a direct destruction of forests or ecosystems (open pit mining, mercury pollution, soiling of water resources and soil, etc.) and indirectly via the settling of forest populations.

2.2 Defining the benchmark for forest emissions

The UNFCCC defines the national forest reference emission levels and/or forest reference levels (FRELs/FRLs) as "[…] benchmarks for assessing each country's the performance in implementing the [REDD + activities]." The decisions taken by the UNFCCC Conference of the Parties also indicates that FRLs should take historical data into account for future projections and adjust these in line with national circumstances (UNFCCC decision 4/CP15). In February 2015 the Republic of the Congo defined the technical protocol for determining its REDD+ reference level. This makes the following points:

- A forest is defined as a minimum surface area of 0.5 hectares, tree cover of a minimum of 30 % and a minimum tree height of 3 metres.

- The activities considered are planned deforestation, unplanned deforestation, planned degradation and unplanned degradation. Planned here means "authorised by competent state structures". It is stated that planned deforestation only started in the Republic of the Congo in 2012 and therefore is not present in historical date. Reforestation is not included in this preliminary reference level.

- Carbon reservoirs taken into account are the above-ground living biomass and the below-ground living biomass.

- The historical period which is chosen for the calculating of the FREL is the period 2000–2010 or the period 2000–2012.

- Depending on the progress of the National Forest Inventory (NFI) work, the emission factors (EF) will be calculated using either NFI data or other sources.

Adjusting the historical data according to national circumstances can be justified where historical emissions do not reflect probable future emissions, for example in countries with historically low deforestation levels and with a strong population growth. The models can help to highlight which factors have a major impact on future deforestation and therefore can be useful for adjusting to national circumstances. However, any model used to support the development of a FREL/FRL must be clearly documented, including across all data and hypotheses used, and be regularly updated in order to include new data, as well as be in line with the national communications and the GHG inventories. This can be a challenge for models which can be complex and which use a lot of different data.

The UNFCCC states that the FRELs/FRLs must maintain consistency with the national GHG domestic inventories, particularly regarding the definition of the forest used, provide transparent, complete, consistent and accurate information including methodological information, used at the time of construction of the FREL/FRL. It also agrees that a step-wise approach may be useful and acknowledges that sub-national

FRELs/FRLs may be elaborated as an interim measure (UNFCCC decision 12/CP.17). These provisions makes it possible for countries to improve their FREL/FRL over time by incorporating better data, improved methodologies and, where appropriate, taking additional carbon pools.

In accordance with the common position note of the COMIFAC countries, who want reference levels to be based on historical emissions and take into account future policies on economic and social development, the reference level proposed by the Republic of the Congo should be calculated based on an adjusted historical reference level.

3 The model

3.1 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 the Republic of the Congo 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 31).

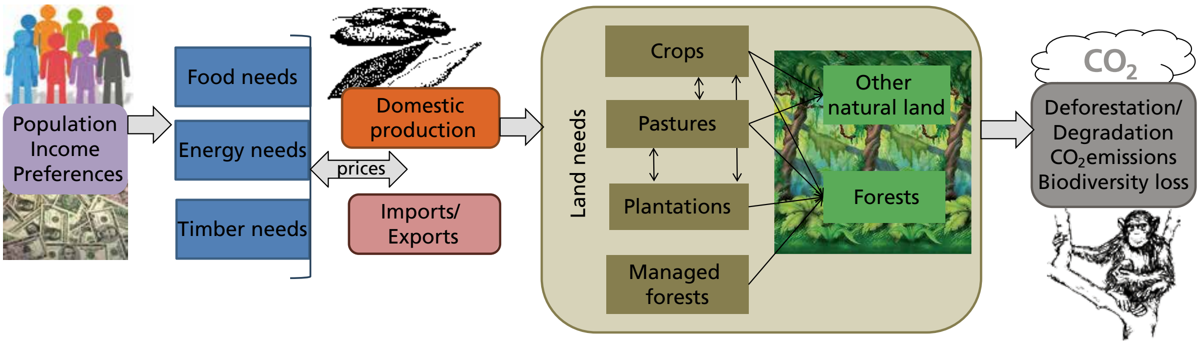

Figure 1: Future deforestation depends on future needs in terms of food, wood and energy in the GLOBIOM-ROC model

The main characteristics of the GLOBIOM model are the following.

- Balanced market 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 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 balanced 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.

- Spatial balanced 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 equalling 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. 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).

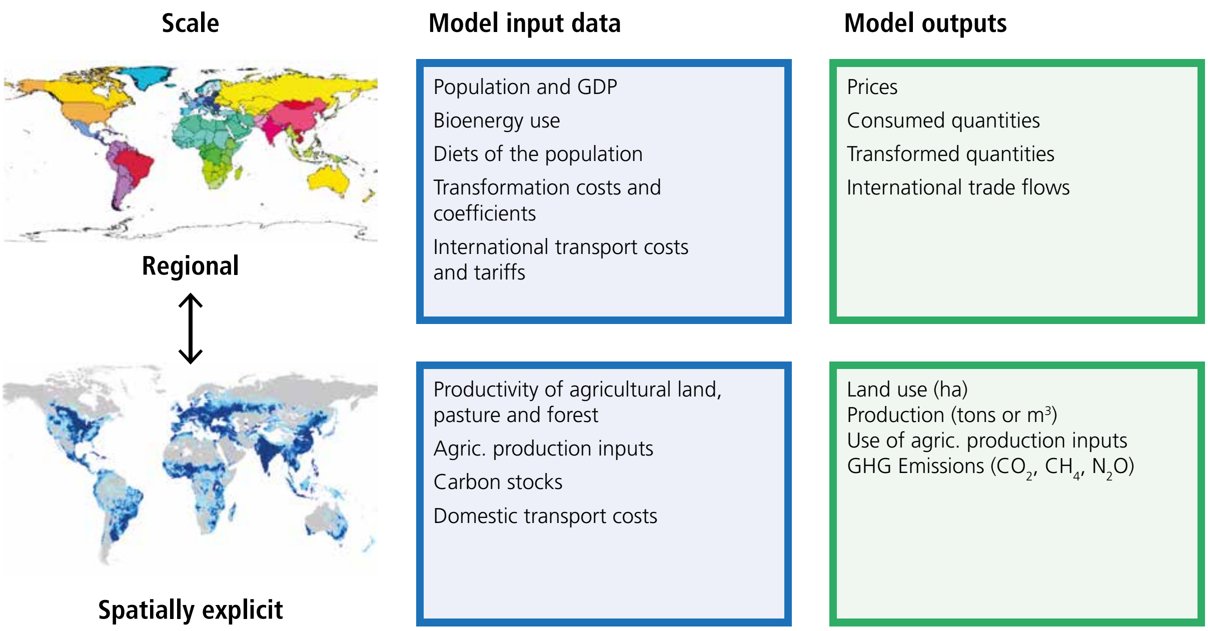

Figure 2: Main input and output data of the GLOBIOM model at different levels

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 10km which are in the same country (dashed line), a same pixel whose size is ~50 x 50km (blue grid), and a similar homogenous response unit (HRU- Homogenous Response Units) (there are 4 HRUs in the figure on the left represented by orange, violet, green and yellow surfaces). The Homogenous 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 EPIC biophysical model simulations which calculates the productivity potential for 17 crops and for the GLOBIOM economic model. In total there are 217,707 simulation units globally whose size varies between 10 x 10km and 50 x 30km (in the example below, 27 simulation units are represented with each having a different colour in the image to the right).

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 . Productivity and production costs vary according to biophysical potential and management type (Herrero et al, 2008; Sere et Steinfeld, 1996). Currently 18 crops, five forest products and six livestock products (4 types of meat, eggs and milk) are included in the model.

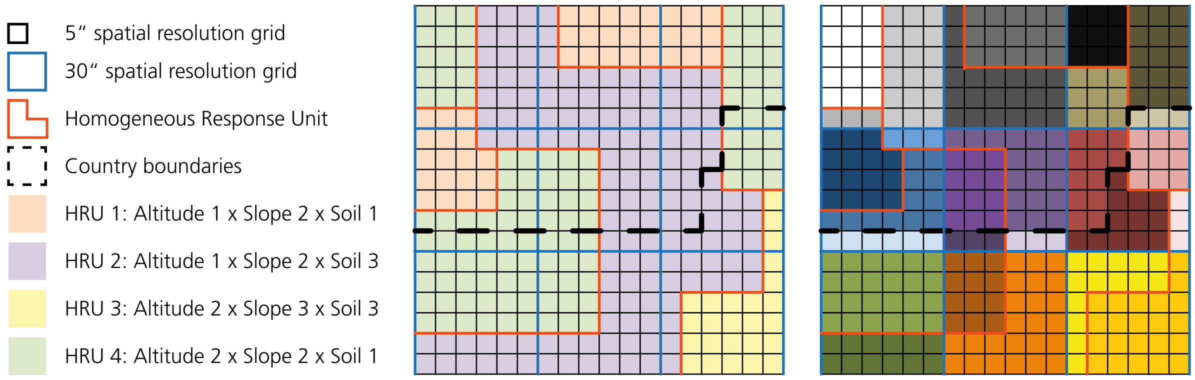

Figure 3: Elements used for defining the simulation units

3.2 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.

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 pushed 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 4.4.5.)

- "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 licences 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 "RED-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).

3.3 The GLOBIOM model adapted to the Republic of the Congo

For the REDD-PAC project it has been decided to enlarge the sub-regional model to all COMIFAC countries (the 6 countries named above plus Rwanda, Burundi, and Chad) and to develop national models for 3 pilot countries: DRC, the Republic of the Congo (ROC) and Cameroon. The COMIFAC region is linked to the other regions of GLOBIOM whereas the Republic of the Congo can also trade with the other sub-regions of the COMIFAC space: Cameroon, 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.

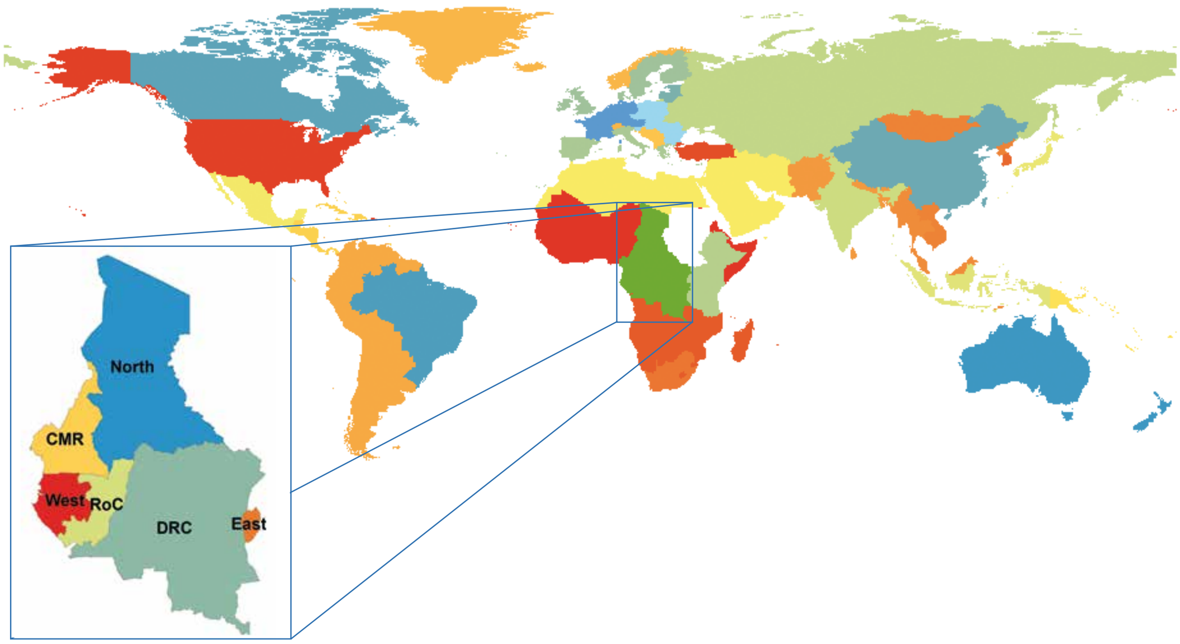

Figure 4: The Republic of the Congo (RoC) is a sub-region of the COMIFAC zone (left) which is linked to the 29 other regions of the global model (top)

In total, the Republic of the Congo includes 1,420 simulation units whose size varies 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 administrative level of the Republic of the Congo (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 ~50 x 50km, which results in 218 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.

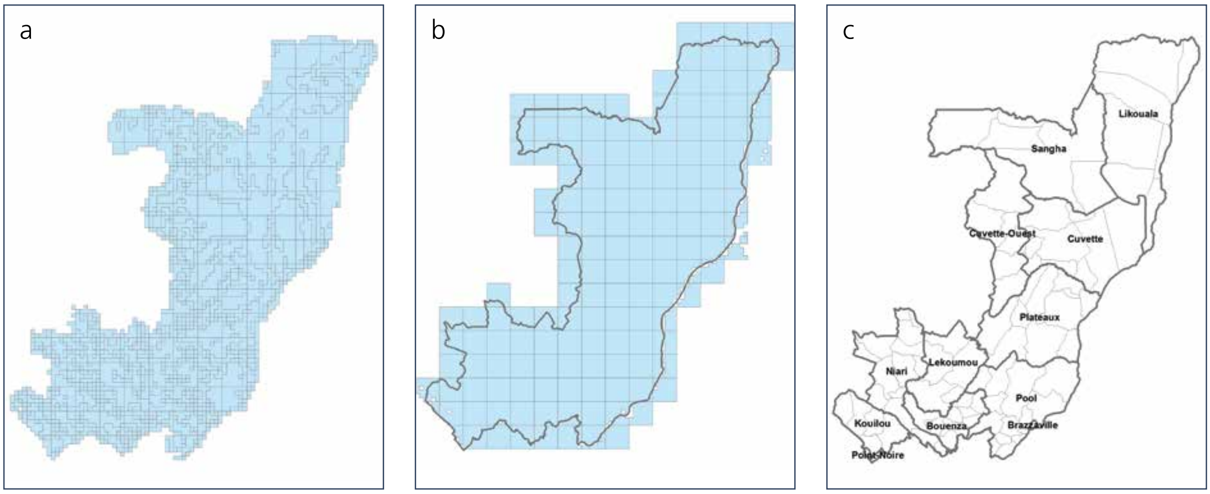

Figure 5: The simulation units (a), the 30 ArcMin grid (b) and the departments (c) in Republic of Congo

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 the Republic of the Congo 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. However, the breakdown of the cultivated land seems to cause some problems. It has therefore been decided to choose a new vegetable cover map for the ROC which will be presented in section four of this document.

Special attention has also been paid to improving the representation of the deforestation drivers and of the forest degradation in ROC. The causality diagrams of deforestation and forest degradation by sector have been established during a workshop held in Brazzaville 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.

3.4 The main drivers of the deforestation in the Republic of the Congo 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 Brazzaville on 29 and 30 January 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, we explain how this is represented in GLOBIOM.

3.4.1 Food needs

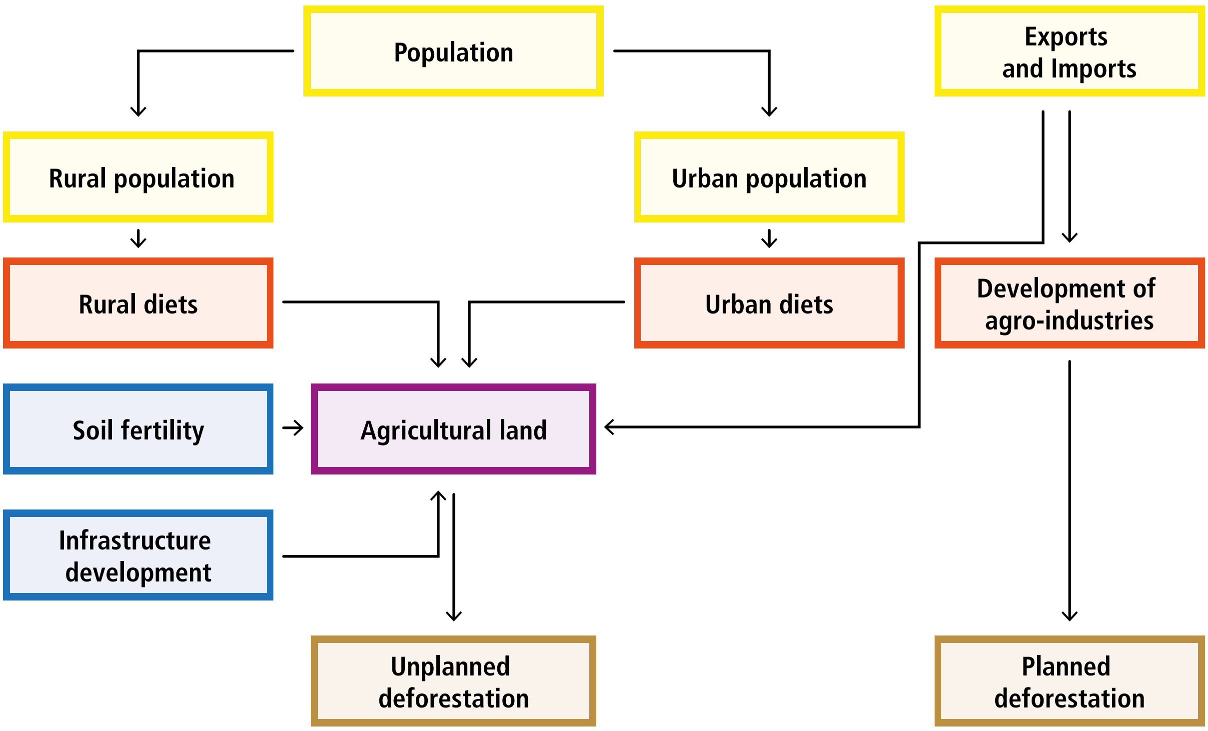

Figure 6: The impact of food needs on forest degradation and deforestation. Diagram made during the group work.

Description of the flow chart: The food needs depend on the evolution of the Congolese population but also on the breakdown of this population between rural and urban which have different food needs (Figure 6). If the food demand is satisfied by local production, this is translated into land needs for agriculture, i.e. the area under cultivation. The area under cultivation will also depend on the change in soil fertility and in the development of infrastructures. The new land needs for subsistence agriculture can lead to unplanned deforestation. The development of agro-industries is determined by the change in demand outside the country for certain products such as palm oil, cacao and coffee in accordance with the state granting these concessions. This can lead to planned 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 cropland 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 (www.iiasa.ac.at/EPIC). 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 have more advantageous prices.

3.4.2 Energy needs

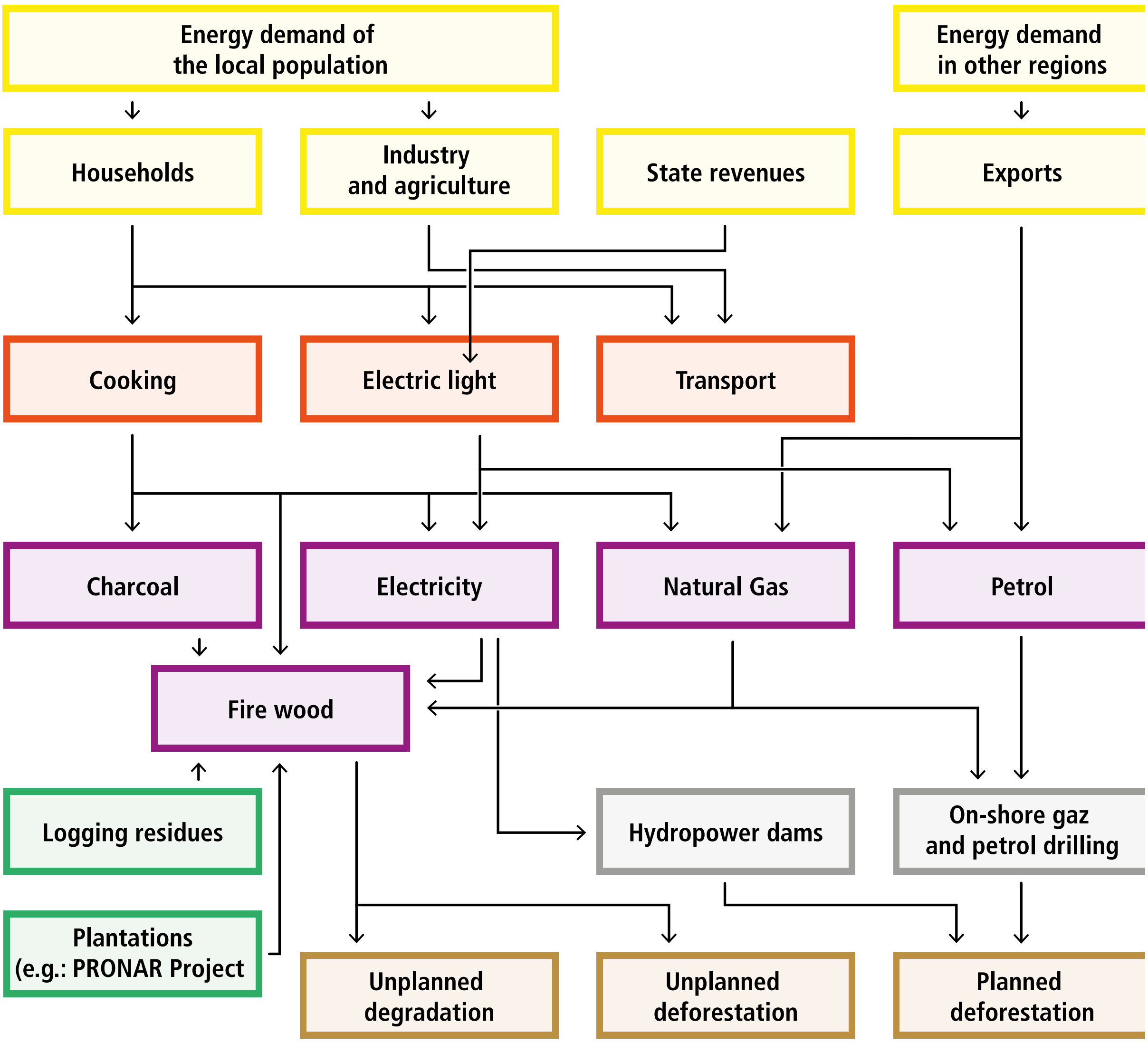

Figure 7: The impact of energy needs on forest degradation and deforestation – Diagram made during group work at the Brazzaville workshop

Description of the flow chart: The workshop participants started by identifying the household energy needs. Their energy demand for cooking can be satisfied by coal or firewood which are currently the main sources of supply but also by electricity (heating plates), gas or petrol which can be alternatives in the future. The recurrent collecting of fire wood also causes degradation or unplanned deforestation but the impact also depends on the efficiency of households and the carbonisation of wood to produce coal (Figure 7). The impact of firewood needs on forests can be mitigated by the use of waste from logging or from fast rotation plantations as envisaged in the ProNAR (National Programme of Afforestation and Reforestation; "Programme National d'Afforestation et de Reboisement" in French) project.

Representation in the model: The model only represents the agricultural, forestry and bio-energy sectors. The removals of firewood can be associated with subsistence farming or be carried out informally in unmanaged forests. In the GLOBIOM model, we have introduced the cooking energy demand for the Republic of the Congo according to our own calculations. It depends on the growth of the total population and on the share of the population living in rural and urban areas, respectively. Indeed, charcoal is preferred by urban households as it has the advantage of being easy to transport and store, and because its energy content is double the energy content of firewood, whereas in the rural area where wood resources are easy to access, wood is by far the most dominant energy source.

We assume in the model by default that 60 % of urban Congolese households use charcoal for cooking and that the rural population only use wood for heating. As coal and fire wood have different energy yields (Figure 8), we use the estimates of the UN regarding growth in rural and urban populations to calculate the average energy use for cooking at the country level (same hypothesis for all scenarios). So, in 2000, with 58 % of urban households the average energy content is equal to 6.02 GJ/m^3 at the national level (58 % x 5.14+42 % x 7.24 GJ/m^3), but it 2030 with 71 % of urban households, this average energy yield falls to 5.75 GJ/m^3 in 2030 (71 % x 5.14+42 % x 7.24 GJ/m^3). The growing urbanisation of the population will lead to an increase in energy needs from wood, because if charcoal production technology and cooking stoves remain the same as today the use of coal doubles the need for wood compared to the traditional cooking methods in rural areas.

In order to calculate the initial energy demand for cooking, we use average energy consumption per 2000 inhabitant of wood for fire wood (production of fire wood reported by the FAO) adjusted by the growth of the population and the change in energy efficiency following a larger use of charcoal owing to the increasing urbanisation.

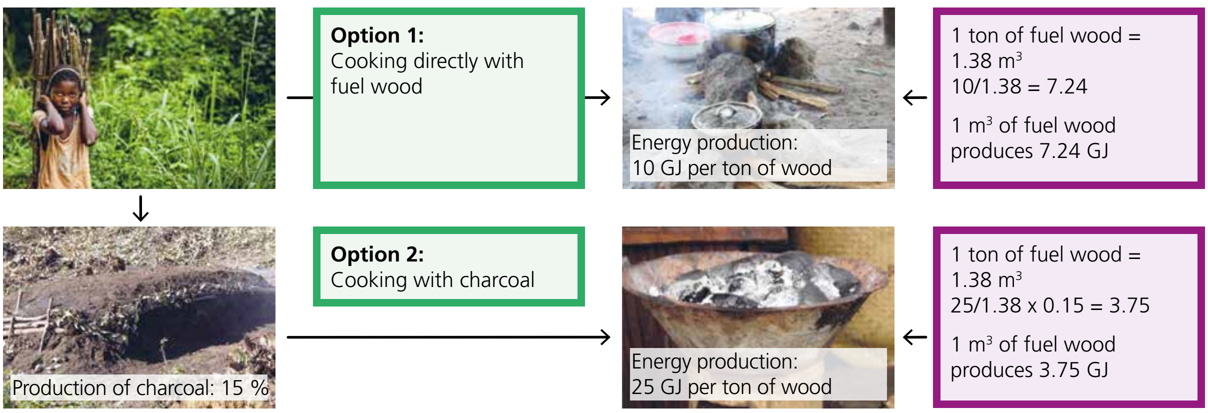

Figure 8: Conversion of fuel wood and charcoal into energy for cooking

3.4.3 Lumber needs

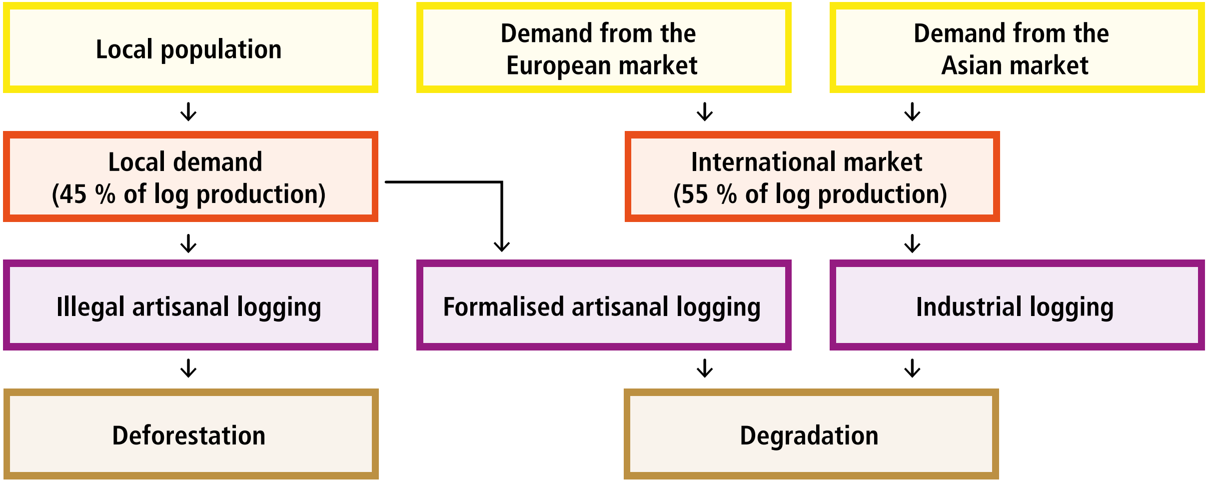

Figure 9: The impact of lumber needs on forest degradation and deforestation – Chart created during group work at the Brazzaville workshop

Description of the flow chart: The participants identified three separate markets – demand from the local population and the European and Asian markets. To satisfy these needs, three types of logging take place in the Republic of the Congo: industrial logging, formal artisanal logging as well as illegal logging. Industrial logging meets the needs of the European and Asian market whereas artisanal illegal logging supplies the local market. Whereas formal industrial logging and formal artisanal logging can, in practice lead to forest degradation, recurrent illegal artisanal logging can lead to deforestation (Figure 9). Currently in the Republic of the Congo, artisanal licences are no longer issued, only existing concessions are subject to a formalisation process.

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 as well as flooded forests are classified as not available for logging.

3.4.4 Mineral needs

Description of the flow chart: Mineral needs come mainly from demand from outside the Republic of the Congo. Mining licences are granted by the Congolese State after compliance with the legislative framework has been checked and several studies have been conducted. The authorisation of mining licences consequently leads to planned deforestation linked to the exploitation of the minerals. However, the building of transport infrastructure to transport the minerals to the towns or ports and the settling of the workforce with their families can cause the spontaneous development of gold mines and agriculture. The corollary of these indirect effects can be deforestation as well as the non-planned degradation of the forests (Figure 10).

Representation in the model: The "mines" module 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 Congolese household. 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.

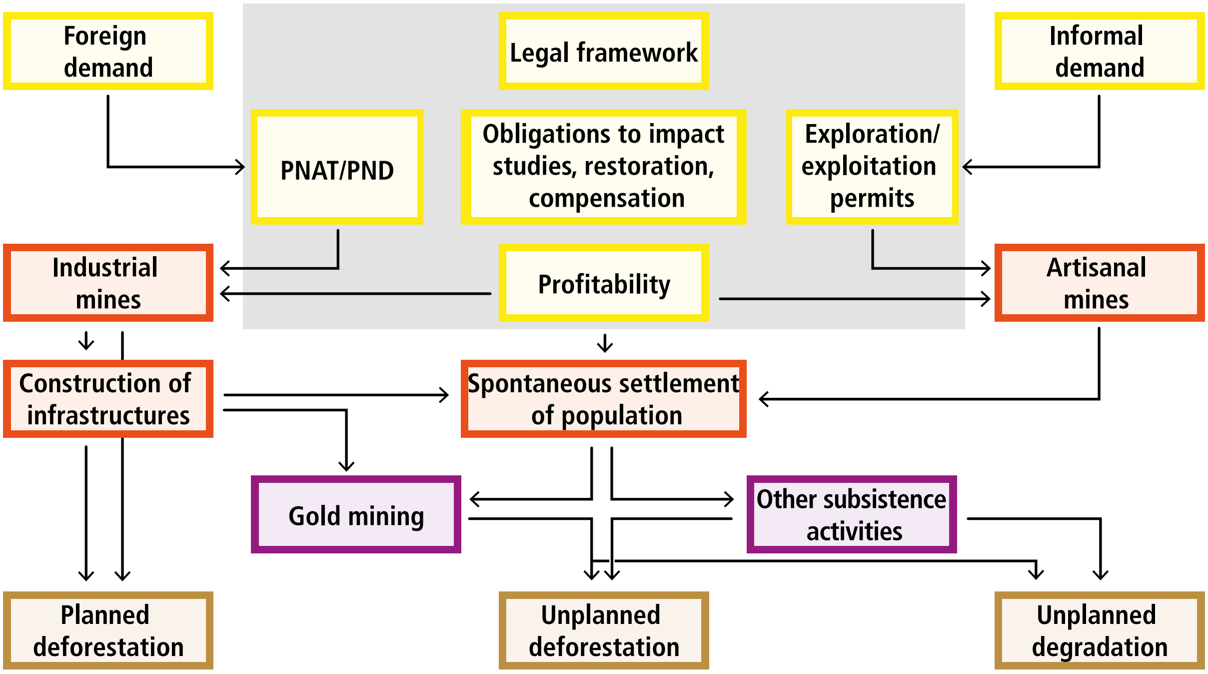

Figure 10: The impact of mining on forest degradation – Chart created during group work at the Brazzaville workshop

4 The land use map

4.1 Global vegetation maps

4.1.1 GLC 2000

The Global Land Cover 2000 map was produced by the Joint Research Centre using the satellite images of the SPOT 4 VEGETATION 1 programme between November 1999 and December 2000 (http://www.cnes.fr/web/1468-vegetation.php) 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.,* 2003 for Africa) and then merged to create a global map at a spatial resolution of 1 km at the Equator.

4.1.2 GlobCover 2005–2006

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.

4.1.3 MODIS collection 5

The MODIS vegetation map was made 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.

4.2 The regional land cover maps or those specific to the Republic of the Congo

4.2.1 UCL 2005

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.

4.2.2 FACET

The FACET forest map (Central African forests assessed by remote sensing – Forêts d'Afrique Centrale Évaluées par Télédétection (Mane *et al.,* 2012) map uses Landsat and MODIS satellite data. 8881 Landsat images with less than 50 % could cover produced between 2000 and 2010 have been used whereas a set of measures derived from MODIS between 2000 and 2009 have made it possible to standardise the Landsat images for the forest classification and for the change to the first cover (Potapov *et al.,* 2012). The forest is broken down into three classes: the primary dense humid forest, secondary dense humid forest and other wooded areas. The forest definition of the first used is a minimum canopy cover of 30 % and a minimum height of 5 m. Unfortunately, non-forest land is not differentiated between the different types of vegetation and the cultivated land. The basic vegetation map is available for 2000 while the deforestation maps were produced for the 2000–2005 and 2005–2010 periods at a spatial resolution of 60 m.

4.2.3 GAF

The main objective of the GAF study was to determine the historical forest cover dynamics in the Republic of the Congo on the basis of high resolution satellite imagery over the periods 1990–2000 and 2000–2010. For the historical periods of 1990 and 2000, satellite data is mainly composed of Landsat TM and ETM scenes while for 2010, SPOT4 and SPOT5, DMC, RapidEye, Landsat 7 and Landsat 8 scenes were used. As for FACET, the maps produced by the consortium led by GAF do not distinguish between non-forest classes.

4.3 Comparison of the existing maps for the Republic of the Congo

For the Republic of the Congo, the six maps described previously have been analysed: GLC2000, Globcover, MODIS, UCL2010, FACET and GAF. In order to better understand the existing maps a first step has been to aggregate them into the same classes of vegetation (consult annexed Table and www.geo-wiki.org for the display). We tried to be coherent with the definition of the forest according to the forest definition submitted by the Congolese government to the UNFCCC: the canopy cover should represent more than 30 % of the surface area with a minimum forest area of 0.5ha and a height in excess of 3 m. This definition is more restrictive than the one employed by the FAO where the minimum canopy cover should only be greater than 10 % (FAO 2010). The different types of vegetation that are represented in GLOBIOM are: cropland, pasture, dense humid forests, dry forests, flooded forests, other flooded areas and other natural lands.

It was decided to rather use a hybrid card or multiple cards can be used to best represent a certain class of plant cover or vegetation cover of a certain region.

There are great uncertainties with regard to current land use in the Republic of the Congo, particularly for arable land (Figure 11 and Figure 12). Three similar terms used in this report require definition. Cultivated land corresponds to land bearing temporary and permanent crops; arable land in the definition used here is the above plus associated fallows. Agricultural land comprises all arable land plus pasture. The total surface area of arable land varies from between 1.3 and 5.4 million hectares in the four vegetation maps studied. The geographical breakdown is also very different from one map to the other. GLC identifies the arable land mainly in the areas of Cuvette and Cuvette Ouest whereas MODIS and UCL identifies large areas of arable land in Pool and Plateaux. On the basis of the discussions with the national experts it seems that this was significantly overestimated in relation to the reality and Globcover has been selected as being the most representative of the reality.

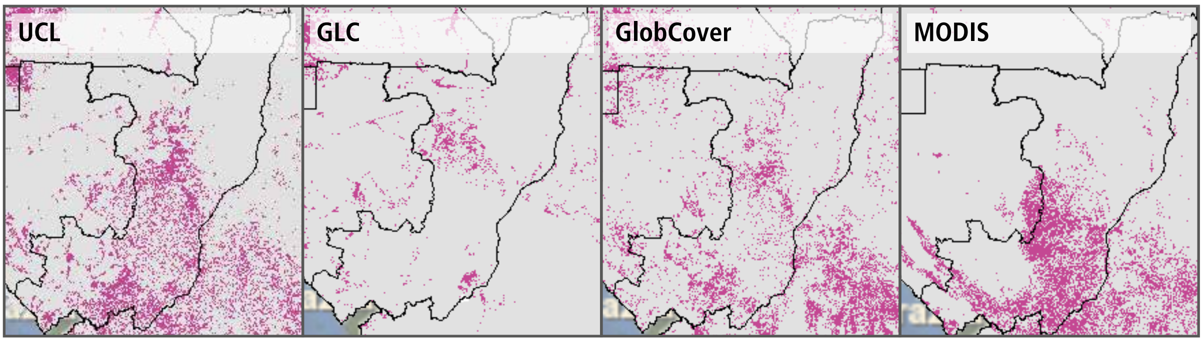

Figure 11: Location of cropland in the Republic of the Congo according to different sources

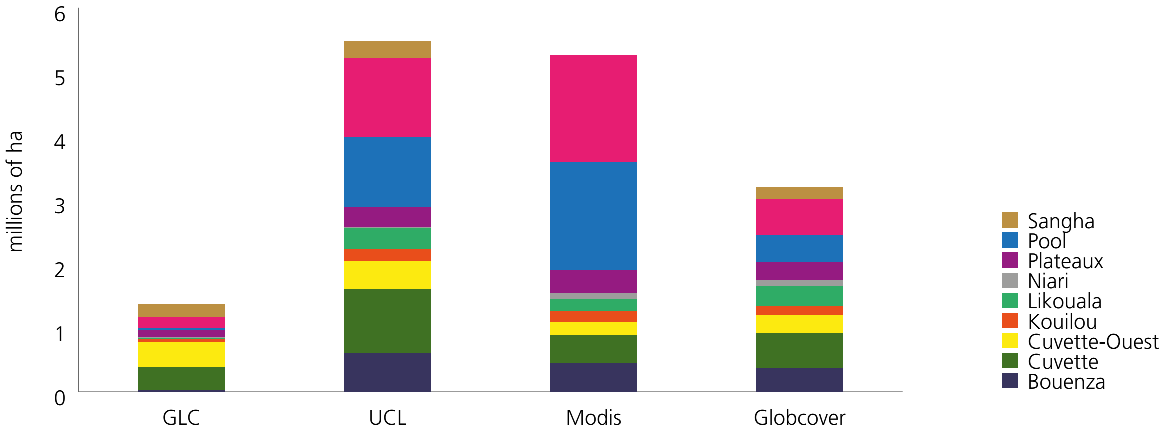

Figure 12: Distribution of cropland according to different vegetation maps

The uncertainties are less pronounced for forest land but the total forest surface area nevertheless varies between 21.5 and 26.9 million hectares according to the maps (Figure 13). The GlobCover map was also used for forest surfaces in the Hybrid map except for the flooded forests class which seemed a little overstated in GlobCover according to the observations of the projects; national experts and was replaced by that of the UCL map. There is a good agreement between the sources about the forest area in the Sangha and Likouala, the main forest departments of the Republic of the Congo, but uncertainty is higher in other departments (Figure 14). However, we see a good agreement between the Globcover map which has been used in our hybrid map and the FACET and GAF maps.

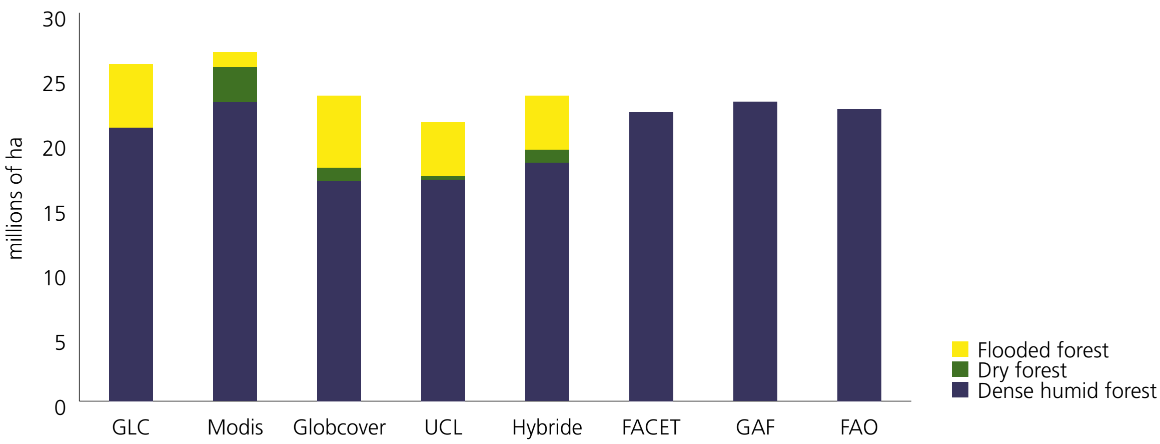

Figure 13: Breakdown by forest type according to different sources

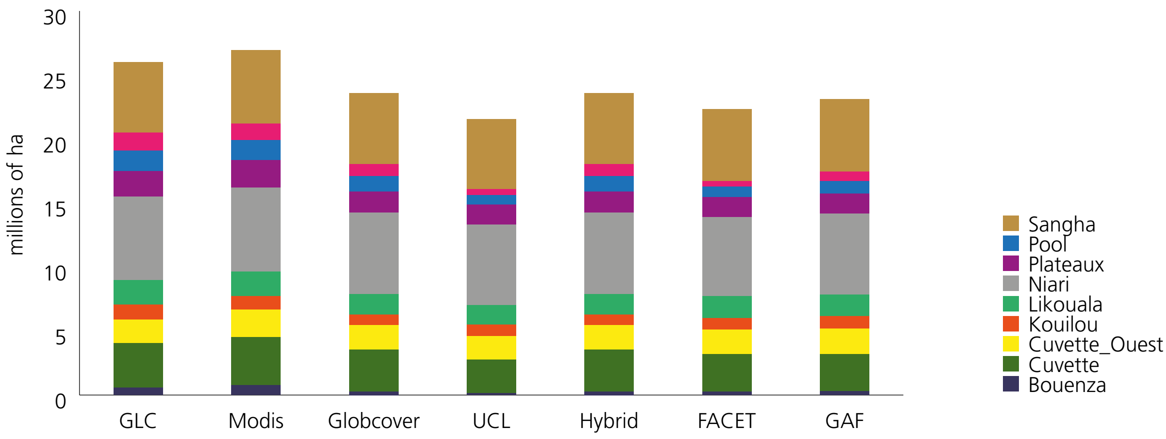

Figure 14: Distribution of forest land according to different land cover maps

4.4 Harmonisation of the vegetation map with the various uses

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. Cropland 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.

4.4.1 Forest concessions and the protected areas

The maps of forest concessions and protected areas incorporated in the model for the base year 2000 comes from the WRI Interactive Forest Atlas of the Republic of the Congo which represents the data for approximately the year 2006. The area under active forest concessions was 11.8 million hectares, the area under unallocated forest concessions was 3 million hectares and protected areas covered about 3.5 million hectares (Figure 15).

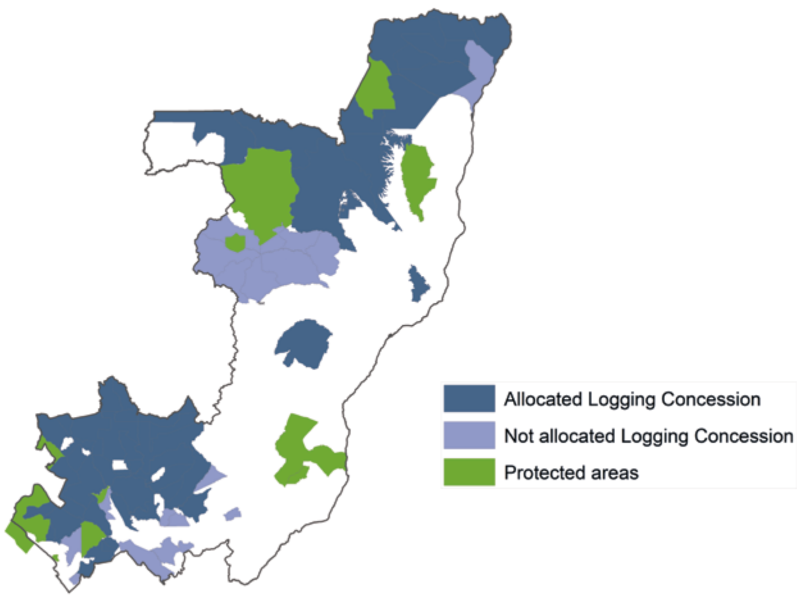

Figure 15: The forest concessions and the protected areas listed in 2006 in the Republic of the Congo by WRI

We sometimes observe an overlapping of forest concessions and protected areas in the Congo Basin. 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 16). This explains why the protected areas in the model can be less that the official surface area (Table 1). Protected areas are then divided by land cover class: in the model, 84 % of the area of the protected areas is included in the forests class of which 70 % is in the "dense humid forests" vegetation class.

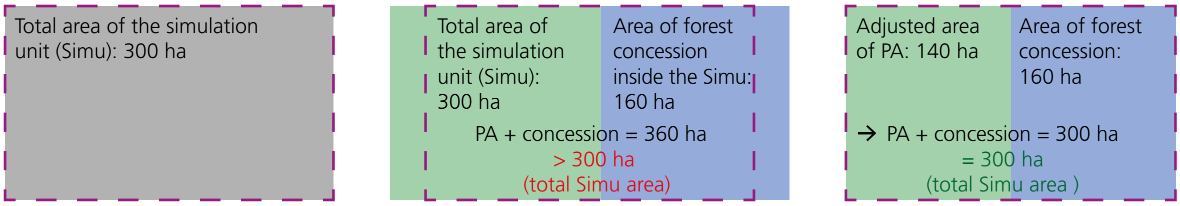

Figure 16: Procedure for adjusting the protected areas if there is an overlapping of uses

We recall here that the forests managed in the model correspond to sustainably managed forests, that is to say with sampling rates that 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 the Republic of the Congo (in millions of hectares)

	Initial forest area data	Total forest area in the model	Of which dense humid forests	Of which flooded forests	Of which dry forests	Of which other natural land
Protected area	3.5	3.3	2.3	0.3	0.2	0.5
Natural forests	11.8	10.2	10.2			

In total, there are therefore 13 million hectares 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 the Republic of the Congo.

Since 2006, other forest concessions were granted in RoC and have been added to the "managed forests" class for the periods after 2010. This represents an additional area of forest of almost 2.5 million hectares that cannot be converted to other uses in the baseline scenario (Figure 15).

4.4.2 Cultivates areas

For the Republic of the Republic of the Congo, the agricultural statistics are unfortunately very limited and unreliable. We initially looked at the data provided through the study carried out by SOFRECO-CERAPE in 2011. A first challenge was to convert processed products into equivalent primary product (Table 2).

Table 2: Conversion coefficient for cassava products in fresh roots

Product	fresh roots	Cassava chips	Cassava chips	Chikwangue
Conversion coefficient in	1	2.56	2.02	1.79

Source: Ngonde Nsakala, (s. d.)

However, whereas cassava is the top consumer product in the country, production is only provided for five departments with a distribution unrelated to the population distribution and so it seemed to us to be difficult to use this data to inform the model (Figure 17). We then used the information from an OTF report (2009) for the World Bank on cassava in the Republic of the Congo and we found more reasonable estimates on cassava production and on cassava supplies from the two main cities of Pointe-Noire and Brazzaville. These figures represent production estimates for 1997 and inquiries in the urban centres.

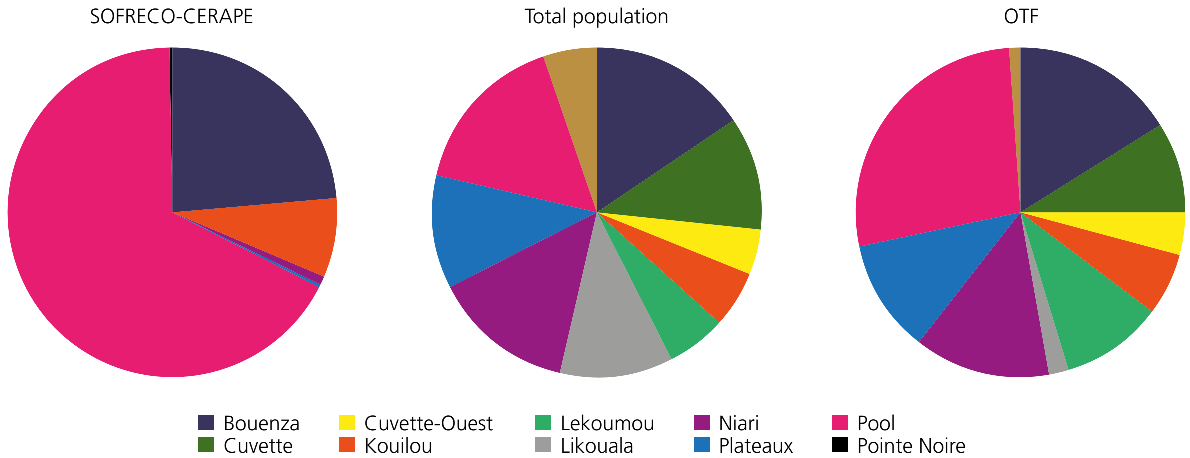

Figure 17: Comparison between the production breakdown of cassava reported in the SOFRECO-CERAPE study (left), the breakdown of the population by province (centre) and the breakdown of the cassava production reported by the OTF study (rights)

We have also tried to reconstruct the production data on the basis of the consumption. According to the FAO and the Ministry of Agriculture and Livestock (MAE), the average consumption per habitant and by year in rural zones is 425 kg whereas the average urban consumption is 175kg per year (OTF 2009) . For simplicity, we consider Brazzaville and Pointe-Noire as urban areas whereas the other departments are entirely rural. We thereby obtain the total consumption of cassava per year and per department. The production is calculated as the total consumption of the rural areas plus the share of the urban production which comes from each department by using the OTF data.

For example for Pool, in 2000 the population was estimated at 219,511 and the average per capita consumption at 425 kg, which gives us a total local consumption of 93,292 tonnes per year. The population of Brazzaville was estimated at 1,256,839 in 2000. If the average per capita consumption was 175 kg per year, while the total consumption of cassava Brazzaville was 219,946 tons. Similarly for Pointe Noire, with a population of 581,632, the total cassava consumption is estimated at 101 785 tonnes. The total cassava production in Pool in 2000 is estimated at 93,292 plus 57 % of the consumption of Brazzaville and 9 %

of consumption of Pointe Noire which gives us 227,823 tonnes (Table 3). The total production obtained in this way is 840 thousand tonnes on 2000, which is very close to the production reported by the FAO (816).

This method, although it is based on several assumptions, also has the advantage of making projections for local production in the future based on changes in the population by department. For other model crops (sweet potato, peanut, corn, rice, beans) we use the same production distribution as calculated for cassava. For sugar cane, we use the data provided by SARIS Congo on their plantation in Bouenza (12,000ha).

In the model, we need the initial surfaces by culture. In the absence of any other information, we used the average yield per crop in the Republic of the Congo reported by the FAO to convert the surface area production data by department. We thereby obtained a total surface area of farmland of 143 thousand hectares.

Table 3: Estimation of the consumption and of the production of cassava in 2000 by department

	Local cons. (1000T/an)	From the cons. in Brazzaville	Prod. for Brazzaville (1000T/an)	From the cons. in Pointe-Noire	Prod. for Pointe-Noire (1000T/an)	Total prod. (1000T)
TOTAL	853.3		206.8		101.8	840.1
Bouenza	90.4	6 %	13.2	30 %	30.5	134.2
Cuvette	64.5	6 %	13.2	0 %	0.0	77.7
Cuvette Ouest	26.3	4 %	8.8	0 %	0.0	35.1
Kouilou	31.8	0 %	0.0	18 %	18.3	50.1
Lekoumou	33.3	0 %	0.0	17 %	17.3	50.6
Likouala	32.7	0.0 %	0.0	0.0 %	0.0	32.7
Niari	79.9	2 %	4.4	26 %	26.5	110.8
Plateaux	64.5	19 %	41.8	0 %	0.0	106.3
Pool	93.3	57 %	125.4	9 %	9.2	227.8
Sangha	14.8	0.0 %	0.0	0.0 %	0.0	14.8
Brazzaville	219.9	0.0 %	0.0	0.0 %	0.0	0.0
Pointe-Noire	101.8	0.0 %	0.0	0.0 %	0.0	0.0

4.4.3 Agricultural fallows

To obtain the total agricultural areas, the fallows should also be added. We assume that the fallow period decreases with population density. Three thresholds are considered :

- for a population density below 20 inhabitants per km², 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 km², 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 km², 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 restoration of the soil fertility through long fallow period is particularly widespread in the dense humid forest areas but in the savannah areas, the fallow time is generally shorter. We assumed that in the Batéké plateaux area and in Pointe Sud, the fallow time was reduced to two years (the land multiplier coefficient of cultivated land is equal to 2). Figure 18 shows the heterogeneity of the cultivated land multiplier coefficient in obtaining the total arable land bearing in mind the different fallow practices across the country.

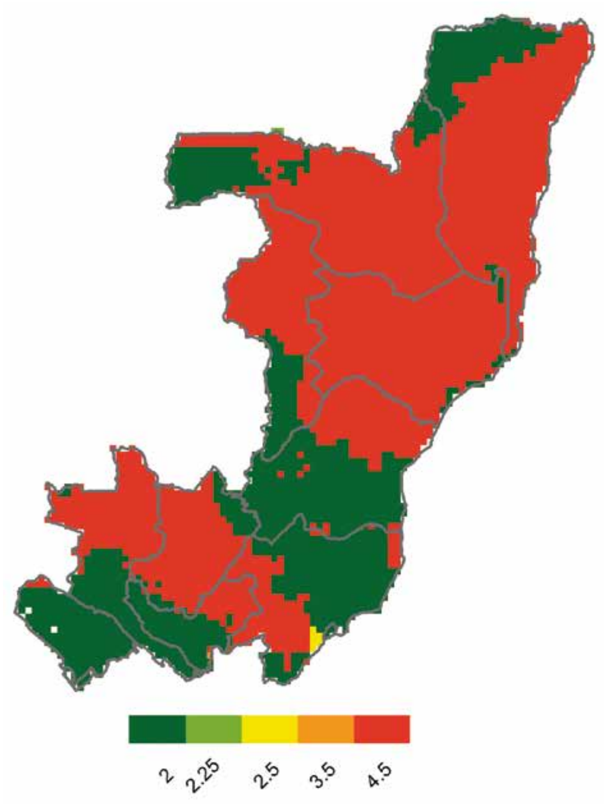

Figure 18: Arable land multiplier coefficient to taken into account the different fallow times

4.4.4 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 and Mosnier, 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. 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.

- The 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.

- The type of soil. 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.

Our results show that the Republic of Congo has a total of 28.55 million hectares of land suitable for the industrial cultivation of palm oil, corresponding to 83 % of the national land area (Figure 19). Most of the land suitable for oil palm cultivation is in suitabilityclass 3 out of 5, that is to say an average potential productivity level. The biophysical conditions necessary for having a very high potential for oil palm cultivation are not met in the Republic of the Congo. One third of suitable land is occupied by land that has only a marginal production potential, i.e. the oil palm can grow in these regions but the productivity tends to being low.

From a climate-topography-soil perspective the north of the country is more favourable to oil palm cultivation, with the exception of permanently flooded areas in the north-east as well as Niari and Lekoumou departments. The central regions (Plateaux and Pool) have a low production potential and part of the Kouilou department is not at all favourable because of the strong presence of sand in the soil of this department.

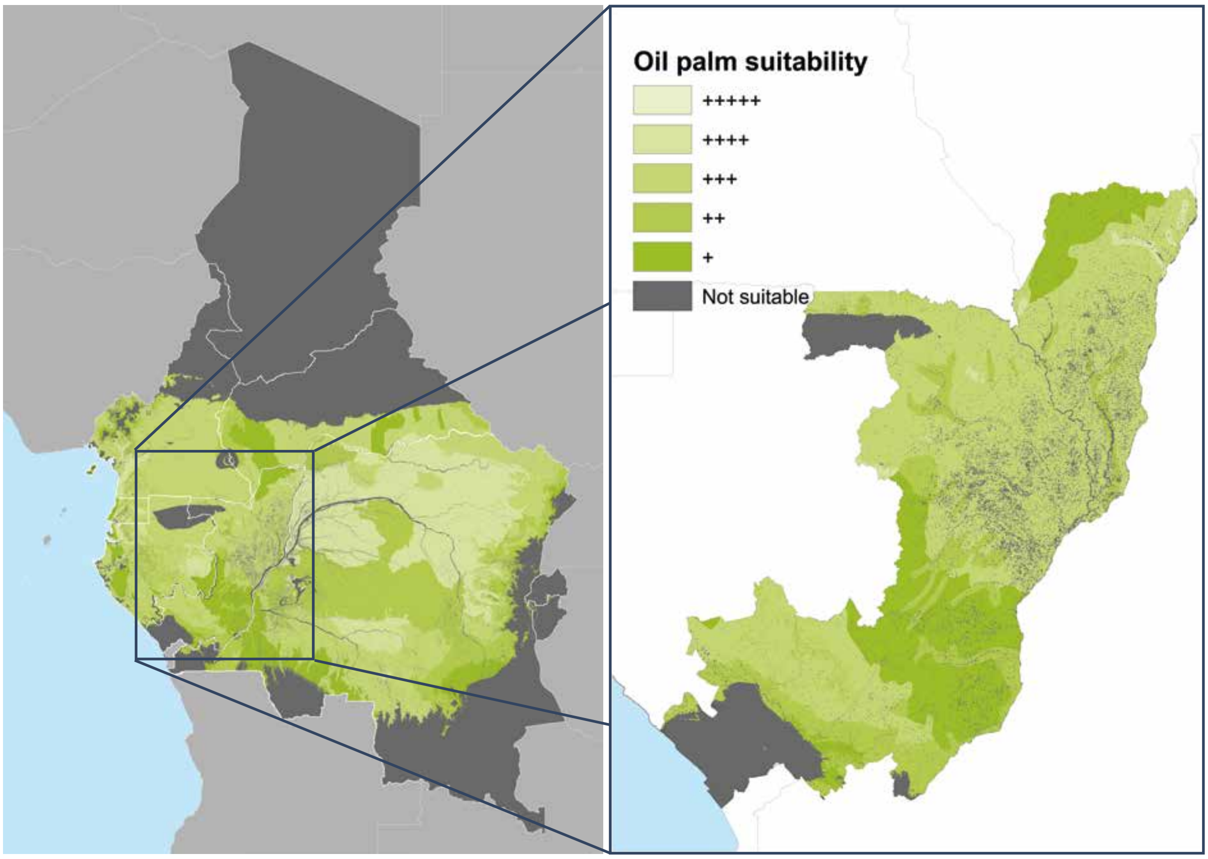

Figure 19: Map of biophysical potential of oil palm in the Republic of Congo where green means very high potential, red corresponds to low potential and dark grey shows areas which are not suitable according to Pirker and Mosnier (2015)

In addition, based on a literature search we estimated the area of oil palms cultivated in 2000 (Table 4). In 2000, the sector was dominated by the " Sangha Palm" plantation in the Sangha department. Unlike in Cameroon where small producers play an important role in the sector, small producers of palm oil are hardly present in the Republic of the Congo.

Table 4: Palm plantation area in 2000 by department and by production type.

Department	Small producers	Industrial plantations
Kouilou	5	
Niari	30	
Lekoumene	15	
Bouenza	30	
Pool		200
Plateaux	20	
Cauvette		1,000
West Cuvette	124	
Sangha		5,000
Likouala		342
Total	**225**	**6,542**

Source: Carrere, 2013; FAO, 2016; Lescuyer and Ngouhou, 2014

4.4.5 Process of spatial allocation of arable land for the base year (2000) to simulation units

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 determine 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.

We arrive at a total agricultural land area of 500,000 hectares in 2000 for the Republic of the Congo, of which two thirds are composed of fallow . The difference between the agricultural land class of the original land cover map and the agricultural land thus calculated is 2.494 million hectares which are reassigned to the "other natural lands" class. The geographical distribution of calculated arable land remains very close to the original map, but with smaller areas per simulation unit. (Figure 20). We particularly see on the map that in the majority of the simulation units, the cultivated area is only between 1,000 and 5,000 hectares or less than 2 % of the total area of the simulation units.

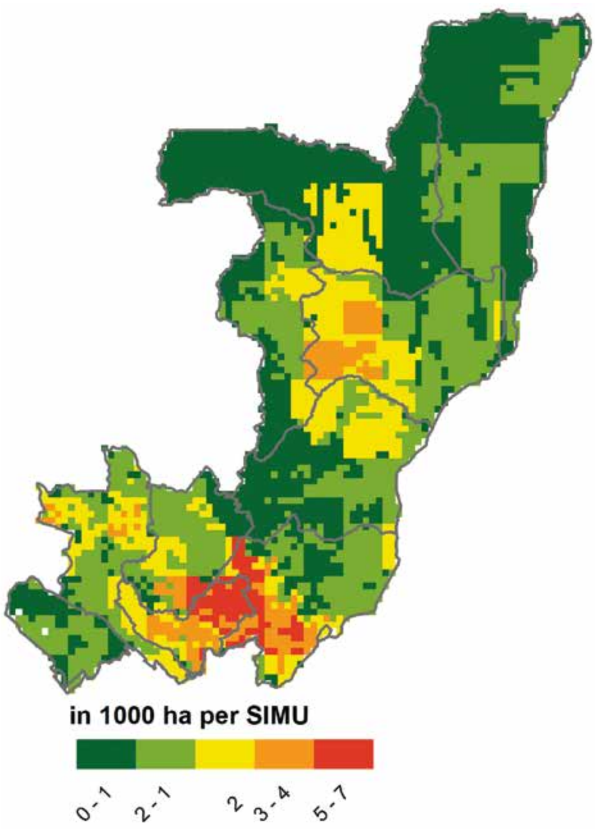

Figure 20: Area of arable land in 2000 per simulation unit (in thousand of hectares per simulation unit)

4.4.6 Livestock

The Statistical Yearbook of the Direction Générale de l'Economie (DGE) and the Ministry of Agriculture and Livestock 2011 and the 2010 Report by the Directions Départementales d'Elevage were used to obtain statistics on livestock in the Republic of the Congo. The first source provides aggregated data for the entire country between 2005 and 2010 (in orange Figure 21) whereas the second source provides workforce data by department but only for a year. These two sources are close at the aggregate level for cattle where the report of the Directions Départementales d'Elevage records a number of heads of cattle 35 % higher than the statistical yearbook of the EDG/MAL for 2009 and for pigs where there is also a large difference. Conversely, the difference with the FAO figures is high: FAO reports a herd size seven times, six times and three times higher for cattle, goats and sheep respectively than EDG/MAL.

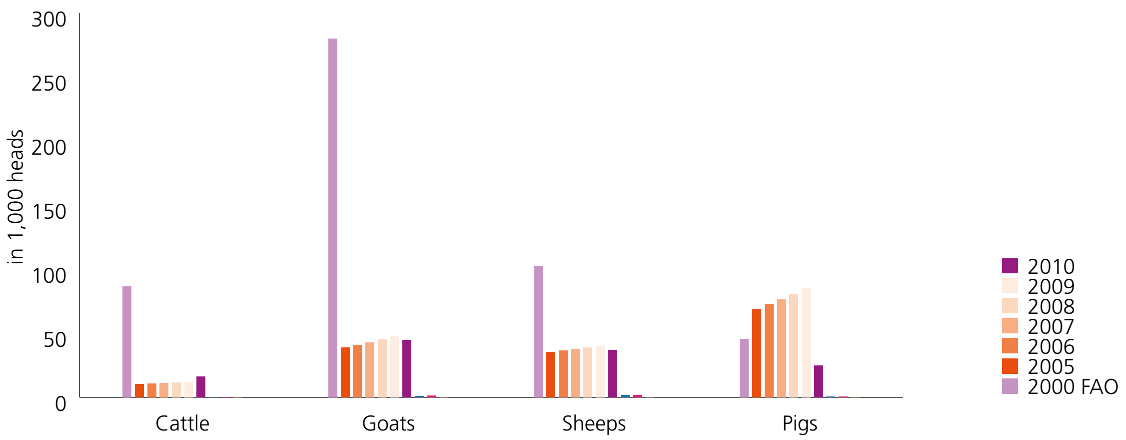

Figure 21: Comparison of herd size per species according to the sources

In terms of distribution of the cattle herd, there is a fairly good agreement between the statistics of the EDG/MAL and FAO-ILRI for Bouenza and Cuvette which represent more than 40 % of the national cattle herd (Figure 22). Conversely, one of the main differences between the figures reported in the statistics of the EDG/MAL and the FAO-ILRI data concerns the Niari department: it is of little importance for the breeding of cattle, sheep and goats according to the FAO- ILRI while it has as much as 20 % of cattle and 35 % of sheep and goats, respectively according to EDG/MAL statistics.

Generally speaking large differences are seen between the distribution of livestock of sheep and goats according to statistics of the EDG/MAL and FAO. As the FAO-ILRI national statistics have a ten year data gap, it may be that the differences observed reflect changes in the livestock between 2000 and 2010 but they may also reflect the great uncertainties in the sector.

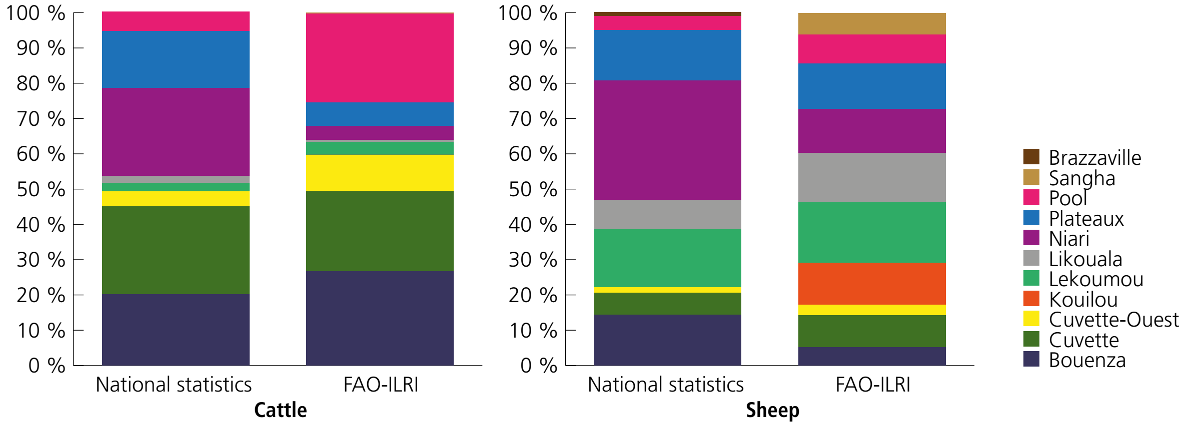

Figure 22: The herd size of cattle and sheep by source and department

Given the uncertainties in the data available for the livestock mentioned above, we decided to keep the default model data for the livestock sector (FAO-ILRI) . In the model, ruminants are represented on the level of simulation units where they determine the pasture areas depending on the level of forage consumption as estimated with the RUMINANT model. This leads to an estimated grazing area of 620,000 hectares in the Republic of the Congo (Figure 23). Pigs and poultry are shown in GLOBIOM in an aggregated manner only on national level. However, through the use of certain crops for their feed, the livestock sector can indirectly lead to an expansion of arable land.

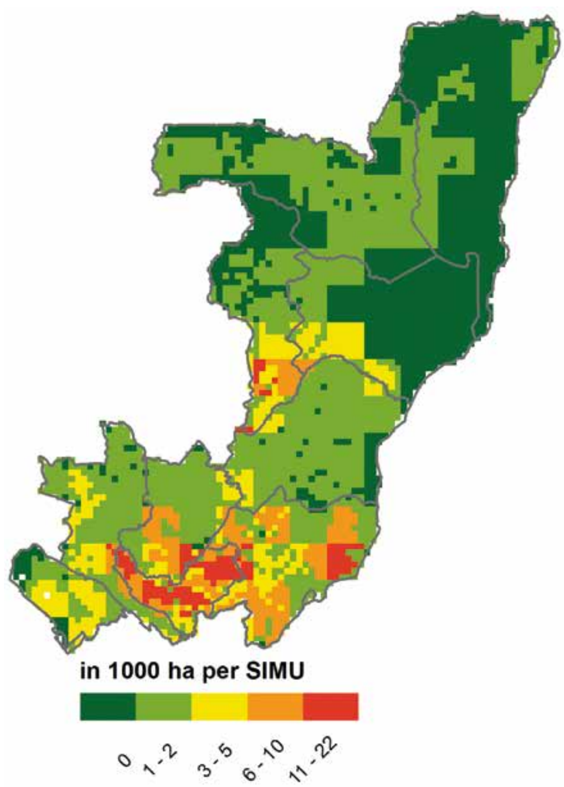

Figure 23: Area of pasture in 2000 per simulation unit (in thousands of hectares per Simulation Unit)

5 The calculation of greenhouse gas emissions and impact on biodiversity

5.1 The calculating of emissions

5.1.1 The emissions linked to changes in land use

The calculating of the Greenhouse Gas (GHG) emissions linked to the change in land use is based on the carbon content of each type of vegetation. The carbon estimates in the live above and below ground biomass (Kindermann *et al.,* 2008) are used by default in GLOBIOM for the forest carbon content. These estimates are adjusted to match the FRA-FAO 2010 carbon inventory for each country. For the short rotation forest plantations (e.g. eucalyptus, poplar, pine), the carbon content is calculated on the basis of their potential productivity. For the carbon contained in the other natural land, we use the biomass map of (Ruesch and Gibbs, 2008). By using this approach, the carbon content varies between the vegetation types and between the spatial units. CO_2 emissions (or CO_2 sequestration) are calculated as the difference between the carbon content of the final type of vegetation and the original vegetation type. For example, for deforestation due to the expansion of arable land, as the carbon content of the cultivated land is assumed to be zero, emissions will be equal to the carbon content of the forest in the above- and below-ground biomass in a certain spatial unit. In this study, we do not take the carbon in litter into account, dead wood, and soil outside the living biomass.

Given the importance of calculating emissions under REDD+, we decided to use alternative biomass maps to calculate emissions from deforestation. Two pantropical maps on biomass in the above-ground woody vegetation were incorporated into our database: (Baccini *et al.,* 2012) of the Wood Hole Research Centre (WHRC) and (Saatchi *et al.,* 2011) from NASA. Both use similar input data on the height of the forests and the canopy structure obtained from a combination of satellite images like MODIS and a laser remote sensing system (LiDAR), but use different field data for the calibration and different spatial modelling methods (Mitchard *et al.,* 2013). This results in significant differences in the estimates of the biomass between the two maps, especially for the Congo Basin (Figure 24). The authors point out that the carbon content of the two maps tends to converge at the national level but as emissions linked to deforestation strongly depend on the location of the deforestation, the choice of one map or the other may significantly affect the emissions from deforestation calculated at the national level. The map below (Figure 24) shows the differences in biomass estimates between the two maps for the Republic of the Congo: the positive values (tonnes of biomass per hectare) indicate a higher carbon content in the map of Saatchi et al . than in the Baccini *et al.* map and vice versa for negative values.

The maps from the WHRC and NASA only take above-ground biomass into account. 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 above 125 tC/ha, the median value of the biomass below the ground is 23.5 % of the biomass above the ground. For comparison purposes, the confidence gap provided by the IPCC is a ratio of between 6 % and 33 % between the biomass below the ground and the biomass above the ground.

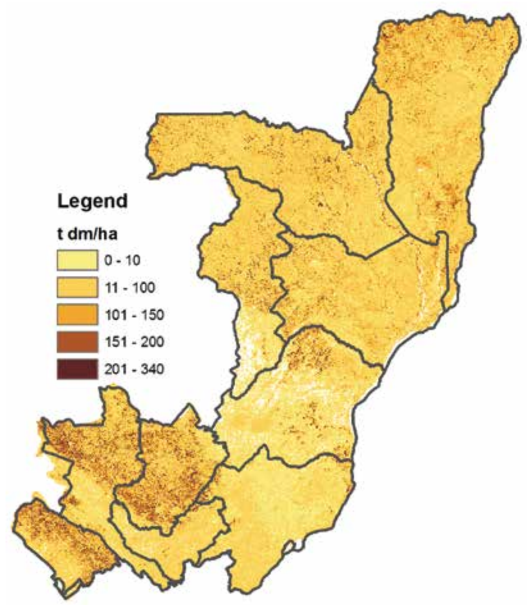

Figure 24: Difference in carbon content between the NASA map and the WHRC biomass map for the Republic of the Congo (in tons dry matter/ha) Source: http://biomass.geo-wiki.org/

5.1.2 Emissions linked to forest degradation

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

Several studies can provide us with 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 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 . 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 coming from multiple concessions in the Congo Basin and from the relevant literature. They make the assumption that the management 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 5: Total emission factors and by type of impact for different types of forest logging

Type of logging	tC in the harvested wood	tC for the damage caused to the remaining stand	tC for the damage caused by the infrastructure	TOTAL in tC per m^3 of wood extracted
Formal reduced impact logging	0.25	0.5	0.24	0.99
Convention formal logging	0.25	0.50 x 1.1= 0.55	0.24 x 1.1 = 0.26	1.06

5.1.3 Emissions linked to agriculture

Emissions linked to agriculture include the emissions linked to livestock and the emissions linked to 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. The accounting for the emissions follows the Tier 2 approach established by the IPCC, for each 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 rice growing.

5.2 The calculation 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 factors of loss of biodiversity globally. The conversion of natural ecosystems can cause the destruction of the biodiversity they contain and the ecosystem services they provide, and results in a loss or fragmentation of species habitats. These impacts depend on the location, the total area, and the nature of the new land uses.

In this section, we present the methods used in assessing impacts on biodiversity in more detail. Many variables are potentially relevant for assessing the impacts on biodiversity and in the spatial planning of the implementation of the Aichi Targets, according to the aspect considered. Information about potential changes in land use and deforestation can be used to target certain areas to fight against the decline in natural habitats (Aichi Target 5). The overlaying of information on 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) . The lack of data available in the Congo Basin region is a recognised problem; however, several relevant data sets have been identified during this project.

5.2.1 Impact on the ecosystems

The territory of the Republic of the Congo is divided into 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 made. Within the framework of this study we use the eco-regions identified by WWF (Olson *et al.,* 2001).

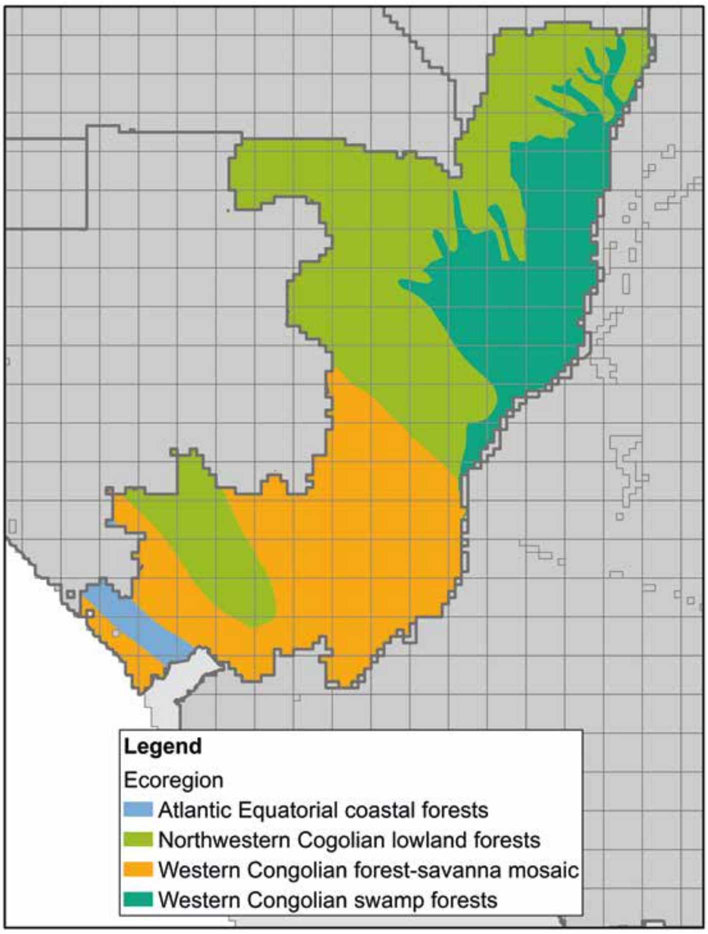

Figure 25: Map of the eco-regions of the Republic of the Congo, source: Olson *et al.,* 2001.

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, the Republic of Congo is home to endangered species of great apes, which have the potential to support the development of ecotourism activities, a key ecosystem service. The Republic of Congo is also a signatory to the Kinshasa Declaration on protecting Great Apes.

The distribution of species richness may differ depending on the 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).

The impact assessment on the group of 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 . 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 habitat is shared by many species, and the more this represents a large proportion of a species' habitat in the country (endemism level). Figure 26 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.

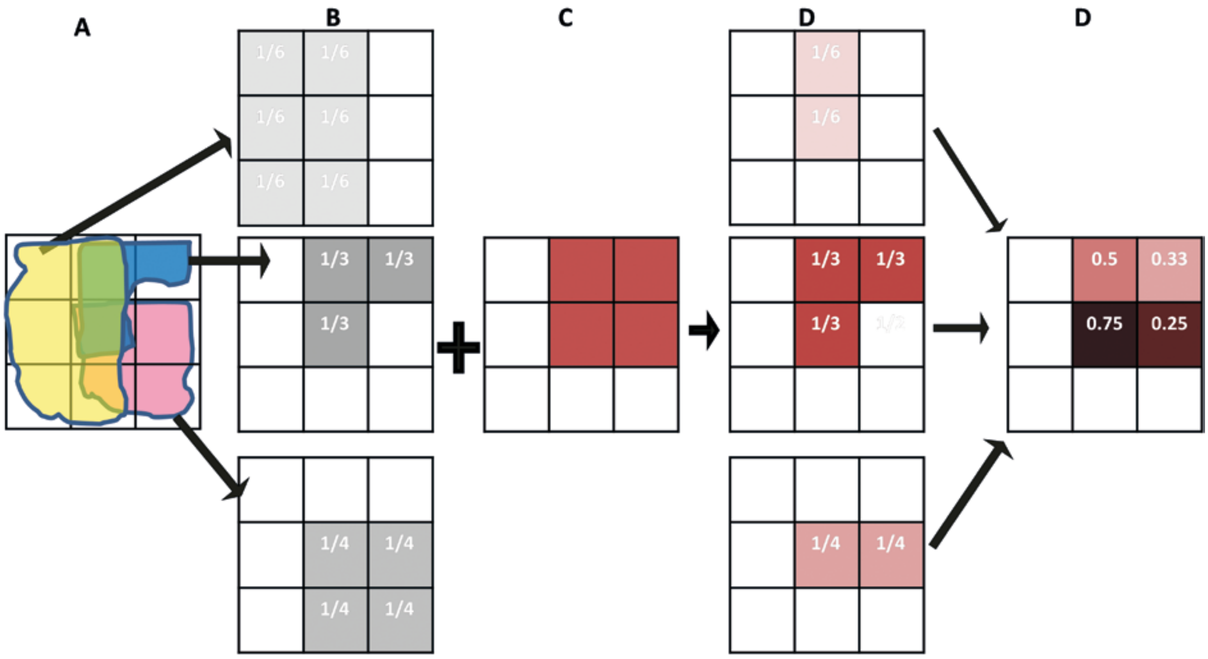

Figure 26: Method of calculation of the composite index of combined species habitat change.

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 can be seen as what would happen in the absence of new government policies with moderate growth of global population and wealth.

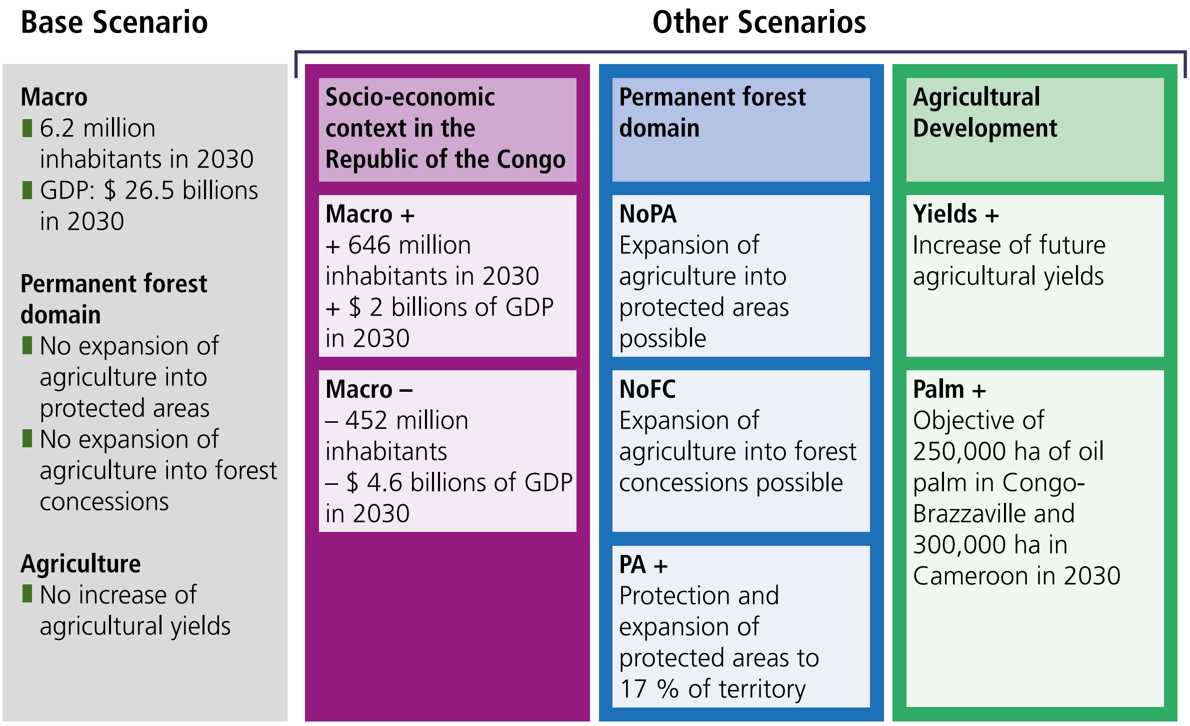

Figure 27: The base scenario hypotheses are presented to the left whereas the changes introduced in each scenario are described on the right (one scenario for each white box)

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 28). For each scenario, population and GDP projections were carried out for each country, resulting in different average per capita levels of GDP.

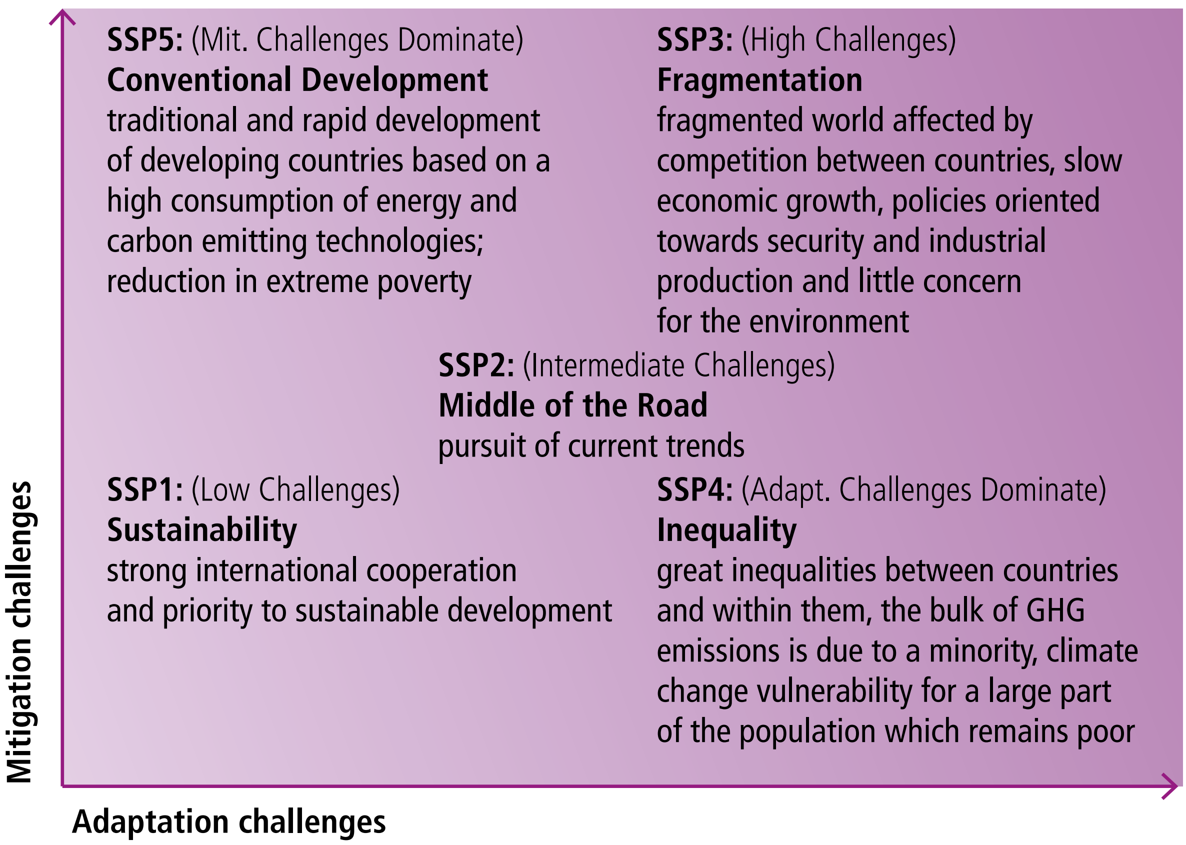

Figure 28: Socio-economic development trajectories prepared within the framework of the IPCC (Source: O'Neill *et al.*, 2013)

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 the Republic of the Congo in the SSP2 is generally much greater than the world average: By 2030 the Republic of the Congo 's population is expected to double and GDP is expected to almost triple compared to 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) (Figure 29). As the population changes are not symmetrical to changes in economic growth, the two scenarios result in a growth in the average GDP per capita which is lower than in the SSP2. Both scenarios lead to average GDP per capita projections in 2030 lower than in the SSP2: -2.5 % in Macro+ and -10 % in Macro- for the Republic of the Congo. These alternative scenarios will influence future deforestation by changing food consumption and demand for lumber and firewood (see section 3.4.1; (Valin *et al.*, 2014).

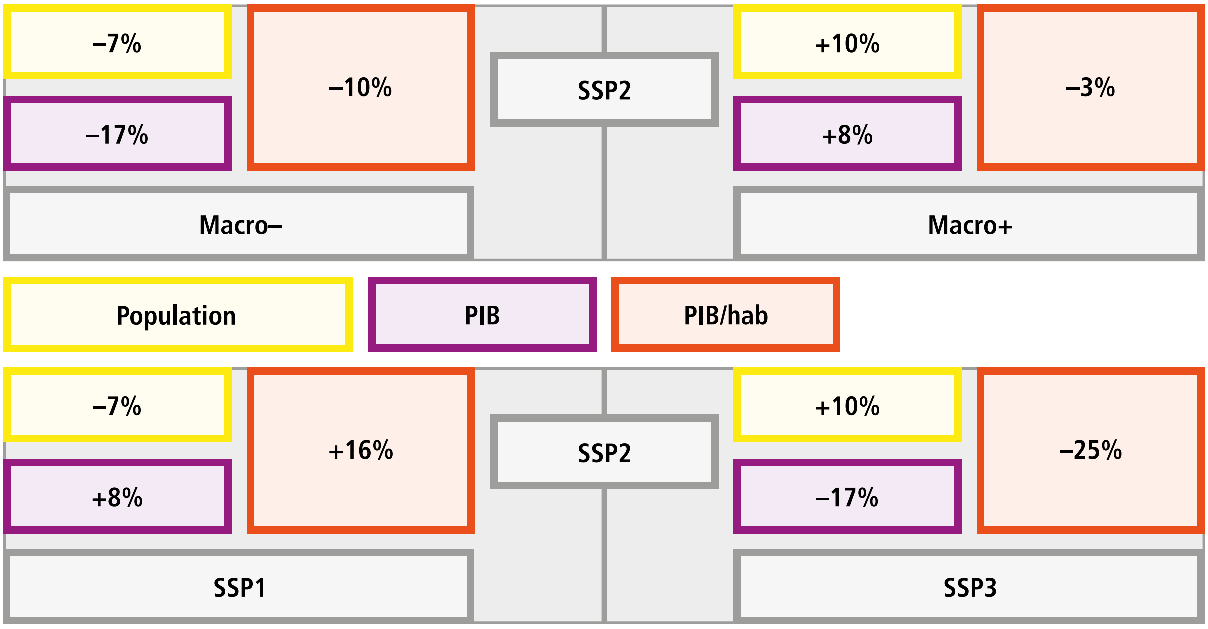

Figure 29: Change of assumptions in GDP growth, population growth and growth in GDP per capita in the SSP1 and SSP3 compared to SSP2 (left) and by construction for the Macro + and Macro scenarios (right) for the Republic of the Congo

The diet in the Republic of Congo is mainly based on the consumption of tubers and cereals (Figure 30, left). This is similar to other Central African countries but is not so common in other parts of the world. The average consumption of meat and dairy products is very low 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. The average per capita consumption of eggs, beans, cereals, oil and sugar is predicted to rise sharply in the coming decades, and this is especially so in the SSP1 where the average level of GDP per capita is high (Figure 30 right) .

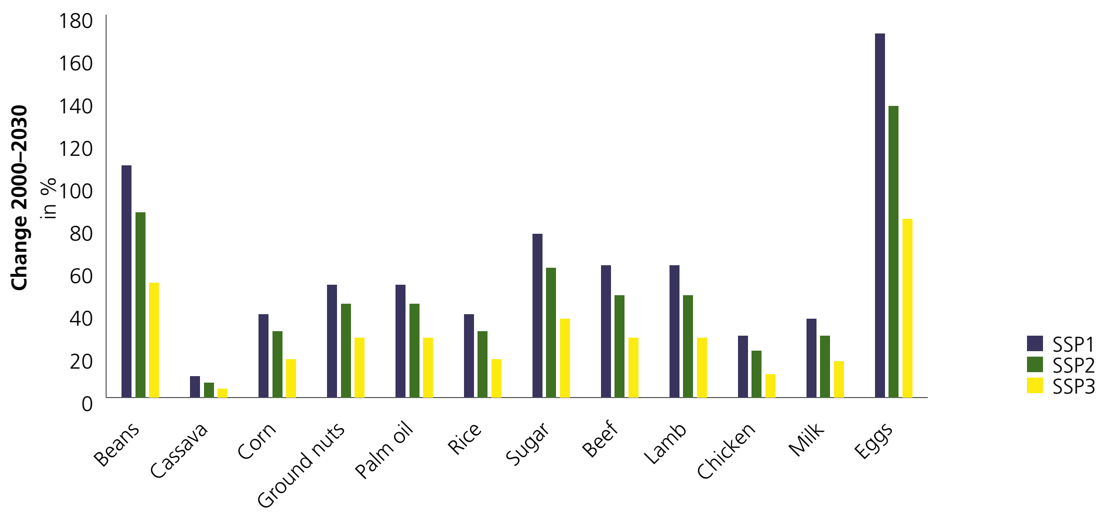

Figure 30: Evolution of food consumption structure in the Republic of the Congo by product group in the baseline scenario (left) and change in consumption per food product per capita in 2030 compared to 2000 in the Republic of the Congo for different SSPs (kcal per capita per day)

6.2 Permanent forest area

By default in the model, it is not possible to convert permanent forest areas — which includes protected areas and forest concessions in the Congo — to other uses. As discussed in Section 4.4.1, this represents a total of 15 million hectares of protected forests with 12.7 million hectares only covered by logging concessions.

6.2.1 Alternative scenarios for the protected areas

The effectiveness of the numerous protected areas in the sub-region remains limited owing to a lack of resources. According to our analysis where we overlay protected areas and areas deforested between 2000 et 2012 (Hansen *et al.,* 2013), we estimated that 96 km^2 of protected areas were deforested in the Republic of the Congo between 2000 and 2012 (Bodin *et al.,* 2014). The rate of deforestation in protected areas was below the national average, but this can be because of reduced accessibility in the protected areas (few or no roads) and a lower population density in and around the protected areas.

"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.

In the latest National Biodiversity Strategy and Action Plan (submitted in 2015 to the CBD), the Republic of the Congo mentions the objective of conservation of at least 17 % of inland water and terrestrial areas and 10 % of marine and coastal areas, including areas that are particularly important for biodiversity and the provision of ecosystem services, by 2020 (Target 11). The means envisaged are the establishment of ecologically representative and well-connected protected areas managed effectively and equitably, and other effective area-based conservation measures integrated into the overall landscape and seascape.

Although the primary objective of protected areas is the conservation of biodiversity, their location may also depend on other associated ecosystem benefits including the reduction of greenhouse gas emissions. Three scenarios were developed to explore the potential impact of an increase in protected areas to cover 17 % of the country, taking into account these two potential targets.

"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.

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 costs and implementation, or even the consent of indigenous 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).

6.2.2 Forest concessions

The Forest Code, dated 20 November, 2000, defined the legislative framework of a forest concession and particularly the important role of a management plan that specifies goals for the unit it covers, and the means of achieving them (République du Congo, 2000). Forest concessions are part of the permanent forest area, and as such permanent forest cover is to be maintained. However, because of a failure to comply with the forest code, the loss of average annual forest cover in forest concessions between 2000 and 2012 in the Congo is estimated at 96 km^2 (9,600 ha (Bodin *et al.,* 2014). We note two things: the first is that the rate of deforestation in the concessions is similar to the average deforestation rate for the whole of the Republic of the Congo for the period, and the second is that it represents nearly 10 % of the total deforestation.

Moreover, in the past forest concessionaires only interested in short term gains left 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 development

6.3.1 Change in 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 the Congo 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 6).

Table 6: Rate of agricultural yields growth in the RDMT+ scenario

	Average annual rate	Rate over the 2000–2030 period
Beans	1.4 %	50 %
Cassava	0.5 %	16 %
Corn	3.4 %	175 %
Peanuts	2.7 %	122 %
Oil Palm	0.7 %	25 %
Potatoes	1.7 %	65 %
Rice	3.5 %	181 %
Sugar cane	0.7 %	25 %
Sweet potato	1.1 %	40 %

6.3.2 Palm oil plantations

There is a strong political will in the Republic of the Congo to reduce palm oil imports, which are rising in order to meet local demand. The government would like to encourage the reopening of abandoned oil palm plantations and the initiation of new plantations to gradually reduce the palm oil imports between 2020 and 2025, and move to a status of net palm oil exporter. A target of 350,000 tonnes per year of palm oil exports in 2035 is mentioned with areas of more than 100,000 hectares of oil palm plantations in both industrial and smallholder plantations. The three largest plantation projects are ATAMA in the Sangha (60,000 ha), Eco-Energy Oil also in the Sangha (30,000 ha) and BIOCONGO Global Trading in Cuvette and Cuvette West (60,000 ha). Taking into account all ongoing plantation projects, the Republic of the Congo could have 300,000 hectares of oil palm plantations compared to 6,760 at present (see attached table).

"PALM+" scenario: This scenario forces the palm oil areas to reach 50,000 hectares in 2020 and 300,000 in 2030. These aims are introduced at the national level — in other words the model is free to choose in which departments the plantations are allocated on the basis of maximising the expected profit and the available land.

6.4 Reforestation objectives

The ProNAR programme is a vast project of forest plantations with the aim of establishing 1 million hectares of plantations between 2011 and 2020. The ambitions of the project are to create numerous jobs in rural areas with an estimate of approximately ten jobs created per 100 hectares planted; the wood produced is destined for the production of wood energy and for export markets in the form of pulp for paper making and particle boards. 850,000 hectares out of this 1 million hectares will actually be planted and 150,000 hectares will be used for the development of infrastructure (Table 7). 340,000 hectares are destined to be agro-industrial perennial plantations such as palm oil, cocoa or rubber.

Table 7: Distribution of the plantation area based on the three components covered by ProNAR

	Area	Description
Total area objective of PRONAR	1,000,000 ha	Plantations and infrastructures
% infrastructures (tracks, fire breaks etc.)	15 %	
Area to be planted	850,000 ha	area planted/productive
Areas not planted (protection, human occupation etc.)	30 %	
Total area effected by PRONAR (with land title)	1,300,000 ha	area with land title
Pillar 1: Industrial forest plantations	50 %	
	425,000 ha	area planted/productive
Short rotation plantation (for industry or fire wood)	80 %	
	340,000 ha	area planted/productive
Plantation with medium rotation length (for lumber)	20 %	
	85,000 ha	area planted/productive
Pillar 2: Agro-industrial plantations (oil palm, cocoa etc.)	40 %	
	340,000 ha	area planted/productive
Pillar 3: Smallholders agro-forestry plantations	10 %	
	85,000 ha	area planted/productive

Source: Ministry of the Forest Economy and sustainable development of the Republic of the Congo, Forest and Economic Diversification Project (PFDE), 2014

"REFOR" scenario: In this scenario, we set a goal of 1 million hectares of fast-growing forest plantations by 2020. We hypothesize that these plantations cannot be developed on forest land, that is to say, forest plantations cannot replace natural forest.

This corresponds to the partial implementation of the Cancun safeguards (UNFCCC, 2011).

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 the Republic of the Congo 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 remote sensing products monitoring historical changes of forest cover can be used for the Republic of the Congo: FACET (2000–2010), GFC (2001–2010) and GAF (2000–2010). According to these sources, historical deforestation varies between 16 and 23 thousand hectares per year for the Republic of the Congo (Figure 31). In terms of spatial distribution of this historic deforestation, different sources agree on the significance of the Kouilou department for national deforestation statistics (between 13 and 17 % of national deforestation) but differ quite substantially for other departments: for example, the department of Likouala underwent 17 or 11 % of the total deforestation according to GFC and GAF, respectively, but only 3 % according to FACET.

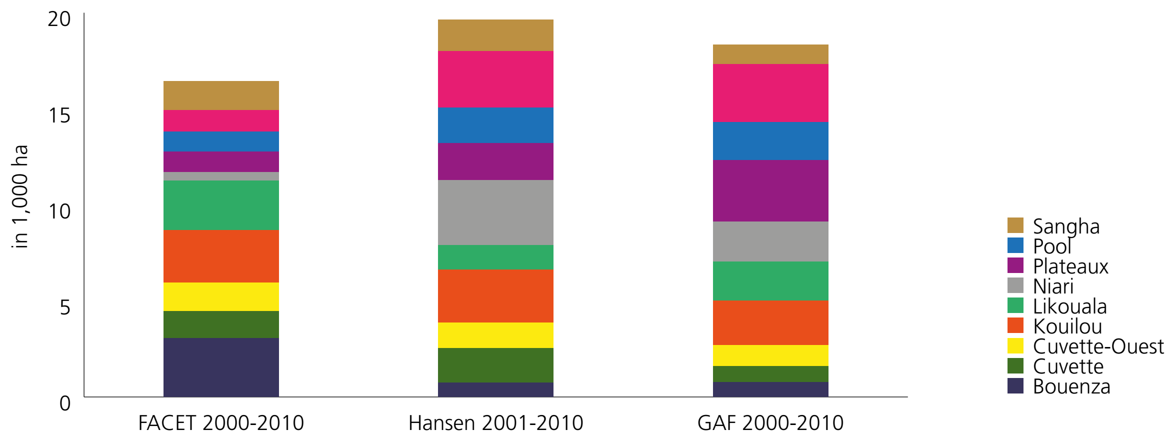

Figure 31: Average historical annual deforestation for the whole of the Republic of the Congo and by department between 2000 and 2010 (FACET, GAF) or 2001 and 2013 (GFC)

The analysis by the GAF research office (results presented by BRL Ingénerie & 4 C Solutions, 2014) is the only one that provides figures on the subsequent use of the deforested land: 78 % of deforested area over the period 2000–2010 was converted to arable land, 15 % to infrastructure/facilities, and 14 % to grassland/savannah-like woodlands or other natural lands. These results support the qualitative analysis of the deforestation drivers which was presented in the previous section with three quarters of deforestation explained by the expansion of agriculture. However, variations between the total area deforested and the spatial allocation of the deforestation according to the sources underline the significant uncertainty that remains linked to the historical deforestation and the need for further validation of these estimates from data collection in the field.

7.2 Comparing modelled and observed deforestation over the 2000–2010 period

The total deforestation estimated by the model between 2001 and 2010 is 160 thousand hectares. For comparison, the observed deforestation was 164 thousand hectares according to FACET (Mane *et al.*, 2012), 183 thousand according to the GAF Research Office (BRL Ingénerie & C 4 Solutions, 2014), and 235 thousand according to Hansen. Our estimates are the closest to the historical observations of FACET but they are also relatively close to the GAF observations.

If we now look at the geographic allocation of this deforestation we first note that the deforestation estimated by the model is for most of the departments within the range of the historical observations from the three available sources (Figure 32). For Bouenza, the model tends to overestimate the historical deforestation, while for Kouilou, Likouala and Sangha, the model tends to underestimate the historical deforestation compared to all the other sources. The departments of Pool, Bouenza and Cuvette are those where the deforestation estimated by the model between 2001 and 2010 is the greatest.

For Likouala and Sangha, the differences could be explained by the fact that only 24 % and 39 % of deforestation is attributed to agricultural expansion in these regions according to the GAF analysis, while a significant part is attributed to the building of infrastructure.

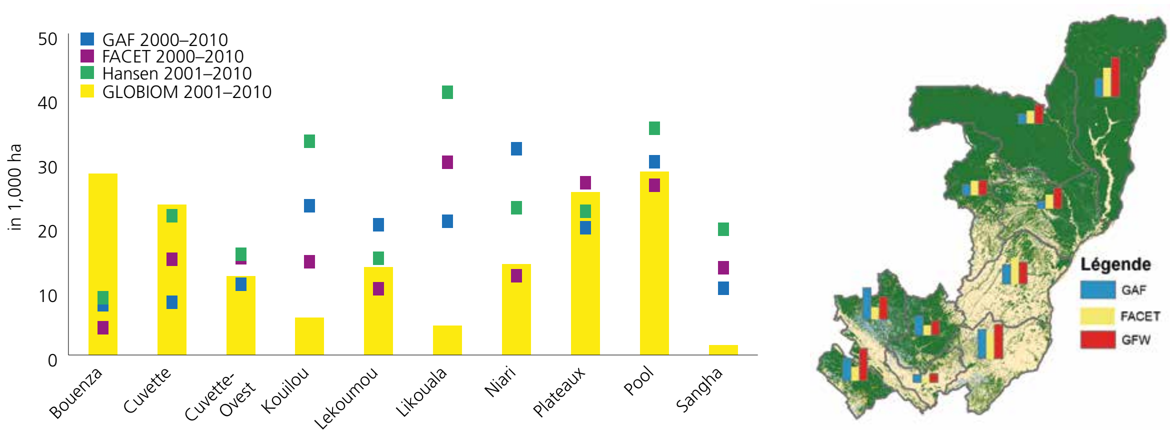

Figure 32: Comparison of the deforestation calculated by the model (GLOBIOM 2001–2010) with the deforestation observed according to the different sources between 2000 and 2010 in the provinces of the Republic of the Congo

The difference between the estimated deforestation by the model and the observed deforestation can be explained by several factors:

- the non-inclusion of certain causes of deforestation by the model: GLOBIOM simulates deforestation which is caused by the expansion of arable land only, whereas in reality, deforestation is also caused by factors such as infrastructure construction, urban sprawl, forest fires or mines;
- problems in the representation of the links between agriculture and deforestation in the model such as errors on the estimation of productivity of land, fallow periods, or production costs that influence the location and extent of deforestation;
- measuring errors in the historical deforestation on the basis of the analysis of satellite images.

7.3 Change in cultivated areas and crop production

For the nine main crops represented in GLOBIOM, both the production and the cultivated area calculated by the model are very similar to those reported by the FAO in 2010 (Figure 33). In terms of cultivated area, the projections by GLOBIOM in 2010 are only 2 % below the area reported by the FAO: 219 thousand of hectares calculated by GLOBIOM compared to an FAO estimate of 224 thousand hectares. For cassava, which is by far the leading crop in the Republic of the Congo, the estimated areas are 4 % below those observed, according to the FAO, and the difference in production is 8 %.

The total agricultural land is particularly influenced by the fallow area in the Congo because of the long periods the land is put to rest after a short cultivation period. It is also one of the parameters for which we have no data to verify that our estimates are correct. According to our results, fallow land is two-thirds of the agricultural land: for an increase in cultivated land of 60 thousand hectares between 2000 and 2010, fallow surfaces increased by 112 thousand hectares.

Compared to the geographical allocation of agricultural production we unfortunately do not have elements of comparison for 2010 due to the lack of agricultural statistics at the sub-national level in Congo.

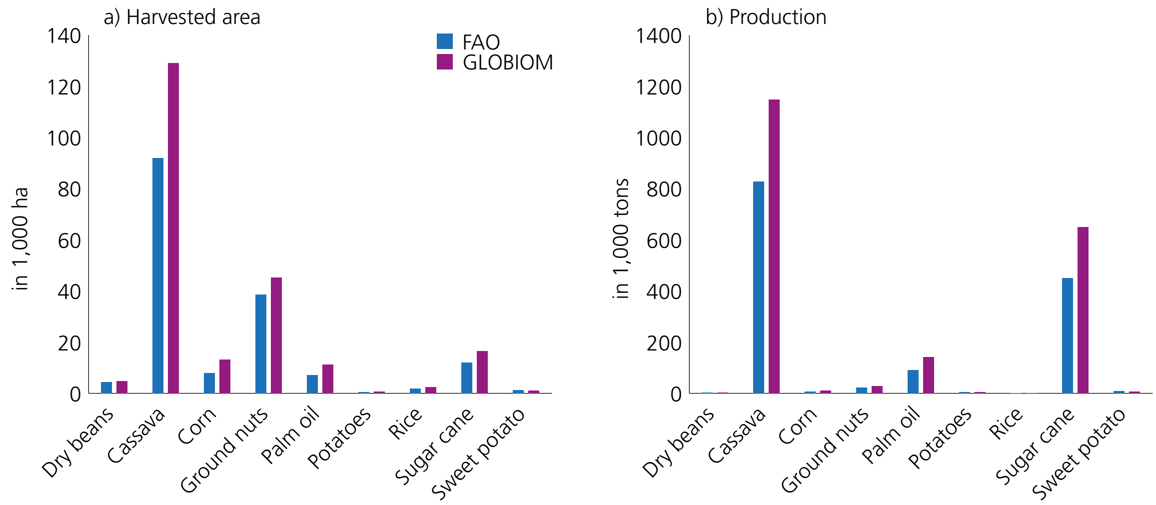

Figure 33: Comparison per crop between production calculated by the model in 2010 and production observed by the FAO in 2010 (a) and between the harvested area calculated by the model in 2010 and the harvested areas observed by the FAO in 2010 (b) in the Republic of the Congo

8 Results for the period 2010–2030 in the base scenario

8.1 Deforestation and other land use changes

In Figure 34, we see the area which is lost (negative values) or gained (positive values) by each vegetation type in each 10-year period at the national level. As we assume that the territory of the Republic of the Congo remains fixed (no change of borders), the only way to extend a certain type of plant cover is by reducing another. So if we add what has been lost by some types of vegetation (hatched in the figure) and what has been gained by other kinds of plant cover, this gives us zero.

There is increasing pressure on the natural vegetation types over time: in the base scenario, deforestation goes from 157 thousand hectares between 2000 and 2010 to 253 thousand hectares between 2020 and 2030, an increase of 60 % (hatched green in the figure). Deforestation is mainly caused by the expansion of crops (in yellow) and a small proportion by the expansion of pastures (in red). We also note a sharp increase in the conversion of savannah (hatched red) to agricultural land: 45 % of the agricultural land expansion occurs in savannah over the 2020–2030 period.

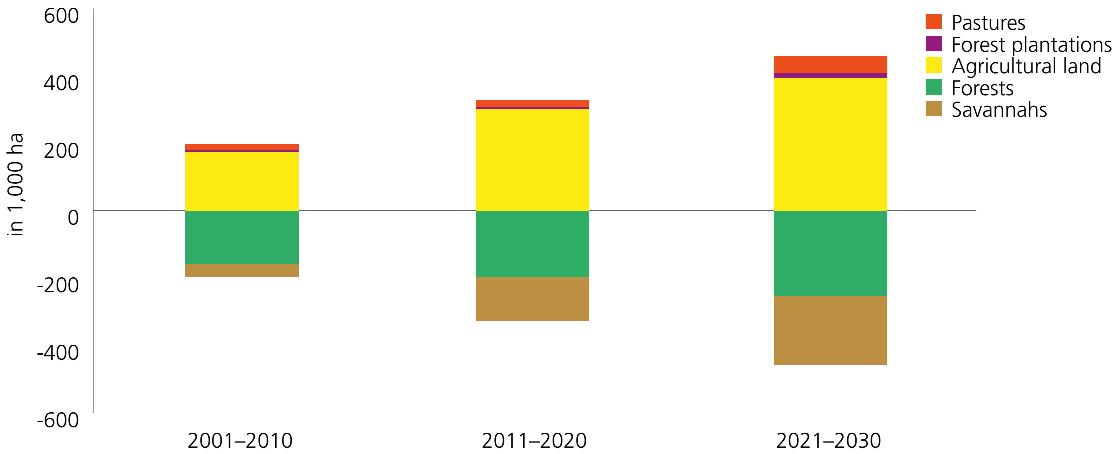

Figure 34: Net gains and losses of land for each type of vegetation for each simulation period (period of 10 years) in thousands of hectares

Specifically, we estimated that two-thirds of deforestation between 2010 and 2030 comes from the expansion of cassava, groundnuts and related fallow. The area for sugarcane cultivation increases over the period but the associated deforested area remains fairly stable with 14,000 hectares per year on average. On the last simulation period, the expansion of oil palm and pastures pushes deforestation up: 20,000 hectares of forests are converted to oil palm and 45,000 hectares to pastureland (Figure 35).

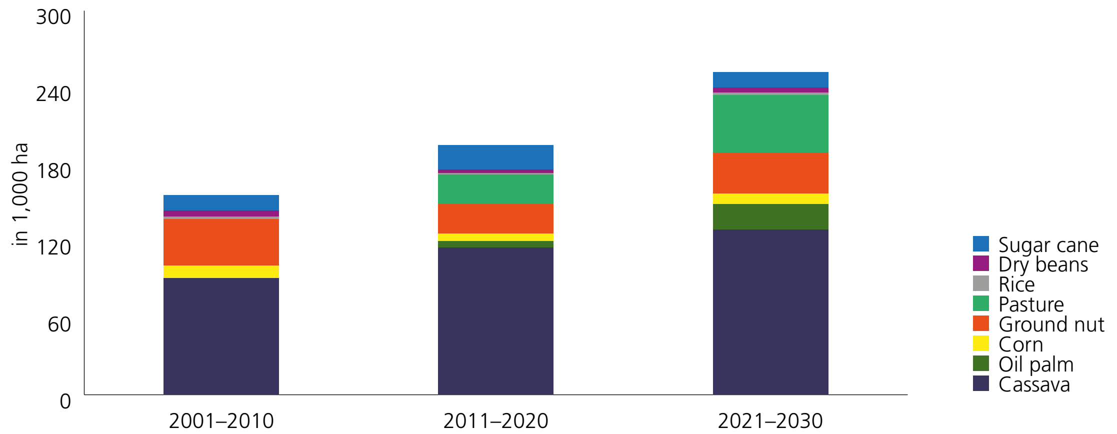

Figure 35: Projections on deforestation by cause in the Republic of the Congo for each simulation period

A third of the predicted deforestation between 2011 and 2030 occurs in the department of Cuvette, where it is mainly explained by the increase of food crops and pastures. Plateaux, Likouala, Niari, Cuvette West and Bouenza follow with deforestation of between 40,000 and 60,000 hectares between 2010 and 2030. We note that while deforestation in Plateaux and Cuvette-Ouest is explained by the 80 % expansion of cassava, peanuts and corn, in Bouenza sugar cane causes 56 % of deforestation and in Likouala palm oil causes 37 % of deforestation (Figure 36).

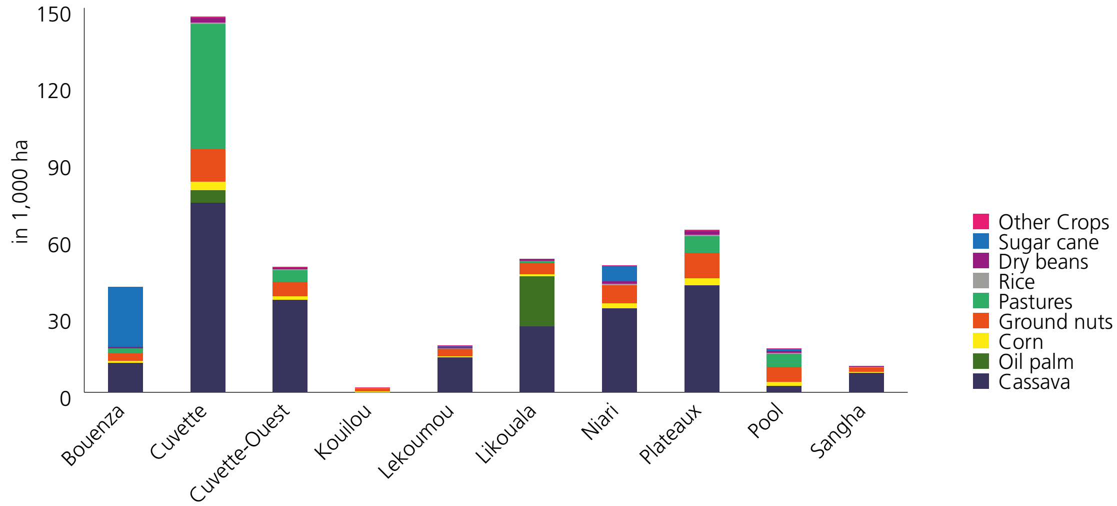

Figure 36: Breakdown of the deforestation calculated between 2011 and 2030 by cause for each department

8.2 Agricultural production and consumption

The average consumption of calories per capita per year increases by 35 % between 2010 and 2030 in the Republic of the Congo. The production of calories of plant origin (crops) follows the increase in consumption over the period 2010–2030 which means that the deficit in calories of plant origin remains almost constant (Figure 37). Conversely, the increase in consumption of calories of animal origin (meat and milk) is mainly satisfied through an increase in imports. Production slightly increases to cover 28 % of local needs for meat and milk in 2030.

The Republic of the Congo manages to sufficiently increase the local production of cassava to meet the needs of the population without resorting to imports.

Conversely, cereal imports, including rice and wheat, almost double between 2010 and 2030 (+ 88 %). The country multiplies its exports of sugar by 10 and becomes self-sufficient in palm oil but this is not sufficient to offset the increase in the imports of other goods. The commercial deficit value of the Congo in agricultural products increases by 25 % over the period.

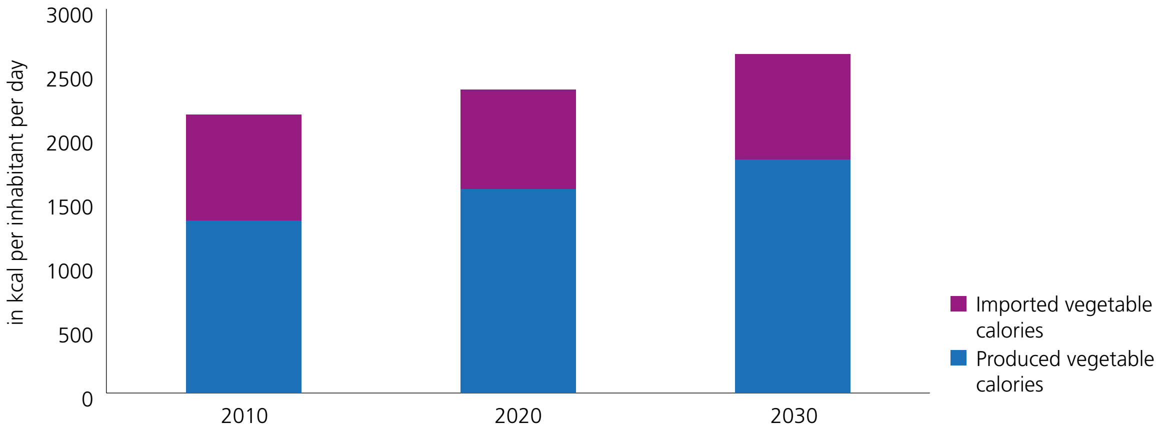

Figure 37: Change in the production of calories of plant origin per capita per year and in the deficit to cover the average consumption of calories of plant origin per capita per year

8.3 Forest management

As we have fixed the area under forest concessions to its current extent, and as we only take into account the non-flooded, dense humid forests in the concessions, we have12 million hectares of managed forests in the Congo in 2030 (see section 4.4.1). Log production therefore remains similar to what it currently is, that is to say, 1.5 million m^3, of which about 60 % is processed into sawn timber and veneer. Production of firewood goes from 1.6 million m^3 per year in 2000 to 3.6 million m^3 in 2030 to meet the energy demand of the national population. In our simulations, firewood mainly comes from fallow land. Forest degradation due to firewood is not recognized because agricultural fallow land is no longer considered forest in the model.

8.4 Emissions

We use four maps of alternative biomass to calculate the emissions from the deforestation in the Congo: Saatchi (Saatchi *et al.* 2011), Baccini (Baccini *et al.*, 2012), FRA2010 (Kindermann *et al.*, 2008) and Avitabile (Avitabile *et al.*, 2016). Our results show emissions from deforestation as between 244 and 28 million tCO_2eq over the period 2011–2030. The emissions caused by deforestation increase between 55 % and 68 % between 2010 and 2030 depending on the biomass map used. The choice of the biomass map gives a difference of 15 % of the emissions due to deforestation at the national level over the period 2011–2030 (Figure 38).

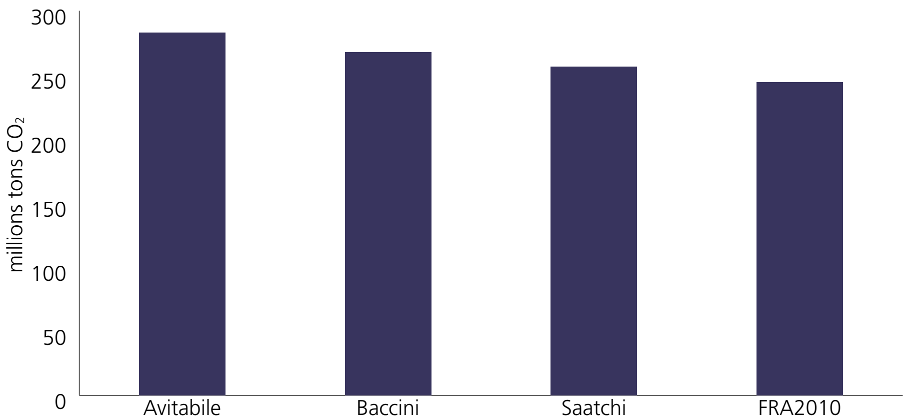

Figure 38: Emissions due to total projected deforestation for the Republic of the Congo between 2011 and 2030 using different biomass maps

The average carbon intensity obtained (or emission factor per hectare) varies between 148 and 171 tC/ha over the period 2011–2030 (Table 5). This is very close to the carbon density estimated in the literature for historical deforestation over 200–2010 for the Congo (Harris *et al.*, 2012) where the median value was 160 tC/ha, the minimum value of 147 tC and the maximum 171 tC/ha.

Table 8: Change in the emission factors for deforestation according to the biomass map used

Unit	Biomass map	2001–2010	2011–2020	2021–2030	2011–2030
in tCO_2/ha	Saatchi	594	565	576	570
	Baccini	579	579	610	595
	FRA 2010	530	541	547	543
	Avitabile	617	605	649	628
in tC/ha	Saatchi	162	154	157	155
	Baccini	158	158	166	162
	FRA 2010	145	147	149	148
	Avitabile	168	165	177	171

There are two other key sources of emissions from land use in the Republic of the Congo: logging and the conversion of other natural lands for agriculture. As agriculture uses almost no inputs and livestock is small in our simulations, very few emissions come from this sector in the Congo (less than one million tonnes of CO_2 from 2011 to 2030).

If we use the emission factor for formal conventional logging, we get 110 million tonnes CO_2 from forestry concessions over the period 2011–2030, which represents 20 % of total emissions (Figure 39). Using the same biomass maps described above, we estimate 120 million tonnes of CO_2 emissions from the conversion of savannah into agricultural land. We must therefore almost double emissions from deforestation to obtain the total emissions between 2011 and 2030. Total emissions from the conversion of natural land to agriculture and forestry in the Congo are estimated at 513 million tCO_2 over the period 2011–2030.

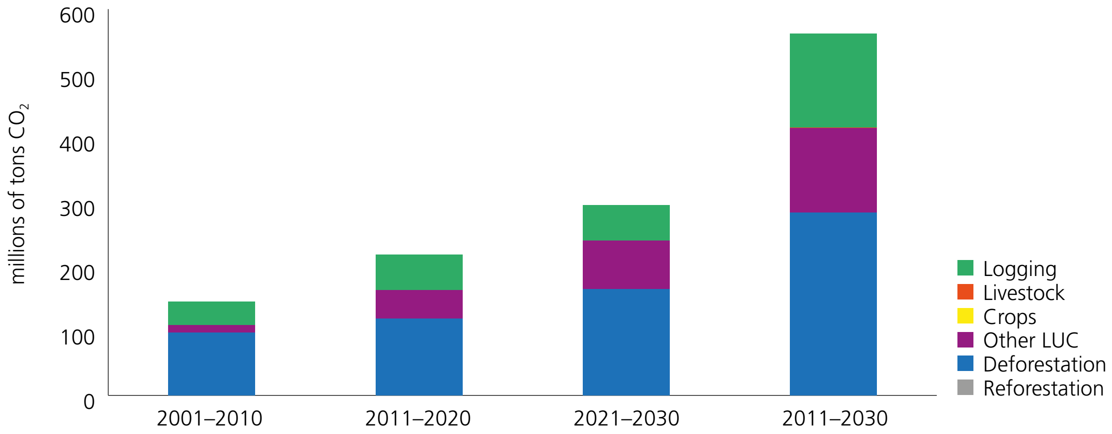

Figure 39: Emissions by source per period of 10 years or accrued over the period 2011–2030 in the Congo

8.5 Potential impact on biodiversity

The decrease in both forest areas and other natural land in the baseline scenario is a threat to biodiversity in these areas and the services to the populations that they provide. However, the change in projected land use, and the resulting pressures on biodiversity, are not evenly distributed among the different ecosystems of the Republic of the Congo (Figure 40). Furthermore, the main drivers of the land-use change are not the same in the different eco-regions. The Northwestern lowland forests of the Congo will, according to the projections, lose most of its unexploited forests through their conversion to exploited forests. However, forests in the Western Congolian forest-savanna mosaic are projected to undergo the largest proportion of full conversion to cropland.

The total loss of natural habitat due to conversion to cropland is likely to have a much greater impact on species than the change from unexploited forest to exploited forest. The impact of forest exploitation varies considerably depending on management. The management model for concessions adopted by the Republic of the Congo is a sustainable model focused on “creaming” of few species and the renewal of stocks. Therefore, in theory at least, it does not cause a permanent loss of forest cover or extinction of tree species. In terms of impacts on wildlife, forest concessions can be managed to help preserve biodiversity but can also, through the creation of tracks, open previously unreachable areas and lead to over-hunting, thus potentially endangering certain species.

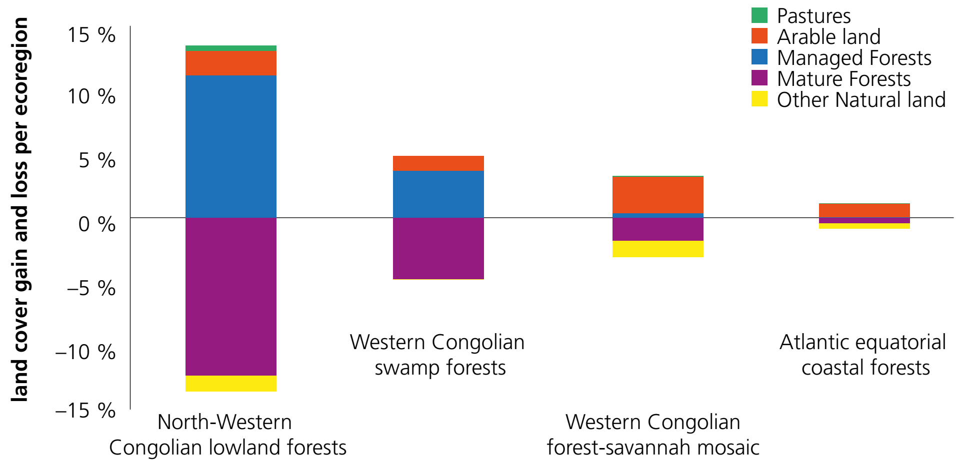

Figure 40: Total variation of the use of land over the period 2011–2030 in the eco-regions of the Congo.

The change shown in Figure 40 is the percentage of the total area of the eco-region undergoing a change in land use; for example, for the North Western Lowland forests, there has been an increase in the proportion of arable land, managed forests and pastures, and a corresponding decrease in undeveloped forest and natural lands across13.6 % of the area of the eco-region between 2010 and 2030.

Combining data on forest loss between 2010 and 2030 with data on the range of great apes highlights a loss of habitat over much of the country in the reference scenario (Figure 41). The total loss is less than 2 % of the total area of their range in the country. However, as this loss is very dispersed, there is a risk that it will increase the fragmentation of the great apes' range. Furthermore, the distribution of this loss means there are many areas where there may be a decline in the potential services that the apes can provide, including their role in supporting the development of eco-tourism activities.

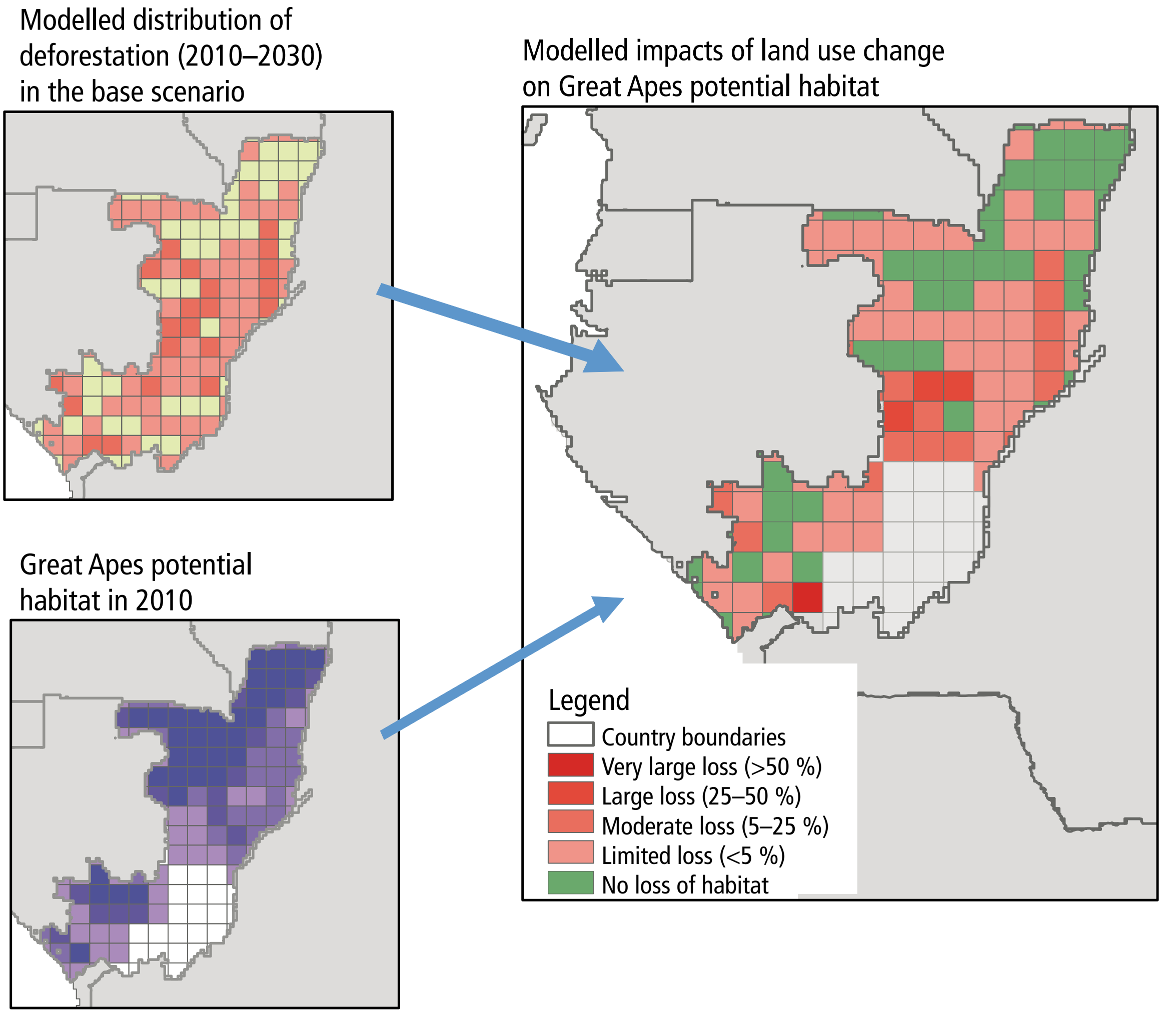

Figure 41: Modelling the impact of deforestation on the potential habitat for apes by simulation unit.

The projected loss of natural vegetation will impact not only on great apes, but on all species present in these areas, and on the potential services they can offer. Combining the information on projected changes in land use (including forests and savannahs) with the information about species distribution and habitat requirements emphasizes that 11 of the 946 species assessed are estimated to lose over 5 % of their potential habitat available in the country in the baseline scenario, and 465 are estimated to lose more than 2 % of their potential available habitat. Combining information on the proportion of habitat lost (or gained) for each species in an area produces an index on the total "combined species habitat" loss (or gain) in different areas. The loss will be greater in areas where there is both a large amount of conversion and many species who lose their habitat (Figure 42).

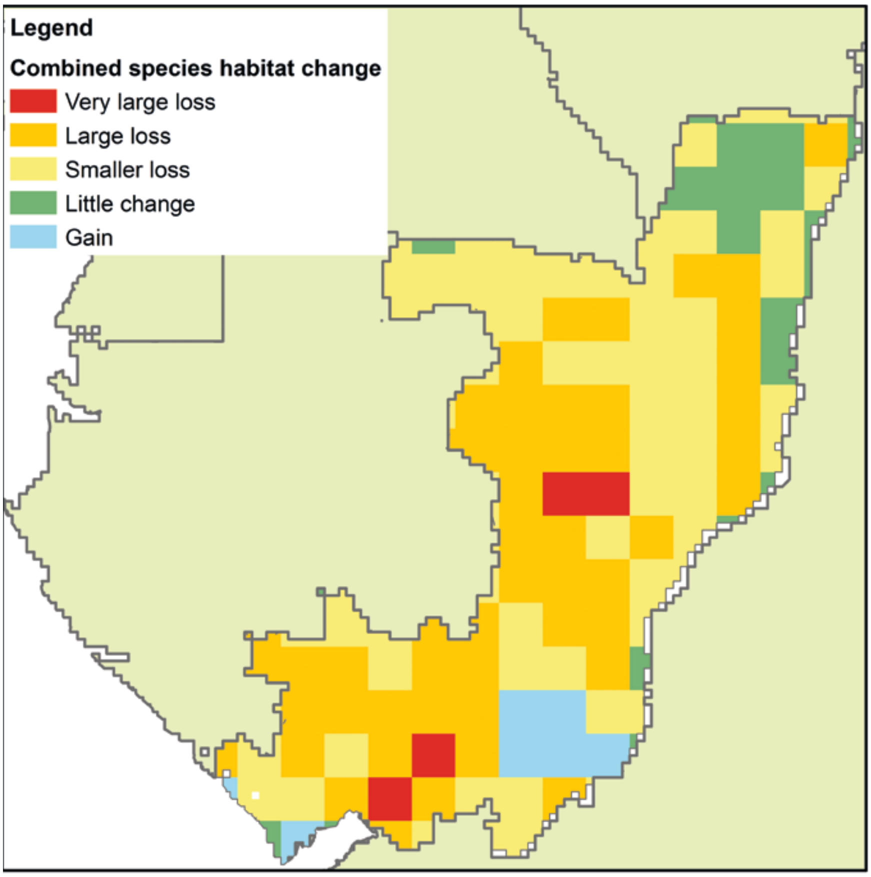

Figure 42: Map on the “combined species habitat” loss (or gain) between 2010 and 2030 for all species, weighted by the relative endemism of each species.

9 Results for the alternative scenarios

9.1 Deforestation and other changes in land use

The total deforestation between 2010 and 2030 in the Republic of the Congo is estimated to lie between 314 and 697 thousand hectares. The lower bound of this corresponds to a deforestation reduction of 30 % compared to the baseline scenario and the upper to an increase of 55 % (Figure 43).

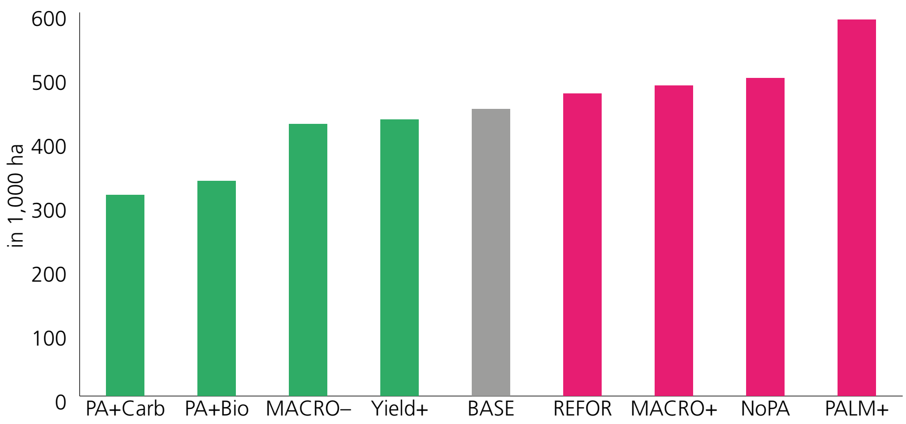

Figure 43: Cumulative total deforestation over the period 2010–2030 according to different scenarios: scenarios in green reduce future deforestation in relation to the base scenario, while red scenarios increase future deforestation.

The worst scenario is that there may be a conversion of forests into forest concessions (NO_FC). The other scenarios that increase pressure on the forests of the Congo are oil palm development goals (Palm+), non-compliance with protected areas (No_PA) and a greater increase in population and in GDP (Macro+). A goal of 1 million hectares of tree planting (Refor) also causes an increase in deforestation with regard to the baseline scenario. Plantations cannot be established in the forest but a greater occupation of the other natural lands can cause the displacement of certain agricultural activities from savannahs to forests. The increase in deforestation is limited to 5 % in this scenario.

Factors that could lead to lower deforestation in the coming decades include the expansion of protected areas to cover 17 % of the country (PA+). However, the expansion of protected areas is based on areas where population pressure is likely to be particularly high in the future. Note that the expansion according to a carbon criterion (PA + Carb) reduces deforestation by 5 % more than in the expansion scenario according to a biodiversity criterion alone (AP + Biod). A lower demographic and economic growth (Macro-) also reduces deforestation compared to the baseline scenario, but only by 5 %. Importantly, deforestation could be reduced with only small effects on economic or demographic growth through investment in improved agricultural production techniques (Yield+).

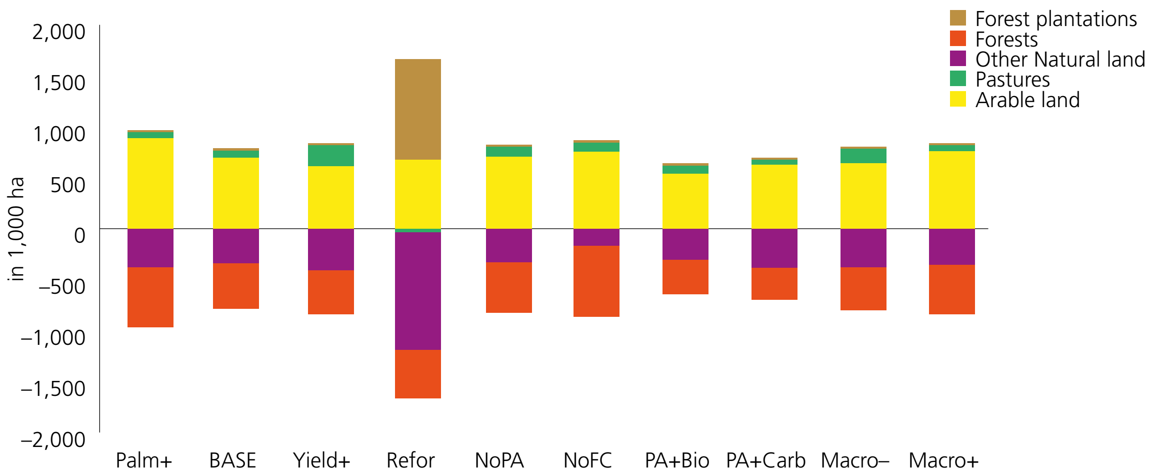

Figure 44: Conversion or expansion of the different types of soil occupation over the period 2011–2030 for each scenario. As the total land area is fixed, the sum of these changes is equal to zero for each period.

For all the changes in land use over the period 2011–2030 in Congo, we see the largest conversion of savannah in the scenario of forest plantations (Refor). This is not surprising since the objective is high — 1 million hectares of plantations — and use of savannah is the only possibility for expanding plantations in this scenario. It should also be noted that this is also at the expense of pastures and to a lesser extent, crops. Another interesting scenario is the expansion of the oil palm plantations (Palm+). This is the scenario that has the strongest increase in cultivated land. However, if forest concessions and the existing protected areas are respected, almost half of that expansion occurs in the savannahs (Figure 44). On the contrary, if the conversion of forests becomes possible in the forest concessions that exist today, without any particular aim of agricultural expansion, there is a greater increase in deforestation due to a significant relocation of certain agricultural activities from the savannah to the forest (No_FC compared to Base).

9.2 Agricultural production and consumption

Both scenarios the expansion of the protected areas (PA+) and the increase in population (Macro+) lead to a reduction in production per capita of calories, especially the production of animal calories, which decrease between 20 and 30 % compared to the baseline case (Figure 45). The increase in agricultural yields (Yield+) increases the production of calories per capita both of vegetable and animal origin. Indeed, the increase in crop yields also benefits the livestock supply chain by increasing its feedstock and hence reducing cattle feed prices. The expansion of oil palm plantations leads to a sharp increase in the production of vegetable calories linked to the ramp-up of palm oil production. In the scenarios of non-compliance with the forest concessions or protected areas (No_FC), there is a very small increase in the production of calories: it confirms that the increase of deforestation in these scenarios is not caused by an increase of production, but by a change of production location.

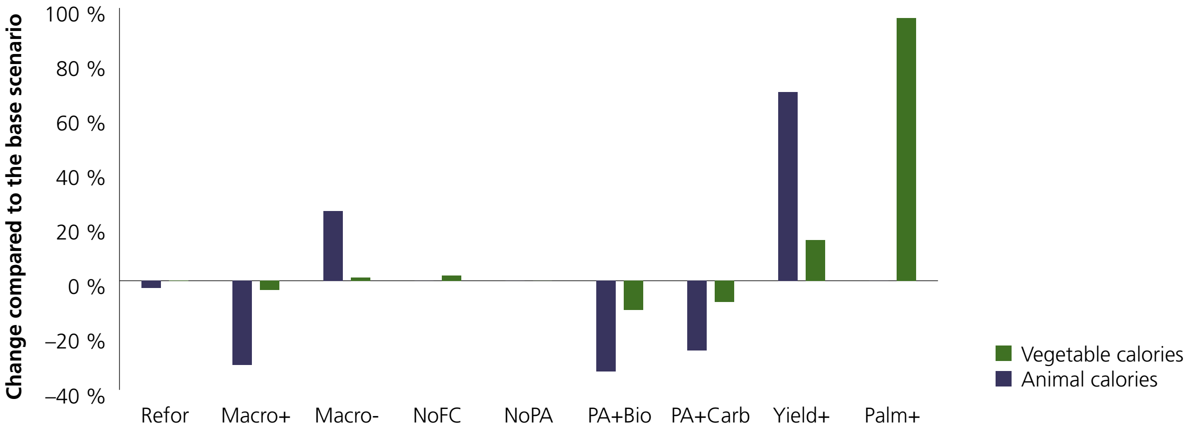

Figure 45: Impact of the different scenarios on the average calorie production per capita in 2030

9.3 Emissions

The estimated emissions due to deforestation over the period 2011–2030 vary between162 and 649 million tCO_2 across the scenarios, corresponding to a variation between -34 % and +130 % in relation to the baseline scenario (Figure 46). It should be noted that emissions from deforestation increase faster that the deforested areas in the event of non-compliance with the forest concessions (No-FC), which implies that deforestation occurs in forests particularly dense in carbon in this scenario. The uncertainty about the carbon content of forests also increases in this scenario with a difference of 268 million tCO_2 between the estimates using the map of Kindermann *et al.* (minimum) and Avitabile *et al.* (maximum).

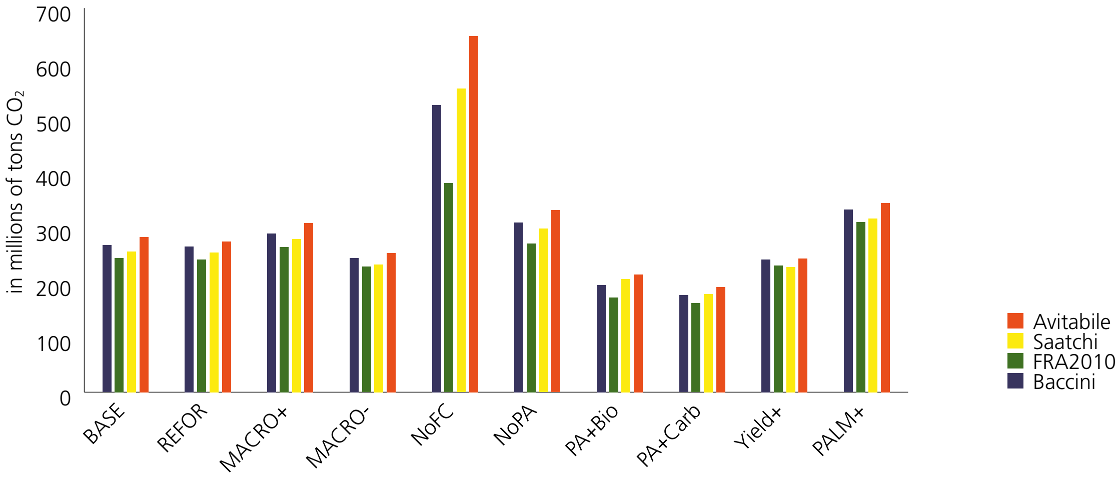

Figure 46: Variation in the emissions due to the deforestation over the period 2011–2030 according to the scenario and the biomass map used

In addition to the deforestation, the conversion of other natural land and industrial logging are the main sources of estimated emissions for the Republic of the Congo (section 8.4). Overall emissions vary between 471 and 688 million tCO_2 over 2011–2030 when using the biomass map of Avitabile *et al.* (2016) which amounts to a variation between –14 % and + 25 % compared to the baseline case (Figure 47). Despite the removal of emissions linked to industrial logging in the scenario of retrocession of existing forest concessions, total emissions increase because of the sharp increase in emissions from deforestation. In addition, there is a risk that, in reality, more wood is extracted informally in hence non-managed forest with larger related emissions in the event of the retrocession of the concessions. In the scenario of forest plantation expansion, we expected a reduction of emissions linked to carbon sequestration in the plantations. In fact the expansion of plantations is a source of additional emissions. This is because in our simulations plantations are located in the savannahs that have an initial carbon content that is often higher than the sequestration that can be expected from the planting of fast-growing trees. Thus, the prior identification of low carbon savannahs is needed to be able to connect the plants to potential REDD + credits. Direct emissions from agriculture are marginal in all scenarios. We also tested the impact of the transition from a conventional operation to a managed operation in the forest concessions. The difference in emissions is 10 million tCO_2 over 2010–2030 or less than 2 % of total emissions.

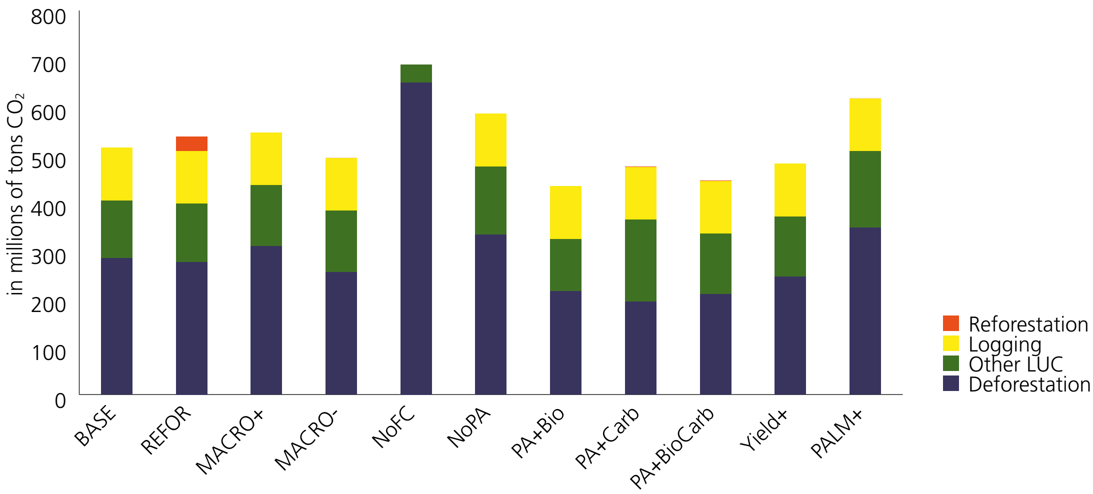

Figure 47: Emissions by source accrued over 2010–2030 according to different scenarios in the Congo

9.4 Impact on biodiversity

The impacts on biodiversity vary between the different scenarios and which one has the most impact depends on the aspect of biodiversity in question. Figure 48 shows the total impact on the habitat of the Western Lowland Gorilla (Gorilla gorilla) and Chimpanzee (Pan troglodytes). Where deforestation leads to loss of areas representing a habitat for the two species, the area is effectively represented twice in the figure. Consequently, the scenarios where each species loses its habitat in different places have an equivalent impact to the scenarios where the two species lose their habitat in the same place. In the areas where the species coincide, the area of species habitat loss can therefore be greater than the deforested area. The expansion of oil palm plantations, the failure to respect protected areas and the suppression of forest concessions lead to an increase in the loss of the habitat of the great apes in relation to the basic scenario. This underlines the importance of ensuring that the protected areas and the forest concessions are effectively kept, particularly where the potential to grow oil palms is high.

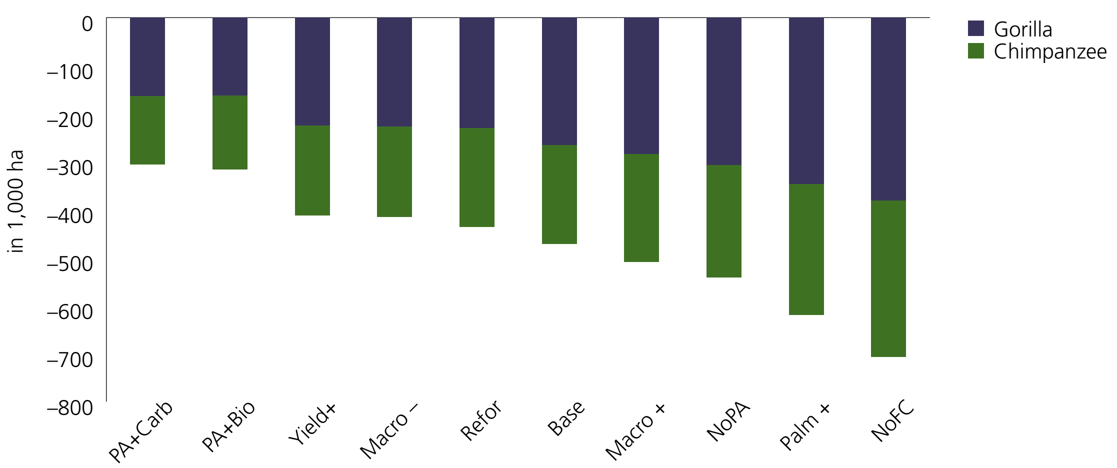

Figure 48: Impact of the different scenarios on the loss of potential habitat for the great apes 2010–2030.

When looking at all species, the scenario which projects a loss of habitat for the largest number of species is the scenario that includes the objectives of forest plantations (Refor). In this scenario it is estimated that 249 of the 946 species assessed would lose more than 5 % of their habitat, of which 17 are protected by law and two have been identified as globally threatened (Figure 49).

In all other scenarios, less than 30 species including a protected species, are expected to lose more than 5 % of their habitat. The planting of trees on 1 million hectares in 2020 led to the conversion of natural land (including natural grasslands and savannahs) which leads to a negative impact on the species in these areas. Savannah species for which habitat loss is projected include some that are hunted, such as the Southern Reedbuck (Redunca arundinum), the Spur-winged Goose (Plectropterus gambensis) and the Bushbuck (Tragelaphus scriptus). These results highlight the potential risk of an increase in plantations for the protection of biodiversity. Carefully evaluating the locations of new plantations can help to limit their impact on the most important areas for biodiversity.

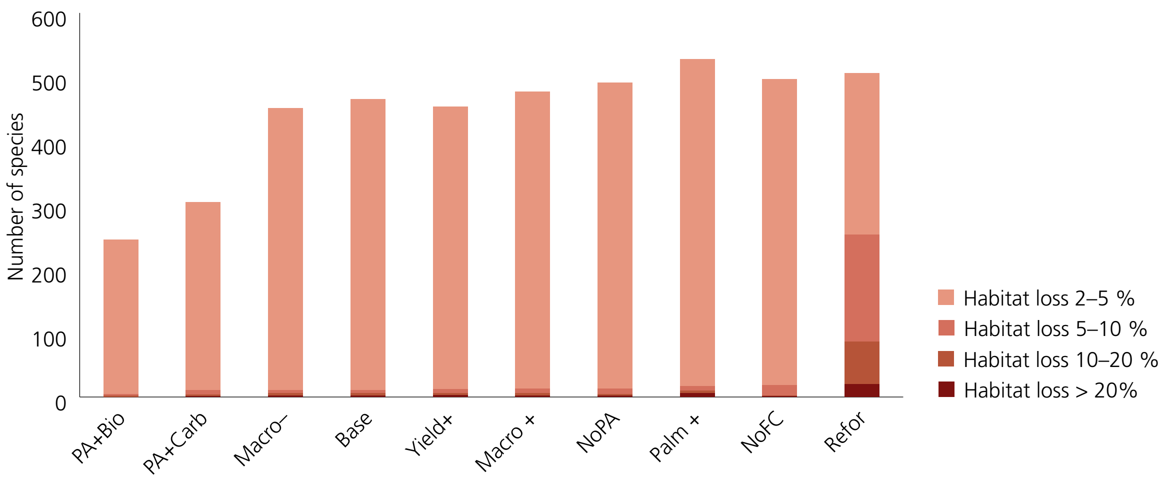

Figure 49: Number of species whose potential habitat is lost over the period 2010–2030.

The scenarios in which the loss of habitat is minimal for all species, including the great apes, are those where there is an expansion of protected areas, which highlights the important role that these can play in the protection of biodiversity and ecosystem services (e.g. tourism related to apes). The scenario in which protected areas are extended on the basis of the location of the most endangered species' potential habitats unsurprisingly lead to a greater reduction in loss of habitat for all species. It is also the only scenario that prevents any species losing more than 20 % of their habitat. Although in practice, protected areas are created based on many other criteria (presence of specific species or ecosystems, ecosystem services, views of local stakeholders or feasibility), this simulation makes it possible to determine to what extent an expansion based on the single criterion of avoidance of habitat loss could contribute to this objective.

The ranking of the protected area expansion scenarios is different for the great apes. The scenario based on the biodiversity criteria allocates the expansion of protected areas on the basis of future habitat pressures for a wide range of species, including non-forest species, and these criteria may not be the most effective for protecting the habitat of great apes, which tend to coincide with areas of dense forest with high carbon content. This highlights the potential for trade-offs between protecting a wide range of species and focusing on individual species or ecosystem services.

10 What factors can reconcile multiple objectives?

Policy makers are often faced with the need to achieve several goals with limited resources. It is therefore important to identify policies that can help to achieve several goals at once.

10.1 Millennium Development Goals (MDG's) and Sustainable Development Goals (SDG's)

The Millennium Development Goals (MDG) were adopted by the 193 Member States of the UN in 2002 in New York. The eight objectives cover the major human challenges with quantified targets for the progress to be made by 2015. Within the framework of this study, two of these goals are particularly important:

- Eradicating extreme poverty and hunger (Goal 1): Targets included halving the proportion of people whose income is less than one dollar a day between 1990 and 2015; ensuring full employment and work for all, including women and young people; finding decent and productive work; and halving the proportion of people suffering from hunger between 1990 and 2015.

- Ensuring environmental sustainability (Goal 7): Targets included integrating the principles of sustainable development into country policies and programmes; reversing the loss of environmental resources and reducing the loss of biodiversity by 2010 and attaining a significant decrease in the rate of loss.

In 2013, during the evaluation of the achievement of these targets for different countries, the data availability problem was stressed: "In many countries, the availability, frequency and quality of data to measure poverty remains low […]. Institutional, political and financial barriers hinder the collection, analysis and public access to data. It is urgent to improve the household survey programmes for measuring poverty in these countries." The Congo is unfortunately one of these countries. Nevertheless, an evaluation by the Centre for Global Development indicates that in 2011 the Congo had already achieved the target of halving the proportion of people who suffer from hunger . For the reduction of poverty, the goal was to drop to 18 % of the population living on less than a purchasing power parity (PPP) dollar per day in 2015 (PRSP 2005) but we could not find the data relating to changes in the poverty rate according to the ECOM2 household survey (2011).

In 2015, UN member states adopted a new sustainable development programme with 17 global targets (SDG's) that take the continuation of the millennium development goals for the period 2016–2030. As for the latter, quantified targets have been set for each goal.

- The eradication of poverty in all its forms (Goal 1)

- The elimination of hunger (Goal 2): the targets include doubling agricultural productivity and incomes of small farmers by 2030, and to ensure the sustainability of food production systems and implement resilient agricultural practices which contribute to the preservation of ecosystems, strengthen the capacity to adapt to climate disasters and climate change, and gradually improve the quality of the land and soil.

- Preserving and restoring the land ecosystems (Goal 15): this includes the promotion of the sustainable management of all types of forests, the end of deforestation, the restoration of degraded forests and the increase of afforestation and reforestation, which is quite close to the REDD+ objectives. Special emphasis is also placed on the preservation of biodiversity in goal 15, including the fight against poaching and the protection of endangered species.

10.2 Multi-objectives analysis

Here we compare the impact of each scenario on three goals: food security, the fight against climate change and the protection of biodiversity. For each of these goals, we selected two indicators that can be calculated using the results of the model. For economic development and food security we selected a) the average production of vegetable calories per capita in 2030 and b) the value of net agricultural imports of plant origin in 2030. This may echo the sustainable development goal 2 to eliminate hunger and ensure food security but also goal 8 for an inclusive economic growth creating jobs for all. For the fight against global warming we retained c) the emissions from the agricultural sector and change in land use in the period 2011–2030 and d) only emissions from deforestation between 2011 and 2030. These indicators are relevant for measuring progress towards sustainable development goal 13, to combat global warming, and the commitments of the Republic of the Congo made to reduce emissions of greenhouse gases in the negotiations at the UNFCCC and in particular, under the REDD+ process. Finally for the conservation and sustainable use of biodiversity we consider e) the loss of the potential habitat of great apes in the country and f) the number of species that lose more than 5 % of their potential habitat in the country between 2010 and 2030. This is directly related to the sustainable development goal15 for the preservation of biodiversity.

Table 9: Comparison of the scenarios comparing their contribution to several goals (green indicates getting closer to achieving a goal while red means a moving farther away from the goal).

	Economic development and food security		Climate change mitigation		Conservation and sustainable use of biodiversity	
	Calories produced per capita[a)]	Net imports[b)]	Total emissions[c)]	Emissions due to deforestation[d)]	Loss of habitat by the great apes[e)]	Number of species losing their habitat[f)]
BASE	*2303*	*171*	*404*	*282.0*	*1.5 %*	*11*
MACRO+	–3.3 %	12.3 %	7.9 %	8.9 %	8.1 %	18.2 %
MACRO–	1.1 %	–18.5 %	–5.2 %	–10.4 %	–11.9 %	0.0 %
No PA	0.0 %	1.4 %	17.4 %	17.2 %	14.9 %	18.2 %
No FC	2.0 %	–10.7 %	70.3 %	129.6 %	50.0 %	72.7 %
PA+ Bio	–10.8 %	39.9 %	–19.6 %	–24.4 %	–33.1 %	–54.5 %
PA+ Carb	–7.8 %	28.7 %	–9.7 %	–32.2 %	–33.6 %	–45.6 %
REFOR	–0.1 %	0.3 %	5.9 %	–3.0 %	–7.4 %	2209.1 %
YIELD+	14.9 %	–32.0 %	–8.0 %	–13.8 %	–12.5 %	9.1 %
PALM+	96.3 %	0.5 %	25.6 %	21.9 %	31.4 %	54.5 %

a. calorie output per capita in 2030 on the basis of the 18 crops represented in the model (in kcal per inhabitant per year)
b. value of agricultural imports in 2030 on the basis of 18 the crops represented in the model (in M US$)
c. total emissions from the agricultural sector and changes in land uses between 2011 and 2030 (in Mt CO_2)
d. total emissions from deforestation between 2011 and 2030 (in Mt CO_2)
e. share of the potential habitat area of the great apes converted to other uses between 2011 and 2030
f. number of species that lose more than 5 % of their potential habitat in the country between 2011 and 2030

According to our results, the increase of agricultural productivity combined with lower population and economic growth would lead to significant gains for agricultural development, climate change mitigation and biodiversity conservation (Table 9). Conversely, combining stronger economic growth with increased population would result in a worsening of all the indicators. We observe trade-offs for the other tested policies, such as a gain for agricultural development but losses to the environment in the oil palm expansion scenario (Palm+), and agricultural expansion into forest (No FC scenario), or gains for climate and biodiversity but losses to agricultural development as in the scenarios on the expansion of protected areas (PA+). Although it may lead to other benefits which are not considered here, the large-scale reforestation plan is negative for most of our indicators but particularly for biodiversity, with a strong increase, from 11 to 167, in the number of species at risk of losing more than 5 % of their potential habitat.

11 Discussion of the results

The Republic of the Congo submitted its Forest Reference Emission Level (FREL) to the UNFCCC in January 2016. First, we compare our results with the FREL then we discuss the factors that could affect our results and potentially lead to differences.

11.1 Comparison of our results with the national FREL

In January 2016 the Republic of the Congo submitted a national FREL to the UNFCCC . The calculation of the FREL was done jointly with FAO and is based on the "historical adjusted" approach that increases the rate of deforestation observed in the past by an adjustment factor which must reflect national circumstances (Republic of the Congo, 2016). However, the deforestation adjustment factor chosen by the Republic of the Congo only includes deforestation planned by the state: the contribution of mining to future deforestation is estimated at 1.7 thousand hectares per year and the development of oil palm plantations at 23.8 thousand hectares per year, which gives a total of 25 thousand hectares of planned deforestation per year up to 2020.

The results we have obtained with GLOBIOM show an average deforestation per year over the 2011–2020 period of between 13.5 and 29 thousand hectares in the scenarios including deforestation of 19.6 thousand hectares in the baseline scenario. The first conclusion that can be derived from this comparison is that future deforestation submitted in the FREL is within the range of estimates from GLOBIOM even if the FREL is somewhat at the top of the range: the average deforestation for all our scenarios is around 20 thousand hectares.

However, these are not the same causes which are advanced in both approaches. While 92 % of future deforestation in the FREL comes from the development of oil palm plantations, the expansion of oil palm only explains a maximum of 7 % of future deforestation in the results of our study. In the expansion of oil palm plantations scenario, we set as a target to increase the planted area to 50,000 hectares in 2020 and 250,000 hectares in 2030. The underlying assumptions madein the FREL include a rapid increase of oil palm acreage that are planned by the state with 120,000 hectares of new plantations already established between 2015 and 2020 and reaching 305,000 hectares in 2030. If these surfaces are expressed as an annual average, in GLOBIOM oil palm plantations increased by 4,000 hectares per year while in the FREL they increased by more than 23,000 hectares per year, or more than five times our projections. On the other hand, in the model, only a third of the expansion of plantations comes at the expense of forests (see section 11.2), while in the FREL the entire plantation expansion is expected to occur in forests.

Another important aspect is the expansion of agricultural land to meet the increasing local demand for food. Except for the production of palm oil which can also meet local demand, the FREL does not take into account these needs when adjusting for future deforestation. Now, according to our results, in addition to the 16,000 hectares per year of unplanned deforestation due to agricultural expansion between 2001 and 2010, the rising food needs of the population leads to increased unplanned deforestation of around 4,000 hectares per year over the period 2011–2020 in the baseline scenario. The omission of unplanned deforestation therefore significantly skews estimating future deforestation in the Republic of the Congo.

Emission factors per stratum related to the predominant soil type were used for the calculation of the FREL. According to this methodology, emission factors used for deforestation vary between 92 and 151 tonnes of carbon (tC) per hectare depending on the type of stratum. In this study, we used different above-ground biomass maps available and used a ratio of 23 % to calculate the carbon in the below-ground biomass as a function of above-ground biomass (Section 5.1.1). Although this ratio is lower than that used in the FREL, the average emission factor for deforestation is 139 tC/ha in the FREL which is lower than average emission factors of this study, which vary between 147 tC/ha and 165 tC/ha depending on the biomass map used. Emissions from deforestation over the 2015–2020 period is estimated at 19.6 million tCO_2 per year in the FREL against 11 million tCO_2 per year on average from all of our scenarios and biomass maps used (in a range of 7 to 26 million tCO_2 per year over 2011–2020).

Finally, the biggest difference comes from emissions due to forest degradation. According to the FREL, the total net emission related to logging are 21.6 million tonnes of CO_2 equivalent per year over the period 2015–2020 against 7.2 million tonnes of CO_2 equivalent per year over the period 2011–2020 in our estimates. The different assumptions made on the extracted log volumes partly explains this difference: 2.5 million m^3 per year in the FREL against 1.5 million m^3 in this study (Section 8.3). But the main reason is the differing assumption in the emission factor: the emission factor used in the FREL is 5.2 tCO_2/m^3 for certified concessions and 8.3 tCO_2/m^3 for non-certified concessions while we use a factor of 1.06 tC/m^3 or 3.89 tCO_2/m^3 for all concessions (Section 5.1.2). The problem is that the damage factor which is used for reduced-impact logging (0.91 tC/m^3) is drawn from the study of Brown *et al.* (2005) . However, this factor corresponds to the total emission for forest logging per extracted m^3, including e.g. skidding trails. According to the study by Brown *et al.* the emission factor related to damages only is 0.66 tC/m^3.

Thus, the damage factor of the non-certified logging used in the FREL should also be less than 1.32 tC/m^3 instead of 1.82 tC/m^3. The last point on which there is a difference is the use of the biomass expansion factor applicable to the hardwood extraction in the FREL, which increases the extracted wood-related emissions by a factor of 1.55, giving 0.51 tC/m^3 instead of 0.25 tC/m^3 in our assumptions.

11.2 Agriculture

According to our results, increased agricultural yields is a “win-win” strategy, that is to say, it can meet several objectives of a different nature at the same time: agricultural development, food security, the fight against climate change and biodiversity protection.

Several articles have shown, however, that an increase in agricultural yields may in fact be accompanied by an increase in deforestation (Byerlee *et al.,* 2014; Hertel *et al.,* 2014; Rudel *et al.,* 2009). The underlying economic mechanism is that an increase in productivity tends to lower the production cost per unit and therefore the price of agricultural commodities. These lower prices stimulate consumption which can potentially increase more than can be attained only by increasing productivity per hectare, thereby leading to an increase in cultivated surfaces. On the production side, it is crucial to know which technologies can be used, their cost, and their impact on productivity. On the demand side it is important to know how the consumer reacts when facing a price change (price elasticity of demand). It is also important to understand what the main constraints for farmers are in order to increase the chances of these new practices being adopted (labour input, input costs, investment security, etc.). As part of a project for the World Bank where the CongoBIOM model was used for the first time, we also found that increasing crop yields led to an increase in deforestation (Mosnier *et al.,* 2012).

However, the model has undergone significant changes since, which may explain the difference in the outcome in this study. Following this study, we will therefore conduct an in-depth sensitivity study in order to analyse in detail the conditions under which increased agricultural yields lead to a reduction of deforestation in the Congo Basin with GLOBIOM or not.

On a given site, conversion to agriculture causes the complete disappearance of the forest in our model. In reality, the recurrent slash and burn system that is still the most common agricultural system in the forests of the Republic of the Congo, often keeps valuable trees on the site during the farming cycle. In addition, two to three years of cultivation are usually followed by several years of fallow, thus allowing the regeneration of forests on abandoned land (Makana and Thomas, 2006; Russell *et al.,* 2011). The growth in carbon stocks is particularly rapid during the first 20 years after farming ends. This can result in a carbon sequestration from 3 to 9 tC per year per hectare depending on soil fertility and the length of the fallow period (Palm *et al.,* 2000). According to our results, there could be more than 900 thousand hectares fallow in 2030 in the Congo. Although some areas have shorter fallow periods and less fertile soils which can reduce forest regeneration capacity, agricultural fallows in forest area could represent an important national carbon sink. The contribution of the traditional agricultural system to carbon sequestration in the Congo Basin will be the subject of a more detailed assessment in our future work.

An important part of the expansion of oil palm takes place in non-forest areas in the model. However, in reality, most agro-industrial oil palm plantations have historically been based in the forest. One possible explanation for this result is the fact that many forest areas that have not previously been allocated for industrial logging concessions or protected areas, while benefiting from more favourable biophysical conditions, are more difficult to access than some areas with a lower potential but closer to existing transport infrastructure. In the future it is possible that the agro-industrial investors will be ready to build their own access roads, but this represents an additional cost.

Another explanation is that the yield of oil palm is not differentiated within a simulation unit (~ 50 x 50 km). Thus, for the border areas between forests and non-forests, the model sees no potential difference between these two types of vegetation, whereas in reality there may be. A final explanation is that the benefits to the cutting of the forest during the setting up of the agro-industrial plantations are not taken into account whereas investors often do take the so-called conversion wood into account in their calculation of return on investment. These points will be explored in detail in our future work.

11.3 The socio-economic context

Similar to an increase in agricultural yields, lower economic and population growth lead to improvements in all the indicators considered in this study compared to the baseline. In reality, the impact of economic growth on deforestation is ambiguous. According to the forest transition theory (Mather, 1992), the increase in GDP is initially accompanied by a reduction of the forest, but after a certain GDP level is reached, the forest area increases again. In this theory, the increase in deforestation can be caused by the growing demand for wood by the industry, urban development and agricultural expansion in the first phase, whereas a change in perception of forests by a population which has become predominantly urban, more intensive agriculture and economic growth based on the service sector may explain the reduction of deforestation in the second phase. However, it is uncertain whether this theory can be applied in the Republic of the Congo. The country's economic growth is largely dependent on the increase in oil revenues which represent nearly 70 % of GDP (PRSP 2012). Some authors have highlighted the fact that this context is particularly unfavourable to the development of an agricultural sector which is subject to strong competition from imports because of an overvalued exchange rate (Wunder, 2003). Moreover, as economic growth relies heavily on a single industry, the impact of economic growth on household incomes in other sectors is dependent on mechanisms for redistributing existing wealth. Assuming a uniform distribution of the fruits of economic growth within Congolese households, it is likely that our results overestimate the impact of a stronger economic growth on food demand.

The Congolese population, although growing rapidly, is mostly urban, and is predicted to be increasingly so in the coming years. Thus, growth of the population in the countryside is partially offset by migration to the cities where the population has more access to imports of agricultural goods.

The unemployment rate is estimated at around 30 % in Congolese towns and particularly affects the young (PRSP 2012) but as farming is not profitable and the conditions of rural life can be quite rudimentary, it does not attract young people. Could this trend be reversed in the coming decades? Improving living conditions in rural areas through access to education, health services or electrification should increase the attractiveness of rural areas and promote the development of income generating activities.

11.4 Logging

Despite our efforts to collect data, modelling concurrent informal and formal logging still merits further efforts. In the model, the two types of logging are in direct competition on the markets where the price is the same for everyone, whereas in reality the export markets and the local markets are quite differentiated: international markets are accessible for concessionaires only and the local markets which are generally less concerned about the origin of the wood and using more species (Bayol *et al.,* 2014). There is also variation in requirements in terms of sustainability and traceability of logging by recipient countries. This study is based on an assumption of compliance with management plans in the concessions. The FLEGT (Forest Law Enforcement, Governance and Trade) Action Plan, which should ban imports of illegal timber in Europe, should strengthen their implementation but there is risk of "leakage" of illegal timber exports to Asian markets that currently have little concern for sustainability. For informal logging, we still lack information about the availability of wood resources, the location of the logging and the long-term impact on populations. Thus, although several studies emphasise the importance of the informal sector in the countries of the Congo Basin, with extracted timber volumes being close those of the formal sector (Lescuyer and Cerutti, 2013; Ondele-Kanga, 2012), it has not been possible to represent degradation linked to informal logging and associated emissions in this study.

We tried to estimate emissions from the formal logging in the Congo on the basis of existing forest concessions and the current production of logs.

According to our results, emissions from logging represent 20 % of the total emissions from changes in land use and agriculture over the period 2011 to 2030 in the Republic of the Congo. Adoption of RIL practices and the forest certification are promoted by the government of the Republic of the Congo. At present 21 % of the area under concession is certified, representing 2.5 million hectares (Bayol *et al.,* 2014). Using the corresponding emission factors estimated in the literature, we show that the increased adoption of RIL for all forest concessions in the Congo would have a positive impact, with 10 million tons of CO_2 avoided during the period 2011–2030; although this only represents 2 % of total emissions projected to be released over the period. However, our results show that logging concessions have a crucial role to play in limiting future deforestation in the Republic of the Congo.

11.5 The expansion of protected areas

In two scenarios, the location of the simulated expansion of protected area is based on a single criterion: the loss of species habitat in the PA+Bio scenario and the loss of carbon in the PA+Carb scenario. Therefore, these scenarios are likely to represent the maximum possible impact on these specific indicators of an expansion of protected areas to 17 % of the total land area of the country. In fact, the expansion of protected areas will depend on a variety of criteria, including a number of different aspects of biodiversity, and should ideally be developed in the context of systematic conservation planning (Worboys et al 2015). Systematic conservation planning includes identifying national conservation priorities (e.g. targets for certain species or certain types or elements of vegetation); an examination of the extent to which the current conservation network meets these objectives; and the selection of additional areas to fill gaps. The PA+Bio scenario is based on an overall threat affecting all mammals, amphibians and birds for which data is available, and does not take into account gaps in species habitat coverage, or the fact that protected areas can be developed to protect specific species.

Connectivity between areas and the protection of intact landscapes are also two important elements in the planning of protected areas (Worboys et al 2015) which are not included in the "PA+' scenarios. In the "PA+" scenarios, the richest areas in biodiversity or with the greatest carbon loss in the base scenario were selected for the expansion of protected areas, even if they were a small part of a single cell. Protecting larger areas of natural habitat can reduce the pressures from fragmentation and increase the resilience of these areas; this could concentrate the location of protected areas and therefore their impact on land use in comparison with the modelled scenarios. In addition, areas rich in biodiversity or high carbon content that are most likely to undergo a change of land use (that is to say, the areas selected in the "PA+" scenario for protected area expansion), may also be areas with high opportunity costs for developing protected areas and restricting land use changes, making the development of protected areas in these places more difficult. Overall, although the "PA+" scenarios do not represent the full reality of where the expansion of PAs is likely to occur — because the location of new protected areas must be a political decision with the full, prior and informed consent of local people — the scenarios do show that protected areas can support the conservation of biodiversity and carbon stocks in the Republic of the Congo.

11.6 Large scale afforestation and reforestation

Finally, according to our results, the afforestation and reforestation scenario of 1 million hectares does not lead to a reduction in emissions but to an increase, despite the carbon sequestration occurring inside plantations. This is due to the high carbon content of non-forest land converted to plantations and the type of plantation management used in the model. In reality, major zoning work is carried out to identify areas suitable for plantations for the ProNAR, which could limit the conversion of carbon-rich land. Furthermore, the short rotation plantations that were considered in the model should represent only 340,000 hectares. In fact, there are plans to dedicate the same area for agro-industrial plantations. If they do not have a carbon content higher than short-rotation trees, they can still prevent an expansion of these plantations into the forests whose carbon content is even higher. In the future, it would be interesting to estimate the precise impact of ProNAR with GLOBIOM according to the different implementation procedures envisaged.

12 Conclusion

According to moderate projections, 6 million people will live in the Congo in 2030, 72 % 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 15,000 hectares between 2000 and 2010 to 25,000 hectares between 2020 and 2030, causing emissions of 238 million tCO_2 between 2010 and 2030. 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 425,000 and 697,000 hectares depending on the scenario, compared to 449,000 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. The Republic of the Congo 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 ecotourism. The model predicts a loss of habitat for great apes in Bouenza, Eastern Cuvette and Southern Likouala. 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 occurs 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 et Chomitz 2011). The lack of funding for protected areas in Central Africa already makes the effective management of the existing protected areas difficult (Wilkie et al, 2001).

By comparing the results of several scenarios on agricultural production, land-use change emissions and the conservation and the sustainable usage of biodiversity, it seems that an increase in agricultural productivity and lower economic and demographic growth would lead to significant gains for agricultural development, climate change mitigation and biodiversity conservation. Conversely, combining stronger economic and population growth would result in a degradation of all the indicators. Trade-offs are observed for all other tested policies. For example, under the oil palm expansion and agricultural expansion into forest concessions scenarios there is a 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 state should initially identify the areas most suitable for plantation development. According to our results, an objective of 250,000 hectares of oil palm would translate into an increase in deforestation of 140,000 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 the Congo 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.

The formulation and implementation of effective policies to reconcile development and environmental protection in the coming decades in the Congo faces a major obstacle: the lack of information on the current situation of the country, especially in rural areas. The level and types of food consumption in different parts of the country, the location of land under production, the use of different modes of agricultural production, land fertility, and the connectivity of the agricultural production areas to urban markets, are all aspects that will greatly influence future deforestation in the Republic of the Congo. The ability to measure progress towards the achievement of various development goals, reduction of greenhouse gas emissions and biodiversity conservation, require the collection and centralisation of continuous high-quality statistics. The availability of more accurate and timely data would greatly improve the accuracy of the results of this type of modelling exercise, in order to better inform policy decisions in complex situations which may involve trade-offs between different objectives.

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Annex

List of the improvements made to GLOBIOM

Improvement	Implemented in CongoBIOM 2010	Implemented in GLOBIOM 2012–2016
Introduction of the permanent forest area	Protected areas, forest concessions and other forests of the permanen forest area cannot be converted for other uses.	Update of forestry concessions and protected areas over the period 2010-2020 by integrating the 2015 data. Alternative scenarios with possible conversion of permanent forest areas.
Adjusting wood harvesting rates in managed forests	Taking into account the concentration of harvest from only a few commercial species (selective logging) based on a literature review.	Adjustment of harvest rates by type of forest (e.g. dense humid forest, dry forest, …).
Estimated emissions from forest degradation related to forestry under concession	Use of the emission factors of Durrieu of Madron *et al.* (2010): 3.41 tCO_2/m^3 for conventional concessions, 3.05 CO_2/m^3 for concessions with management plan, 2.97 tCO_2/m^3 for certified concessions.	No change compared to 2010.
Making the demand for firewood and forest degradation related to firewood collection spatially explicit	Firewood demand established by simulation unit. Introduction of a new class of "degraded forest" for the collecting of firewood.	Firewood demand implemented on national scale but intensity of removals depends on the spatially explicit population density. Firewood can also come from agricultural fallows.
Wood processing	Timber processing coefficient for the Congo Basin: 0.38 instead of 0.59.	A larger number of wood products are considered.
Entering in the coffee and cocoa model for the Congo Basin	Using SPAM (Spatial Production Allocation Model) maps to allocate the coffee and cocoa per simulation unit and for the productivity estimates.	Errors discovered in SPAM data and no available statistics. Cocoa and coffee and not taken into account explicitly.
Calculation and introduction of internal transportation costs	Collection of current and planned transport infrastructure data. Calculation of transport costs to the nearest city (> 300 000 inhabitants) or to the nearest port for each pixel.	No update for planned infrastructure. Transport costs on the basis of planned infrastructure are now integrated in all scenarios including the baseline 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

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

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COMIFAC – Commission des Forets d'Afrique Centrale

IIASA

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