Modelling Land Use Changes in the Democratic Republic of the Congo

2000–2030

A report by the REDD-PAC project

Supported by:

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

based on a decision of the German Bundestag

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FINANCIAL SUPPORT

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

CITATION

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

ACKNOWLEDGEMENTS

The authors thank the participants of the various workshops held in the framework of the REDD-PAC project in Doula and Kinshasa. A special thanks to Bruno Hugel and Fabien Monteil, Jean-Paul Kibambe, Hassan Assani, Herve Kashongwe, Carlos de Waisseige, Landing Mane and Terry Brncic for their helful inputs at different points of time during this study.

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CBD	Convention on Biological Diversity
CN-REDD	REDD+ National Coordination Body
COMIFAC	Central African Forests Commission
COP	Conference of the Parties
DIAF	Forest Management Department
EF	Emission Factor
ER-PIN	Emissions Reduction Project Idea Note
ER-programme	Emissions reduction programme
FAO	Food and Agriculture Organization of the United Nations
FAO-ILRI	FAO and the International Livestock Research Institute
FCPF	Forest Carbon Partnership Facility
FIP	Forest Investment Program, Forest Investment Program
FLEGT	Forest Law Enforcement Governance and Trade
FREL/FRL	Forest Emissions Reference Levels/Forest Reference Levels
GDP	Gross Domestic Product
GLC	Global Land Cover
GLOBIOM	GLOBal BIosphere Management Model, GLOBal BIosphere Management Model
Gt	Gigatonnes
IPCC	Intergovernmental Panel on Climate Change
JRC	Joint Research Center
LiDAR	Light detection and ranging
LTBI	Industrie de Transformation des Bois de la Likouala
MDG	Millennium Development Goal
Mha	Million hectares
OSFAC	Central African Forest Observatory
REDD+	Reduction of Emissions from Deforestation and Forest Degradation
REDD-PAC	REDD+ Policy Assessment Center
R-PP	REDD+ preparation plan, REDD+ Preparation Plan
SDG	Sustainable Development Goal
NBSAP	National Strategy and Action Plan for Biodiversity
SSP	Shared Socioeconomic Pathways
tC	Tons carbon
TCCCA-principle	Transparent, complete, coherent, concise and accurate
UCL	Université Catholique de Louvain
UNEP-WCMC	United Nations Environment Programme, World Conservation Monitoring Centre
UNFCCC	United Nations Framework Convention on Climate Change
UN-REDD	REDD+ Program of the United Nations
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 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, hence leading to difficult choices when designing policies.

The Democratic Republic of the Congo (DRC) is the biggest country in terms of land surface and the most populous country in Central Africa. Dense humid forests cover 155 million hectares corresponding to almost two thirds of the country's territory. While today being inhabited by about 81 million people, according to projections of the United Nations towards the end of this century DRC will be ranked tenth on the list of the most populous countries worldwide with its population being above 200 million people. Considerable efforts will be needed in order to improve the living conditions of the population without exhausting the country's vast natural resources. It is against this backdrop that in 2009 the DRC has been the first African country to submit a preparation plan for the Reduction of Emissions from Deforestation and Forest Degradation (REDD+).

The core objective of the present study is to assist the national institutions engaged in the country's REDD+ process as well as the planning of the National Strategy and Action Plan for Biodiversity (NBSAP) through identifying the areas exposed to the strongest pressure on forests in the future and its consequences in terms of agricultural production, greenhouse gas emissions and risk of biodiversity loss.

Models allow to explore the consequences of anticipated future developments in a simplified framework. The REDD+ Policy Assessment Center (REDD-PAC) has adapted the GLOBIOM land use model to the Congo Basin context.

GLOBIOM (for *GLOBal BIosphere Management Model)* is a global economic model which represents the competition for land use between the agriculture, forestry and bioenergy sectors. The model provides results for the years 2000–2030 in ten years time steps, where the first model period 2000–2010 allows to test the model's capacity to reproduce past trends in land use.

Deforestation is modelled as a consequence of changes in production and consumption, and for all countries of the world at the same time. Thus, it is easy to check the validity and consistency of the estimates. It is also possible to avoid estimating reference levels that over-estimating future deforestation, unrelated to change in demand. The spatially explicit nature of the results ensures the consistency of the deforestation calculated at the sub-national level with the total deforestation at the national level. The spatially-explicit nature of GLOBIOM also allows to take into account the heterogeneous distribution of carbon and biodiversity across the country's landscapes.

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 simulation period is 2000–2030. The first 2000–2010 period allows to test the capacity of the model to reproduce past trends ("validation period") whereas results for subsequent simulation periods allow to quantify future developments. The national model covers the DRC as part of the Congo Basin region of the model which includes all the COMIFAC countries. As such, DRC can trade with the other COMIFAC countries and with the other regions of the World. The DRC is covered by 1,190 spatial units which output results for agricultural production and changes in land use from one simulation period to another.

It is very important for the modelling work to have a good representation of the initial situation in terms of land cover and land use. The location of notably cropland in DRC varies significantly from one land cover map to another and the absence of a recent agricultural statistics service creates severe problems regarding the reliability of agricultural statistics for the DRC. Therefore, a hybrid land cover map was created through the combination of the best land cover maps and agricultural statistics available after consultation with local experts.

According to moderate projections, 105 million people are expected to live in DRC in 2030, half of which in cities. Moreover, the average GDP per head is set to almost triple 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 and thus deforestation.

Our results show an average increase in annual deforestation from ca. 374,000 hectares in the period 2010–2020 to 643,000 hectares between 2020 and 2030, causing the emission of 7.2 Gt CO_2 over the 2010–2030 period. About 60 % of the projected deforestation is caused by the expansion of cassava associated fallow land, and 15 % from the expansion of oil palm. Furthermore, the DRC we also project an increase of imports of agricultural good over the simulation periods and about 20 % of the expansion of agricultural land is projected to occur in non-forest areas, i.e. savannahs and other natural lands. These two factors mitigate the impact of the increasing local demand on forests but they can also lead to other problems.

The DRC is home to four species of Great Apes: Chimpanzee (*Pan troglodytes*), Bonobo (*Pan paniscus)*, Mountain Gorilla (*Gorilla beringei)* and the Western Lowland Gorilla (*Gorilla gorilla gorilla)*, whose existence is strongly dependant on the presences of natural forests for their habitat. These are also species which represent an important potential for the development of ecotourism. The model projects a particularly worrisome habitat loss in the East of the DRC. Besides the direct loss of habitat, the expansion of agriculture land is likely to lead to an increase of contacts between men and wildlife and hence higher risks of poaching.

Accumulated deforestation between 2010 and 2030 varies between 8 and 13 million hectares in the scenarios which were tested as compared to 11 million hectares in the base scenario. The improvement of agricultural yields, the expansion of protected areas and a slowed-down growth of both population and economy could reduce future deforestation whereas the uncontrolled expansion of agriculture into protected areas of forest concessions and a stronger growth of population and economy spur deforestation as compared to the base scenario.

An increase of agricultural productivity could reconcile the objectives of food security, climate change mitigation and biodiversity conservation. Conversely, the combination of stronger growth of both the population and the economy entails a degradation of all objectives. For other politics which were tested, trade-offs between different objectives can be observed.

The non-respect of permanent forest areas ("domaine forestier permanent" in French) or protected areas lead to gains for the agricultural development but an increase of emissions and loss of biodiversity. The expansion of protected areas reduces deforestation while at the same time leading to increased emissions. This at first glance surprising result highlights that depending on the location and the criteria used to create new protected areas, there is a risk of “leakage” of anthropogenic pressure away from biodiverse but less carbon-rich areas towards unprotected, carbon-rich forests.

The results of this model-based analysis of land use change suggest that deforestation in DRC might lead to the emission of 7 Gt CO_2 over the period 2010–2030 and the loss of more than 10 % of the potential habitat of 300 species, including 42 threatened species.

A comparison of results from different scenarios in terms of agricultural production, emissions from land use change and impacts on the conversation and sustainable use of biodiversity show that slower population growth and an increase of agricultural yields could help to reconcile the fulfilment of different objectives at a time. However, given the little information available about the agriculture sector in DRC it appears to be a difficult task to put in place efficient strategies for agricultural intensification. Therefore, it is important to invest in a system to collect and regularly update statistics about populations and the agriculture sector in the DRC in order to allow for a diagnosis about the actual barriers to agricultural intensification.

If our results show that a strong economic growth could have negative impacts on forest cover through a rising demand for agricultural products, in reality it all depends on how the fruits of this growth will be used. A stronger economic growth economic growth can create employment in off-farm sectors and it can allow to invest in the development and propagation of innovative technologies which in turn can contribute to an increase in productivity in the agriculture sector.

The results of this study also show the importance of an effective management of protected areas for the protection of species, which contributed to the prevention of extinction of species one ot eh international objectives of the Strategic plan for Biodiversity 2011–2020. Given that existing protected areas are lacking financial resources, these results also confirm the importance of financial and technical support for an effective management of protected areas.

1. Introduction

The emissions linked to the conversion of tropical forests are estimated at close to 1 gigaton 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 acronym "REDD+" 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 Democratic Republic of the Congo (DRC) is the most populous country in central Africa with well 80 million inhabitants and the 11th biggest country worldwide with a territory of more than 235 million hectares (Wikipedia). The country's population is very young, with 50 % of inhabitants being aged 16 years or less (Enquête 1–2–3, 2014). According to the United Nations the DRC will become the tenth most populated country in the world towards the end of the 21st century; the country's population will then count more than 200 million inhabitants.

The landscape of the DRC is dominated by dense humid forests which cover 155 million hectares (Mha), corresponding to almost 2/3^{rds} of the country's territory (FACET). The economy is dominated by extractive industries – minerals and petrol – and by agriculture. More than 70 % of the population works in the agriculture sector and one fourth in commerce and services but the vast majority (89 %) of employment are located in the informal sector (Enquête 1–2–3, 2014). Poverty is diminishing but still remains at a high level with 65 % of the rural population living with less than 1.6 USD Dollar per day and 60 % of the urban population living with less than 2.3 USD per day (Enquête 1–2–3, 2014).

Considerable efforts will be needed in order to improve the living conditions of the population without exhausting the country's vast natural resources. The DRC has been one of the most active countries during the starting phase of the REDD+ initiative which translated in the submission of the Emissions Reduction Preparation Plan (ER-PP) in 2009. The DRC can therefore be considered a REDD+ pioneer country.

Phase 1 of REDD+ is the preparation phase and it implies the development of certain key elements of the mechanism. 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 allowing to explore the impact of different factors on land use and identify the areas subject to the strongest conversion pressures, the models can assist in the development and implementation of strategies to avoid or reduce deforestation and forest degradation. The modelling can also make it possible to test the potential impact of different policies. This evaluation can be made simultaneously in terms of emissions, agricultural protection and biodiversity, thereby enabling better integration of these different problems in the planning and preparation of policies.

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

c. **A robust and transparent national forest monitoring system for the monitoring and reporting of the 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 DRC is party to the Convention on Biological Diversity (CBD), 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 CBD in October 2010, breaks these three large areas down 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 DRC is expected to soon submit its revised NBSAP's streamlined with the objectives of the strategic plan of Aichi for biodiversity over the period 2011–2020. The COMIFAC Convergence Plan, which also covers the DRC, also promotes the adoption of sustainable forest management policies in the sub-region.

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

The REDD-PAC project seeks to provide understanding about 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 DRC. 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 situation of the REDD+ initiative in the DRC

2.1. Key milestones of the REDD+ process in DRC

- **January 2009:** The DRC obtains 0.2 Million (M) USD from the Forest Carbon Partnership Facility (FCPF) and 1.8 M USD from the REDD+ Program of the United Nations (UN-REDD) to support the REDD+ process in DRC.

- **May 2009:** The governance structures of the REDD+ process in DRC consisting of a national committee, an inter-ministerial committee and a national coordination body (CN-REDD, for "Coordination Nationale REDD") are created by prime minister decree.

- **March 2010:** The DRC is the first African country to have submitted the approved REDD+ preparation plan (R-PP) and received additional funding of 3.4 M USD from the FCPF and 5.5 M USD from the UN-REDD program to allow for the implementation of the R-PP in DRC.

- **June 2011:** The DRC is the first African country to have an approved investment plan for REDD+ approved by the Forest Investment Program (FIP) where 60 M USD are foreseen to fund investment projects which have a link with REDD+ with the support of the World Bank and the African Development Bank.

- **November 2011:** The funding for seven REDD+ pilot projects is approved by the Congo Basin Carbon Fund (Figure 1). These projects generally incorporate three components: a forest conservation component to reduce the expected future deforestation, an agroforestry component and the distribution of improved cook stoves in order to reduce the use of fuel wood.

- **December 2012:** A national forest cover monitoring system and a national REDD+ fund are put in place in order to develop national REDD+ standards and to have a national REDD+ framework strategy. Training sessions in satellite imagery processing were carried out by staff of the Food and Agriculture Organization of the United Nations (FAO) with staff of the Forest Management Department (DIAF for "Direction d'amenagement forestier") of the DRC in order to build the DIAF's staff capacities and to ensure continuity of the national forest cover monitoring system.

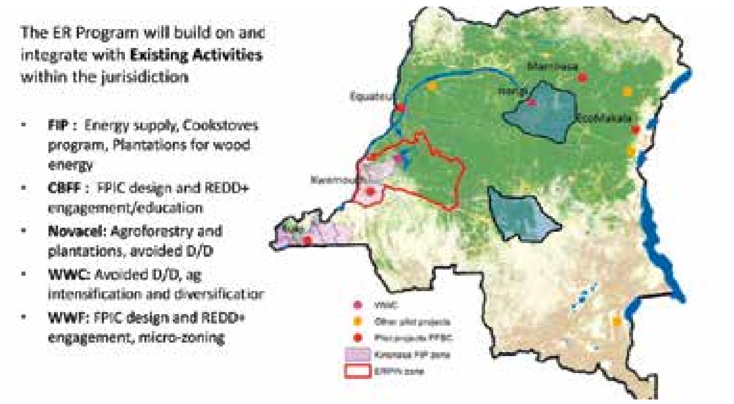


Figure 1: Map of REDD+ pilot projects (colored dots), the FIP core investment zones (grey shaded ares) and the Maï-Ndombe national emissions reduction pilot area (red outline). Source: EU REDD Facility

The years 2013 and 2014 constituted a landmark period for the REDD+ process in DRC. Following the independent mid-term evaluation of the preparation process carried out in 2012, the national coordination was restructured. Focal points have been recruited for each one of the eleven provinces of the country. In the wake of the important costs of this deployment of personnel, it was decided to concentrate the investments on five provinces only and to create synergies between the work on Forest Law Enforcement Governance and Trade (FLEGT) and REDD+ in DRC. The main objective of this period was to close the REDD+ preparation period and to mobilize funds for the investment phase (Figure 2).

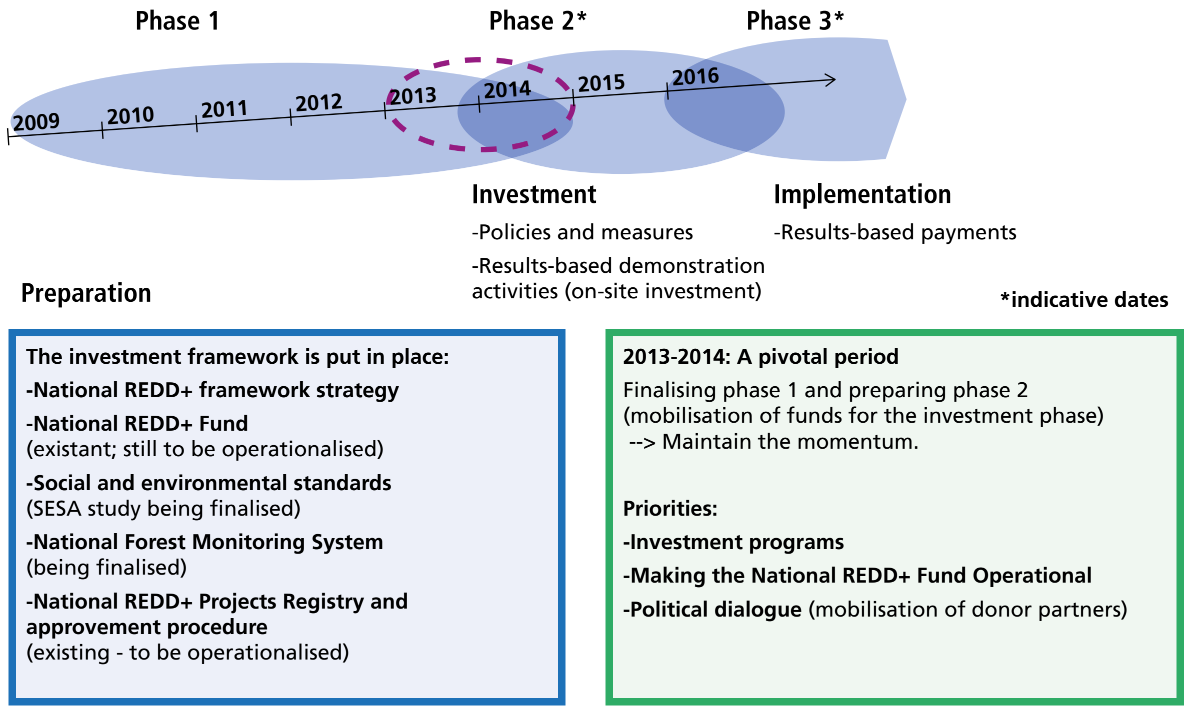


Figure 2: Scheme of the REDD+ process in DRC – Communication of the National REDD+ Coordinator Victor Kabengele during a REDD-PAC workshop in February 2015 in Kinshasa.Translated by the authors.

- **January 2015:** Agreement on the instruments and environmental and social safeguards with the World Bank and national "validation" at end 2015.

- **May 2015:** Final report about the auto-evaluation of the Readiness Package (R-Package) of the DRC approved by the FCPC participants committee.

- **June 2015:** The Emissions Reduction Project Idea Note (ER-PIN) for the Maï-Ndombe is finally validated by the stakeholders.

- **January 2016:** Re-submission of the Maï-Ndombe emissions reduction program document to the FCPF.

2.2. Studying the drivers of deforestation

Following the finalization of the REDD+ preparation plan (R-PP) several studies were carried out in 2010 and 2011 in order to improve the understanding about the drivers of deforestation in DRC.

One first qualitative study was performed by UNEP in the context of the post-conflict environmental assessment (UNEP, 2011). Another qualitative study was carried out by a consortium of civil society actors. Data collection for the UNEP-study was undertaken at 32 sites in 18 districts located in 10 provinces of the DRC (the Katanga province was excluded) by the means of semi-structured interviews. The main direct drivers reported by these qualitative studies are shifting agriculture and forest clearing for the production of charcoal. In some regions smallholder lumber exploitation and mining can also be important causes of deforestation and forest degradation (see the cases of Ituri and Kasaï for example).

Indirect cause mentioned are the economic aspects linked to poverty and the unemployment in particular of young people, institutional aspects linked to the recurrent wars throughout the last decades as well as governance failure and the construction of infrastructures.

One quantitative study carried out by Université Catholique de Louvain (Defourny *et al.,* 2011) in the context of the UN-REDD program. The authors estimate the magnitude of deforestation and forest degradation based on the Central African Forest Observatory *(OSFAC in French acronyms for "Observatoire des Forêts d'Afrique centrale") (Ernst et al., 2013)*. The first carried out a univariate statistical analysis in order to identify and quantify the influence of different spatial variables assumed to have explicative power for the change of forest cover for the period 1990–2000–2005. Subsequently, the application of a multivariate statistical analysis allowed to establish explicative models which by combining the wealth of available information on potential drivers. These analyses were carried out both at national and subnational level in order to reveal local particularities. The study finds that five variables are most correlated with observed deforestation both for the period 1990–2000 and 2000–2005: the area of the "rural complex"[1] , population growth, the area of degraded forests, the fragmentation status of a forest and the state of the road network. Out of these drivers population growth sticks out as main predictor for the quantity of forests affected by deforestation and forest degradation[2].

The national REDD+ framework strategy (published in 2012) however notes that the 1990–2010 land use history is marked by a "contradiction of the formal sector and the strong inclination of the Congolese economy towards a smallholder-driven exploitation of mineral resources". Considering the improvement of the political context in DRC, international determinants linked to the increasing globalization of commodity markets in general and the regional economic integration such as the evolution of the raw materials markets and tariff policies are likely to play a stronger role in shaping the landscapes of the DRC in the future.

2.2.1 Principles of the UNFCCC

The UNFCCC defines Forest Emissions Reference Levels and/or Forest Reference Levels (FREL/FRL) as "*a toole to evaluate the performance of each country concerning the implementation of* [REDD+] *activities.*" The decisions taken by the Conference of the Parties (COP) set out that:

1 «The rural complex is a mosaic of fallows in the forest, house gardens, staple crops such as cassava, corn, ground nuts, banana etc) and smallholder cropland. This land use is prevalent in areas of strong human influence in the DRC.» (p. 11)

2 It should be noted here that the last population census in DRC has been carried out in 1984. Therefore, the maps of the distribution of the population used by the author were created based on a number of hypothesis: province-specific population growth rates were used based on de Saint Moulin (2006) and applied to the population density for the year 2005 as estimated by Kibambe and Defourny.

- The FRL should be based on **historical data** for future projections and adjust them taking into account national circumstances (UNFCCC, decision 4 / CP15). The adjustment of historical data to national circumstances can be justified by the fact that historical emissions do not reflect the level of likely future emissions, for example in countries with low historical deforestation rates and strong population growth.
- The FRL should maintain **coherence with national GHG emission inventories,** notably with respect to the forest definition used.
- The FRL should be based on data and reasoning leading to its development which satisfies the TCCCA-principle), i.e. information about it should be transparent, complete, coherent, concise and accurate.
- Countries are free to choose a **stepwise approach including the development of sub-national FLR's** (UNFCCC, decision 12/CP.17). This disposition allows countries to revise and improve their FRL after the first submission as better data becomes available, improved methodology can be deployed or reliable information about supplementary carbon pools becomes available.

2.2.2 Establishing a national FRL

As set out by a common position paper of the COMIFAC countries, which argues that FRL's should be based on historical emissions while taking into account future policies regarding the economic and social development, the FRL envisaged by the DRC should be calculated on the basis of a historically adjusted reference scenario. Models can help to bring to light which are the factors which have an important impact on the future evolution of deforestation and can be helpful for the adjustment of the FRL to national circumstances.

In the REDD+ framework strategy of the DRC from the year 2012 it is mentioned that the DRC prefers an adjusted "top-down" approach with a national reference subsequently broken down to provincial and local levels following an iterative adjustment process with regional pilot initiatives such as Maï-Ndombe, the Forest Investment Program (FIP) core investment areas and REDD+ pilot projects integrated in the national REDD+ registry.

A preliminary national reference level had been presented using results based on four different approaches: i) on the basis of historical deforestation rates, ii) using explicative variables and risk cartography of the UCL and feeding into possible different scenarios about the future development, iii) deforestation projections based on the Congo21 model from the Millennium Institute and iv) deforestation projections based on the GLOBIOM model which we also use in the present study. To that end, two scenarios have been tested using the GLOBIOM: "Continuation of status-quo and improvement" and "optimistic growth".

The preliminary national reference level has then been obtained by using the four most extreme scenarios and by using a mean of the eight other scenarios. According to a business as usual scenario this reference level had foreseen the clearing of a forest areas of 15 Mha between 2010 and 2035 corresponding to emissions of 5.5 gigatons (Gt) of CO_2 to the atmosphere. This represents an average annual deforestation rate of 0.41 %. Some of the shortcomings of this approach are that forest degradation has not been taken into account and the emissions had been calculated using a national-scale emission factor of 100 tons carbon (tC)/ha.

2.2.3 The elaboration of a reference level in the Maï-Ndombe pilot region.

The Maï-Ndombe ER-programme is located in the former province of Bandundu, north-east of Kinshasa and covers the former districts Maï-Ndombe and Plateaux; in the course of a administrative reform both districts where merged to a province by its own, the province Maï-Ndombe (Figure3). The Maï-Ndombe province covers an area of 12.3 Mha, two thirds of which are forests. This region is characterized by waste plateaus of tree savannahs, gallery forests in the West and dense humid forests and swamp forests in the East. The bonobo, the chimpanzee, the elephant and the leopard are among the emblematic species present in this zone and the human population counts about 8 million inhabitants (Maï-Ndombe ER-PIN, 2014).

Figure 3: Location of the Maï-Ndombe ER-program area in DRC.

For the Maï-Ndombe ER-program document submitted to the FCPF a reference level and envisaged emissions reductions needed to be calculated against which future possible payments for avoided emissions will be calculated.

The methodology adopted for the FRL elaborations is a stratified approach where first different land cover types are defined, then land use specific for each land cover type is defined and subsequently broken down to specific activities. The land cover types considered for the Maï-Ndombe area are primary forests, secondary forests and non-forests and other land uses (water, settlements). The land uses differentiated for the region are planned deforestation, unplanned deforestation, planned degradation and afforestation. The land cover type-specific emissions factors (EF) is 218.4 tC/ha for primary forest and 120.3 tC/ha for secondary forests. Subsequently, emissions per forest stratum are calculated by overlaying data on historical deforestation and land cover types.

The adjustment of historical deforestation to expected future rates is based on population growth with assumptions being made about the changing fallow periods in order to calculate the demand for new agricultural land. Also, expansion and upgrade of the road and water distribution networks as well as the future supply of fuel wood to Kinshasa are mentioned as factors to be taken into account for the adjustment but without clarifying how their influence is quantified. The resulting adjustment of the deforestation rate is 0.057 % p.a. of the forest cover amounting to an FRL of 30 $MtCO_2$ over the period 2010–2030, 5 Mt CO_2 of which results from the adjustment.

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 DRC as one of the project's 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 of the country (see section 5.2.).

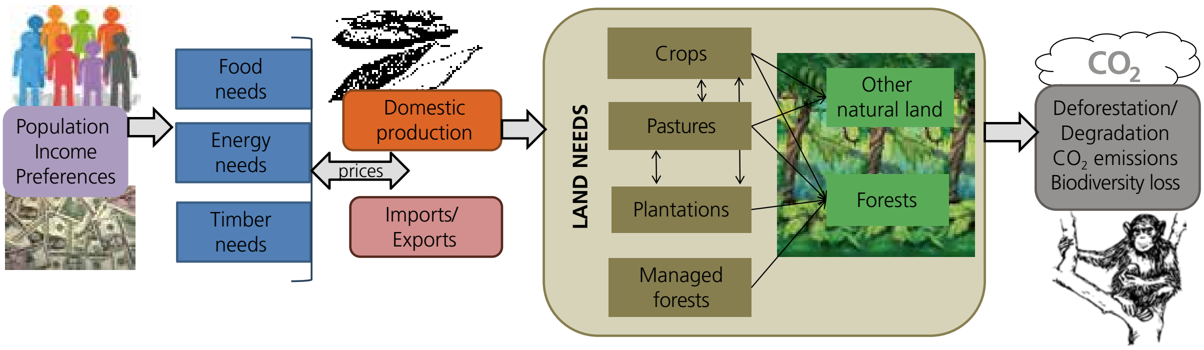


Figure 4: Future deforestation depends on future needs in terms of food, wood and energy in the GLOBIOM-DRC model

- **Market equilibrium 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 increase 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[3] under a certain number of constraints, notably the market equilibrium constraint. A constraint which is very important is the constraint on land availability: in each spatial unit the total amount of land is fixed. Therefore, in order to increase the area used it is either necessary to decrease another use or convert natural land into productive land if there is any still available. Some constraints can also make it possible to include agents' non-economic objectives such as satisfying food needs at the local level (self-consumption).

- **Partial equilibrium model:** Contrary to a general balanced model which encompasses all the sectors of the economy, GLOBIOM focuses on some sectors of which land is the main production factor: crops, breeding, livestock, and bio-energies. These sectors compete in land use inside the model.

- **Spatially 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 run 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.

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

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 5).

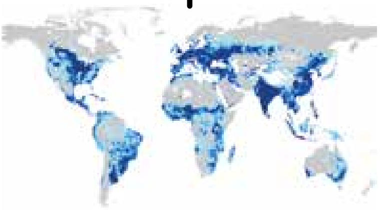
Scale	Inputs	Outputs
 Regional ↑	Population and GDP Bioenergy use Diet patterns (FAO, 2006) Processing costs and coefficients International trade costs	Prices Demand quantity Processed quantity Bilateral trade flows
 Spatial	Land productivity for crops, grass, timber Input requirements Carbon stock (Internal transportation costs)	Land use (ha) Production (ton/m³) Input use GHG emissions (CO_2, CH_4, N_2O)

Figure 5: Main input and output data of the GLOBIOM model at different spatial resolution levels.

In GLOBIOM all the entry spatial data is available at the simulation unit level. Figure 6 shows how the simulation units have been constructed. The simulation units are defined by the combination of pixels whose size is ~10x10km which are in the same country (dashed line), a same pixel whose size is ~50x50km (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 Environmental Policy Integrated Model (EPIC) which calculates the productivity potential for 17 crops used as input data for the GLOBIOM economic model. In total there are 217,707 simulation units globally whose size varies between 10x10km and 50x30km (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 (four types of meat, eggs and milk) are included in the model.

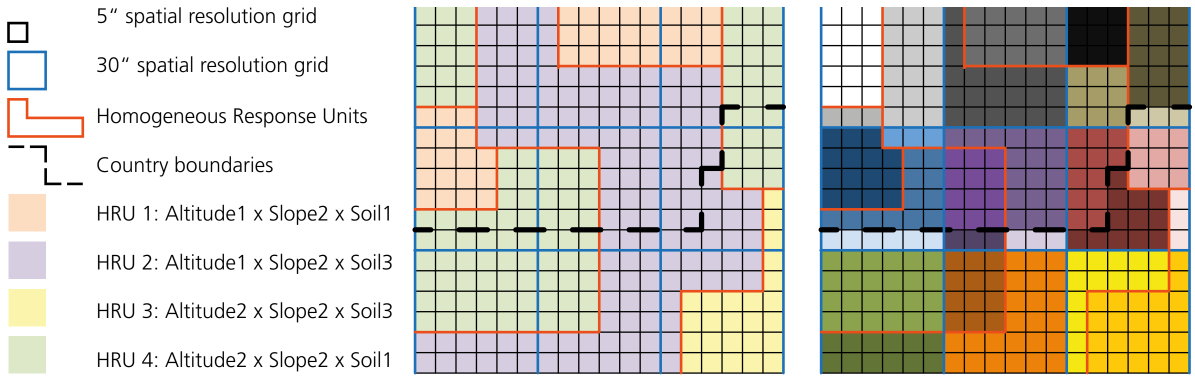


Figure 6: Elements used to delimit simultion units.

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 highlighted the impact of roads development 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 licenses which have been issued.
- "There is a need to strengthen capacities in the Congo Basin about the REDD+ issues.". Several workshops and sessions by the "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 DRC

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 three pilot countries: DRC, the Republic of the Congo (ROC) and Cameroon. The COMIFAC region is linked to the other regions of GLOBIOM whereas the DRC can also trade with the other sub-regions of the COMIFAC space: the Republic of the Congo and Cameroon, the West region, which includes Gabon and Equatorial Guinea, the North region which includes Chad and the Central African Republic and the East which includes Rwanda and Burundi.

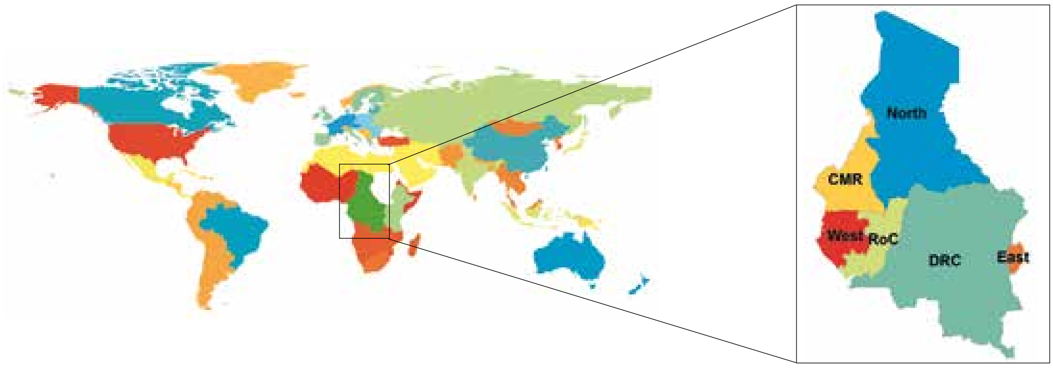


Figure 7: The DRC is a sub-region of the COMIFAC zone (left) which is linked to the 29 other regions of the global model (right)

The DRC is comprised of 2,490 simulation units whose size vary between ~50,000 and 300,000 hectares (Figure 8a). All of the model's spatial entry data is integrated at the level of a simulation unit. Some production statistics are available from the first (province) and second (district) administrative level of the DRC (Figure 8c). 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 optimization process is ~50 x 50km, which results in 239 spatial units (Figure 8b). As a comparison, in the other GLOBIOM regions outside the COMIFAC the spatial resolution during the simulations was four times coarser.

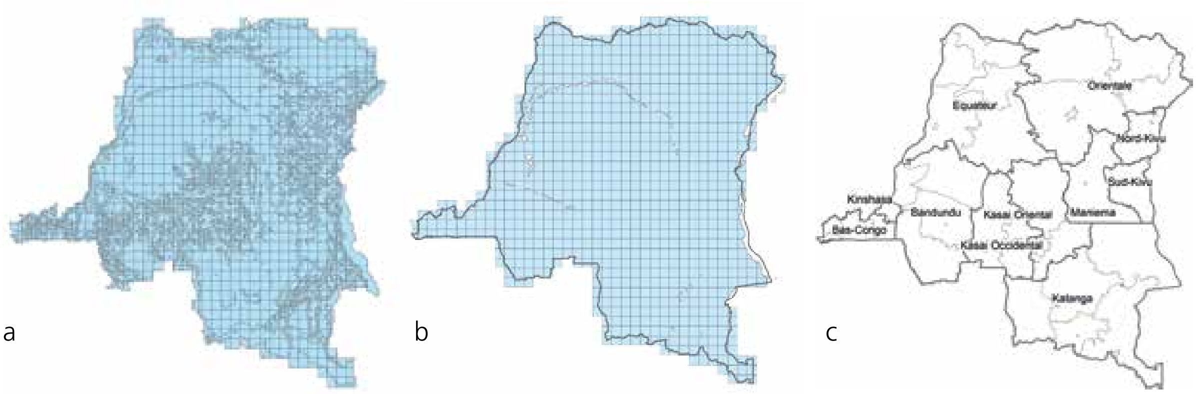


Figure 8: Simulation units (a), the 30 ArcMin grid (b) and the provinces and districts (c) in DRC.

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 DRC 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 information in the model. Land cover maps are produced by analysing satellite data, but the strong presence of cloud cover and the generally small size of field plots 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. On these grounds, it was decided to choose a new land cover map for the DRC which will be presented in section 4 of this document.

Special attention has also been paid to improving the representation of the deforestation drivers and of the forest degradation in the DRC. The causality diagrams of deforestation and forest degradation by sector have been established during a workshop held in Kinshasa with representatives of the different ministries and of the CN-REDD (see 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 DRC and their representation in the GLOBIOM model

This sections draws on causal schema for demand for different types of agricultural goods and their mediate impact on forest cover as elaborated by representatives of different ministries who participated in the REDD-PAC workshop in Kinshasa on February 2nd and 3rd 2015 in Kinshasa. There, causality chains were established and described as participants know them from their experience ranging from each type of demand for commodities to its influence on deforestation and forest degradation. Subsequently, it is described how each causality chain is represented in GLOBIOM for the DRC.

3.4.1 Food demand

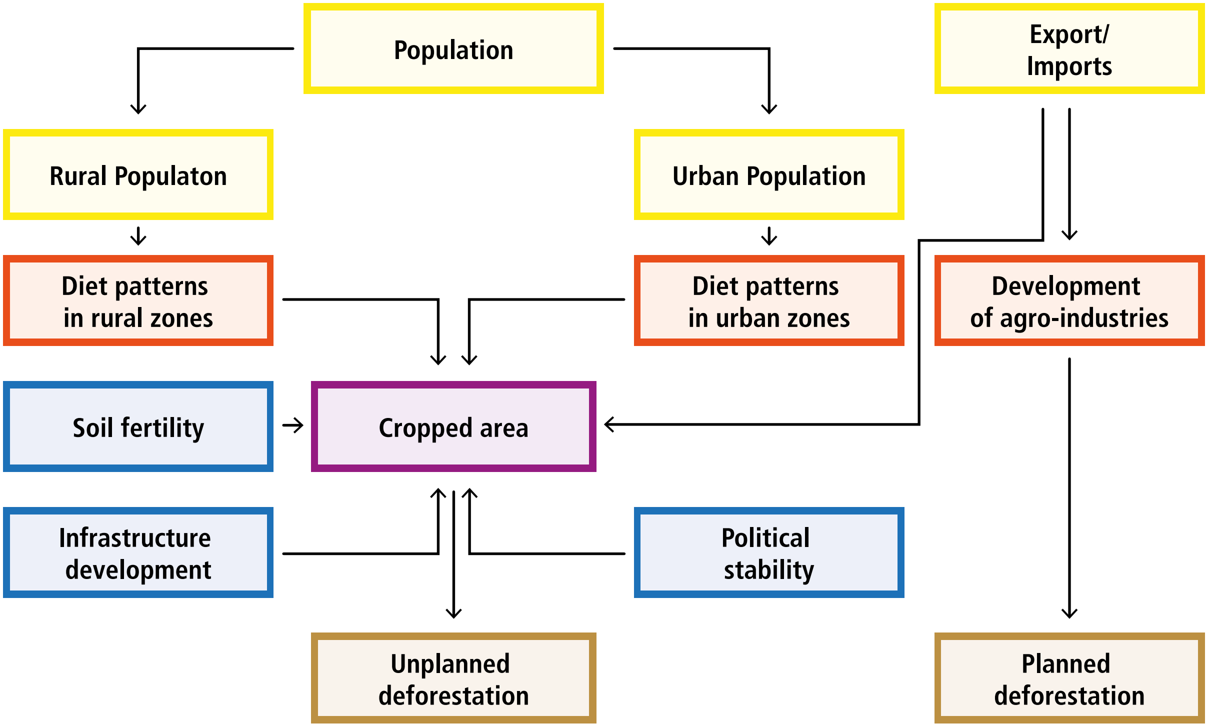


Figure 9: Impacts of food demand on forest degradation and deforestation – Causal diagram established during group work.

Description of the causal diagram: The demand for food in DRC depends on the evolution of population but also on the distribution of this population across rural and urban areas, where dietary patterns are different (Figure 9). If the rising food demand is mainly satisfied by local production, then this demand translates into a demand for agricultural land. This demand for land for agriculture could be more or less great depending on the evolution of soil fertility and development of infrastructures. New demand for land for agriculture can lead to unplanned deforestation. The development of agro-industries is driven by the evolution of international demand for certain products such as palm oil, cocoa and coffee. The state has an important role in this sector through the attribution of concessions which 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 & Bruinsma, 2012)2006. 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 demand.

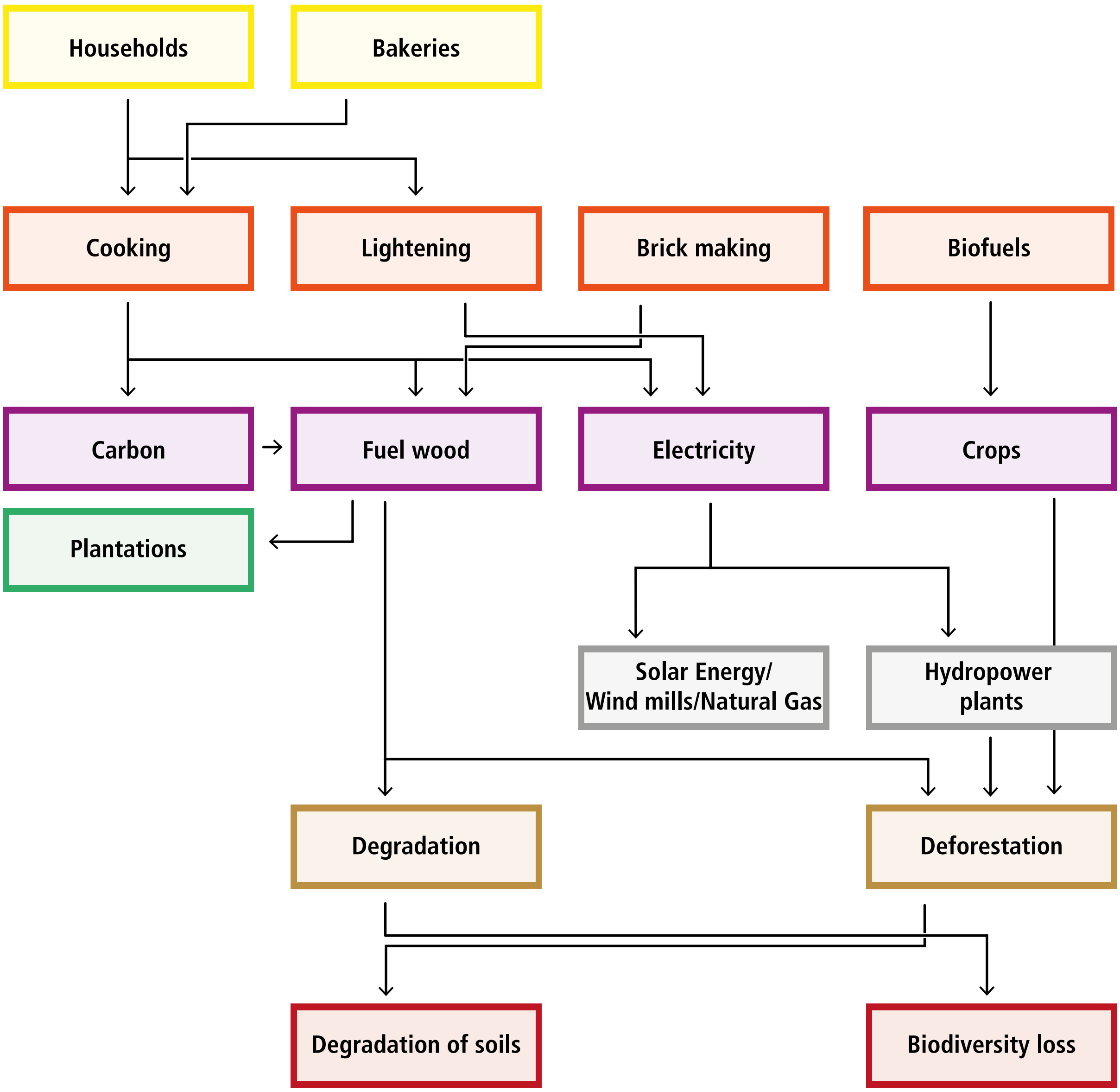


Figure 10: Impact of energy demand on deforestation and forest degradation – Causal diagram established during group work

Description of the causal diagram: The different uses of fuel wood in DRC are: cooking, electric light and the making of loam bricks. Energy needs mainly come from households a and bakeries and can be satisfied through charcoal or fuel wood which are currently the main energy supply sources. Electricity is the main energy source for illumination and could also replace fuel wood for cooking in the future, notably following the construction of new hydropower dams and the development of renewable sources of energy. The recurrent collection of fuel wood leads to forest degradation and in some cases even to deforestation (Figure 10). Sourcing of these forms of bio energy is also associated with deforestation and the expansion of agricultural lands for cropping. The workshop participants identified the loss of biodiversity as well as the degradation of soils as main consequence of deforestation and forest degradation.

Representation in the model: In the model the fuel wood demand depends on the evolution of the total population as well as the split between urban and rural populations. This is because charcoal is preferably consumed by urban households due to easier handling for transport and storage and also because it's relative energy content is double of that of fuel wood, whereas in rural areas fuel wood dominates the marked due to its easy availability. In the model, by default the hypothesis is made that 70 % of the urban households in DRC use charcoal for cooking and whereas the rural population uses exclusively fuel wood. Since charcoal and fuel wood have different energetic yields (Figure 11), we use the estimates of the UN concerning the future evolution of rural versus urban populations to calculate the average energy yield for cooking on the national level over all scenarios. The growing urbanization of the population will entail an increase in energy sourced from wood. This is because we make the assumption that the charcoal production technology and the cook stoves remain the same as they are today but the increased use of charcoal linked to the growing urbanization results in a doubling of the wood consumption compared to the traditional cooking methods in rural areas.

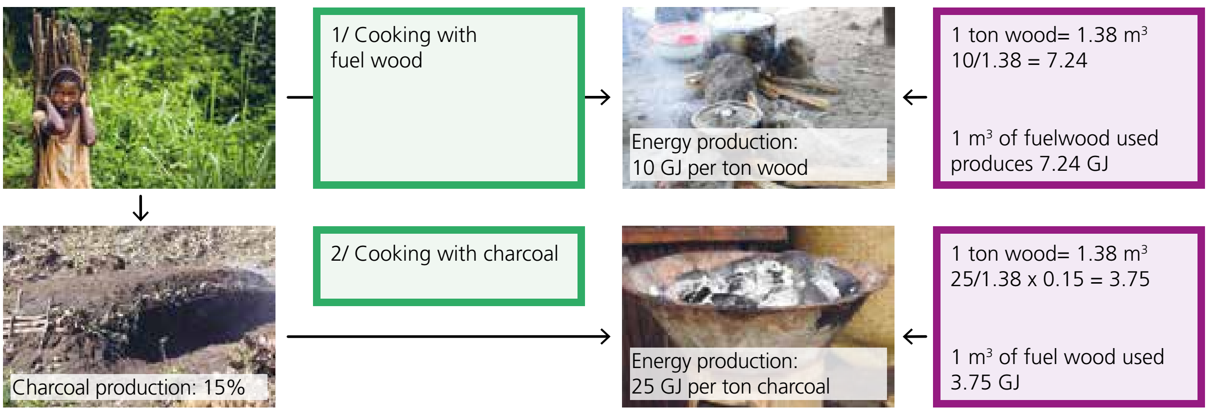


Figure 11: The conversion process of fuel wood and charcoal into energy for cooking

3.4.3 Demand for wood

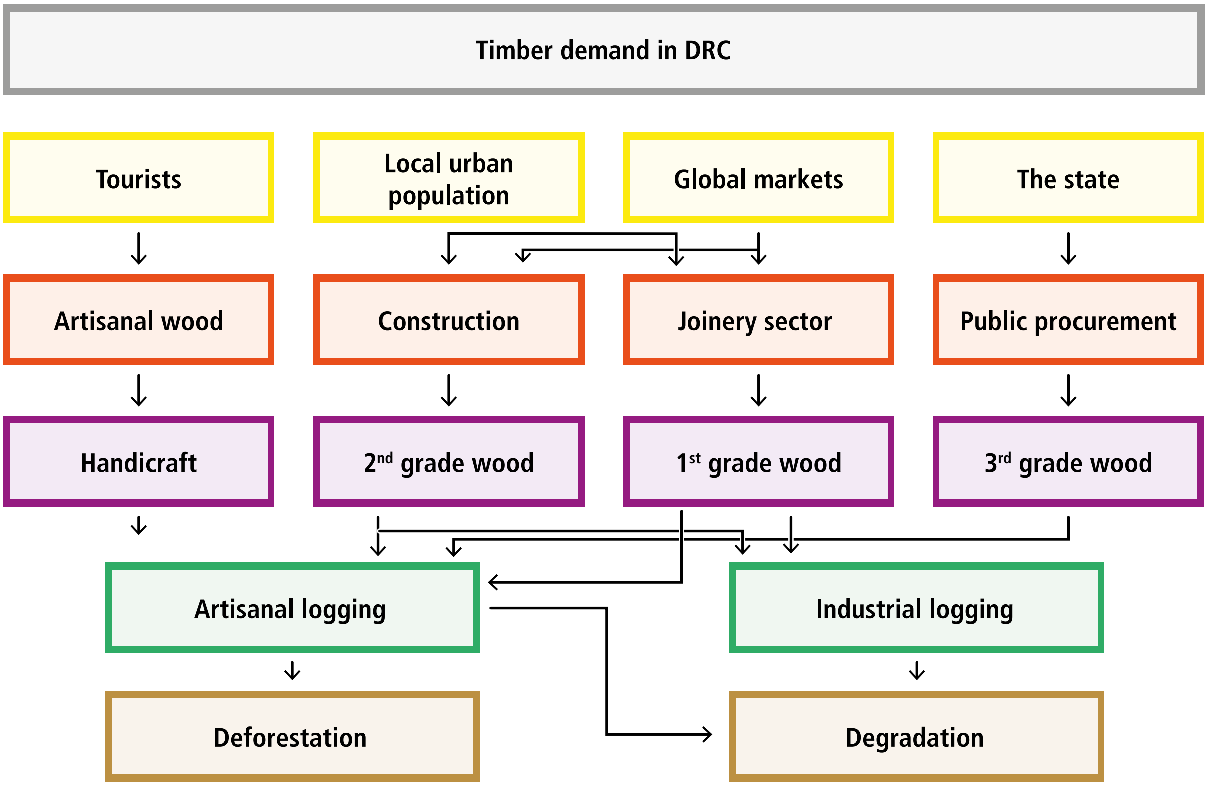


Figure 12: The impact of timber demand on deforestation and forest exploitation – Causal diagram established during group work

Description of the causal diagram:

Four consumer groups of wood were identified: tourists for handicraft, the local population and global markets for lumber and carpenters and the state who are procurement wood for public works (Figure 12). Wood of prime quality is used for carpentry, second quality wood used in construction and wood of third quality is used for construction in the public space. The quantity of wood used for handicraft is negligible compared to other uses of wood.

Two types of logging exist in the DRC to satisfy these demands: industrial logging and artisanal logging. According to the participants, industrial logging mainly responds to the demand of global markets and to a smaller extent to that of the local population, whereas artisanal logging supplies mainly the local market. Artisanal logging is the more important driver of deforestation and forest degradation whereas degradation linked to industrial logging should decrease with the obligation to providing forest management plans in the future.

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

3.4.4 Demand for minerals

Description of the causal diagram: The minerals market in the DRC is mainly driven by international demand. Mining permits are attributed by the Congolese state once the conformity with the legal framework is verified and a number of exploratory studies are carried out. The authorization of mining permits consequently leads to planned deforestation as a direct impact of mining activities. However, the construction of transport infrastructures to take minerals to the closest city or harbour and the settlement of miners with their families can induce spontaneous development of "wild mining" and agricultural activities. These indirect effects can have unplanned deforestation and degradation as indirect outcome (Figure 13).

Representation in the model: The "mines" module of the model is in the process of being developed. Once the spatial data concerning these mining activities is available, the envisaged modelling approach is to estimate the direct impact in terms of the mine size and type of mineral mined and indirect impact according to the number of workers multiplied by the average size of a 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.

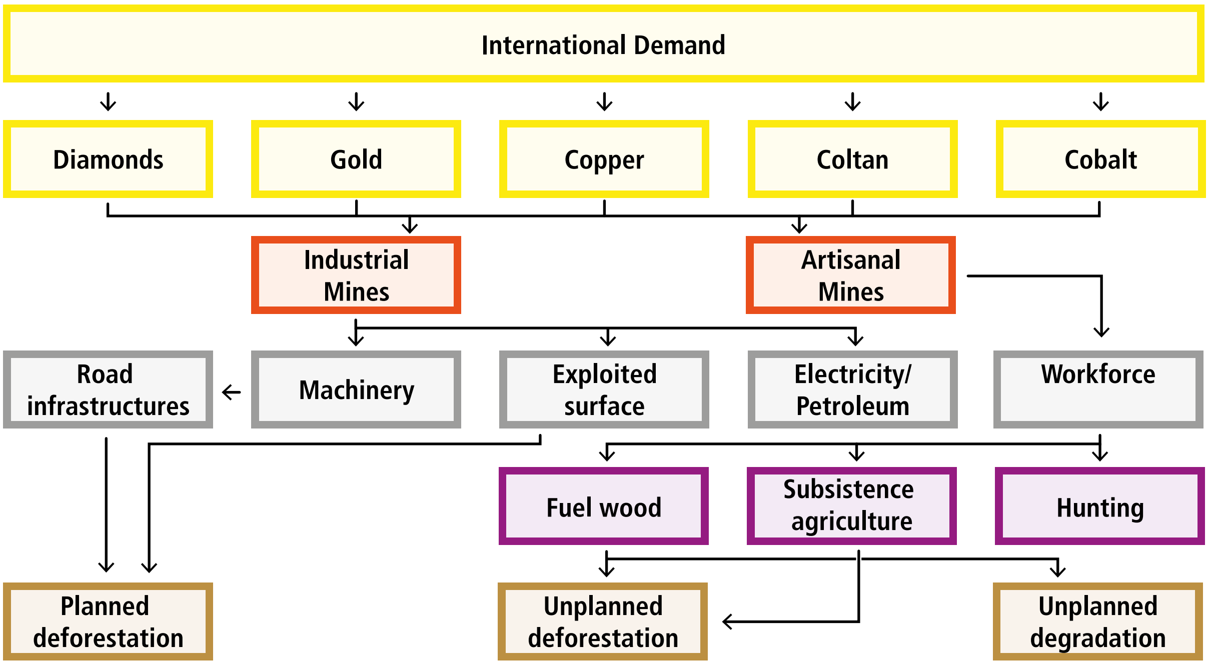


Figure 13: The impact of mining on forest degradation and deforestation – Causal diagram established during group work

4. Land cover maps

It is very important for the modelling work to have a good representation of the initial situation. Land cover in the base year is therefore the first layer of information. Through the combination with information about agriculture and forestry activities occurring on the land, a land cover map also serves as a basis to establish a land use map, thus allowing for estimating production in the land-based sectors and as well as the delivery of a number of ecosystem services.

4.1. Global land cover maps

4.1.1 Global Land Cover (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 and the FAO vegetation classification system (Di Gregorio and Jansen, 2000). In all, 22 classification classes have been mapped. Regional maps have initially been prepared (consult (Mayaux *et al.*, 2004) for Africa) and then merged to create a global map at a spatial resolution of 1 km at the equator.

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 built by the American Space Agency (NASA) on the basis of MODIS satellite images. The global vegetation maps have been produced for each year between 2000 and 2010 at a spatial resolution of 500 m. 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. DRC-specific land cover maps

4.2.1 UCL 2000

This land cover map of the DRC has been created by the Geomatics department of the Catholic University of Louvain (UCL for "*Université Catholique de Louvain*" in French acronyms). Land cover in this map is represented through 18 land cover classes with a special focus on vegetation forms in DRC. The dataset used to produce the land cover classification is composed of 366 daily images obtained during the year 2000 by the VEGETATION sensor mounted on the SPOT-4 satellite, This map which is part of a series of three maps published in 2006 also represents seasonal characteristics of the vegetation (Vancutsem, Pekel, Evrard, Malaisse, & Defourny, 2009) which contains the majority of the tropical forest cover of Central Africa and a large diversity of habitats. In spite of recent progress in earth observation capabilities, vegetation mapping and seasonality analysis in equatorial areas still represent an outstanding challenge owing to high cloud coverage and the extent and limited accessibility of the territory. On one hand, the use of coarse-resolution optical data is constrained by performance in the presence of cloud screening and by noise arising from the compositing process, which limits the spatial consistency of the composite and the temporal resolution. On the other hand, the use of high-resolution data suffers from heterogeneity of acquisition dates, images and interpretation from one scene to another. The objective of the present study was to propose and demonstrate a semi-automatic processing method for vegetation mapping and seasonality characterization based on temporal and spectral information from SPOT VEGETATION time series. A land cover map with 18 vegetation classes was produced using the proposed method that was fed by ecological knowledge gathered from botanists and reference documents. The floristic composition and physiognomy of each vegetation type are described using the Land Cover Classification System developed by the FAO. Moreover, the seasonality of each class is characterized on a monthly basis and the variation in different vegetation indicators is discussed from a phenological point of view. This mapping exercise delivers the first area estimates of seven different forest types, five different savannas characterized by specific seasonality behavior and two aquatic vegetation types. Finally, the result is compared to two recent land cover maps derived from coarse-resolution (GLC2000.

4.2.2 UCL 2005

This map covers eight countries of the Congo Basin: the DRC, Cameroon, the Republic of Congo, the Central African Republic, Gabon, Equatorial Guinea, Burundi and Rwanda through the use of ENVISAT-MERIS satellite data disposing of a spatial resolution of 300m collected between December 2004 and June 2006 and images from the SPOT VEGETATION sensor collected between 2000 and 2007 at the spatial resolution of 1km (Verhegghen, Mayaux, de Wasseige, & Defourny, 2012). 20 land cover classes were distinguished based on the same typology used by the FAO.

4.2.3 FACET

The FACET map uses data from the Landsat and MODIS satellites. 8881 Landsat images with less than 50 % cloud cover produced between 2000 and 2010 were used where a number of measures derived from MODIS between 2000 and 2009 allowed to normalize LANDSAT imagery for the classification of forest types and changes in forest cover (Potapov *et al.*, 2012). In this map forest is composed of three classes : tropical humid primary forest, secondary tropical humid forest and other forested lands. The forest definition used comprises a minimum canopy cover of 30 % and a minimum height of 5meters. Non-forested lands are unfortunately not further distinguished between different types of vegetation and agricultural lands. The reference land cover map is available for the year 2000 whereas deforestation is mapped for the periods 2000–2005 and 2005–2010 at a spatial resolution of 60m

4.3. Comparison of existing maps and creation of a hybrid map

The six maps described above were analysed: GLC2000, Globcover, MODIS, UCL2000, UCL2010 and FACET. As a first step they were aggregated to land cover classes represented in GLOBIOM in order to make the maps comparable (see table in the annex and www.geo-wiki.org for the visualization). These classes are cropland, pasture, forests, swamp forest, wetlands, and other natural lands. To account for potential differences in land cover maps linked to different forest definitions, we further differentiated the forest class in dense humid forest and dry forests for this comparison exercise. Accounting for large differences between the different land cover maps and in order to ensure best representation of certain land cover classes it was finally decided to create a hybrid map where the best fitting elements of several land cover maps for certain regions could find best representation.

There are large uncertainties as to the actual land use in DRC, particularly for arable land (see Figures 14 and 15). The total area of cropland varies between 8 and 36 Mha across the five land cover maps compared. Large differences also exist between these five maps in terms of the spatial distribution of these lands. According to the GLC map there is no cropland in Katanga and little in Bandundu which are however known as important arable areas. According to UCL cropland is relatively homogenously distributed over the full territory whereas according to MODIS cropland is concentrated Southern and East of the dense humid forest area. Based on discussions with national experts, the MODIS land cover map was considered the most realistic in terms of the distribution of arable land across the DRC, with the exceptions of the Equateur and Orientale province where the arable land areas appeared too small. For these two provinces the GLC 2000 map was used which finds a total area of agricultural lands of 20 million hectares

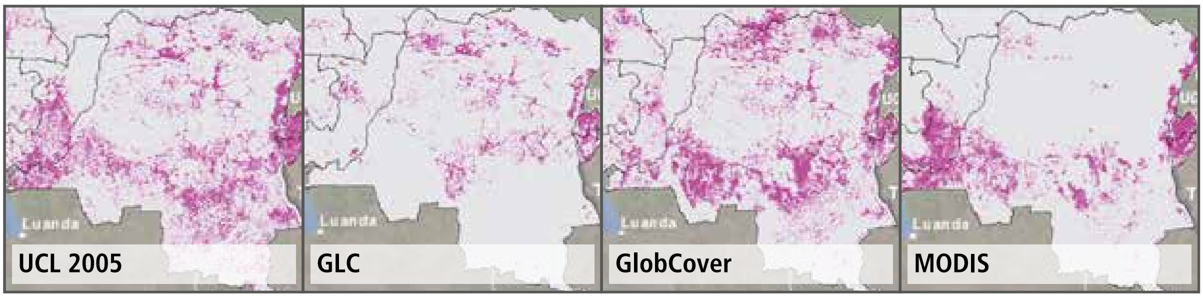


Figure 14: Location of arable lands in DRC according to different land cover maps.

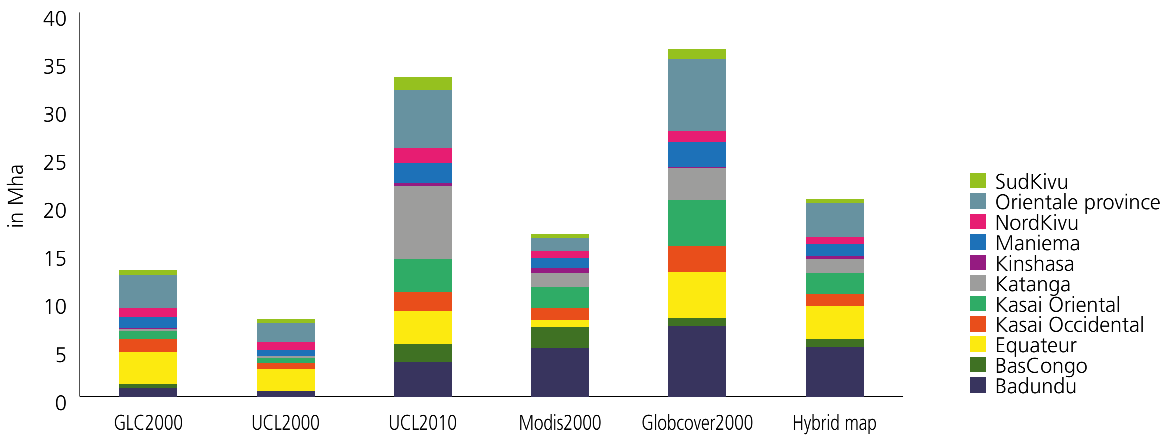


Figure 15: Distribution of arable lands per department according to different land cover maps.

For forest areas the total surface varies between 138 and 206 Mha across the different maps (Figure 16). Variability diminishes when considering dense humid forests only with areas ranging between 95 and 120 Mha (with the exception of GLC which did not have an explicit dense humid forest class). Hence, the variability of the forest area depends on the forest definition used, in particular in dryer areas. This is also reflected by the distribution of forest areas across provinces with a stronger variation being visible for the Katanga and Bas-Congo provinces (Figure 17). Based on national expertise it was decided to use the GlobCover maps to delimit forest areas, except for the «swamp forest » class which appeared to be overestimated by GlobCover and which was therefore replaced by UCL 2005. This leads to a total forest area of 150 Mha in 2000, 110 Mha of which are composed of dense humid forests. This is close to the 153 Mha estimated by FACET.

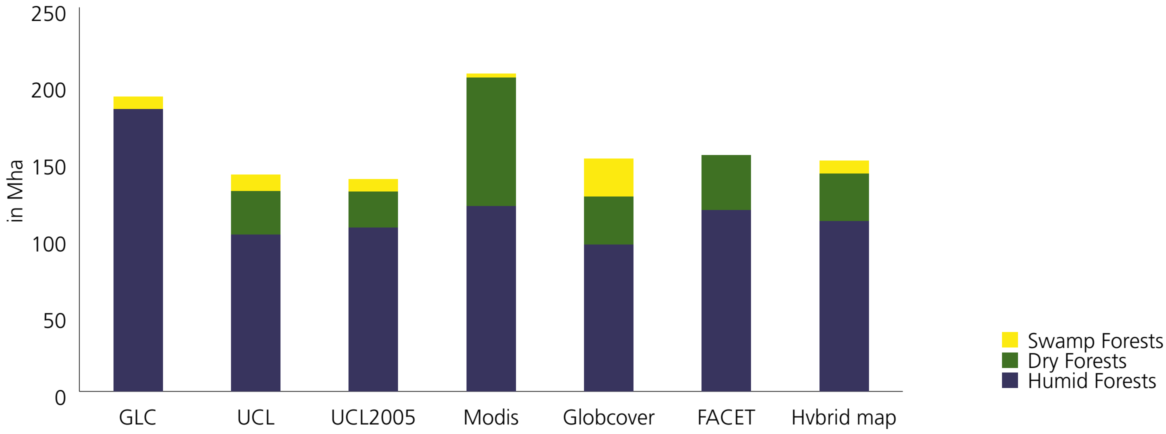


Figure 16: Distribution of forest area by forest type and source.

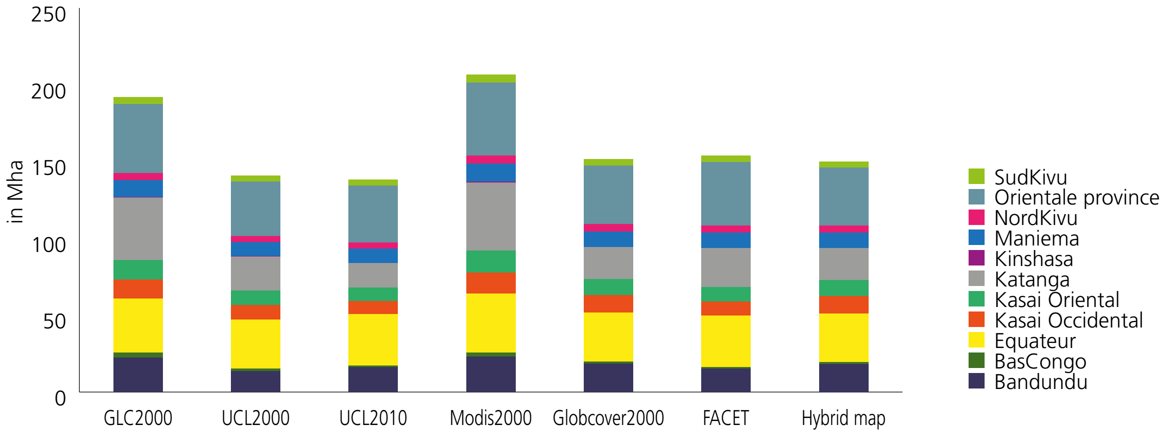


Figure 17: Distribution of forest areas per province according to different land cover maps.

4.4. Harmonising land cover and land use

In a second step, the maps of protected areas, forest concessions, and 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 Logging concessions and protected areas

The maps of forest concessions and protected areas used in the model for the base year 2000 was sourced from the WRI Interactive Forest Atlas of the DRC which represents the data for approximately the year 2007. The area under active forest concessions was 12.4 Mha and protected areas covered about 25.6 Mha (Figure 18).

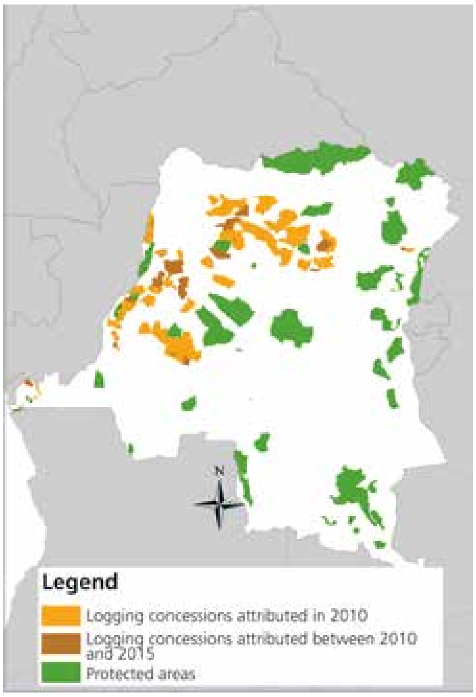


Figure 18: Forest concessions and protected areas reported by WRI.

We sometimes observe an overlapping of forest concessions and protected areas in the DRC. 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 19). This explains why the protected areas in the model can be less that the official surface area (Table 1).

For the DRC this reduces the total surface of protected areas by 5 %. Protected areas are then divided by land cover class: in the model, 78 % of the surface of protected areas is included in the forests class of which 66 % is in the « dense humid forests » class.

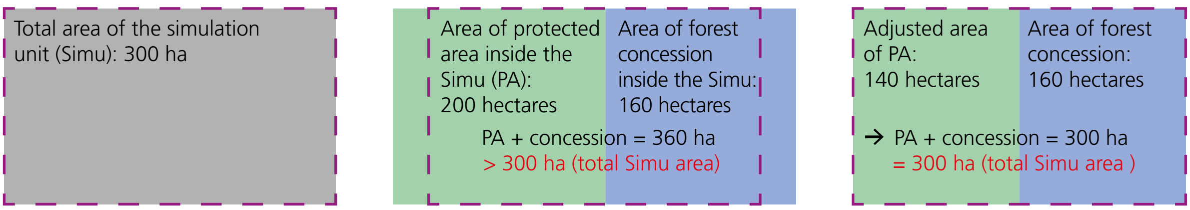


Figure 19: Procedure for adjusting the protected areas (PA's) if there is an overlap of land uses.

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

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

	Initial concessions area	Total area in the model	of which dense humid forests	of which swamp forests	of which dry forests	of which other natural lands
Protected areas	25.6	24.2	15.9	0.9	2.9	4.4
Forests under concession	12.4	12.2				

In total, there are therefore almost 31 Mha of forests that cannot be converted for other uses thanks to forest concessions and protected areas, which represents more than half of the total forest area in DRC.

Since 2007 – the reference year for the concessions data used – a number of other logging concessions have been allocated in DRC and these were thus added to the "managed forest" land use class for the periods after 2010. This represents an additional forest area of 3 Mha which in the base scenario cannot be converted in the model (Figure 18).

4.4.2 Agriculture areas

We could access annual agricultural statistics concerning agricultural production sourced from the Ministry of Agriculture for the period 2006–2011.However, the numbers reported should be taken with caution as the last great agricultural censes in DRC dates from 1970 and the last population census from 1984. The last on the campaign for the collection of agricultural statistics dates from 1996–97 with the exception of local data collection initiatives which could have taken place in the context of certain projects which however cannot be accessed easily. This means that agricultural statistics available are based on projections calculated by making assumptions about a certain annual growth rate in production. Given the lack of alternatives, we use these statistics despite the known shortcomings but are awaiting a national-scale data collection campaign to produce genuinely new data. It should also be noted that these statistics were available in pdf format only which caused additional delays to bring the data in Excel or .csv format and hence make it accessible for the model.

It has also become necessary to make some adjustments to the data in order to obtain agricultural production specific per district and per crop in the base year 2000. Agricultural production for 2000 is calculated by dividing the production reported for 2006 – the next year for which statistics are available – by the annual growth rate between 2006–07 to the power of six for the six years lying between 2000 and 2006[4]. In order to obtain estimates for agricultural areas which are not reported by statistics we use crop and province-specific yields which are reported by the province-specific PNSAR publications[5] and apply them to agricultural production reported by statistics. With the exception of potato in Kasaï Oriental the yields reported by PNSAR are close to those reported by the FAO for the year 2000 (Figure 20) which gives reason to consider them an acceptably good source of data (Figure 21).

4 We obtain the same annual growth rate over the entire period 2006–2011 which confirms that the statistics are in fact projections.

5 These monographies have been produced for the provinces Orientale, Bas-Congo, Bandundu, Equateur, Kinshasa, and Kasai Oriental.

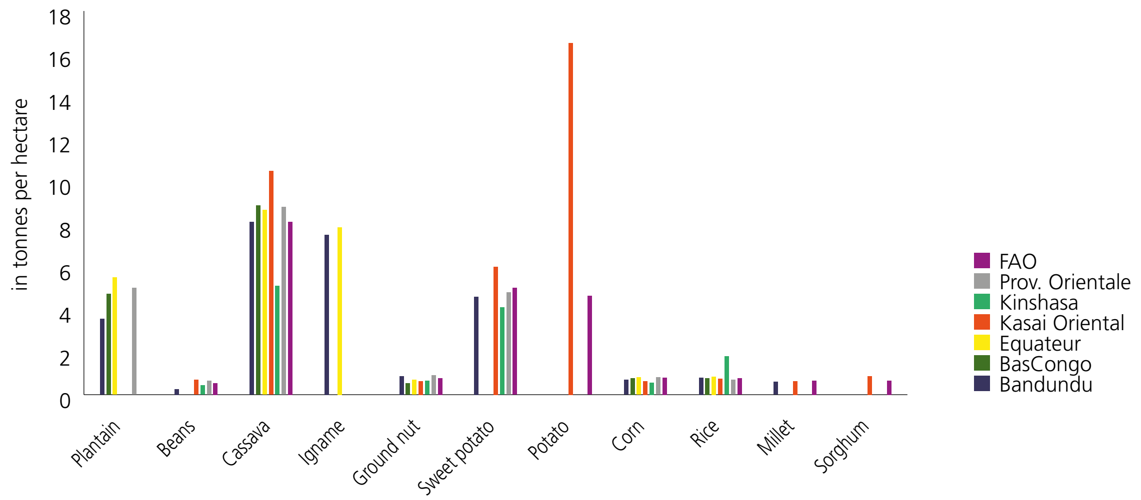


Figure 20: Average yields per crop according to province-level statistics by PNSAR and the national average according to the FAO.

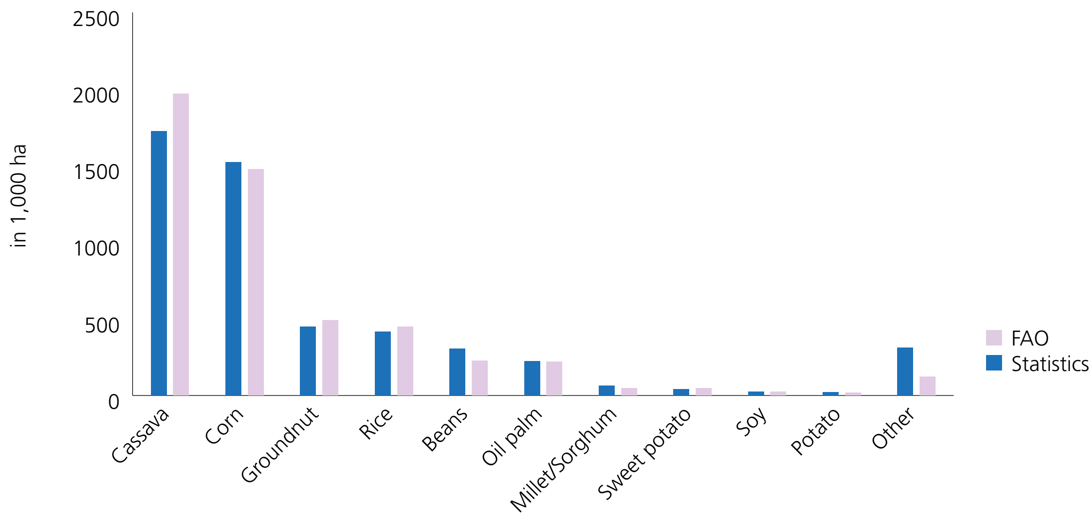


Figure 21: Agricultural areas estimated for the year 2000 on the basis of agricultural statistics and the FAO.

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

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

The fallow time also varies as a function of the agro-ecological zones. The technique of restoring soil fertility by leaving areas fallow for a longer period is particularly widespread in the dense humid forest areas whereas fallow periods are generally shorter in the savannah areas. Hence, the assumption is made that in dry temperate zones the fallow period is generally two years only. We hypothesized that in the zones of the Batéké plateau and in the Southern part the fallow period is reduced to two year (*resulting in a fallow multiplier coefficient applied to cropland of 2).* Figure 22 shows the heterogeneity of this fallow multiplier coefficient across the country which takes into account the different fallow practices applied in the country. In dry forest areas of the South of the country and in the areas disposing of a strong population density (East) fallow multiplier coefficients are lower. No fallow is assumed for perennial crops (oil palm, coffee, banana).

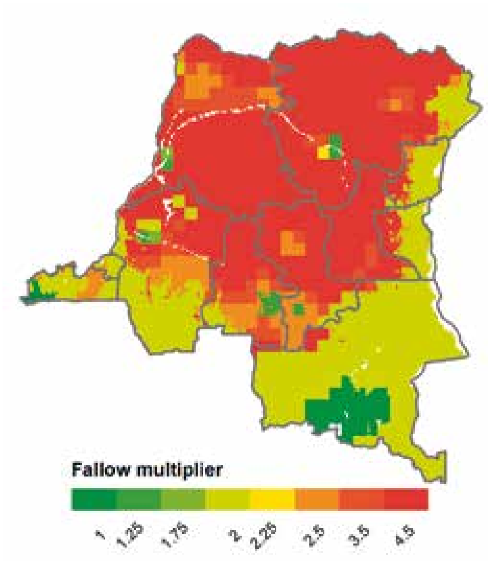


Figure 22: Land multiplier coefficient to obtain total arable land corresponding to the varying fallow times.

4.4.3 The role of 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 & 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[6]. As many natural constraints to cultivation may be lifted with certain cultivation techniques, we calculated the production potential of oil palm in two cases: the first reflects the case of agro-industrial plantations where we assume that adequate management techniques can be applied ("best management"), and the second case rather reflects the small producers who do not have the means to invest the capital required to develop best-standard plantations and who therefore remain limited by the natural constraints ("minimal management"). The bio-physical criteria that are taken into account are listed below.

- **Climate.** Four climatic factors are particularly important for oil palm: the average annual temperature, the average temperature during the coldest months of the year, annual rainfall and the number of months that receive less than 100 mm of rainfall.

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

- **Soil type.** Several types of soils can be problematic for the growing of oil palm: soil which is naturally poor in nutrients (*ferralsols* and *acrisols*), saline soils, very sandy soils with low capacity for water retention (*podzols*), rocky soils that prevent a good grip of the roots, peat soils, and frequently flooded wetlands.

- **Topography.** Steepness of lands increases the costs and efforts of maintenance and harvesting of plantations and also present a risk of erosion. Elevated areas are also less suitable due to lower temperatures.

Our results show that the DRC has a total of 166.95 Mha of land suitable for the industrial cultivation of palm oil, corresponding to 71 % of the national land area (Figure 23). Most of the land suitable for oil palm cultivation is in suitability class 4 out of 5, which corresponds to an elevated potential productivity level. Notably in the interior of the DRC bio-physical factors are united to have a very high potential for oil palm cultivation. In particular in those regions where the dry season is longer than 2–3 months, the potential for oil palm cultivation is projected to be lower. From a bio-physical viewpoint the Orientale province harbours the most favourable land whereas the provinces Katanga and Bandundu are only moderately suitable or even unsuitable for oil palm cultivation.

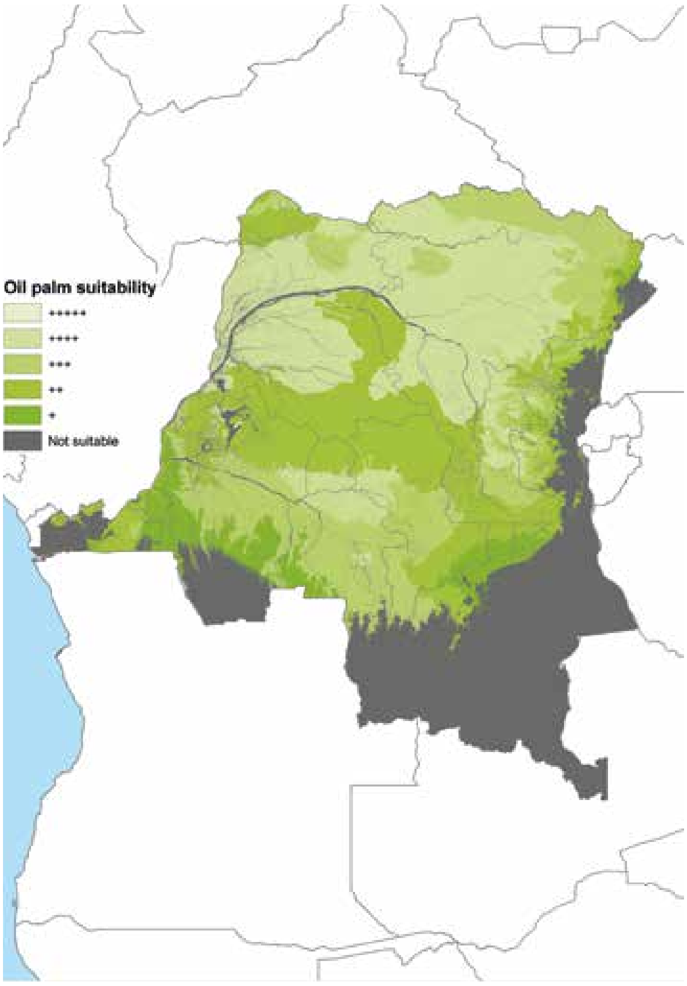


Figure 23: Map of biophysical potential of oil palm in the DRC and in the Congo basin where green means very high potential, red corresponds to low potential and dark grey shows areas which are not suitable according to Pirker and Mosnier (2015).

4.4.4 Allocation of cropland statistics to simulation units in the base year (2000)

Both cultivated and fallow areas are allocated to simulation units using a "cross-entropy" method where the maps on transportation costs to the nearest town, potential productivity and population density are used to 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 obtain a total arable land area of 13 Mha in 2000 for DRC, 40 % of which is composed of fallow[7]. The difference between the agricultural land class of the original land cover map and the agricultural land thus calculated is 7 Mha which are consequently reassigned to the "other natural lands" class. The geographical distribution of thus calculated arable land remains very close to the original map, but with a more homogenous distribution across the country (Figure 24). We particularly see on the map that in the majority of the simulation units the cultivated land area is in the range of 5,000 to 20,000 ha corresponding to less than 7 % of the area of a simulation unit.

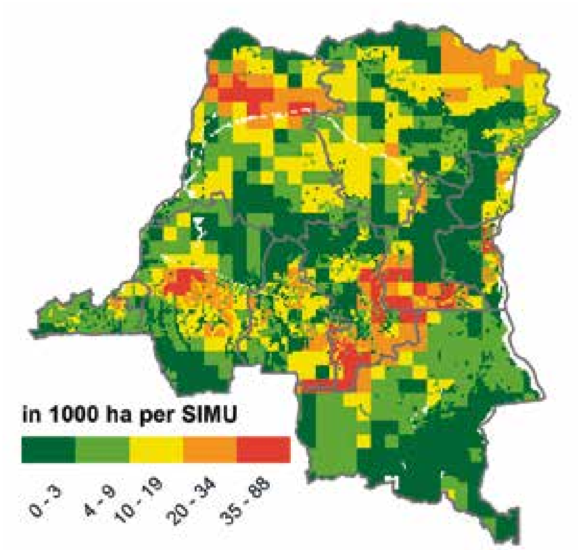


Figure 24: Map of arable land in 2000 in 1000 ha per simulation unit.

4.4.5 Livestock sector

We sourced data about the livestock sector from the research and statistics department of the Central Bank of the DRC. Data is available for bovines, goats, sheep, pigs and chicken in 1000 heads for the year 2006 and 2010 per province. In terms of the total number of heads the numbers are close to those reported by the FAO and the International Livestock Research Institute (FAO-ILRI) for the year 2000. Also with respect to the distribution of the bovine livestock herd across the country national statistics are similar to what we have in the default version of the model with the exception of Maniema (Figure 25). For sheep and goats differences are a bit stronger, notably with a higher portion of the herd being located in Maniema and both Kasaï provinces (Figure 26). However, given that the differences between reported numbers are not that

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

strong and that the deviating reporting years between national statistics and FAO could explain part of the differences, we opted for keeping FAO-ILRI data to represent the livestock sector in GLOBIOM-DRC.

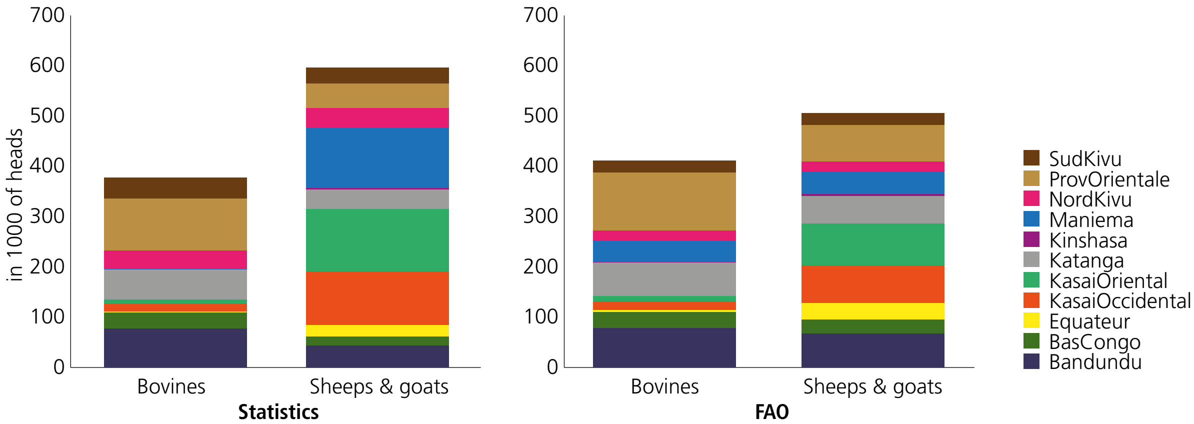


Figure 25: Comparison of the distribution of bovine and goats and sheep per department.

In the model ruminants are represented at the resolution of a simulation unit where they determine the area of pasture as a function of grass consumed, the latter being estimated for different species of livestock using the RUMINANT module of the model. This leads to an estimated pasture area of 4.8 Mha for DRC which are separated from other natural lands. The spatial distribution of pasture as estimated for the year 2000 can be seen in Figure 26. Pigs and poultry are represented in an aggregated manner in GLOBIOM (only at the national level). However, through the use of certain crops for their feed an increase of numbers of poultry can indirectly lead to an expansion of agricultural land.

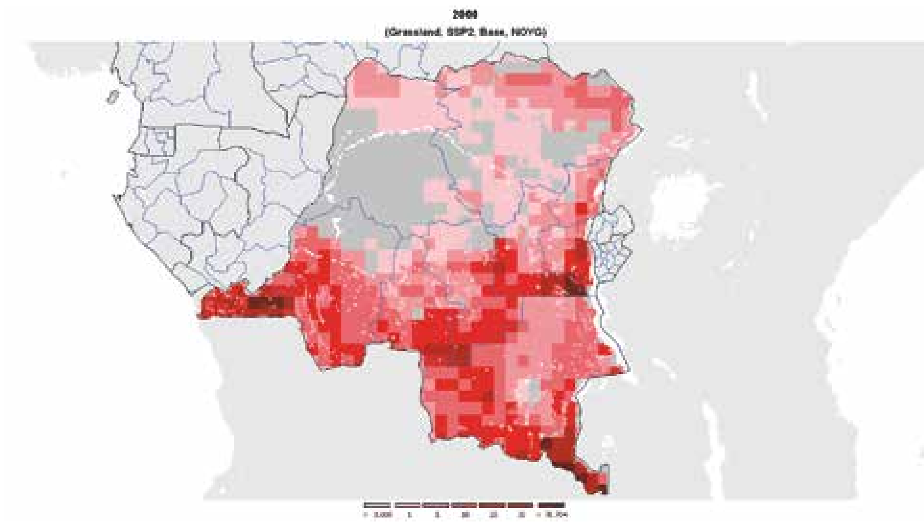


Figure 26: Pasture area in 2000 (in 1000 ha per simulation unit)

5. Calculating greenhouse gas emissions and the impact on biodiversity

5.1. Calculation of GHG emissions

5.1.1 Emissions from land use change

The calculation 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 Global Forest Resources Assessment (FRA) of the FAO for the year 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. 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.

Both the maps of WHRC and NASA only account for above-ground biomass (AGB). We estimate living, below-ground biomass (BGB) as a function of AGB using AGB:BGB coefficients estimated by Mokany *et al.* (2006): for dense humid forests with AGB above 125 tC/ha, the median value BGB value 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.

5.1.2 Emissions linked to forest degradation

Although three economic activities have been identified as major causes of forest degradation in DRC (these are, formal logging, informal extraction of construction wood and fuelwood, see Section 3.4), we only present in this study the emissions related to forest degradation inside officially established concessions (Section 4.4.1).

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[8]. This amounts to 0.99 tons 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 tons 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 tons 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 Table 2 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 2: 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**

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

5.2. Calculating 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)[9]. 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 of land use change on ecosystems

The territory of the DRC 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).

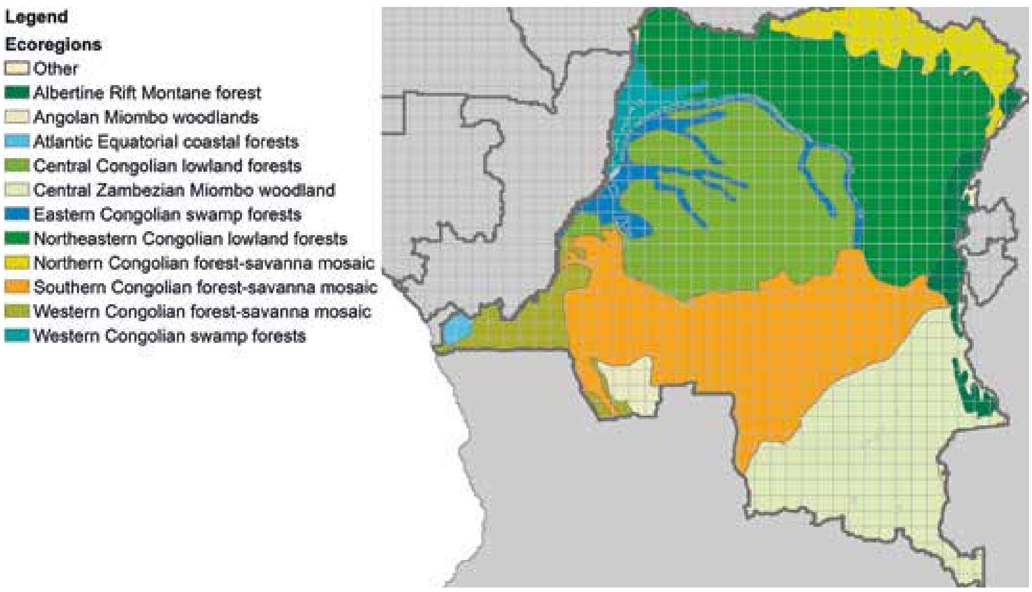


Figure 27: Map of the eco-regions of the DRC. Source : Olson *et al.*, 2001

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

5.2.2 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. The DRC is home to three species of Great Apes – the Bonobo, the chimpanzee, and the Mountain Gorilla – which have the potential to support the development of ecotourism acidities, a potential key ecosystem service. The Democratic Republic of the 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.

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 28 presents the methodology used to calculate this composite index of "combined species habitat change":

A. We start from maps of species range.

B. We calculate the habitat distribution for each species taking into account their degree of endemism in each cell (i.e. calculating the proportion of the potential area cell represents and so giving a higher score to species with small range, shown here in darker grey).

C. We use future land use projection calculated by the GLOBIOM model, which shows where potentially suitable vegetation for each species is destroyed.

D. Combing the species range data and land use change data we calculate where each species loses (or wins) potential habitat and the proportion of their habitat it represents (represented here by various shades of red)

E. The sum is made of the loss (or gain) in potential habitat for all species.

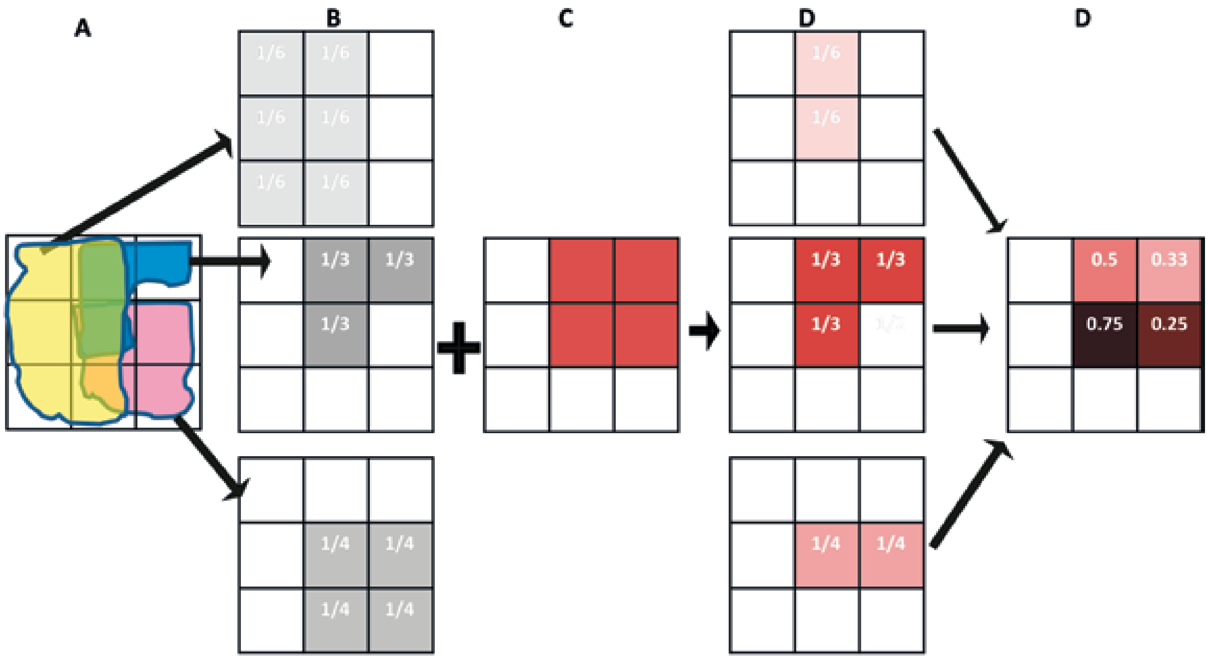


Figure 28: Method of calculation of the composite index of combined species habitat change.

5.2.3 Impact on non-timber forest products.

Forest are not only important for the intrinsic value of biodiversity which they bear but also for the services which they deliver to local populations and for the economy of the forest-rich country in general. For example, non-timber forest products (NTFP's), fuel wood and construction wood contribute significantly to local subsistence and to the national economies in the Congo Basin (Ingram, 2012). Recent studies confirm the importance of revenues which local populations generate from NTFP's (Angelsen *et al.*, 2014). However, data is scarce which would allow to quantify the spatial variation of NTFP's or that of ecosystems services in general.

Recent information could be identified for certain NTFP species, including *Prunus africana*, a tree whose bark is widely used as a medical product and whose likely distribution area is presented in Figure 29 (Vinceti *et al.*, 2013). Ideally, the identification of priority areas for NTFP's should be complemented using information about the actual utilization of these resources by local populations but this information is not available at current. Combination of information about the potential prunus harvesting areas with areas where future forest cover loss is likely allows to determine the magnitude of the impact of different land use scenarios on potential ecosystem services and the areas where this impact could be reduced.

Information on *Prunus africana* is available in terms of the probability that the species might be found in different zones. This information is detailed into areas where it is highly probable that *P. africana* is present (probability of presence >50 %) and zones where it is possible to find the species (probability from 50 to

13 %). Given the fact that GLOBIOM runs at a spatial resolution of 30′ x 30′ (ca. 50 x 50 km) as described in previous sections, a number of hypotheses must be made to fusion both datasets, *P. africana* potential distribution ranges and GLOBIOM outputs. Taking the example of a simulation unit which is fully covered by forest and where *P. africana* can potentially occur on 50 % of the area. If the model predicts a loss of 25 % forest cover, it is necessary to know whether this land cover change occurs inside or outside of the potential distribution range of *P. africana*, which a priori is not possible, i.e. it is not known where a change occurs inside a simulation unit. To that end, we assume that the land cover changes are distributed uniformly over the simulation unit, independent from the likely distribution of *P. africana*.

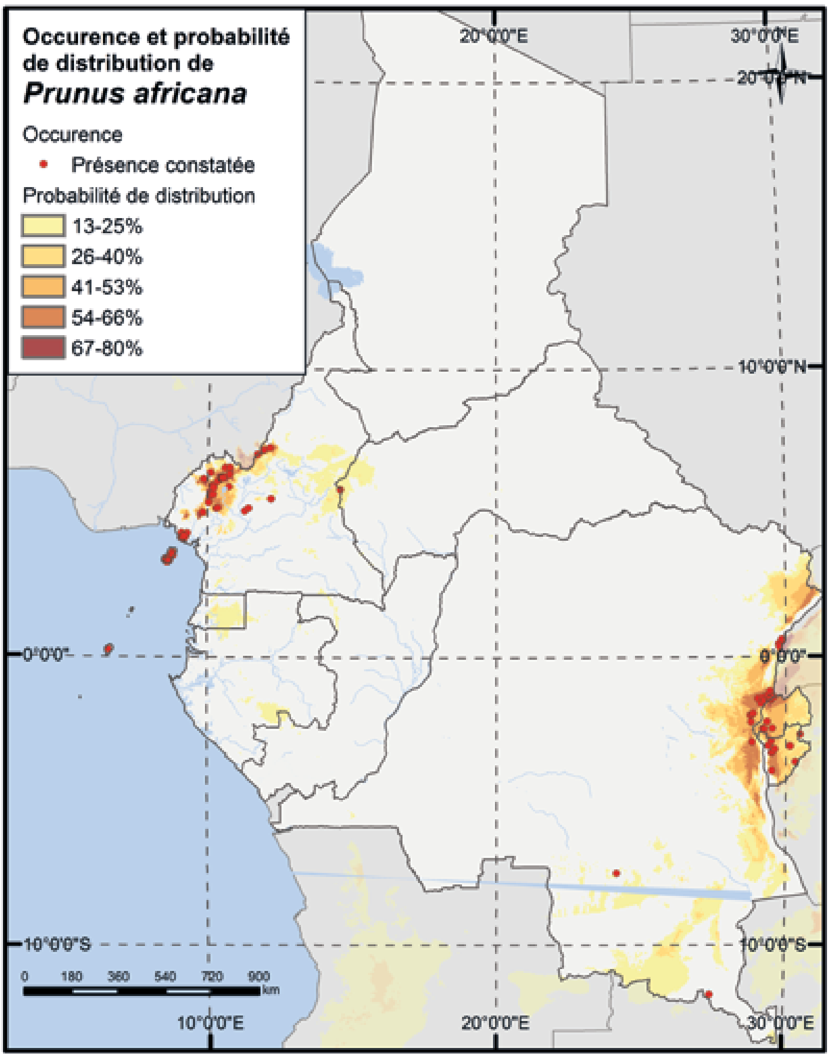


Figure 29: Occurrence and probability of distribution of *Prunus africana* in the Congo basin.

6. Description of 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. Alternative scenarios have the objective of exploring the impact of a different socio-economic context or of more laxist (non-respect of laws in place) or more ambitious policies with the implementation of new policies. All scenarios tested in this study are presented in Figure 30.

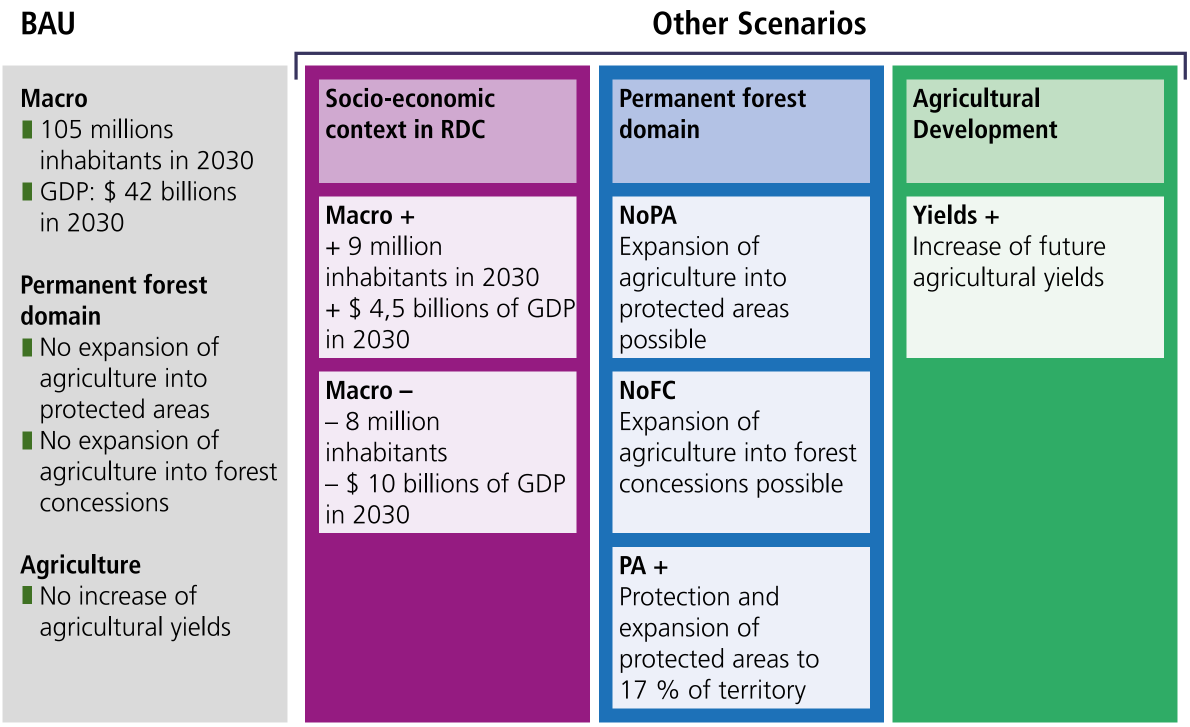


Figure 30 Hypothses underlying the base scanario are presented at the left hand side whereas changes introduced in each alternative scenario are presented in three colored pillars where each scenario is represented by a white box.

6.1. The 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 neighbouring countries.

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

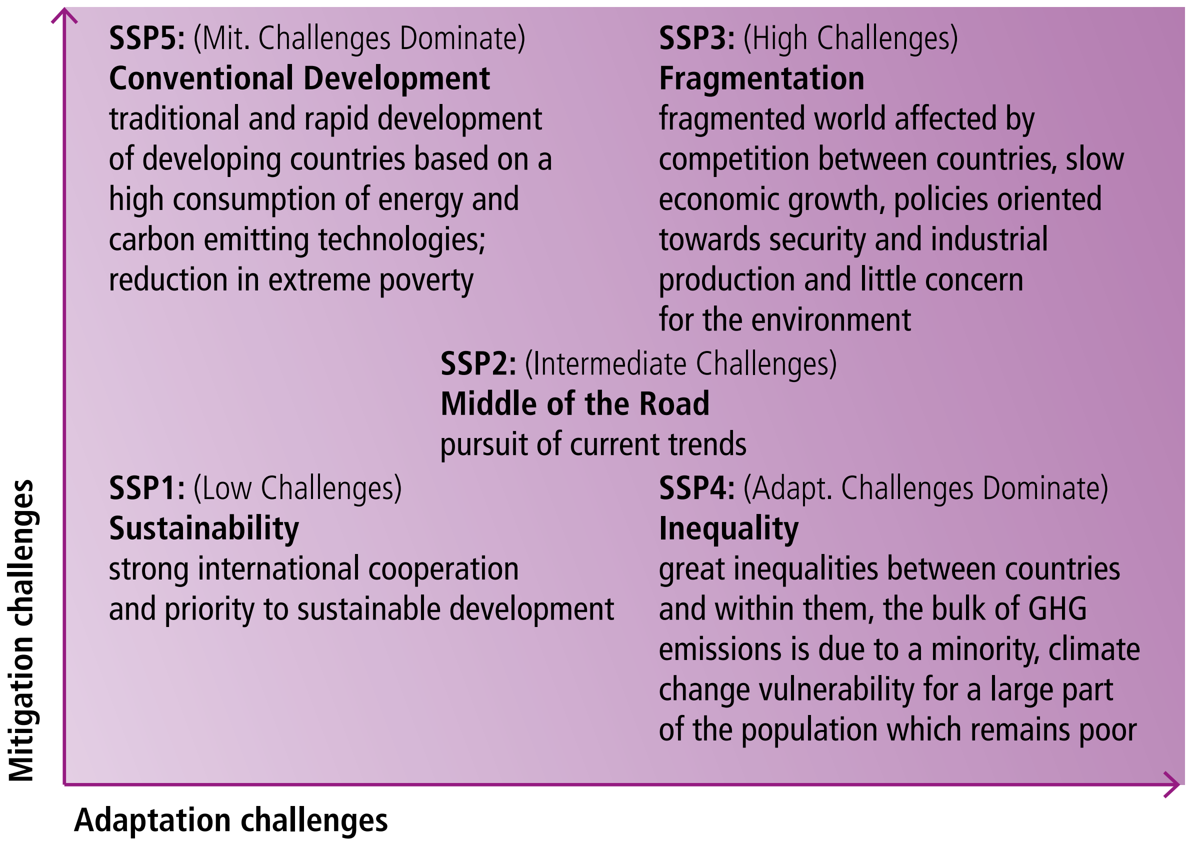


Figure 31 Socio-economic development trajectories prepared within the framework of the IPCC
Source: (O'Neill *et al.*, 2013)

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 DRC in the SSP2 is generally much greater than the world average: By 2030 DRC's population is expected to more than double and GDP is expected to be five times higher compared to the year 2000.

«Macro -» and «Macro +»scenarios: As alternative scenarios to explore the role of the population and of the economic context of future deforestation, we test two scenarios that combine different SSPs scenarios. These scenarios were desired by participants at the sub-regional workshop on the presentation of the project results in Douala in September 2015. «Macro +» is the combination of the most optimistic GDP projection (SSP1, +) and the highest population projection (SSP3) while «Macro-» is the combination, from the first three SSPs, of the most pessimistic GDP projection (SSP3) and the lowest population projection (SSP1). Both scenarios lead to average nominal GDP increases of +2 % in the Macro+ scenario and –18 % in the Macro– scenario, respectively, by 2030 for the DRC. These alternative scenarios will influence future deforestation through changing food consumption and demand for lumber and fuel wood (see section 3.4.1; Valin *et al.*, 2014) climate change, and bioenergy expansion. In the reference scenario (SSP2.

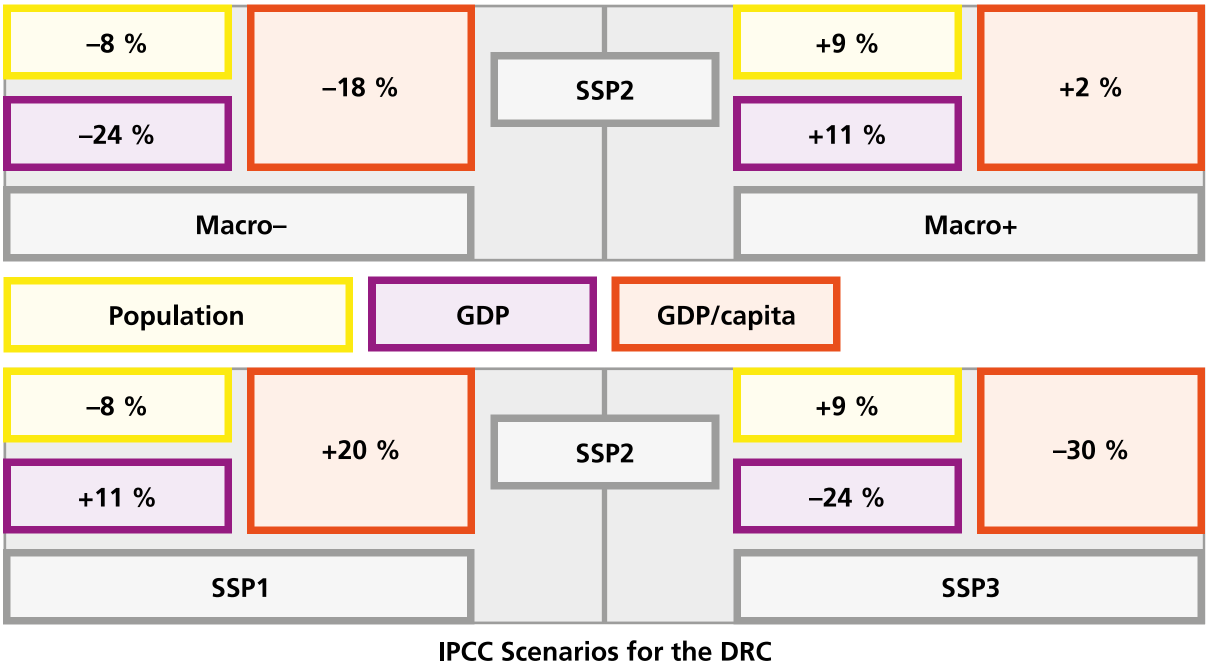
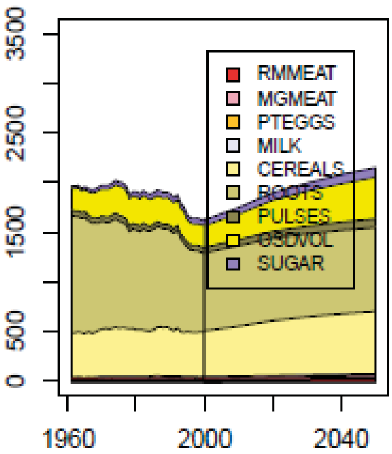


Figure 32: Hypotheses on the evolution of the GDP (red boxes), population (yellow boxes) and GDP per capita in the SSP1 and SSP3 scenarios as compared to SSP 2 and hence for the Macro+ and Macro- scenarios for the DRC.

The diet plan in the DRC is mainly based on the consumption of tubers and cereals (Figure 33). This is similar to other Central African countries but it is not so common in other parts of the world. The average consumption of meat and dairy products is very low in the DRC and although the anticipated increase is relatively large, meat and dairy products will continue to represent a small part of the daily intake of calories in 2030 only. The average per capita consumption of eggs, beans, cereals, oil and sugar is generally expected to rise sharply in the coming decades, and this is especially true under the SSP1 scenario where the average level of GDP per capita is high.



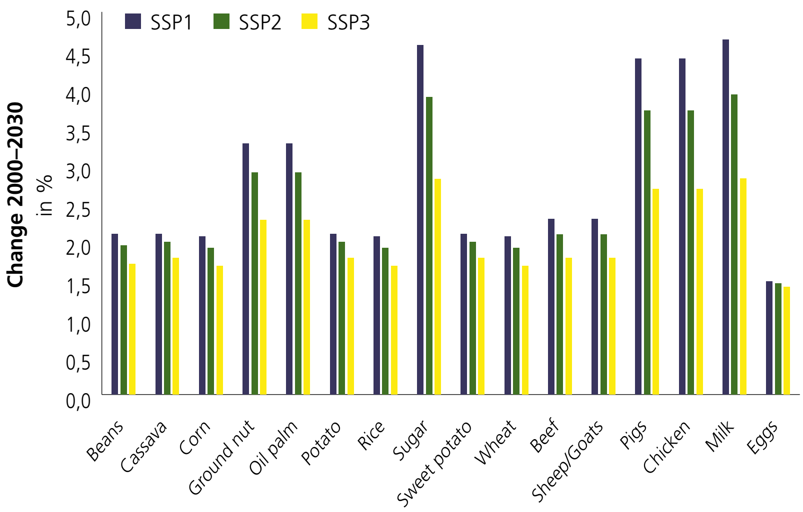


Figure 33: Projected evolution of the diet patterns in DRC per group of products in the base scenario (Figure on the left) and changes in calories consumption per food product per capita in 2030 for different SSP's as compared to the year 2000 (chart on the right hand side).

6.2. The permanent forest estate

Per default, conversion of forests to other uses is not possible in protected areas and forest concessions. The permanent forest area (« Le domaine forestier permanent » in French) is essentially comprised of protected areas (PA's) and logging concessions in the DRC. As discussed in section 4.4.1, this presents a total of 15 Mha of forests which are in the permanent forest estate with 12.7 Mha alone being covered by forest concessions.

6.2.1 Alternative scenarios for 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 most recent action plan for biodiversity the DRC sets out as an objective to bring at least 17 % of the terrestrial territory and inland waterways and 10 % of marine and coastal areas under protection. This includes the conservation of particularly important zones for biological biodiversity and the services delivered by these ecosystems by 2020, which corresponds to the Aichi Objective 11. To reach this objective, the maintenance and expansion of an ecologically representative, well connected and effectively and fairly managed network of protected areas and other effective means of conservation, integrated in the marine and terrestrial landscape will be needed.

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

"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.

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

6.2.2 Logging concessions

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

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

6.3. Agricultural development

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).

Therefore, in the baseline case, we assume that there is no technical progress allowing for an exogenous improvement to yields in DRC 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 modernization 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 3).

Table 3: Development of agricultural yields in the YIELD+ scenario

Crop	Yield growth over the period 2000–2030
Beans	30 %
Cassava	56 %
Corn	183 %
Ground nut	55 %
Oil palm	73 %
Potato	52 %
Rize	119 %
Sugar cane	23 %
Sweet potato	16 %

7. Validation of the model for the period 2000–2010

7.1. Comparison of GLOBIOM results for historical deforestation with different sources of remote sensing

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 DRC 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.

Two maps of past forest cover, produced on the basis of remote sensing data are available for the DRC: FACET and GFC, which is also referred to as the Hansen map. According to FACET, cumulative historical deforestation between 2000 and 2010 accounted for 3.7 Mha whereas Hansen reports 4.8 Mha over the same period, which represents a 30 % plus as compared to FACET. In terms of spatial distribution of this historical deforestation, the different sources are in line with respect to the important role of the provinces Orientale and Equateur for the historical deforestation, followed by Kasai Occidental and Bandundu. There is bigger uncertainty around the deforestation in Katanga which represents 0.7 Mha according to Hansen but only 0.373 Mha according to FACET.

Using GLOBIOM, we estimate a deforested area of 3.7 Mha between 2000 and 2010, which corresponds very well to the deforestation by FACET. A closer look at the spatial allocation of this modelled deforestation shows that the model tends to overestimate deforestation in the Bandundu and the Bas-Congo provinces whereas it tends to underestimate the deforestation in the provinces Equateur, Orientale, Kasaï Occidental (Figure 34). For the provinces Katanga, Maniema, both Kivus and Kasaï Oriental, our estimates are close to the observations of both FACET and GFC.

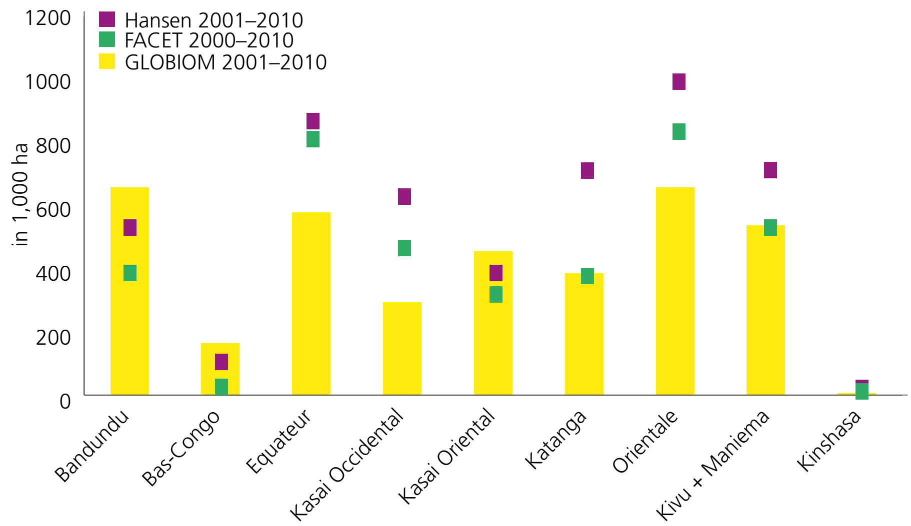


Figure 34: Comparison of GLOBIOM modelled deforestation over the period 2001–2010 and remotely sensed deforestation according to Hansen and FACET.

With the approach presented here we simulate deforestation driven by agriculture land expansion only which comprises cropland, fallow and pastures. In reality deforestation is also caused by other factors such as the construction of infrastructures, urban sprawl, forest fires or mining. Therefore, the difference between the deforestation estimated by the model and observed deforestation can be explained by several factors:

- The non-consideration of certain drivers of deforestation in the model;
- Errors ins the representation of the links between the agriculture sector and deforestation in the model;
- Errors in the observation of historical deforestation by the referenced third-party products

7.2. Evolution of cropland area

When analysing the evolution of cropland areas in DRC between 2000 and 2010 according to FAO, one observes a stagnation and in some crops even a reduction of areas over the period (Figure 35). Knowing that this period has seen a strong increase of population and that the civil war ended at the beginning of the decade, these data do not seem to appropriately reflect the reality. This was confirmed by the participants in the workshop held in Kinshasa in January 2015. The participants' perception rather was that there had been an increase of per capita food consumption rates over the decade. As already discussed, the national statistics are also calculated based on the hypothesis of a certain growth rate. Therefore, it is difficult to confront our results about cropland areas and agricultural production with independent information.

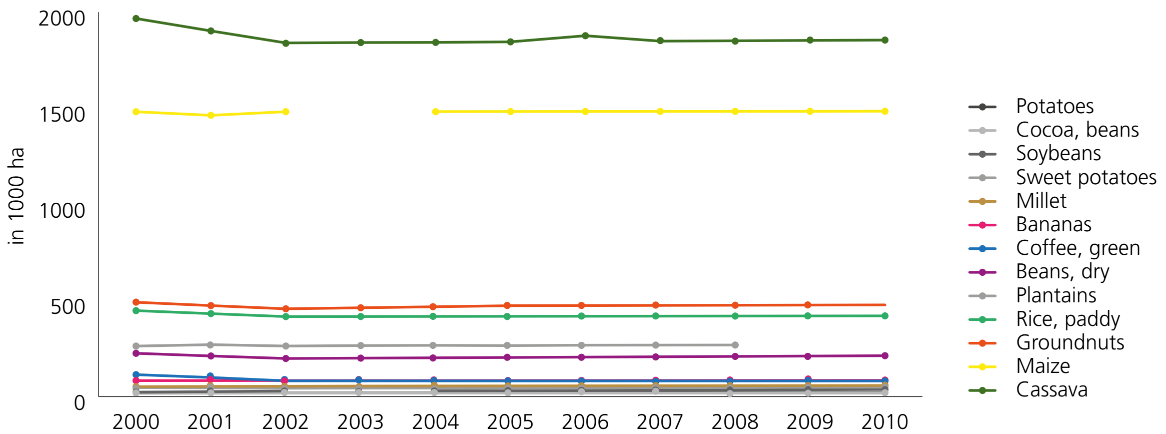


Figure 35: Evolution of harvested areas in DRC between 2000 and 2010 according to the FAO.

According to out results, at the national level, 42 % of the deforestation between 2000 and 2010 is caused by the expansion of cassava, 27 % by corn and 12 % by rice. There are however big differences between provinces: in the two Kasaï provinces, expansion of corn is the main cause of deforestation and in the Kivus expansion of beans is also a significant contributor to deforestation whereas rice expansion of rice cultivation is a driver particularly in Maniema and the Orientale province (Figure 36). Oil palm cultivation leads to a bit of deforestation in the Equateur province but it is not a major cause of deforestation over the base period 2000–2010 in Equateur nor in the rest of the country. Information about the evolution of the dietary pattern per province since the year 2000 could also help to validate the model results.

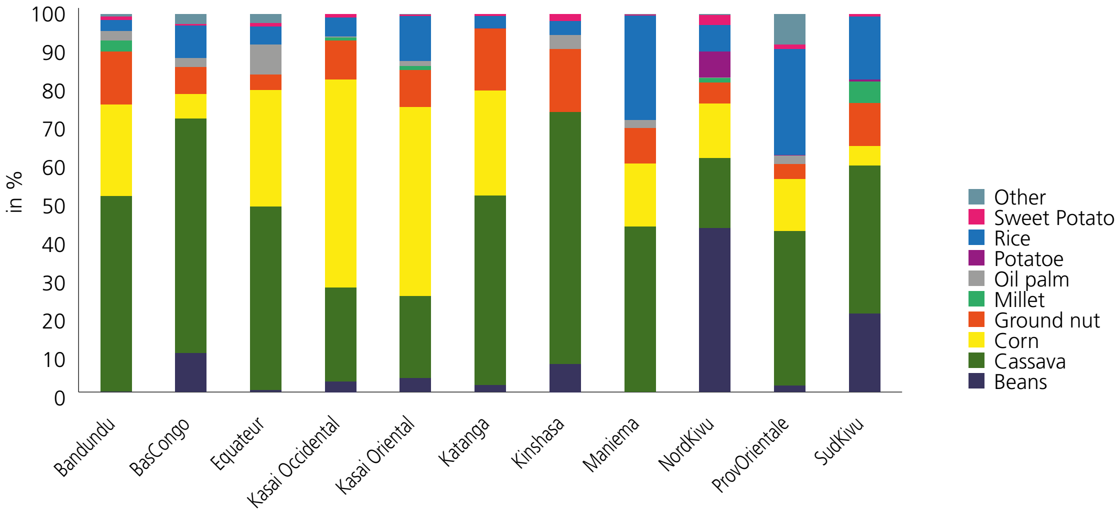


Figure 36: Agriculture drivers of deforestation calculated for the period 2000 and 2010 per province and at the national level according to model results.

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

8.1. Deforestation and other land use changes

The forest area lost (negative values) or gained (positive values) at the national level over the period 2000–2010 for each land cover type is presented in Figure 37. One can observe an increasing pressure on the natural vegetation land cover types over the simulation periods in order to satisfy the increasing demand for land for cropping: in the base scenario, deforestation increases from 3.7 Mha between 2000 and 2010 to 6.4 Mha in the period 2020–2030, which is an increase of 72 % (in green in the figure). In the model, deforestation is exclusively caused by the expansion of cropland (in yellow). We note that although there are 53 Mha of natural land other than forests in DRC, according to our results the expansion of cropland mainly occurs in forests. Only in the last simulation period (2021–2030) we note an increasing rate of conversions of non-forested natural lands to cropland. In total, we project that 2.2 Mha of non-forested cropland an 12 Mha of forests will be converted to cropland over the period 2011–2030 in the DRC.

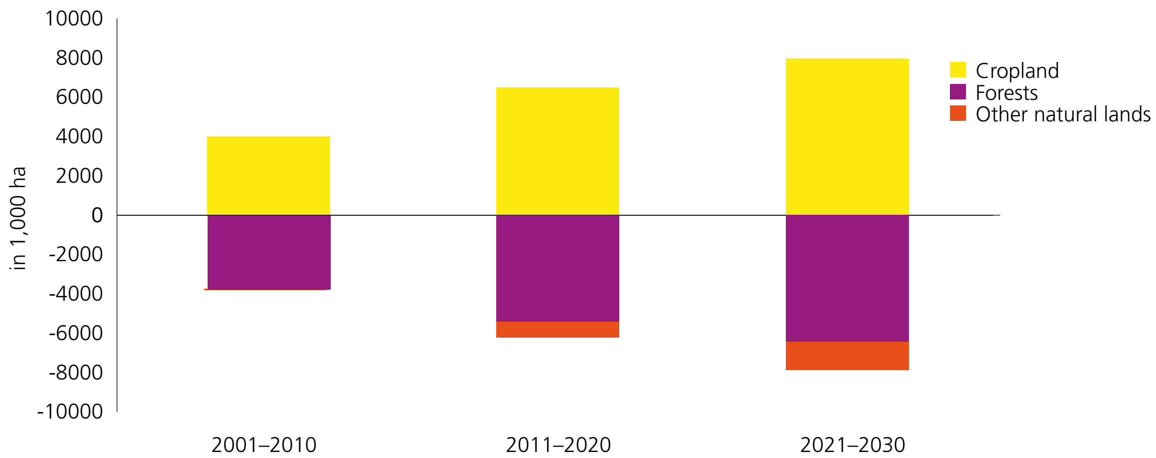


Figure 37: Net area gains and losses for each land cover type and for each simulation period of 10 years (in 1000 ha).

More in detail, the share of cassava driving deforestation increases over the period and represents almost two-thirds of the total cropland expansion into forests. Further, whereas corn was the second biggest driver of deforestation over the period 2011–2020, it's share diminishes over time. It should be noted that these areas comprise fallow areas which are associated to annual cropland (see section 4.4.2). Hence, we estimate that in the year 2030 a bit more than half of cropland area are fallows. According to the model results the expansion of oil palm plantations could become an important driver of deforestation in the decades to come, in particular over the period 2021–2030 where it provokes a bit more than a million hectares of deforestation in DRC (Figure 38).

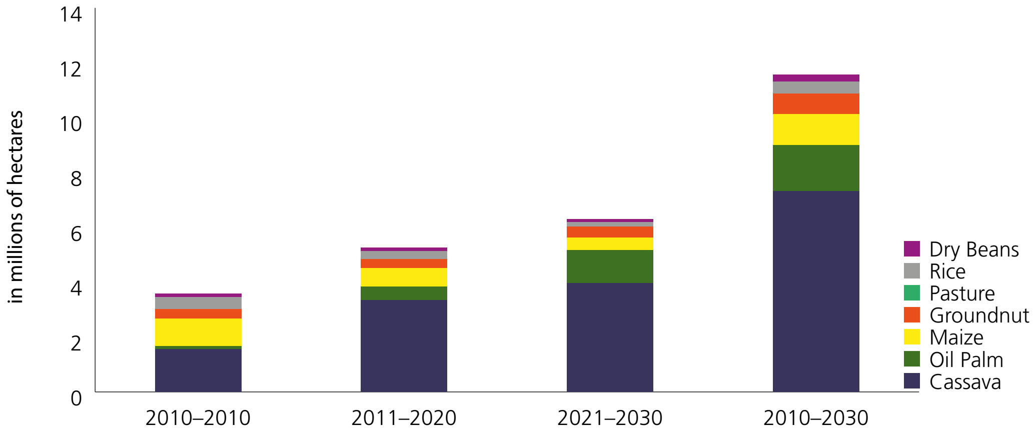


Figure 38: Projections of deforestation per driver in the DRC for each simulation period in the base scenario.

Close to one quarter of the total projected deforestation by the model over the period 2011 and 2030 is located in the Orientale province where it is mainly related by the increase of cropland for cassava and oil palm plantations[10]. The Bandundu province is also projected to see a strong deforestation rate owing to the expansion of cassava cropland and to a lesser extent corn and ground nut. According to our results there could also be a strong expansion of oil palm plantations in the Maniema province. The Katanga province represents 10 % of total deforestation between 2001 and 2010 and it's share increases to 14 % over the period 2011–2030 (Figure 39).

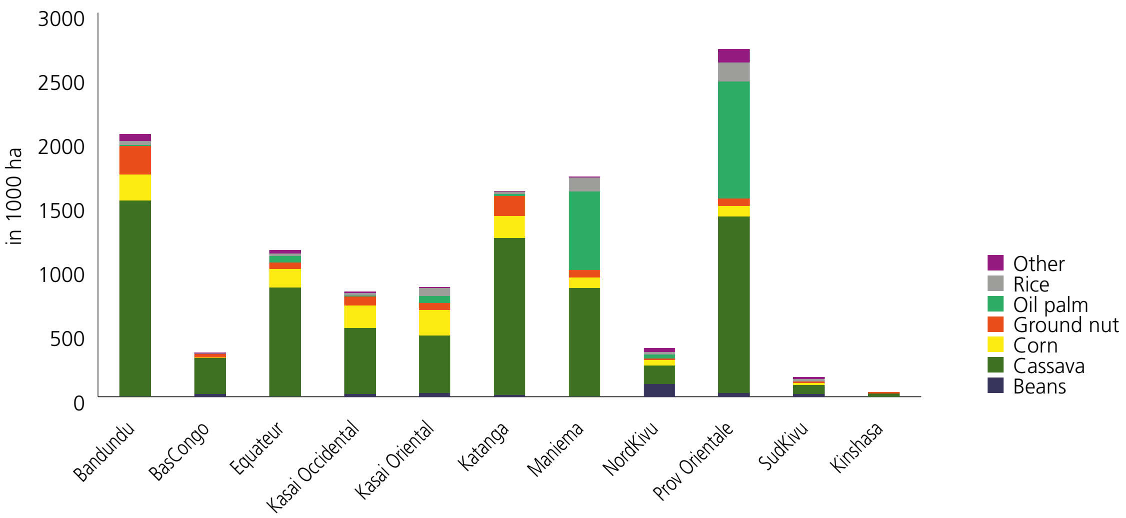


Figure 39: Composition of projected future deforestation between 2011 and 2030 per driver for each province

8.2. Production and consumption of agricultural commodities

According to our results, a strong increase of per capita food consumption can be expected for the DRC in the decades to come: the average calories consumption per capita per year increases by 70 % from 2010 to 2030. The production of calories also increases over the period but less rapidly than the consumption which is projected to entail an increase of the share of consumed calories which come from imports of food (Figure 40). The increase of food imports is particularly pronounced for calories from animal origin where imports are projected to represent more than 80 % of the consumption by the year 2030. Imports

10 Maps of projected future deforestation with the model can be visualized on the website http://rdc.moabi.org/fr/.

of cassava are also likely to increase in the future but at a lower level such that imports account for ca. 4 % of the national cassava consumption in 2030. On the other hand, for rice and corn imports represent more than half of the volumes consumed in the DRC in 2030 and the consumption of sugar and wheat, which also sees a sharp rise in the next decades, will be exclusively satisfied by imports.

We have seen in chapter 8.1 that with GLOBIOM we project a strong expansion of oil palm plantations in the decades to come. As a results, model results suggest that the DRC will not need to import any more palm oil after the year 2020. Still, the monetary value of DRC's trade deficit for food stuff multiplies by 3.7 between 2012 and 2030. It should be noted, however, that the feasibility of financing this trade deficit will depend on the country's ability to increase the values of exports from other sectors

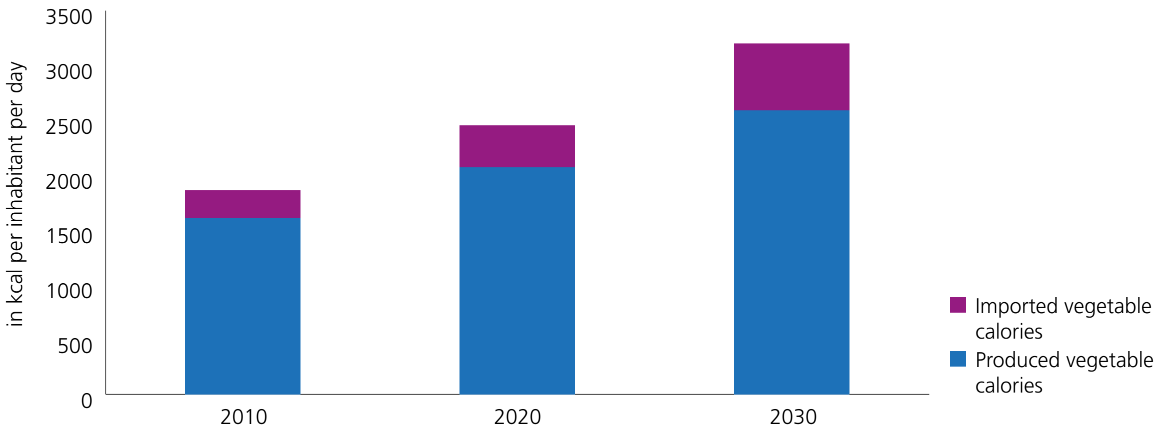


Figure 40: Projected evolution of local production and imports for vegetable calories per inhabitant per year.

8.3. The forest sector

Since we fixed the areas of logging concessions to the current one and over all periods we only take into account the humid, non-flooded forests as being available for exploitation, we obtain an area of 15 Mha of logged forests in the DRC in the year 2030 (see section 4.4.1). Since we do not represent any changes in forest management over time, the production of logs remains at a similar level as today (310,000 m^3). It should be noted that statistics for log production are particularly low in the DRC as compared to other Congo Basin countries: in the Republic of Congo for instance, log production is at a level of 1.5 million cubic meters (M m^3) per year for about the same concessions area; this is an extraction rate (m/ha) which is almost five times higher than in the DRC.

In contrast, to the logging sector, the production of fuelwood sees a sharp increase from approximately 90 M m^3 in 2010 to 150 M m^3 per year in 2030 in order to satisfy the growing energy demand of the population of the DRC. In our simulations, the fuelwood mainly comes from fallow areas. Therefore, forest degradation due to fuelwood collection is not taken into account since in calculating emissions in order to not double-count emissions from agricultural expansion and fuelwood production.

8.4. Emissions from land cover change

We use four different biomass maps to calculate a realistic range of estimated emissions linked to deforestation in the DRC: the maps of Saatchi (Saatchi *et al.* 2011), Baccini (Baccini *et al.*, 2012)especially in the tropics. Here we use multi-sensor satellite data to estimate aboveground live woody vegetation carbon density for pan-tropical ecosystems with unprecedented accuracy and spatial resolution. Results indicate that the total amount of carbon held in tropical woody vegetation is 228.7Pg C, which is 21 % higher than the amount reported in the Global Forest Resources Assessment 2010 (ref. 3, the FAO-FRA (FRA2010 ; Kindermann *et al.*, 2008)information on forest biomass is available from a mixture of sources, including in-situ measurements, national forest inventories, administrative-level statistics, model outputs and regional satellite products. These data tend to be regional or national, based on different methodologies and not easily accessible. One of the few maps available is the Global Forest Resources Assessment (FRA and Avitabile (Avitabile *et al.*, 2016). Our results show that emissions from deforestation range between 5 and 8.5 gigatons CO_2 over the period 2011–2030. Emissions from deforestation increase between 73 and 88 % between 2010 and 2030, depending on the biomass map used. We see that the choice of one or another biomass map leads to a difference of emissions from deforestation of 70 % at the national level over the period 2011–2030 (Figure 41).

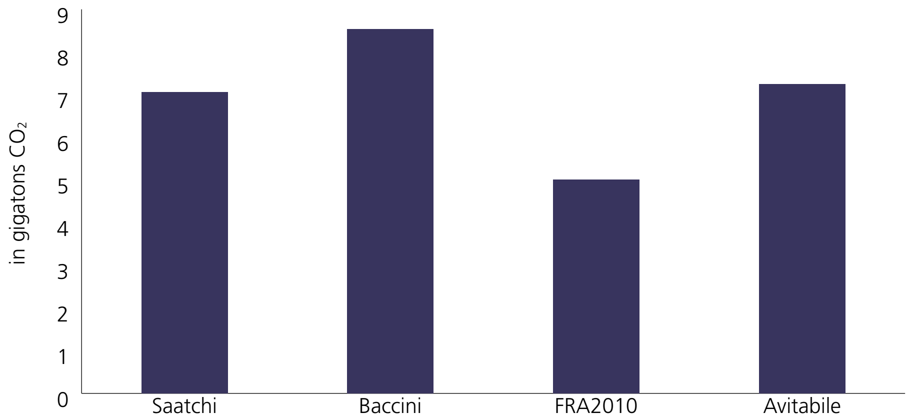


Figure 41: Total projected emissions from deforestation for the DRC between 2011 and 2030 with different biomass maps.

The average carbon density (i.e. the emission factor per hectare in the case of conversion) varies between 115 and 197 tC/ha over the period 2011–2030, depending on the biomass map used (Table 4). These values are generally higher than the emissions factor estimated in the literature for the past deforestation from 2000 to 2010 in the DRC (Harris *et al.*, 2012) where the median value was 128 tC/ha.

Table 4: Evolution of emission factors for deforestation depending on the biomass map used.

Unit	Biomass map	2001–2010	2011–2020	2021–2030	2011–2030
in tCO_2/ha	Saatchi	575	591	602	**597**
	Baccini	682	706	735	**722**
	FRA 2010	420	421	425	**423**
	Avitabile	572	595	627	**612**
in tC/ha	Saatchi	157	161	164	**163**
	Baccini	186	193	200	**197**
	FRA 2010	115	115	116	**115**
	Avitabile	156	162	171	**167**

We have seen that the official wood production in logging concessions is very low in the DRC. As we calculate the emissions from forest degradation as a function of the quantity of wood extracted (plus a damage factor) and not on the area of logging concessions (which in many cases are anyways at least partly inactive) the emissions calculated from it are relatively low with 40 M tCO_2 between 2011 and 2030.

As a reminder, the emissions from the agriculture sector which we account for in this study comprise the methane from rice cropping, nitrogen emissions from crop fertilizers and both methane and nitrogen from the livestock sector. All non-carbon GHG's are converted to CO_2 equivalents (CO_2e) using standard conversion factors. According to our calculations the emissions from the agriculture sector represent 13 M tCO_2e over the time period 2011–2030. Using the biomass map of Avitabile *et al.*, we obtain a result of 535 M t CO_2 from the conversion of other, non-forested natural lands into croplands. But the sum of these other sources remains small as compared to the emissions from deforestation over the entire period 2011–2030 (Figure 42).

We estimate the total emissions from land use change (including deforestation, forest exploitation, conversion of non-forest land and agriculture) to be 7.8 gigatons CO_2 over the time period 2011–2030 (see Figure 42).

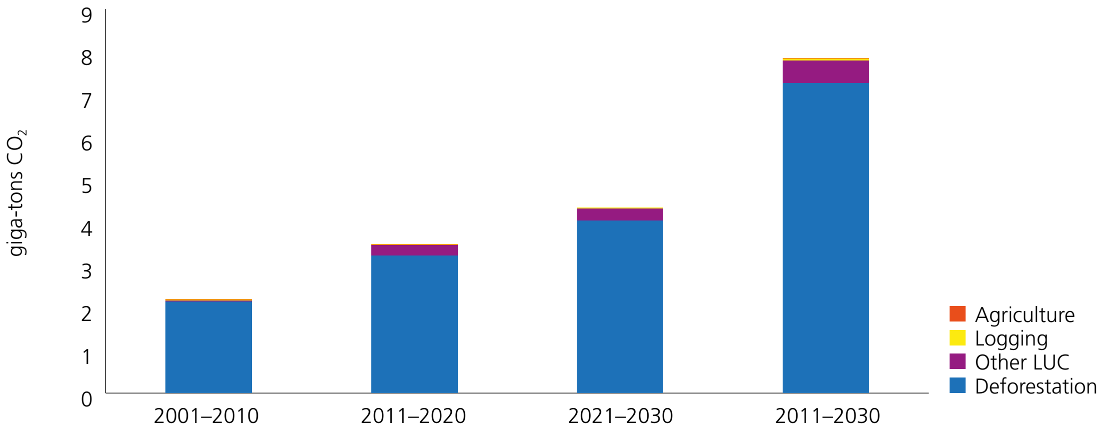


Figure 42: Emissions per source and per 10-years period (three bars at the left hand side) and cumulative over the period 2011–2030 in DRC according to the model.

8.5. Potential impacts on biodiversity

The decline in area of both forested zones and other natural lands un the base scenario represents a menace to biodiversity which is today present in these forest areas and to the services which these zones can provide to the population. Figure 43 presents the share of the total area of each ecoregion concerned. We note that the projected land use change and the resulting pressures on biodiversity are not homogenously distributed across the different ecosystems in the DRC. For instance, the Albertine rift montane forests is projected to experience a strong increase in cropland and pasture land and a decline of the same share of primary forest and other natural lands which today cover a total of 15 % of the ecosystem's area. The main drivers of land use change are also not the same as in other ecoregions. The Eastern Congolian swamp forest will, according to the projections, mostly be taken into informal exploitation. In other ecoregions, however, an important share of non-forested natural lands will be converted to croplands. For instance, 15 % of the area of the Albertine rift montane forests is projected to be converted to cropland over the period 2011–2030. Also, the total loss of natural habitats due to cropland conversion is likely to have a much bigger impact on species than the transition of non-managed forest to managed forest.

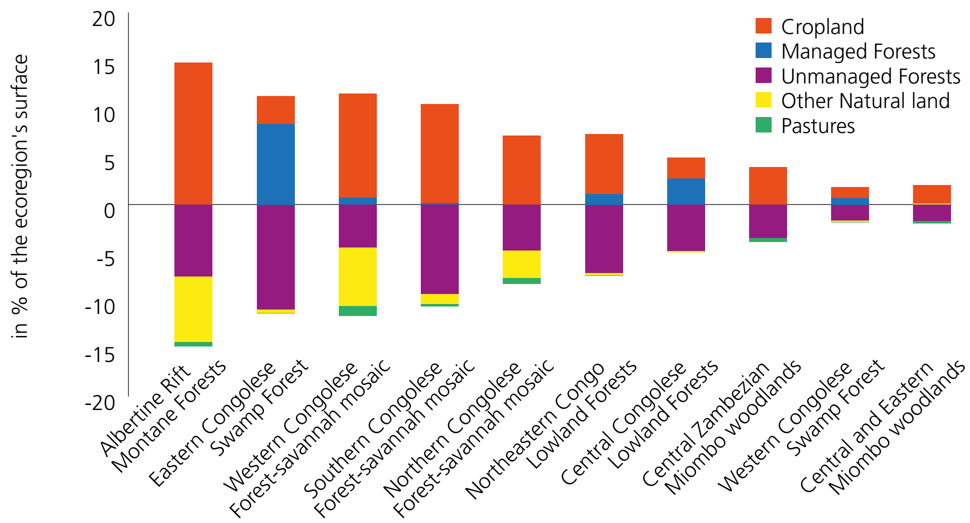


Figure 43: Overview of gains and losses of land use over the period 2011–2030 in the different ecoregions of the DRC.

The combination of information of projected forest loss between 2010 and 2030 with information of the distribution of great apes shows a projected loss of their habitat across the country in the base scenario (Figure 44). The model projects a total habitat loss of less than five percent of their total potential habitat in the country. However, since this loss is very scattered across the country, there is a risk that the land use change will further contribute to the fragmentation of the great apes' habitat.

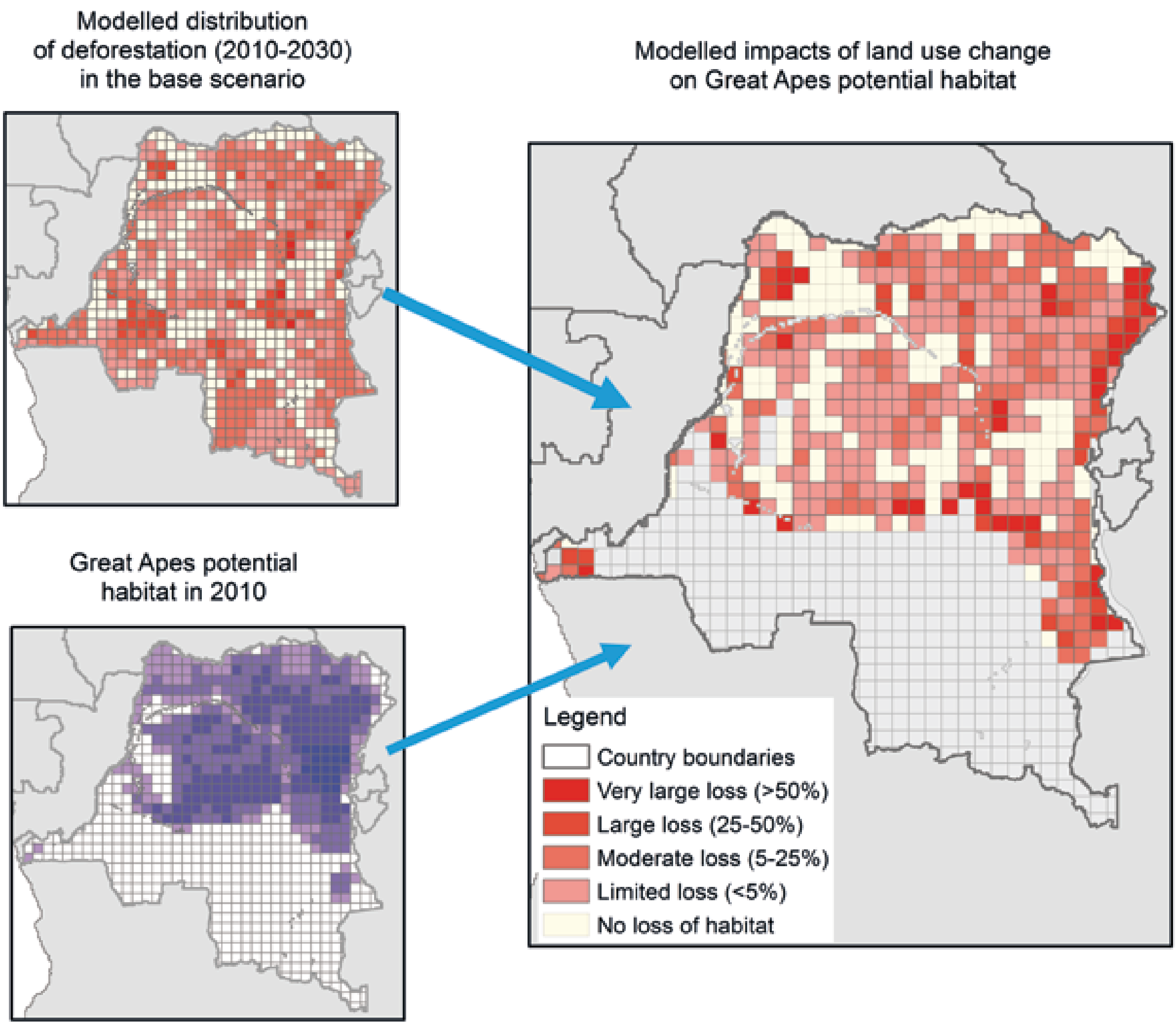


Figure 44: Model results of the impact of deforestation on the potential habitat of great apes per simulation unit.

The estimated loss of natural vegetation will not only have an impact on Great Apes but on all species which are present in the zones threatened of deforestation and on the potential services which the standing forests can offer. The combination of information about projected land use changes (including forests and savannahs) with information on the distribution of species and their habitat requirements shows that 336 out of the 1698 assess species could lose more than 10 % of their potential habitat. According to the global red list of the IUCN, the loss of more than 30 % of the habitat is a criterion to identify a species as threatened by extinction. Further, 23 out of the 336 species projected to lose more than 10 % of their habitat are globally threatened and nine are protected by national law. The combination of information about the proportion of lost habitat for each species in an area produces an species habitat loss index in the different zones; the loss will be bigger in those zones where there is both a big are loss projected and a large number of species which are projected to lose their habitat.

The result of this index shows that in the base scenario the most concerned zones are in the east of the DRC bordering Uganda, Rwanda and Burundi as well as in the Bas-Congo (Figure 45). One can also observe habitat gains at certain locations of the country but these are generally very small and due to abandonment of certain croplands where the natural vegetation returns peu-à-peu over the period 2011–2030.

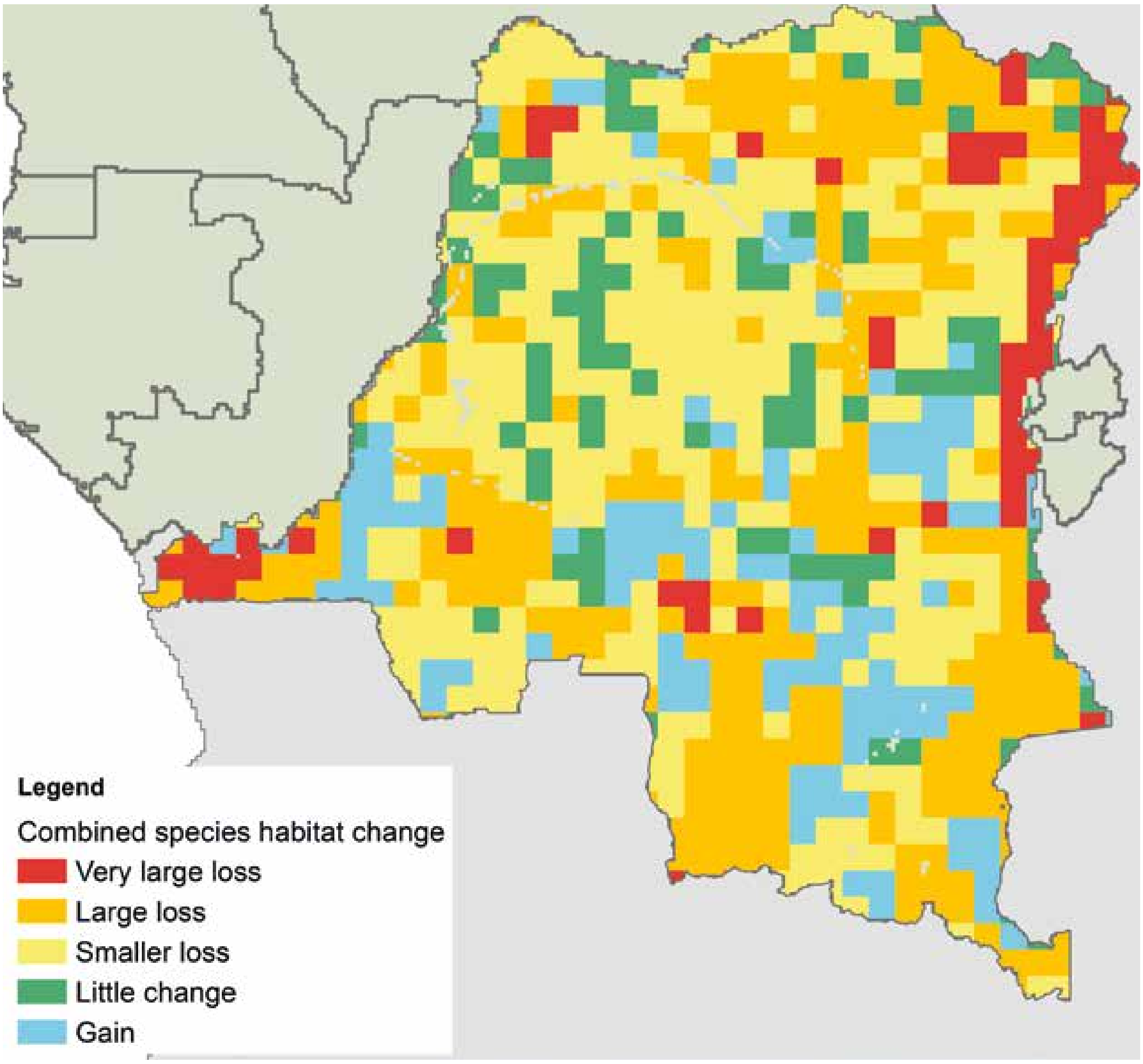


Figure 45: Map of the combined impact of species' habitat loss from 2010 to 2030 for all the species assessed and weighted with the endemism of each species.

9. Result for alternative scenarios

9.1. Deforestation and other land use changes

Total deforestation over the period 2011 to 2030 in DRC varies between 8.6 and 13.4 Mha depending on the scenarios tested; in relative terms this means a 27 % decrease up to a 13 % increase as compared to the BAU scenario (Figure 46). The most pessimistic scenario in terms of deforestation is that with the strongest growth of population and GDP (Macro+). The other scenarios which lead to an increase of the pressure on forest in DRC are the non-respect of protected areas (No-PA) and the non-respect of logging concessions (No-FC) although according to our results the relative increase of deforestation remains relatively low in these scenarios.

Among the factors which could contribute to a relative decrease of deforestation in the next decades we count the expansion of protected areas based on the maximum carbon criterion (PA+Carb), a weaker demographic and economic development (Macro-) and the improvement of crop yields (Yield+). However, we note that only three scenarios lead to variations of more than 5 % away from the BAU scenario. These are the scenarios Yield+ (-27 % of deforestation), MACRO- (-15 %) and MACRO+ (+13 %).

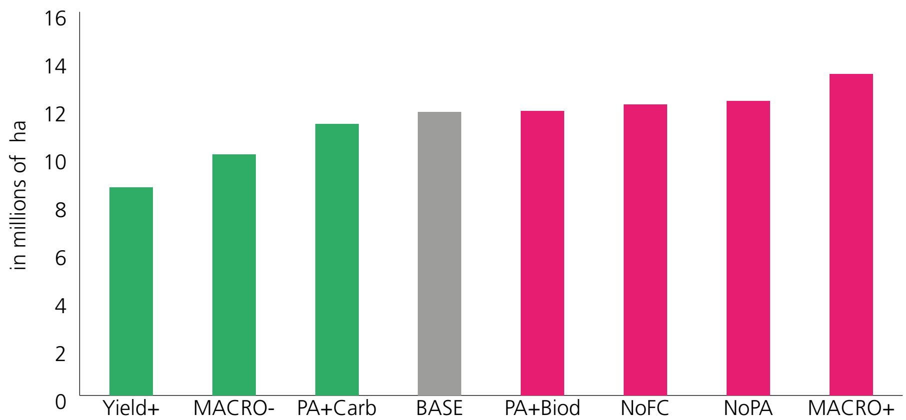


Figure 46: Total cumulated deforestation over the 2011–2030 according to different scenarios: in the scenarios in green deforestation is lower as compared to the BAU scenario whereas deforestation in the scenarios represented by a red bar is higher than the BAU case.

One can also observe some variation among the scenarios in terms of the reduction of non-forest natural lands (Figure 47). The minimum across scenarios is a conversion of 2.3 Mha in the scenarios with the weakest population and GDP growth (Macro-) and in the case of the non-respect of protected areas (No-PA) and the maximum predicted conversion with 2.7 Mha occurs in the scenario where protected areas expand into the most carbon rich areas only (PA+Carb and in the scenario which hypothesizes the strongest economic and demographic growth in the future (Macro+; Figure 46). These results the potential for displacements of land use as a consequence of certain policies, e.g. conversions in low-carbon non-forest natural lands increases as high-carbon (forest) lands gets under protection in the PA+Carb scenario. Also, it might appear surprising that the non-respect of protected areas in the No-PA scenarios has a positive impact on total area of other (non-forest) natural lands whereas the expansion of PA's based on the carbon criterion alone leads to a negative impact. This can be explained by the fact that more forest lands become accessible for conversion to cropland in the first scenario. Since the fertility of forested land is often higher than in savannahs, farmers prefer to expand into forests rather than in savannahs for the same cultivated area. The same mechanism applies in the PA+Carb scenario, except, but in this case more carbon-rich forests come under protection and are therefore less accessible for conversion than savannahs which are generally poorer in carbon. If high-carbon lands become inaccessible, farmers will therefore have to content themselves with the conversion of other natural lands. We also see a light increase in pasture land in the scenario where yields increases (Rdmt+). This can be the consequence of two factors: the improvement of yields allows to reduce the cropland area, which makes that more land is available for raising livestock and the price of fodder for animals decreases, thus making livestock raising economically more interesting.

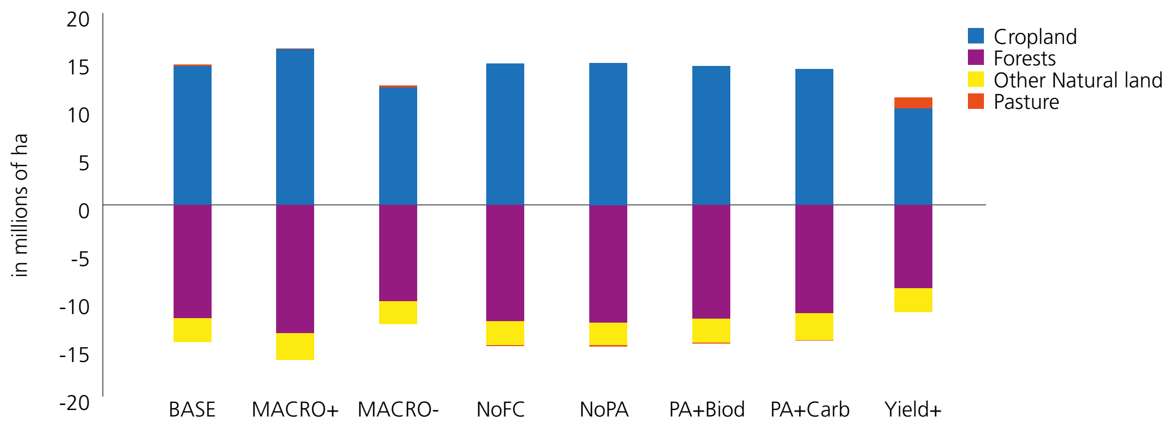


Figure 47: Gain or loss of different land cover types over the period 2011–2030 for each scenario. Since the total area of all lands is fixed, the sum of all changes equals zero for each period

9.2. Agricultural production and consumption

The agricultural production follows the patterns of the demand. Therefore, if food consumption is one the rise fuelled by a growing and/or wealthier population (Macro+ scenario), the food production also increases. On the other hand, if the population grows less and/or wealth increases less fast (Macro-), the demand for food stuff and therefore agricultural production experiences a relative decrease. Similarly, if less a smaller land area can be used for agriculture due to the expansion of protected areas (PA+Biod and PA+-Carb), the total production tends to decrease and if more land becomes available owing to the non-respect of logging concessions (No-FC) or Protected areas (PA-No) as a means to halt conversion, the agricultural production tends to increase. Also, the increase of yields in the Yield+ scenario tends to also clearly increase agricultural production.

We find the same patterns in the production of calories per capita (Figure 48) with the exception of the Macro+ scenario where the increase of the agricultural production does not keep pace with population growth, hence resulting in an overall reduction of per capita calories production. The average per capita calories production from vegetable sources in the year 2030 shows a weak variation across scenarios. Still, two scenarios show interesting effects: in the Macro- scenarios the decrease of revenues (decline of per capita GDP by 18 %, see section 6.1) leads to a downturn of food consumption which is first echoed by imports which decrease by 17 %, which puts a limit to the decrease of local production which remains almost stable (-2,4 %). Results also show that the increase of crop yields leads 1) to an increases of food consumption in DRC (+8 %) owing to the decreasing prices of agricultural products and 2) a significant reduction of food imports by 63 %. The combination of both effects lead to an increase of local production of vegetable calories per capita by 25 % in 2030 as compared to the BAU scenario. Calories from animal production also experience an increase. Interestingly, we also observe a linkage between the increase of yields in the Yield+ scenario and livestock production: Increasing yields reduce prices for fodder for animals, thus leading to a decreased competition for land.

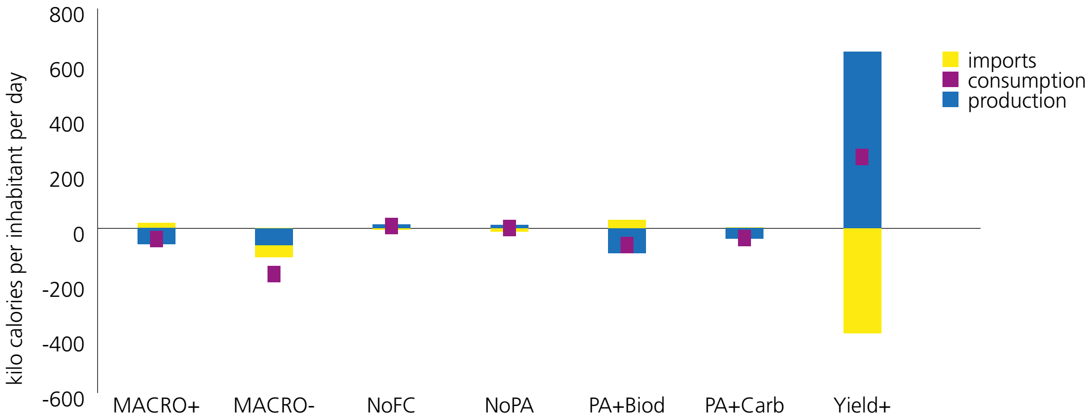


Figure 48: Impact of different scenarios on local production, imports and average consumption of vegetable calories per capita in the year 2030 (change compared with the Baseline scenario)."

9.3. Emissions

Emissions form deforestation over the period 2011–2030 vary between 3.6 and 9.8 Gt CO_2, corresponding to a variation between -32 % and +15 % as compared to the base scenario (Figure 49).Results show that emissions from deforestation in the DRC increase over-proportionally with the deforested areas in the case of the non-respect of logging concessions (No-FC) and in case of a strong economic and demographic growth (Macro+) which is linked to deforestation taking place in particularly carbon-rich forests in these scenarios.

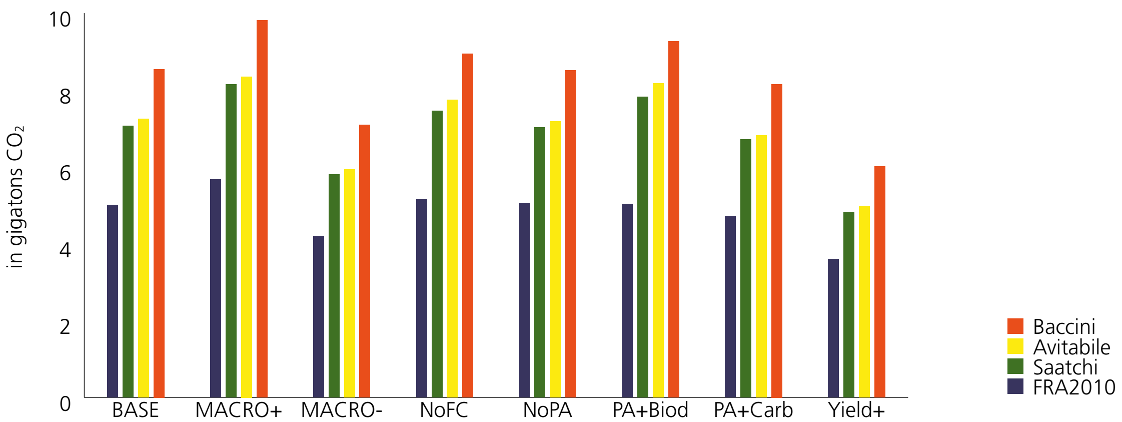


Figure 49: Variation of emissions from deforestation over the period 2011–2030 depending on the biomass map used.

9.4. Impacts on biodiversity

Impacts on biodiversity vary across scenarios and it depends on the aspect of biodiversity impact which scenario has the biggest impact. Figure 50 shows the total impact on the habitat of the Mountain Gorilla (*Gorilla beringei)*, the chimpanzee (*Pan troglodytes)* and the Bonobo (*Pan paniscus)*. The non-respect of protected areas (No-PA) and the Macro+ scenario results in an increase of the loss of Great apes' habitat as compared to the base scenario. This underlines the importance of assuring that the existing protected areas are effectively managed and forest conversions inside these prevented.

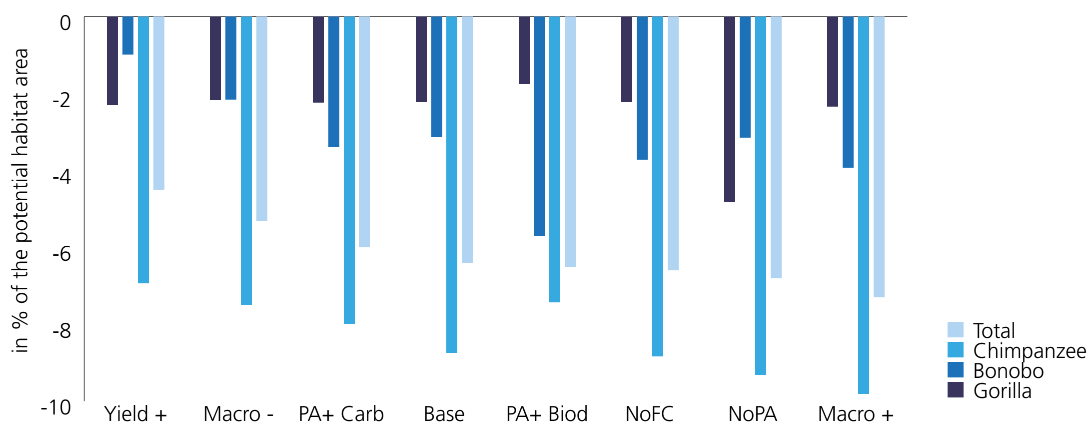


Figure 50: Loss of potential habitat of Great apes until 2030 according to different scenarios.

Looking at all analysed species together, the scenario which provokes a loss of potential habitat for the biggest number of species is the No-PA scenario which assumes a non-respect of protected areas. In this scenario we estimate that more than 200 of the 1698 species assessed will lose more than 20 % of their potential habitat (Figure 51), and of these more than 100 species are projected to lost more than 30 % of their potential habitat in the DRC. According to the criteria of the IUCN, a habitat loss of more than 30 % has the potential to make a species vulnerable to extinction. Among the species which are projected more than 30 % of their potential habitat, 16 are already threatened by extinction and 4 are protected by national law.

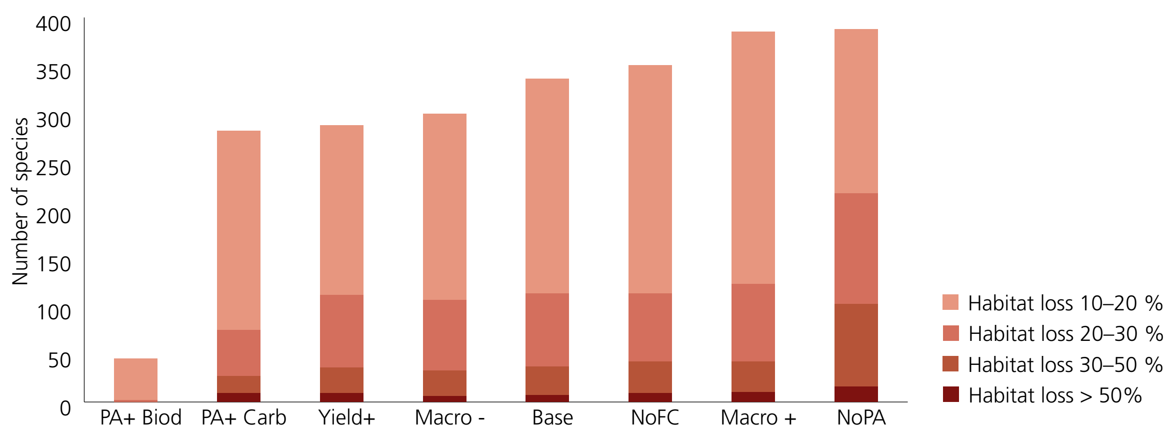


Figure 51: Number of species whose potential habitat is converted to other land uses over the period 2010–2030.

The scenarios where species' habitat loss is least are those where there is an expansion of protected areas, hence underlining the important role that protected areas can play in the protection of biodiversity and potential ecosystem services. It does not come as a surprise that from all the modelled scenarios, the scenario in which protected areas expand with the objective of protecting the habitat of most threatened species (PA+Biod), leads to the greatest reduction of habitat loss as compared to the base scenario. This PA+Biod scenarios is also the only one which prevents loss of potential habitat of more than 30 % for all the species assessed. Even if in practice the choice of the location of new PA's is based on a number of other criteria (such as the actual presence of a specific species or ecosystems, the presence of certain ecosystem services the opinion of local stakeholders or practical feasibility), this simulation allows to determine to which extent an expansion of PA's on the basis of the single criterion of avoided future loss of potential habitat could contribute to preserving this objective.

The evaluation of PA expansion yields a different result for Great Apes. The PA+Biod scenario reduces the loss of potential Gorilla and Chimpanzee habitat but leads to an increased loss of bonobo habitat. The scenarios based on the biodiversity criteria allocated the expansion of PA's on the basis of future pressure on habitat of a large range of species, including non-forest dwelling species. Hence, it may be that a priori these criteria are not an effective protection of the Great Apes' habitat which tend to coincide with zones of dense and carbon-rich forest areas, rather. This underlines the potential trade-offs to cope with between the objective of protecting a large range of species and that of preserving particular species or ecosystem services.

In terms of impacts on ecosystem services, the scenario of non-respect of PA's leads to stronger deforestation in the zones where *Prunus Africana* is probably present, whereas the expansion of PA's based on biodiversity criteria has the least impact. Although the distribution of other ecosystem services, including other non-timber forest products could be different of that of *P. Africana*, our results show the considerable role which PA's can play in the protection of ecosystems. The large error bars in Figure 52 show the uncertainty related to the location of lands use changes inside the simulation units of 50 x 50 km. Depending on the exact location of deforestation in relation to the *P. Africana* potential area, more or less of this ecosystems service will be lost.

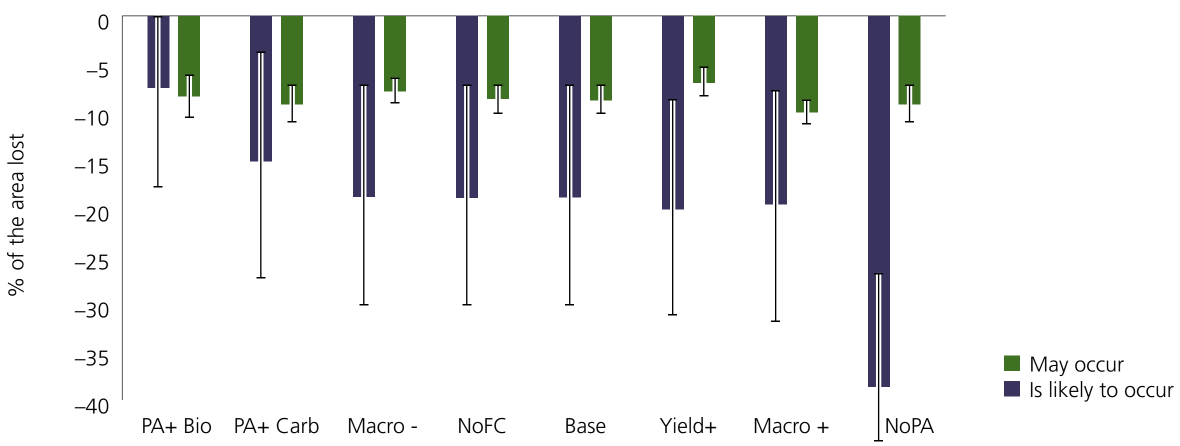


Figure 52: The impact of different scenarios on the possible (green) and likely (blue bar) distribution of *Prunus Africana* in % of the area which is concerned by deforestation. Error bars indicate the uncertainty of *P. Africana* distribution relative to the location of projected deforestation.

10. Which factor scan reconcile several objectives?

Political decision makes are often confronted with the necessity to achieve to fulfil several objectives with limited resources. Therefore, it is important to identify policies which allow for fulfilling several objectives at the same time.

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 DRC is unfortunately one of these countries. Nevertheless, there has been progress during the last years to perform new surveys and share and present the results of these transparently.

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[11] (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 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.

11 http://www.un.org/fr/zerohunger/#&panel1–1

10.2. Multi-objective 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 DRC 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 goal 15 for the preservation of biodiversity.

Table 5: 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	2592	-6919	7802	7243.0	6.4 %	336
MACRO+	-2.3 %	14.8 %	14.7 %	15.2 %	14.4 %	14.6 %
MACRO-	-2.4 %	-25.3 %	-18.1 %	-18.2 %	-16.9 %	-10.7 %
NoPA	0.5 %	-1.9 %	1.5 %	-0.9 %	7.8 %	15.5 %
NoFC	0.5 %	-1.0 %	7.7 %	6.8 %	4.5 %	4.2 %
PA+ Biod	-3.5 %	6.0 %	14.8 %	12.8 %	1.7 %	-86.6 %
PA+ Carb	-1.5 %	1.6 %	-2.1 %	-5.9 %	-5.6 %	-16.1 %
YIELD +	24.8 %	-26.8 %	-30.5 %	-31.3 %	-28.7 %	-14.3 %

calorie output per capita in 2030 on the basis of the 18 crops represented in the model

a. *value of agricultural imports in 2030 on the basis of 18 the crops represented in the model*

b. *total emissions from the agricultural sector and changes in land uses between 2011 and 2030 total emissions from deforestation between 2011 and 2030*

c. *share of the potential habitat area of the great apes converted to other uses between 2011 and 2030*

d. *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 is the only scenario which allows to improve all the indicators at the same time in terms of agricultural development, climate change mitigation and biodiversity conservation (represented by the complete green line at the bottom of Table 5). Inversely, the combination of a stronger economic and demographic growth leads to a lower scoring of all indicators (represented by the complete red line in Table 5). For the other policies tested, we observe trade-offs between gains for the agricultural development on the one hand but losses for the environment such as is the case in the scenarios testing the non-respect of logging concessions and protected areas, or the gains for climate and biodiversity but losses for agricultural development, as they become apparent in the scenario where PA's are expanded with the objective of preserving carbon stocks (PA+Carb scenario).

11. Discussion of results

In this discussion we discuss the factors which could affect our results and potentially lead to different results than the ones found.

11.1. Agriculture

Expansion of subsistence agriculture is mainly driven by the increase of the population of the rural population which lives from local agricultural production. We represent this fact in the model by constraints on the growth of local production such that it satisfies at least the food demand for the growing rural population. However, the only available data on population in the DRC is based on hypotheses about a certain population growth since the last population census carried out in 1984. The actual current distribution of the population on the DRC's territory can in reality be very different from these projections. Between 1996 and 2003 civil wars caused close to 4 million casualties and numerous displaced people. Refugees have also come to DRC from neighbouring countries to escape the conflicts in their countries, notably Rwanda, Angola and the Central African Republic. The High Commissary of the United Nations on Refugees estimated in December 2016 that 2.7 million people have been displaced inside the DR, 60,000 refugees came from other countries and close to one million people have returned to their home places after having been displaced inside or outside the DRC. These movement of persons certainly have an important impact on forest cover once displaced populations are installed on new land. This fact can in part explain the differences between the model results and deforestation observed between 2000 and 2010 in DRC, notably in the Orientale province.

Several articles have shown, however, that an increase in agricultural yields may in fact be accompanied by an increase in deforestation (Byerlee, Stevenson, & Villoria, 2014; Hertel, Ramankutty, & Baldos, 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 & Thomas, 2006; Russell, Mbile, & Tchamou, 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 14 Mha of fallow in 2030 in the DRC. 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.

Agro-industrial plantations in DRC go back to the beginning of the 20th century in DRC: the Lever brothers, founders of the Unilever society, installed their first oil palm plantations in DRC in 1912. Other plantations followed and big transformation units were installed during the colonial time – oil mills, facilities to husk coffee beans, factories to treat rubber, tea, rice, soap mills, flour mills and breweries but these have progressively been abandoned in the 1980s and 90s (Van Reybrouck, 2012). Today, the ministry of agriculture plans to relaunch agricultural production on these sites and encourages foreign investment in this direction. In the framework of the National Programme for Agricultural Investment (PNIA), 20 agro-industry parks are under development in the DRC. The project of the agro-industry park of Bukanga-Lonzo with an area of 80,000 ha, to be established on the territory of the community of Kenge has been inaugurated in 2014 in the former Bandundu province which is now the Kwilu province. This park destined at the production of corn, cassava and chicken is in the hands of South-African owners and managers. The total area of these parks could surpass 1 Mha across ten provinces in the DRC. It would be interesting to estimate the potential impact of these investments on deforestation, biodiversity, the substitution of agricultural imports and the competition or collaboration of smallholder farmers in the future.

11.2. The socio-economic context

A weaker economic and demographic growth could lead to an improvement of most indicators considered in this study as compared to the base scenario. In reality, the impact of economic growth on deforestation is ambiguous. According to the forest transition theory (Mather, 1992), GDP growth will first induce a reduction of the forest area but at a certain level of GDP the forest cover increases again. In this scheme the increase of deforestation can be driven by the growing demand for wood, urban sprawl and the expansion of cropland in the first phase whereas a shift in the perception of forests by a more and more urban population, a more intensive agriculture and economic growth based on the tertiary sector can explain a reduction of deforestation in the second phase of the forest transition curve.

It is obvious that the DRC is located in the first phase of the forest transition which translates into a negative impact of the economic growth on forest cover. GDP has grown on an average of 4.8 % over the period 2000–2010 and in the range of 7 % since 2010 (World Development Indicators). Agriculture contributed around 40 % to total GDP between 2006 and 2010 and about 25 % to GPD growth (Herderschee *et al.* , 2012). Since agriculture employs 60 % of the labour force of the DRC, the economic growth could lead to an increase of revenues of the population which translates into an increase of food consumption. However, one particularity of the country is the fact that minerals represent 80 % of the value of the country's exports whereas the agriculture sector represents less than 2.5 % of official exports. Some authors put forward that in this context the domestic agricultural sector is heavily under pressure from imports due to the overvalued exchange rate of the local currency (Wunder, 2003). According to this principle, the more economic growth is driven by the mining sector, the higher is the probability that the increase in food consumptions will be satisfied by imports. In that case the impact of the economic impact on forest will we weaker than predicted by our results, besides the direct forest conversion caused by the expansion of mines into forest, which is not yet represented in the model.

As to the impact of mines on forest cover, a recent study showed that in the proximity of mines forest cover loss was more frequent in DRC (Butsic *et al.*, 2015). The indirect impacts on forest cover, for instance through the settling of mining workers and their families in proximity to the mines are often more important than the direct impact of the mine as such. In this context, it would be useful to know the number of workers on each mining site in order to take into account the indirect impact of mining in the future. Besides the impact on forest cover, water pollution by mining is a risk not to under-estimate because the consequences of a such pollution are disastrous both for the local populations and ecosystems and they can last until after the termination of the exploitation.

11.3. The forest sector

Despite our efforts put into data collection, the modelling of the co-existence of informal and formal forest exploitation merits further efforts. In the model the two types of exploitation are in direct competition on the market where the price is the same for all the products whereas in reality the export markets, which are essentially reserved for the concessionaires, and the market for local consumers and neighbouring countries, which apply less scrutiny to the origin of the wood and use more species, are quite differentiated (Bayol *et al.*, 2014). There is also a difference in markets' requirements between destination countries for the wood in terms of sustainability and the traceability of the produce. This study is founded on the hypothesis that concessions' management plans are respected. The FLEGT action plan which aims at banning the imports of illegal wood to Europe should reinforce the implementation of management plans, but there is a risk of leakage of exports of illegal wood to other markets which currently apply less scrutiny to the sustainability of the wood sourced.

For the informal logging sector we still lack information to be able to correctly represent it in the model. According to WRI and the Ministry of Environment and Sustainable Development (WRI/MEDD), illegal logging activities take place in the former provinces of Bandundu and Equateur located nearby main road or river connections (rdc.moabi.og). The main problem in modelling the informal logging sector is in knowing what is the volume of wood which is actually marketable and where it is located. The sequence and intensity of logging is an issue: After a logging operation has taken place, it will probably take several years until the loggers come back to the same site. The national production of artisanal sawn timber (in round wood equivalents) is estimated at 3.4 M m^3 per year (Lescuyer *et al.*, 2014) which largely exceeds the formal production from concessions. Our estimates of emissions from forest degradation linked to logging are therefore largely underestimated. According to a back-of-the-envelope calculation, assuming that forest degradation from informal logging is twice as big as the degradation linked to formal logging, total emissions over the period 2010–2030 in the base scenario would increase to at least 7 % with taking into account informal logging.

11.4. The expansion of protected areas

In two scenarios (PA+Carb and PA+Biod) the areas where future PA's should be created were defined on the basis of one single criterion each: the projected loss of species habitat (in the PA+ Biod scenario) and the carbon content in the PA+Carb scenario. As a consequence these scenarios are predisposed to represent the maximum possible impact on the various indicators of expanding protected areas to cover 17 % of the country's land surface. In reality the expansion of protected areas will depend on a large set of criteria, including a certain number of biodiversity aspects and it should be done in the framework of systematic conservation planning (Worboys et al 2015). Systematic planning for biodiversity conservation comprises the identification of national conservation priorities (for example a focus on certain species, certain types or elements of vegetation), an assessment to what extent the current conservation area network responds to the objectives and the selection of supplementary zones to fill the existing gaps. The PA+ scenario is based on an overall menace to mammals, amphibians and birds for which data is available and does not take into account data gaps in the coverage of species or the fact that protected areas could be developed to protect specific species, for example particularly charismatic species.

The connectivity between PA's and intact landscapes are also two important elements in the planning process for PA's (Worboys et al 2015), and these are not considered in the PA+ scenarios. In the PA+ scenarios the zones which are richest in biodiversity or which have the greatest carbon loss in the base scenario were selected for the expansion of PA's, even if these are isolated in the landscape.

The protection of the greatest areas of natural habitat can reduce the pressure linked to the fragmentation and enhance the resilience of these zones; a scenario focusing on this aspect could concentrate location of new protected areas and hence their impact on land use in comparison with modelled scenarios. Further, zones which are rich in biodiversity or carbon which are most exposed to land use change (i.e. the zones selected for expansion of PA's in the PA+ scenario) could also be those zones where there are high opportunity costs to the development of PA's and prevention of land use change, hence making the effective implementation of PA's in these zones very difficult.

Although the PA+ scenarios do not represent the complete reality of the zones where the expansion of PA's is likely to occur – this will in reality be a political decision with the free, prior and informed consent of local populations – the scenarios show that PA's can sustain the conservation of biodiversity and carbon stocks stored in the biomass in the DRC.

12. Conclusion

The GLOBIOM land use model has been adapted and improved with a better representation of the land-based activities and drivers of deforestation starting as of the year 2000 in order to better represent the evolution of future deforestation, associated emissions and impacts on biodiversity in the DRC. However, the authors acknowledge the limits of this type of exercise in absence of more precise and up-to-date data notably on the agriculture sector which is the main driver of deforestation in the DRC. Better statistics would allow to greatly improve the precision of the results produced by this type of modelling exercise the objective of which is to inform the process of policy planning in situations of complex trade-offs between different objectives.

According to moderate projections close to 105 million people will live in the DRC by 2030, half of which in cities and average GDP per capita should almost have tripled as compared to 2010. A more numerous and rich population entails a rise of local consumption of agricultural products and there is the risk that this might translate into an increase of cropland, which will to some extent come at the expense of forests. Our results show an increase of annual deforestation from 374,000 ha between 2010 and 2020 to 643,000 ha over the period 2020–2030, although the DRC increases its imports of agricultural produces by 20 % over the period 2010–2030 and 20 % of projected cropland expansion occurs on non-forest land such as savannahs. Estimated deforestation causes the emission of 7.2 Gt CO_2 over the period 2011–2030 and a loss of more than 10 % of potential habitat for 300 species, of which 42 are threatened. The model also predicts particularly important habitat loss for the Great Apes present in the East of the country. Beside the direct loss of habitat, the expansion of agriculture area will probably also lead to an increase of contacts of men and fauna and consequently to increased poaching. According to our results 60 % of deforestation is provoked by the increase of cropland for cassava and its associated fallows and 15 % by oil palm expansion.

Cumulative deforestation between 2010 and 2030 varies between eight and 13 Mha in the different tested scenarios as compared to 11 Mha in the base scenario. We find that the improvement of crop yields, the expansion and effective management of protected area and a slower growth of population and GDP could reduce deforestation in the future whereas uncontrolled agricultural expansion in PA's or logging concessions and a stronger increase of population and GDP will lead future deforestation as compared to the base scenario. Contingent on the concrete envisaged measures, an increase of agricultural yields could reconcile the objectives of food security, climate change mitigation and the conservation of biodiversity. Inversely, the combination of stronger economic growth and population growth is projected to lead to a deterioration of the fulfilment of all objectives. For other policies tested we observe trade-offs between the fulfilment of different objectives.

If our results show that a strong economic growth could have negative impacts on the forest cover through the increase of the demand for agricultural products, in reality everything depends on the sources (i.e. the sector) that generates this growth and the impact which the economic growth will have on household revenues. A stronger economic growth can create employment opportunities in other sectors than agriculture and allow to invest in the development and the distribution of innovative technologies aiming at improving agricultural productivity. Previous studies shed light on the ambiguous role of improvement of crop yields and deforestation. Therefore, although our results show a positive impact of improved crop yields on forest cover, a detailed sensitivity analysis of the conditions under which these results will materialize in reality or in the contrary lead to increased deforestation should be carried out with the same model framework.

Finally, the results of this study show the importance of an effective management of protected areas for the protection of biodiversity and their potential contribution to preventing the extinction of species, which is one of the objectives of the DRC's National Strategy Plan for biodiversity 2011–2020. Whereas existing PA's are chronically underfunded, our results confirm the importance of financial and technical support for an effective management of PA's.

Other sources of emissions and sequestration of carbon have not been taken into account in this study although they might be non-negligible: emissions from forest degradation linked to informal logging aiming at the local wood market and natural regeneration taking place in fallows. The representation of these aspects will be improved progressively as new data and information becomes available. Meanwhile, simplified working hypotheses could be used to complete the results of this study in order to calculate the total emissions from the LULUCF sector. Numerous carbon stock measurements in different vegetation types across the DRC are underway and in the process of being consolidated and should allow to improve existing biomass maps. This should allow to reduce the uncertainty associated to estimating past and future emissions from deforestation in the DRC.

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Annex

Table 6: Improvements made to the GLOBIOM model in the course of the project

Improvement	Implemented in CongoBIOM 2010	Implemented in GLOBIOM 2012–2016
Spatially explicit allocation of land-based activities		Introduction of a harmonized hybrid land cover map with land use for the year 2000 through combining different data sources. Model results are presented at provincial level and maps of future deforestation are available.
Representation of agriculture and subsistence		Introduction of fallows whose duration varies depending on the population density and the agro-ecological zone. Introduction of auto-consumption constraints in rural areas depending on the diet pattern per province and the growth of the rural population.
Potentiel of the expansion of oil palm		Calculation of the bio-physical potential at a 1 x 1 km resolution for cultivating oil palm in the DRC and other regions in the world.
Validation of model results from the period 2000–2010 by comparing with statistics and		Comparaison of GLOBIOM results in terms of deforestation, cropland area and production per crop with observations from 2000–2010
Emissions from deforestation		-Four biomass maps have been systematically used in order to calculate the emissions from future deforestation in the DRC and the uncertainties associated to it instead of showing emissions from the FAO FRA disaggregated by Kindermann et al -Taking into account the living underground biomass in emissions estimates.
Estimating the impact on biodiversity		Utilisation of several biodiversity indicators to estimate the consequences of land use changes estimated by the model at a 50 x 50km grid level
Introduction of the permaneng forest estate	Land inside PA's, logging concessions and other forests of the estate in DRC cannot be changed to other land uses	-Update of logging concessions and PA's over the period 2010–2020 by integrating data from the year 2015 -Alternative scenarios with conversion possible
Adjustment of wood extraction rates in managed forests	Take account of the concentration of logging on a few commercial species (selective logging) based on a literature review.	Adjustment of extraction rates per forest type (e.g. dense humid forests, dry forests ,…).
Estimation of emissions from degradation linked to formal logging inside concessions	Use of emission factors of Durrieu de Madron *et al.* (2010) : 3.41 tCO_2/m^3 for conventional logging, 3.05 tCO_2/m^3 for logging under a management plan, 2.97 tCO_2/m^3 for certified logging.	No changed as compared to 2010.

Improvement	Implemented in CongoBIOM 2010	Implemented in GLOBIOM 2012–2016
Spatial allocation of the fuelwood demand and forest degradation linked to fuelwood	-Fuel wood demand estimated by simulation unit. -Introduction of a new class of «degraded forest» for the collecting of firewood.	-Fuel wood demand implemented on national scale but intensity of removals depends on the spatially explicit population density. -Fuel wood 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.
Introduction of coffee and cocoa in the model for the Congo Basin	Use of maps from the IFPRI SPAM to allocate coffee and cocoa per simulation unit and for estimates of productivity	Errors detected in the SPAM data and no national statistics available. Therefore, cocoa and coffee not taken into account
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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FINANCIAL SUPPORT

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

Supported by:

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

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