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Modeling impacts of development trajectories on forest cover and GHG emissions in the Congo Basin

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Authors: Aline Mosnier, Petr Havlík and Michael Obersteiner

Other contributors:

- **International Institute for Applied Systems Analysis (IIASA), Laxenburg (Austria)**

Kentaro Aoki
Steffen Fritz
Nikolay Khabarov
Georg Kindermann
Sylvain Leduc
Ian McCallum
Larry Willmore

- **University of Natural Resources and Applied Life Sciences (BOKU), Vienna (Austria)**

Erwin Schmid

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EXECUTIVE SUMMARY

Deforestation rates in Congo have been historically low with an annual deforestation rate of 0.17% over 1990-2000. Over the same period, development has been impeded by poor transportation infrastructures, lost of competitiveness on international markets, conflicts and increased insecurity. With political stability and economic recovering, the pressure on forest may increase in the coming years, and future deforestation rates would rise dramatically.

The GLOBIOM model is a global, partial equilibrium model which focuses on agriculture, forestry and bioenergy. For the Congo Basin region, the CongoBIOM model has been developed to improve the representation of the drivers of future deforestation in the region.

The improvement of transportation infrastructures will be a main driver of deforestation. The only realization of planned and already funded transportation infrastructures in the next years could increase the deforestation by more than three (1.31 million ha deforested per year / emissions of 563 000 T of CO2eq per year).

Increase in agricultural competitiveness will also increase the pressure on forests. We show that yield improvement could lead to 60 000 T of additional carbon emissions from deforestation every year (respectively 0.59 Mha / 175 000 T of CO2eq) and stimulating agro-industrial plantations as cocoa or coffee through lower production costs could lead to 150 000 T of additional carbon emissions from deforestation every year (respectively 0.83 Mha / 267 000 T of CO2eq). Agriculture sector is therefore a main contributor to deforestation, and the model highlights the urgent need for transversal / cross sectorial approach of deforestation.

A global REDD mechanism is represented in this model as a limitation on global emissions from deforestation which implies an additional cost for deforestation. Without any improvement in agricultural competitiveness in Congo Basin, a global REDD mechanism will impact Congo Basin first as it will be more efficient to have deforestation in more competitive area such as Latin America. Therefore, a global REDD mechanism would lead to a sharp decrease of deforestation rates in Congo Basin.

Similarly, having a REDD mechanism in other countries but not in the Congo Basin will give a comparative advantage to Congo Basin and will dramatically increase the agriculture production, and, as the result, the deforestation in the Region.

The CongoBiom model also helped quantifying the impact of REDD mechanism on poverty as it reflects the food price increase - due to the limitation of agricultural lands. A global REDD mechanism would increase food prices by 20 to 30% in average - this highlight the need for compensating mechanism to avoid food crisis in countries where high percentage of the population does not reach food security.

In Congo Basin, to make REDD feasible and acceptable, a dramatic change must occur in agricultural sector to allow increase in production with limited land expansion.

1 INTRODUCTION

The Congo Basin region encompasses six Central African countries – Cameroon, Central African Republic (CAR), Republic of Congo, Democratic Republic of the Congo (DRC), Gabon and Equatorial Guinea. Forest covers approximately 80 % of the basin (GLC2000) with more than half classified as dense forest. Congo Basin contains the largest tropical forest surface in the world after Amazonia. However, in recent decades the tropical forest of the Congo Basin has been threatened less than the Amazonian forest with a rate of deforestation that averaged 0.17% between 1990 and 2000 (Atyi et al., 2009). The Intergovernmental Panel on Climate Change (IPCC) has estimated that deforestation is responsible for 17% of global Green House Gas (GHG) emissions and that protection of forest cover can help in the fight against global warming. The United Nations Initiative on Reducing Emissions from Deforestation and forest Degradation (REDD) in developing countries was launched in 2008 with the main objective of creating incentives for developing countries to reduce emissions from forested land. With a carbon reserve estimated around 24 to 39 GT, Congo Basin countries have expressed a strong interest toward REDD since the beginning.

The methodological issues surrounding the measurement and subsequent compensation of national efforts dedicated to 'Reduced Emissions from Deforestation and Degradation' (REDD) have become a major component of continuing negotiations under the United Nations Framework Convention on Climate Change (UNFCCC). It is vital for the robustness, environmental integrity and economic efficiency of any future REDD mechanism that countries share their responsibilities based on measures of real efforts. This holds irrespective of whether REDD credits are supplied to funds, are made fungible to markets or involve any other REDD implementation design.

A REDD+ mechanism, if poorly designed, might lead to large amounts of "hot air" i.e. emission reduction claims which are not actual, but are inflated due to flawed accounting rules. In particular, if historical emissions are grandfathered high deforestation countries are likely to over-proportionally benefit from REDD funds and regions with historically low deforestation, such as most Congo Basin countries, are more likely not to see strong incentives to participate in an international REDD mechanism as substantial REDD efforts might be required to just stay below historical deforestation rates. To help contain the risk of excessive amounts of REDD+ hot air delivered by high deforestation countries and avoid a low participation rate of low deforestation countries, baselines have to be developed which reflect the most likely future deforestation patters based on rigid driver analysis. Concretely, the negotiations on development adjustment factors for REDD+ baselines shall be informed by an independent science-based baseline methodology, using fact based tools and validated driver data sets. There is a clear need for an open process where the forest information and driver data are shared and validated in an international process and formulae used to compute baselines are jointly agreed.

The Congo Basin countries as they are characterized by low deforestation rates have a strong incentive to act as the leading block to demonstrate the feasibility of fact based development adjustment of baselines.

1.1 The development adjustment factor and the environmental integrity of REDD.

One of the most challenging aspects in designing a REDD mechanism is the estimation of reference levels (RL) and reference emissions levels (REL). They describe the amount of net/gross emissions and removals or respectively the amount of gross emissions from a geographical area under a business-as-usual (BAU) development path. By describing the future emission pathway without any climate protection measures, reference scenarios, are crucial to determine the success of emission reduction performances. BAU scenarios can be solely based on historical emission trajectoria or additionally take into account circumstances such as global deforestation rate, national forest area or explicitly deforestation drivers (Strassburg et al., 2009; Mollicone et al., 2007).

When it comes to setting RL there is less clarity on an agreeable methodology. This is related to different country circumstances and interests. On the one hand, countries such as those of the Congo Basin characterized by low past deforestation rates and potential high future deforestation will certainly not be able to agree to purely historically derived RL. To benefit from REDD and to prevent future deforestation the Congo Basin countries opted for the introduction of so-called ‘Development Adjustment Factor’, which reflect ‘national circumstances’ for RL setting. On the other hand, many developing countries still lack sufficient technical and expert capacity to develop and implement proper RL methodologies. Furthermore, if the process of developing and reporting such RL is not fact based, there is a risk of creating a so-called “lemons market” (Akerlof, 1970). This occurs when the seller knows considerably more about the real quality of a product than the buyer, resulting in a reduced quality of supply of the respective product. In a REDD context, the “lemons” would materialize in the form of globally inconsistent and inflated RL adjustments, leading to an oversupply of cheap REDD credits. Because REDD action induced deviations from the RL would be matched by financial compensation, a credible method for measurement of additional REDD credits is absolutely essential for the financial efficiency of the REDD mechanism in the light of scarce resources dedicated to REDD (Olander et al., 2008) and avoiding the risk of artificial inflation on the market level (Huettner et al., 2009).

Developing fact-based development adjustment factors, as proposed by the Congo Basin countries, will ensure that REDD+ efforts are compensated in a fair manner among REDD countries and will guarantee the environmental integrity of REDD by avoiding inflated emission reduction claims.

1.2 The technical challenge of transparent, fair and efficient reference level setting

Globally consistent DD emission reference scenarios at the national or possibly project level are important for a large number of reasons, including international leakage as well as ensuring transparency, fairness and efficiency. Fairness relates to the issue of an equitable relative distribution of financial resources made available for REDD actions. Compensation of future REDD actions against a historical BAU scenario will favour countries with a high historical emissions on a relative scale. This will increase the risk that future drivers of deforestation geographically shift to historical low deforestation countries and, thus, create asymmetric winner/looser profiles between REDD countries. The Congo Basin countries would be considerably disadvantages under such a REDD compensation scheme due to their historically low deforestation rate and their high development potential of the agricultural sector. In this sense low deforestation countries, such as the Congo basin countries, run the risk to lose out two times under a purely historical baseline setting. First their relative cost competitiveness and supply potential for REDD is decreased and secondly their true baseline will be pushed up due to international leakage of REDD actions implemented in high deforestation countries. On a total market level "over-compensation" of historical high deforestation countries due to a grandfathering rule will compromise both environmental efficiency and cost effectiveness of REDD. Finally, such 'over-compensation' will lead to an inflation of REDD credits (Livengood and Dixon, 2009).

Irrespective of the fact that reliable historical DD data does not exist for the Pan-tropical belt, the currently proposed methods to quantify RL on historical information might be insufficient or at least insufficient without the consideration of national circumstances (drivers) and global data streamlining. Thus, a system of establishing reliable and acceptable RLs based on global forest and deforestation driver information needs to be established. Such as system must account for the basic drivers of deforestation and their likely changes as well as REDD action induced leakage issues as competition for land will intensifies.

1.3 Data and quality requirements for reference level determination

The determination of the 'true' RL will not only shape the global efficiency and equity of REDD, but also become an important component for countries' planning for REDD actions - regardless against which RL emissions reduction will be credited for. It is important to distinguish between the 'true' BAU scenario and the crediting RL (Angelsen

2009). The crediting baseline will be determined by the ‘Development Adjustment Factor’ and eventually be the outcome of a negotiated “formula” or negotiation. Pure reliance on negotiation, however, potentially leads to political bargaining by strong actors. This could disadvantage less powerful developing countries in gaining financial access to REDD resources and threaten the environmental effectiveness of the overall REDD mechanism. Countries with higher readiness such as Brazil will be able to better position themselves as currently witnessed.

In the interest of fairness and efficiency, the final aim for RL determination will be that the ‘true’ BAU scenario and the crediting RL converge or in cases where the tropical countries are willed to take on responsibilities the crediting RL should be below the ‘true” BAU baseline. To achieve this aim, it is essential to set up and implement harmonized and/or standardized rules and procedures for the collection, interpretation and consistent processing of various sources of forest related data. These include earth observation data (Ramankutty et al., 2007; Herold and Johns, 2007) as well as socio-economic data on the basic drivers and pressures for deforestation at national and international levels. There are several data campaigns ongoing in Congo Basin countries most notably the consistent collection of forest information and subsequent reporting by FORAF/OSFAC.

Data consistency and public accessibility, coherence with data interoperability standards as well as compatibility with the respective greenhouse gas (GHG) accounting rules (e.g. Intergovernmental Panel on Climate Change, Group on Earth Observation) are necessary preconditions to effectively negotiate development adjustment factoring. Furthermore, the modelling tools themselves need to be standardized, be subject to peer review and be validated on the national level. Congo Basin countries will need to start the preparation of the necessary data infrastructure, build sufficient analytical capacity and engage in national cross-sectorial validation of baseline and REDD projections. The Congo basin countries have the strongest incentive to build such a system in order to convincingly demonstrate the benefits of its negotiating position to use development adjustment factors correcting baselines. In this way the Congo Basin countries’ REDD negotiation position will contribute to a more efficient and fair REDD mechanism compatible with the very objectives of the UNFCCC.

Robust evidences of a long term rise in deforestation rates in Congo Basin are still missing. This study is a first attempt to fill the knowledge gap on deforestation trends in the Congo Basin region. Based on an adaptation of GLOBIOM, the CongoBIOM model has been elaborated to investigate the role of the predicted main future drivers of deforestation, both internal and external, in Congo basin on land use change and on resulting GHG emissions by 2030. We also consider the potential impacts of the implementation of different reduction levels of GHG emissions globally. This work may allow the Congo Basin negotiators to strengthen their position during international negotiations on Climate Change and provide the decision-makers with substantial background on potential inter-connection between sectoral development strategies and forest cover.

2 GLOBIOM

2.1 A global, spatial, partial equilibrium model

GLOBIOM (*Global Biomass Optimization Model*) is designed for the analysis of land use changes around the world. It is a partial equilibrium model which means that not all economic sectors are included in the model which focuses on agriculture, forestry and bioenergy which are the main sectors involved in land use globally. GLOBIOM is an optimization model that searches for the highest possible levels of production and of consumption, given the resource, technological, and political constraints in the economy (McCarl and Spreen, 1980).

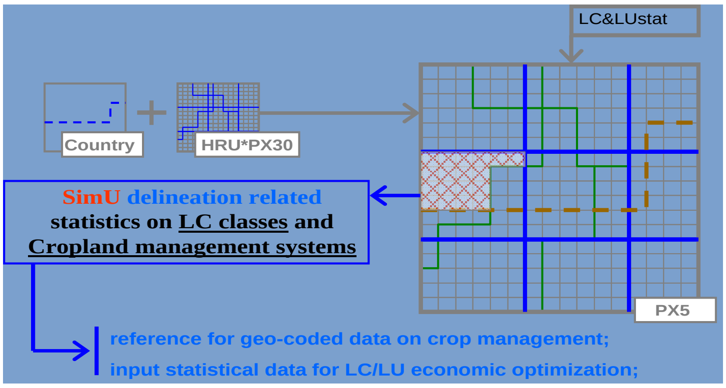
It is possible for one region to consume more of a particular good than it produces, importing the difference (or consume less exporting the difference) but, for the world as a whole, production must equal consumption. The model divides the world into 28 regions, one of which is Congo Basin. It is important to look at the rest of the world when studying land use change in a region because local shocks affect international markets and vice versa. Moreover, there are important leakage effects i.e. that a reduction of emissions in one country can lead to an increase in emissions in other countries if they do not apply the same policies. Bilateral trade flows are endogenously computed between each pair of regions, depending on the domestic production cost and the trading costs (tariff and transportation costs). Two important assumptions underlying this model are that consumers differentiate goods only by price (no quality differences) and that producers are price-takers, with no market power.

2.2 Resolution

In order to enable global bio-physical process modeling of agricultural and forest production, a comprehensive database has been built (Skalsky et al., 2008), integrating information on soil type, climate, topography, land cover, and crop management. The data are available from various research institutes (NASA, JRC, FAO, USDA, IFPRI, etc.) and were harmonized into several common spatial resolution layers including 5 and 30 arcmin as well as country layers. Consequently, Homogeneous Response Units (HRU) have been delineated by including only those parameters of landscape, which are almost constant over time. At the global scale, we have included five altitude classes, seven slope classes, and six soil classes. In a second step, the HRU layer is merged with other relevant information such as global climate map, land category/use map, irrigation map, etc. which are actually input into the Environmental Policy Integrated Climate model (EPIC, Williams 1995, Izaurralde et al. 2006). The Simulation Units are the intersection between country boundaries, 30 arcmin grid (50*50 km) and Homogenous Response Unit (Figure 1). Finally, the representation of production is aggregated at a grid of 200*200 km level.

The other data used come from FAO for the price of producer prices, the production and consumption quantities, and average yield. For the trade, the side fluxes that come from BACI (based on COMTRADE) have been used to calibrate the reference year (Gaulier and Zignago, 2009) and the tariffs come from the MacMap database (Bouet et al., 2005).

Figure 1 : Simulation Unit definition



2.3 Agricultural Sector

A. Supply

So far, 19 distinct crops have been included in the model: wheat, corn, barley, sugar cane, dry beans, palm oil, cassava, cotton, groundnut, millet, chickpeas, potatoes, rice, soy bean, sorghum, sunflower, sweet potatoes, and specifically for sub-Saharan Africa, coffee and cocoa.

Consistently with crop distribution maps from IFPRI (You and Wood, 2006), four management systems are differentiated: the subsistence system, the low input system, the high input system and the high input-irrigated system. For each annual crop, each management system and each simulation unit, the EPIC model computes the yield and the water and fertilizer requirements. The suitability of the lands for different crops depends on the land characteristics such as slope, soil and altitude, but EPIC also takes into account other processes as for instance climate and hydrology. For cocoa, coffee and oil palm which are not yet integrated in EPIC model, the yields are computed by dividing the production by the area per simulation unit (IFPRI). These potential yields are then adjusted to obtain the same average regional yield over 1998-2002 which is reported in FAOSTAT. We assume that each crop which is produced in the base year in the region could potentially be grown in all the simulation units where there is some cropland in the base year.

The transition from one system of production to another is endogenous in the model which means that we can observe an increase or a decrease of the average yield over time without introducing explicit technological change in the model. However, for system stability the surface which is allocated to subsistence agriculture in 2000 is maintained constant in time and the ratio between the high input and low input systems is also kept constant.

The cost of production per hectare is equal to the producer price times the regional yield and adjusted for the input price. However, one limit is that we do not have different fertilizer price data per region. The technologies of production are implicit Leontief function:

Technology 1 (non irrigated system) → yield 1 + constant cost 1 (fertilizer price and use)

Technology 2 (irrigated system) →yield 2 + constant cost 2 (fertilizer price and use, water price and use)

B. Demand

Crops can be used for food consumption, animal feeding or biofuel production. Final demand is modeled by constant elasticity functions parameterized using FAO data on prices, quantities and own price elasticity as reported by Seale et al. (2003). Livestock is indirectly represented through a composite good "animal calories". The needs for livestock production are calculated from on FAO data of between 1998 and 2002 (Supply Utilization Accounts- SUA) and we assume that the quantity of each crop which is required to produce one unit of meat per region stays the same over time. Finally, a growing part of agricultural production is used to produce biofuel. We represent in the model the production of biodiesel from palm oil, soya bean or colza and bio-ethanol from sugar cane, corn and wheat. The coefficients and cost of conversion have been found in the literature.

2.4 Forestry sector

A. Supply

We distinguish three different kinds of forested area in the model: pristine forest, managed forest and short rotation tree plantation. The first category encompasses dense forests but also mixed forest-savannah and mixed forest-cropland. For fast growth forest plantation, suitable areas have been defined according to dryness, temperature, altitude, population density and initial land used. For example, the zones above 3500 m of altitude have been excluded, as well as the zones with population density greater than 1000 habitants/km2 (Havlik et al., 2010).

Primary forest production is characterized on the basis of Simulation Units. The most important parameters for the model are the mean annual increment, the maximum share of logs in the mean annual increment, and the harvesting cost. These parameters are shared with the G4M model – a successor of the model described by Kindermann et al (2006). More specifically, mean annual increment for the "current" management, is obtained by downscaling the biomass stock data1 from the Global Forest Resources Assessment (FAO, 2005) from the country level to the 0.5° × 0.5° grid using the relation between primary net productivity and biomass and the relationship between population and biomass (Kindermann et al., 2008). This downscaled biomass stock data is subsequently used to parameterize the increment curves. Finally, sawn wood share is estimated by the tree size which in turn depends on yield and rotation time. Harvesting costs are adjusted for slope and tree size as well.

Managed forests can be used to produce logs and biomass for pulp wood or fuel wood production. Short rotation tree plantations provide biomass for bioenergy production.

B. Demand

Sawn wood and wood pulp production, and demand parameters rely on the 4DSM model described in Rametsteiner et al. (2007). FAO data and other secondary sources have been used for quantities and prices of sawnwood and woodpulp. For production cost estimates of these products, for example, mill costs, an internal IIASA database and purchased data were used. The energy biomass can be converted into methanol and heat or electricity and heat, where processing costs and conversion coefficients are obtained from the literature. Demand for woody bioenergy production is implemented through minimum quantity restrictions, similarly as demand for other industrial logs and for fuel wood.

2.5 Land use change

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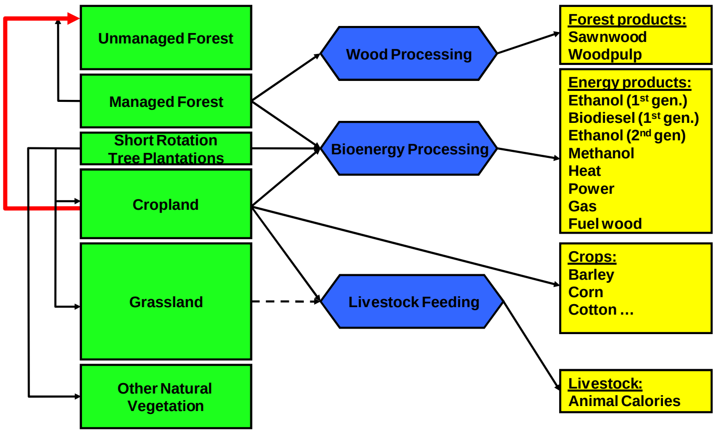
[1] Biomass stock data contain information on forest stock, biomass and carbon.

Land use change options are limited either directly through general assumptions on land use change or indirectly through land specific crop and forest productivity. We make the assumption that cropland can only expand to forests. We also assume that if new cropland is needed, the frontier between existing cropland and forests will move. New settlements in the middle of the forests following the building of new roads are not taken into account at this stage of the study.

Figure 2 : Land cover use products



2.6 Calibration

In order to reproduce the observed quantities for the reference year (2000), the model is calibrated by using the Positive Mathematical Programming (Howitt, 1995), which consists of using the duals on the calibration constraints to adjust the production cost. This process is supposed to correct the problems of specification of the model, and the omission of other unobservable constraints that face the production. It is used to calibrate the crop, sawn wood, wood pulp, and animal calories production.

2.7 GHG accounting

GLOBIOM allows for accounting, and eventually taxing, of the major greenhouse gas emissions/sinks related to agriculture and forestry. The calculation of emission coefficients depends on the emission source. Soil N2O emissions from application of synthetic fertilizers are calculated according to the IPCC (1997) guidelines, on the basis of fertilizer use as simulated in EPIC, or for crops which are not yet simulated, using fertilizer application rates derived from IFA (1992) and FAOSTAT. Coefficients for CH4 emissions from rice production, and from enteric fermentation and manure management, are derived from EPA (2006) by recalculating the total values per activity level. CO_2 savings/emission coefficients for the various bioenergy paths are calculated using parameters from CONCAWE/JRC/EUCAR (2007) and Renewable Fuels Agency

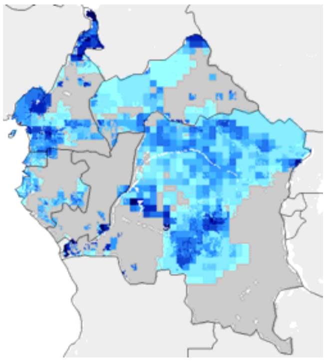
(2008). Greenhouse gas accounts of land use change activities are based on the carbon contents in equilibrium states of the different land cover classes. Carbon content in above and below-ground living biomass for forests is taken from Kindermann et al. (2008). Carbon content in the biomass of short rotation plantations is calculated based on our own estimates of their productivity. Finally, for parameterization of carbon in grasslands and in other natural vegetation, we use the biomass map by Ruesch and Gibbs (2008). The carbon content in cropland is neglected, because it is relatively small and diverse, and no sufficient data is available. CO_2 coefficients for emissions and sinks due to land use change are calculated as the difference in carbon content between the initial and the new land cover classes.

3 CongoBIOM

3.1 Detailed supply representation

In the Congo Basin, the production is represented at the simulation unit level which is the combination of country, 0.5 degree grid (~50*50 km), altitude, slope, and soil class index (Homogenous Response Unit). There are 5049 simulation units in Congo Basin but according to land cover data for 2000 (GLC2000), agricultural production occurs on only 1996 simulation units (Figure 2).

Figure 3 : Share of cropland per simulation unit (% of the total area)

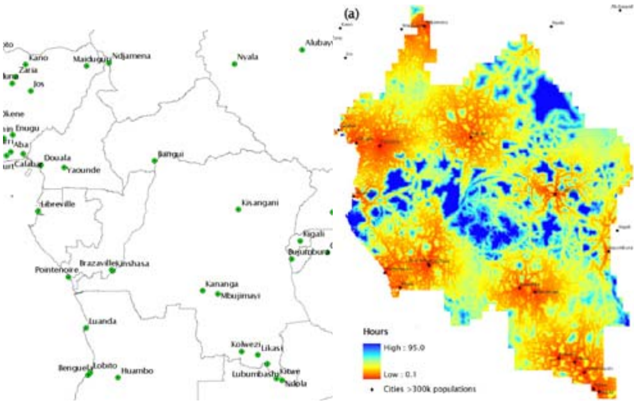


(Grey=no cropland, light blue= low, dark blue= high)

3.2 Internal transportation costs

The internal transportation cost has been estimated on the basis of the average time needed to go from each simulation unit to the closest city above 300 000 people in 2000(including cities in neighboring countries) based on the existing transportation network including roads, railways, and navigable rivers, the elevation, the slope, the boundaries and the land cover using a methodology developed by Nelson (2006).

Figure 4 : Cities with more 300 000 inhabitants in the Congo Basin and neighboring countries and transportation time to the closest city



The transportation cost per ton of primary product per simulation unit (simu) can be expressed as a function of a fixed component (c), a kilometric component (e*d), and a time component (l*h):

$$tc\ (simu)= (c + e*d(simu) + l*h(simu))/\ s$$

Where tc is the transportation cost per ton; c is the fixed cost; e is the kilometric cost; d is the distance in kilometers; l is the labor cost per hour; h is the number of hours; and s is the size of the shipment in tons.

We suppose that most of the carriage of crops is made by truck with an average capacity of 12.5 tonnes. Specific oil prices per country for the year 2000 come from the German cooperation (GTZ). We also use information provided by Teravaninthorn and Raballand (2009) based on truck companies surveys in Central African corridors. Due to the low quality of infrastructure, time-worn vehicles, over-loading, and low maintenance, fuel consumption is very high in Central Africa. It is estimated that in average it is not far from the double of fuel consumption than in France for the same kind of truck (65 liters per 100 km vs. 34 liters per km). The other costs per kilometer (tires, maintenance, bribes) amount 40% of the total kilometric cost on the corridors Douala-N'Djaména and Douala-Bangui. The reported average speed is only around 30 kilometers per hour. We approximate the distance by the total hours necessary to reach the closest big town times the average speed. The annual average wage for a full time truck driver varies across countries. In Cameroon, it is estimated to amount 2604 USD which is one of the highest salary reported for truckers in Sub-Saharan Africa (Teravaninthorn and Raballand, 2009). For the other countries of the region, in absence of specific information for truck drivers, minimum wages from the International Labor Organization have been used.

The same methodology has been used than the one to compute internal transportation costs for crops. For timber, distance to the nearest port seems to us to be the best way to calculate the cost of internal transport, given that most logs and saw wood are exported to Europe and Asia. The ports of Douala (Cameroon), Libreville (Gabon), Pointe Noire (Congo) and Matadi (RDC) have been considered.

For fuel wood, we have set high transportation costs so that the demand will be first fulfilled by the available wood in the same pixel (50*50 km).

3.3 Forestry sector

National Forestry codes have significantly changed in most of the countries of the region during the last years. The attribution of forest concessions for a longer time length -between 15 and 30 years- operating under a management plan approved by the authorities seems to be the pillar of the future forest management in Congo Basin. In 2006, about 36.4 million hectares were allocated in the form of 256 forest concessions among them 87 were already operating under a management plan (State of the Forest 2008). In the new version of the model, we have delineated managed forest area in Congo Basin according to the FORAF concession map. In fact, log production also comes from other permits that are delivered for temporary forest exploitation but it is hard to get information on those permits and the share of these ones in the total log production is declining.

Wood exploitation is very selective in Congo Basin with only few species that are harvested, mainly ayous and sapelli in the North and East of the region and okoume in the South and coastal part. This can explain why we observe such a large difference between average wood extraction rates in Europe for instance and in Congo Basin. Moreover, from national statistics, the average extraction rate in concession area varies dramatically among the countries inside Congo Basin, from 0.02 m3/ha in DRC to more than 1 m3/ha in Equatorial Guinea (Table 1). There are probably several reasons and it is difficult to estimate what really reveals a difference in the potential. In fact, data errors but also forest company strategies to avoid paying taxes or following the rules can also be invoked.

Table 1 : Wood extraction rate in concessions per country

	Cameroon*	**Congo***	**CAR***	**DRC****	**Gabon**	**Eq.Guinea****
Average (m3/ha)	**0,44**	**0,42**	**0,23**	**0,02**	**nd**	**1,05**
Maximum (m3/ha)	1,47	3,13	0,52	0,03	nd	3,38
Minimum (m3/ha)	0,02	0,06	0,02	0,01	nd	0,39

*2005 data, **2000 data, *nd*: no data

Source: Countries

Different extraction rates and the relative importance of wood coming from other permits can partly explain the large gap that we observe for some countries between their share in total area under concession in the region and their share in total log production (Table 2).

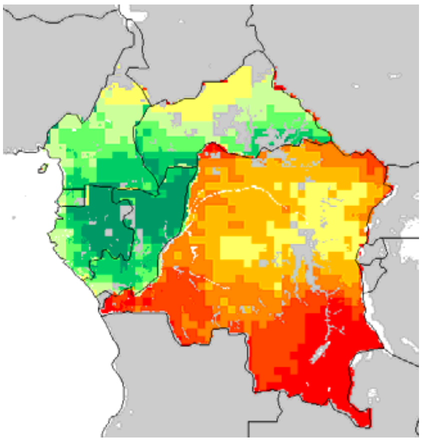
Table 2 : Concession area and log production per country in Congo Basin

	Cameroon	**Congo**	**CAR**	**DRC**	**Gabon**	**Eq. Guinea**	**TOTAL**
Allocated concessions in 2005	6 098 318	11 427 734	2 950 977	12 408 755	5 355 082	35 868	38 276 734
	15,90%	*29,90%*	***7,70%***	***32,40%***	*14,00%*	***0,10%***	*100%*
Log production in 2007	2 296 254	3 054 953	537 998	310 000	3 350 670	524 799	10 074 674
	22,80%	*30,30%*	*5,30%*	***3,10%***	*33,30%*	***5,20%***	*100%*

Source: FORAF

We make the assumption that wood production comes from managed forest where the sustainable average extraction rate is based on the assumption that the average rotation time is 30 years for a potential of wood extraction of 10 m3/ha, which gives an average extraction rate of 0.33 m3/ha per year. However, for Equatorial Guinea and Democratic Republic of Congo, we have considered a lower extraction rate. In Equatorial Guinea the overuse of forests in the last decade decreases the potential of extraction in the next decades. In DRC, the potential of commercial species seems to be lower than in the other countries of the region. The specific log extraction rates per simulation unit are finally adjusted to match this average extraction rate per country (Figure 3).

Figure 5 : Current logs extraction per year (m3/hectare)



(red=low ->yellow->green->dark green = high)

Based on the national experts data, we have replaced the processing coefficient of logs in Congo Basin by 0.38 which is much lower than the world average of 0.59.

3.4 Fuel Wood

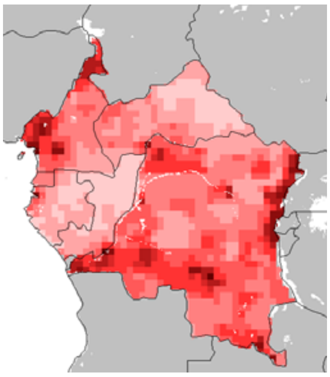
Fuel wood demand in Congo Basin has been disaggregated at the 0.5 degree level (50*50 km). We have made the assumption that the fuel wood use is equal to 1 m^3 per habitant per year. The FAO gives an average of 0.99 m3 per urban inhabitant per year but from national statistics the regional average –urban and rural areas included- is much higher with 1.2 m3 per inhabitant per year (Table 3). We use the population density for 2000, 2010, 2020 and 2030 at the 50*50 km level from Grübler et al. (2007)[2] to compute population number per grid (Figure 6).

Table 3 : Fuel wood and charcoal use per country per year

	National consumption (m3/year)			Average consumption (m3/hab/year)		
	Fuel wood	**Charcoal (wood equivalent)**	**Total**	**Fuel wood**	**Charcoal (wood equivalent)**	**Total**
Congo	1 999 860	1 489 396	3 489 256	0.6	0.45	1.05
Cameroon	20 416 050	1 384 442	21 800 492	1.25	0.08	1.33
CAR	4 332 068	104 966	4 437 034	1.17	0.03	1.19
DRC	56 787 424	2 537 304	59 324 728	1.12	0.05	1.17
Gabon	nd	nd	nd	nd	nd	nd
Eq. Guinea	810 000	nd	nd	0.79	nd	nd
TOTAL	83 535 402	5 516 108	89 051 510	1.13	0.07	1.2

Source: National statistics

Figure 6 : Population density in 2000 (inhabitant/km^2)



(light red=low, dark red= high)
Source: Grübler et al., 2007

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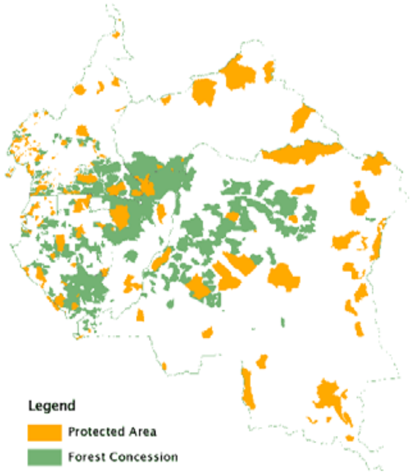
[2] They downscale the United Nations projection per country by using urbanization and the disparity of income between regions. These data have been used in a special report of IPCC on emission (Special Report on Emissions Scenarios -SRES).

In Congo Basin, fuel wood is the main energy source and it is mainly provided by the informal sector through non controlled withdrawal of wood. Fuel wood is estimated to be a major contributor to forest degradation or deforestation around large urban centers. Consequently, the way fuel wood supply is represented in Congo Basin differs from the other regions. If there is a concession or a protected area in the same 0.5 degree grid, we assume that sustainable fuel wood is provided to local population. In the other zones, fire wood gathering is not sustainable and can lead to deforestation. Since the equipment of people who collect fuel wood is generally very basic, we suppose that only half of the available wood can be harvested.

3.5 Land use change

In Congo Basin, almost all the forests belong to the State. This national domain is then split in two components: the permanent forest domain which cannot be converted to other land use and the non permanent forest domain. In the permanent forest domain we usually find the forest concessions and the protected areas. In the non permanent forest domain, temporary logging permits can be attributed or forests can also be under the responsibility of a community. In the model, concessions and protected areas have been delineated according to FORAF maps (Figure 7) and it is not possible to convert these forests in other use. For Cameroon, the permanent forest domain which encompasses municipality forests and forest reserves has been defined more precisely thanks to larger data availability (Atlas Forestier Interactif, WRI).

Figure 7 : Concessions and protected areas in Congo Basin



Source: FORAF

4 SCENARIOS DESCRIPTION

4.1 International drivers

A. Biofuels

There has been a spectacular increase in bio-fuel demand since 2000, primarily because of public sector support. One of the objectives of increased use of biofuel is the reduction of CO2 emissions from fossil fuels. Nevertheless, there is now serious doubt about the capacity of bio-fuels to reach this objective (Searchinger et al., 2008). The link between biofuel development and increased deforestation in the tropics is at the heart of the problem. Sugar cane and palm oil can be used directly to produce first generation bio-fuels, and the climatic conditions are very suitable in tropical countries. The planting of these crops directly compete with forest resources. But even if crops for biofuels are not grown in tropical countries (corn, rapeseed), the reduction of agricultural exports from main exporting regions can increase deforestation globally.

Production of biodiesel from used cooking oil or low grade tallow is possible and some projects are launched to demonstrate the possibility to produce biodiesel from jatropha which can grow on some low productivity land in Asia and Africa (Steenblick, 2006). However, their use is currently marginal in total biodiesel production, and their potential large scale future use is questioned (see FAO, 2008 for discussion on jatropha potential). Biofuel of second generation should also reduce the pressure on land ameliorating the conversion of biomass energy and extending usable biomass resources but the technologies are not yet commercially available.

The scenario on the biofuel consists to double the demand for biofuels of first generation compare to initial projection of POLES model in 2030.

B. Meat consumption

With increases in living standards there is an increase in consumption of animal calories. If we consider that the average annual meat consumption in developed countries is 80 kg per capita and about 30 kg per capita in developing world, and that the meat consumption in developing world is growing fastly, the livestock production should increase sharply in the next decades. The main concerns related to climate change are about the enteric fermentation of ruminants which create methane emissions and deforestation due to pasture expansion or cropland expansion to produce concentrated animal feeding.

In the last decade, mechanized agriculture for soybean cultivation and intensive cattle grazing have been the dominant drivers of land clearing in Amazon forest (McAlpine et al., 2009). Brazil has become the first meat exporter in the last years.

Between 2000 and 2007 poultry meat exports have been multiplied by 23 and cattle meat has been multiplied by 7. In China, the soybean imports have been multiplied by 2.6 between 2000 and 2007 to increase their own livestock production (FAO).

In the scenario, the demand of animal calories increase by 15 % compare to FAO projection in 2030.

4.2 Internal drivers

A. Transportation Infrastructure

In some developing countries lack of transport infrastructures constitutes an important impediment for growth. Rural infrastructure remains highly inadequate and worse, investment in rural infrastructures has been decreasing in most of developing countries since the 90s (Andersen and Shimorawa, 2007). Difficulties in moving output from producer to consumer are particularly severe for agriculture and forestry production located far from urban areas. Poor transport and communications infrastructures isolate countries from the international markets. Limao and Venables (2000) emphasize that the effective rate of protection provided by transport costs is now, in many cases, considerably higher than that provided by tariffs.

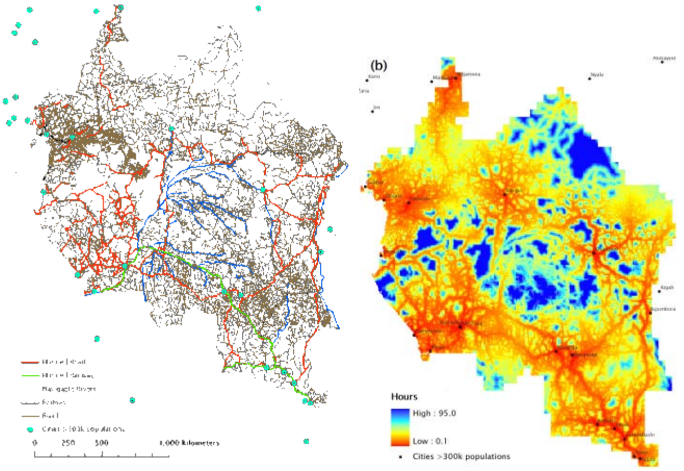
Roads, as a representative of physical infrastructure, accounted for 11-15% of output growth in Thailand and Indonesia (Mundlak et al., 2003). Importance of subsistence farming in developing countries is fostered by poor market accessibility (R. Thompson, World Bank; A. Ruijs et al., 2003; P. Buys et al., 2006). On one hand, high transaction costs make the sales non profitable and on the other hand, they considerably limit the possibility to get food from other sources. When existing roads are not passable during all the year, food production for self consumption is often the less risky strategy. But when there are bad growing conditions one year, this can seriously threaten food security even if other regions in the same country have surpluses.

In the Congo Basin, the transportation infrastructure is characterized by weak density and quality. High quality transport infrastructure requires large investments, normally the responsibility of the public sector, as well as continuing efforts to maintain the road network in good shape. The wars and disorder that many Congo Basin countries have suffered in the past decade, bad management of public money, and difficult weather conditions have led to deterioration of the road network. In the Congo for example, there are only 25 km of paved roads for each 1000 km2 arable land, compared to 101 km on average for Sub-Saharan Africa (AICD, World Bank). In CAR, a recent report mentioned insufficient infrastructures which are scattered haphazardly across the territory and which are usable only a very short period of the year.

On the other hand this raises the issue of the land use change that will occur after road network expansion. Many studies have shown the negative impact that expansion of the transport system has on forest cover (Geist and Lambin, 2002; Freitas et al., 2009). In Brazil, occupation of the Amazon forest was encouraged by the government in the 1960s, 1970s and 1980s and a road network was developed in the forest to facilitate the arrival of colonizers (Pfaff, 1999). A recent case study on Belize also shows that areas which were more likely deforested were closer to roads (Wyman et al., 2009). In the Ivory Coast, forest cover fell from 21 to less than 3 million hectares of forest between 1957 and 1995. The development of a road network, and forest trails in particular, has played a crucial role in allowing agriculture to expand to the detriment of forests in the context of strong demographic pressures, development of cocoa crops and the low salaries prevailing in agriculture (Lanly, 1969; Bertrand, 1983).

However, with return of political stability, good governance and new mining projects, projects to repair existing transport systems and contribute to a new transportation infrastructure have multiplied and are expected to accelerate in the near future. We have included in our database the projects for which the funding is certain. This information has been provided by the ministries for Cameroon, CAR, and Gabon and by the World Bank for DRC and Republic of Congo (AICD). We have recomputed the internal transportation costs on this new basis in assuming that the transportation cost is reduced in the same magnitude as the transportation time (Figure 8). We are however conscious that this may be not the case in the reality[3]. We have introduced the change in transportation infrastructure for the last period of simulation 2020-2030.

Figure 8 : New transportation infrastructure projects in Congo Basin



Source: CIRCA, National statistics, World Bank (AICD)

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[3] From surveys, Raballand et al (2009) have shown that transport costs were higher on that portion of highway recently renovated than other portions of the highway between Cameroon and Tchad, notably because of the lack of competition in the transportation industry. On the other hand, in a 2006 audit of the forestry sector in Cameroon, Karsenty et al. show that regulation also has a significant effect on transport costs. In Cameroon, it appears that, because of regulation, the cost of timber transport is higher on roads than on the trails.

B. Fuel Wood

In Central Africa, it is estimated that fuel wood is responsible for more than 80% of carbon release related to forest use (Marien et al., 2008) and Africa is the only continent where wood is expected to continue to be the main source of energy during the next decades.

If, in rural areas, gathering of firewood is an integral part of the shifting agriculture system, urbanization is usually not followed by changes in consumption of energy, nor by changes in methods of energy consumption, so there is still a high demand for nearby woody resources. Biomass is used principally for cooking of meals and for heating. Cooking constitutes the main purpose of national energy consumption in Cameroon, accounting in 2006 for more than 72 % of final energy consumption and for 96 % of domestic energy consumption (Energy Information System of Cameroon, 2007). The main cooking fires which are used are unfortunately with very low-performance (~15% energy efficiency).

To tackle the problem of forest degradation and deforestation due to fuel wood consumption, several possibilities are considered:

1) Rationalization of fuel wood supply through the use of wood residues from forest exploitation or short rotation tree plantations. A GTZ report for Cameroon estimates that wood residues constitute an important potential for fuel wood with about 50% of standing biomass which is left in the forest and 70% of the processed wood. The Makala project encourages the plantations of acacias around the cities of Kinshasa, Kisangani and Brazzaville in order to provide sustainable sources of fuel wood.

2) Improvement of wood energy conversion during the charcoal production or the transition to more efficient cooking equipment. More efficient equipments are already available and their cost is not prohibitive but it is still less profitable for households to buy these equipments.

3) Substitution of fuel wood with alternative sources of energy. Currently, these alternative sources are marginal because of the initial cost of the equipment, higher prices, and the irregularities in the supply. However, in Libreville the gas is subsidized so that most of the households can use it for their energy needs and fuel wood only represents a small share of total energy consumption. Moreover, it seems that the region has important potential to produce hydro-electricity. The realization of hydro-plants is under study in RDC.

In this scenario, we assume that consumption of firewood per inhabitant decreases from 1m3 to 0.8 m3 per year.

C. Forest Management

Illegal logging is suspected to be widespread in the region but important uncertainty remains. A study from Cerruti and Tacconi (2006) estimates that the illegal logging was around 9% in 2004 in Cameroon while the commonly used assumption is 50%. Moreover, a part of the illegal logging can come from special logging permits which have been delivered by the ministry but are not reported in the official production data. Global witness, as an independent observer of forest activities since 2001, reported a certain number of infractions, but noticed that the number was decreasing and changing in nature. One important problem is now related to the lack of transparency to the concession allocation process which raises concern about the technical suitability of the concessionaires to implement sustainable forest management.

In the next decade, the trend toward better forest management should intensify. Forest operators have now the obligation to exploit concessions in accordance to their management plan which must be approved by the authorities. Approximately one third of the concessions area is already under approved management plan and it is expected that in the next five years most of the management plans in the other concessions will be finalized. Moreover, from zero ha in 2006, FSC certified forest area grew to a total of more than 3 million ha in October 2008. The total area of certified forest could reach 7 to 10 million hectares in the next five years (State of the Forest, 2008). Moreover, the Forest Law Enforcement, Governance and Trade (FLEGT) initiative has been launched by the European Union in 2006 to facilitate legal trade in timber and eliminate illegal timber trading with the EU. Cameroon has signed the first Voluntary Partnership agreement (VPA) in May 2010 that aims to develop measures to ensure the timber sector in Cameroon is both legal and sustainable (CounterBrief LoggingOff, May 2010).

The improvement in forest management could lead to lower CO2 emissions through the harvested quantities of wood, the harvested species and age class composition, and the degradation of the forests due to exploitation. Unfortunately, very few information is currently available on those aspects. When we compare the wood extraction rate in certified forests and in non certified forests from national available statistics, we cannot conclude to lower extraction rates in certified forests. However, the rules enforcement is probably reinforced through certification since the concessionaries are subject to control from external observers.

The main source of emission reduction may come from reduced degradation of forest during logging. Forest exploitation is also a source of carbon emissions. The damages on standing biomass, the residues which are left in the forests and the construction of forest paths and roads are important factors of carbon release during the exploitation that can be lowered through better management practices. Durrieu de Madron et al. (2010) have estimated that emissions can be decreased by 15% when concessions are under management plan and by 18% with certification compared to the traditional exploitation under conventional forest exploitation. Some approximations about the resulting emissions could be around 3.41 tCO2eq/m3 for traditional exploitation, 3.05 tCO2eq/m3 for exploitation under management plan and 2.97 tCO2eq/m3 for certified concessions.

We do not implement specific scenarios on forest management but for informative purpose we compare the emissions related to forest exploitation by 2030 according to different management practices.

D. Agriculture

More than 70% of cultivated land is used for subsistence agriculture and subsistence agriculture has been the main reason for deforestation in Cameroun and in the DRC during the past decade. The population is likely to double between 2000 and 2030. Increased demographic pressure and the lack of resources to increase productivity may seriously threaten forests. However, as shown by Ndoye and Kaimowitz (2000), population increase cannot explain all deforestation in the region. Crops for generation of income, such as coffee, cocoa and palm oil, have also been developed for export to industrialized countries.

The difference between potential yield and observed yield is particularly high in the Congo Basin. This is particularly striking when comparing the yield of agricultural products in the Congo Basin with those in other tropical regions. The 90s have been marked by disinterest of the political class but also international donors for agriculture. Numerous farmers have left their farms or have converted their land to food crops after the fall in prices, liberalization of markets, and devaluation of the local currency (Duguma et al., 2008). However, in the past few years, the role of agriculture as an engine of economic development has been recalled (World Development Report 2008), and the tendency for prices of basic products to increase offers new incentives to invest in agriculture. Cash crops remain also crucial in certain parts of the region: Cameroon is the sixth largest producer in the world of cocoa (Agritrade 2009) and cocoa represents more than 70 % of the income in central Cameroon (Jagoret et al., 2009). Moreover, with the improvement of infrastructure the farmers' access to fertilizers can be facilitated. In this context, we consider two different scenarios for agriculture development in Congo Basin in the next decades.

The first scenario is about an increase in productivity. We assume that this productivity increase is proportional across all the management systems and does not involve higher producing costs for farmers. That could be the case if the state launches a vast campaign to improve agricultural mechanization or subsidizes the distribution of better seeds for example. We assume a lower productivity increase for cash crops than for food crops. One reason could be that the first objective of national policies is to improve food security and consequently, cash crops would benefit only indirectly from the improvements in the food sector. The yields are doubled for food crops and increased by 25% for cash crops.

The second scenario focuses on coffee and cocoa. We simulate a decrease in cost of production of 25 % by 2030 compared to 2000.

4.3 REDD

REDD is a global initiative that began in the context of the post-2012 climate agreement negotiations. The main idea was that important GHG emissions reduction could be achieved quickly and at a low cost by avoiding deforestation and forest degradation (Angelsen et al., 2009). The principle is that the international community should transfer money to developing countries which make efforts to reduce deforestation and improve forest management. The main aspects currently under debate are the activities which are eligible under REDD (scope), the reference period and scale against which the activities are measured (reference level), the form of the financial incentives distribution and the sources of financing (Little REDD Book).

In the REDD scenarios, we implement different limitation levels of global GHG emissions from deforestation compared to the baseline level in 2030. Our purpose here is not to discuss what kinds of mechanisms should be implemented. We only assume that these mechanisms are effective in limiting GHG emissions from deforestation. However, deforestation can be limited only through the reduction of cropland expansion, not through a reduction in demand for fuel wood. In the most constraining scenario we implement a reduction of 90% of the emissions from deforestation in the baseline. Other scenarios reduce emissions by 75%, 50% and 25%. In addition, we test a scenario where Congo Basin chooses to not participate in the REDD process i.e. the Congo Basin does not choose to reduce its emissions while the other regions do.

5 BASELINE

We ran simulations for the period 2000-2030, solving the model for each 10 year-period. Land use changes made in one period are consistently shifted to the next period, introducing recursive dynamics into the model.

5.1 Main Assumptions

A. Population growth

The regional population development is taken from IIASA's SRES B2 scenario (Grübler et al., 2007). World population should increase to 8 billion in 2030 compared to 6 billion in 2000. In the Congo Basin, population should double between 2000 and 2030 with an average annual growth rate of 3.6% between 2000 and 2010 and 2.2% between 2020 and 2030, leading to a total population of 170 million inhabitants in 2030. The direct consequences of this increased population in the model are an increase in final demand for agricultural and forestry products.

In Congo basin, we use the spatially explicit projections of population by 2010, 2020 and 2030 to represent the demand for fuel wood (Grübler et al., 2007). As in other developing regions, the urbanization process is expected to intensify in Congo Basin. From UN estimates (2009), the number of cities in the Congo Basin larger than 1 million inhabitants should jump from 4 in 2000 to 8 in 2025, with 15 million inhabitants in the city of Kinshasa alone. North and South-West Cameroon and the Eastern RDC border will continue to register high population densities. However, at this point, no difference is made between rural and urban markets.

B. Exogenous constraints on food consumption

Composition of demand varies with the evolution of income. From the intermediate scenario of the SRES report (scenario B2), GDP per capita is expected to grow at an average rate of 3% per year over the period 2000-2030 in Congo Basin. Based on the FAO projections, per capita meat consumption will increase in the Congo Basin but will remain far behind meat consumption in intermediate and high income countries (Figure 7).

Figure 9 : Comparison of animal calories intake per capita per day across regions

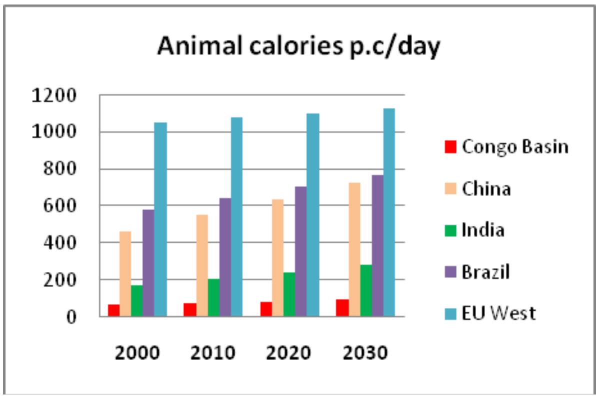
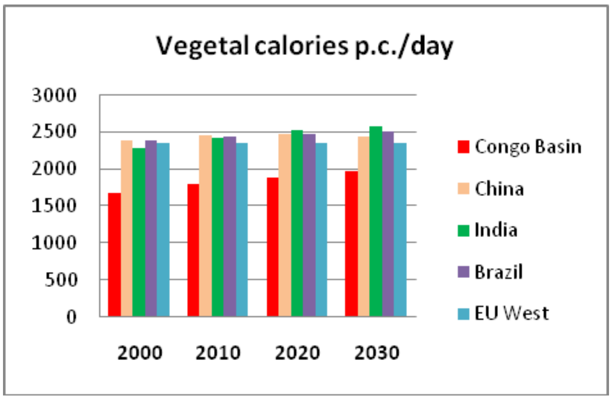
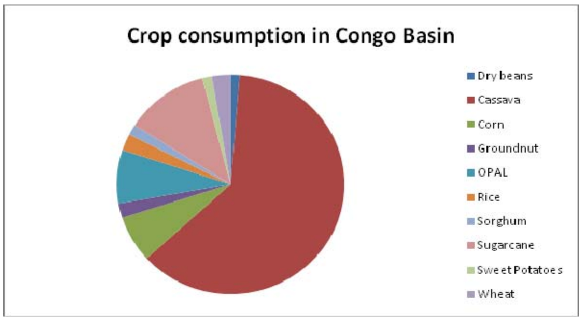


Figure 10 : Comparison of vegetal calories intake per capita per day across region



We have introduced constraints that set minimum calorie intake per capita in each region and that disallow large switches from one crop to another so that the composition of vegetal calories will not differ dramatically between 2000 and 2030. The main crops consumed in the Congo Basin are cassava, sugarcane, palm oil and corn (Figure 11).

Figure 11 : Composition of vegetal calories intake in Congo Basin in 2000



As mentioned above, the model currently restricts coffee and cocoa production to Sub-Saharan Africa. This means that, on international markets, the Congo Basin is assumed to compete only with other Sub-Saharan countries. For cocoa, western Africa is by far the most important producing region in the world, but for coffee, large amounts are produced in South America and in South Asia. Initial demand for these crops is set at the observed imports from Africa in 2000 and is then adjusted for population growth in each period. This assumption means that neither price changes nor income changes influence demand for coffee and cocoa. This assumption will be relaxed in future work.

C. Demand for energy

Another important aspect which is highly uncertain is the impact improved incomes will have on fuel wood use. In the baseline, we make the assumption that fuel wood use per inhabitant remains constant, so that fuel wood demand increases proportionally to population. Bioenergy consumption comes from the POLES model (Russ et al., 2007). Taking into account the currently high trade barriers and domestic support for biofuels, we make the assumption that there is no international trade in biofuels.

D. Other assumptions

The baseline is a situation where technical parameters remain identical to the 2000 level; new results driven only by increases in food, wood and bioenergy demand. There is no change in yields, annual increments, production costs, transportation costs or trade policies. Subsistence farming is also fixed at its 2000 level. No environmental policies are implemented other than the 2000 protected areas. This baseline should be regarded as a "status quo" situation which allows us to isolate the impacts of different drivers of deforestation in the Congo Basin in the different scenarios.

5.2 Description of the baseline

In the Congo Basin demand for crops is projected to increase by 3.12% between 2000 and 2030, and most crops (90%) are used for direct food consumption. There is still no biofuel production in Congo Basin by the year 2030. In the rest of the world, total demand for crops increases by 1.87 % between 2000 and 2030: 59% of crops are used for food consumption, 23% for animal feed and 18% for biofuel production (compared to only 4% in 2000). The additional demand to produce biofuels globally leads to strong increase in demand for sugarcane, rapeseed, palm oil, and corn (maize), which at least double compared to 2000. Rapid growth in consumption of meat more than doubles global demand for cassava and sorghum used in animal feed between 2000 and 2030.

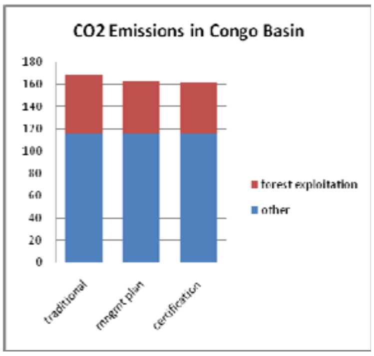
The Congo basin is a small actor on agricultural markets. This reflects the fact that a large share of the population survives on subsistence agriculture and significant amounts of crops are exported from Cameroon to other countries in the region. The Congo basin is a net agricultural importer with wheat based products, sugar and rice being the principle imported food products that are represented in the model. The main agricultural exports outside the region are cocoa and coffee. In 2030, the agricultural trade deficit is slightly reduced in quantity. With higher world prices, there is a progressive substitution local production for imports. All imported quantities in the Congo basin are reduced compared to 2000 except for wheat imports, which grow by 56% over the period 2000-2030. The Congo basin takes advantage of demand for biofuels by increasing its exports of oil palm. The Congo Basin exports 5% of its palm oil production to Europe, but the region remains a marginal player at the global level.

Consequently, the increase in food demand is satisfied by an increase in local production. The main crop which is cultivated in Congo Basin is cassava. From 2.5 million hectares in 2000, cassava expands to 5.5 million hectares in 2030, which represents one third of the total area of cropland in the Congo Basin. The second most cultivated crop is corn (maize) with 20% of total cropland in 2030. These two crops are responsible for almost two-thirds of total cropland expansion in the region. Productivity increases over the period through the use of more inputs and through a reallocation of crops to more productive land. Irrigation remains marginal in 2030. Productivity gains avoid about 7 million hectares of cropland expansion, which would have otherwise been necessary in addition to the observed 7 million cropland expansion. This productivity gain is especially important for corn (maize), cocoa, rice and sugarcane. However, for most crops yields in the Congo basin remain among the lowest in the world. Since we do not allow for cropland expansion in other natural land, cropland expansion leads directly to deforestation. In this baseline, the total area deforested due to agriculture is around 0.3 million hectares per year between 2000 and 2030, similar to the historical rate of deforestation over 1990-2000 estimated from OFAC.

Demand for fuel wood is proportional to population. Assuming annual consumption per capita of 1 m3, total demand grows from 75 million m3 in 2000 to 170 million m3 in 2030. We make a reasonable assumption that, in protected areas or concessions, fuel wood is sustainably provided to the local population. Consequently, the demand for fuel wood which directly causes deforestation is reduced to 40 million m3 in 2000 and 83 million m3 in 2030. This leads to an additional deforested area of 0.1 million ha per year over the period 2000-2030, which is one fourth of the total deforested area in the Congo Basin.

In the Congo Basin, the total managed forests area increases by 10% and the area with short rotation tree plantations grows from 0.86 to 3.5 million ha between 2000 and 2030. In the model, production of logs in the Congo Basin reaches 15.15 million m3 by the year 2030 in the base scenario. From estimates of Durrieu and Matron, total emissions from forest exploitation would amount to 51.6 MtCO2/year if we assume that all concessions remain under traditional management. This is not negligible if we compare this number with the 116 MtCO2eq which are emitted from deforestation in the base scenario over the period 2020-2030. 6 MtCO2 would be saved if the concession is under a management plan and 7 MtCO2 if all the exploited forests use low impact techniques (Figure 12).

Figure 12 : CO2 emissions from deforestation and forest exploitation in Congo Basin



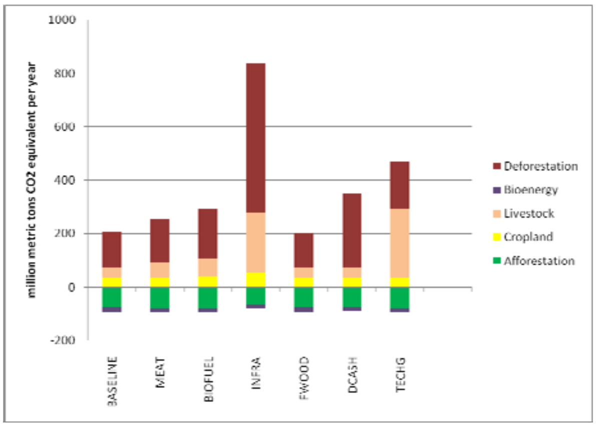
The total production of wood increases fivefold between 2000 and 2030 but most of the production is exported because the cost of wood processing in the Congo basin is very high compared to other regions.

In total, between 2020 and 2030, 4% of the total deforested area and 6% of total CO2 emissions from deforestation come from Congo Basin.

6 DRIVERS OF DEFORESTATION - RESULTS

6.1 Results overview

Figure 13 : Comparison of GHG emissions in Congo Basin between the different scenarios

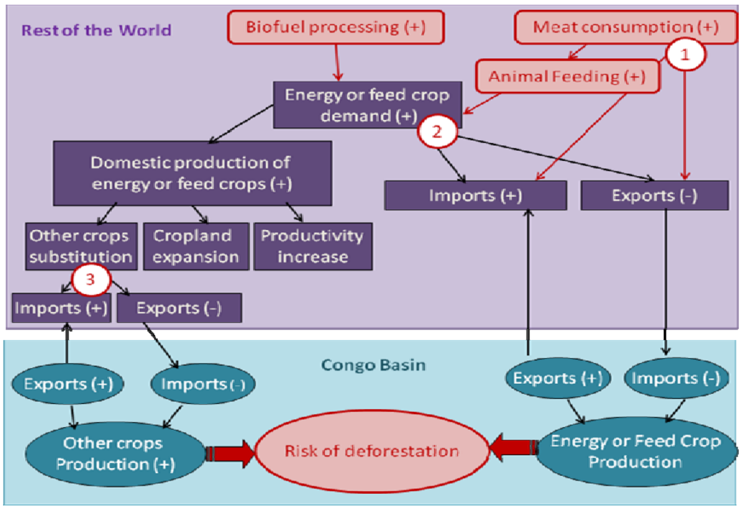


In the next decades, evolution of GHG emissions from deforestation in the Congo Basin will depend crucially on the evolution of internal forces. The improvement of transportation infrastructures has the highest impact on total GHG emissions which are multiplied by four compared to the baseline (Figure 13). This infrastructure scenario has been built using planned infrastructures which are already funded. This means forests of Congo Basin will be certainly under more pressure during the next years and that historic scenario is not relevant to estimate future deforestation in the Congo Basin. In terms of emissions from deforestation, the reduction of production costs for cash crops has also large effects with 267 MtCO2 per year over the period 2020-2030 compared to 116 MtCO2 in the baseline. Technological change in agriculture increases more slightly emissions from deforestation (175 MtCO2) but strongly increases emissions from livestock sector resulting in more than two times total GHG emissions in the Congo Basin in the baseline. We notice that afforestation for short rotation plantations could offset a significative part of emissions from deforestation in the region. However, this raises the issue of only considering the GHG emissions to account for the forest value. The losses in terms of biodiversity are most probably not compensated by mono-tree plantations.

6.2 International drivers

The two external scenarios that we implement deal with a global increase in crop demand, in the first case to produce more biofuels and in the second to produce more meat. Figure 14 describes how these external shocks could affect deforestation in the Congo Basin.

Figure 14 : Channels of transmission of international crop demand increase to deforestation in Congo Basin



The first channel of transmission (1) is through trade of the product itself: when demand for meat increases in a region, this region can increase its meat imports and/or decrease its meat exports. The second channel (2) is through trade of an intermediate product used in production of the final product: the region can increase the domestic production of meat or biofuels and import more energy crops or more crops for animal feed. The last channel of transmission (3) is through trade of other crops: if the region increases the domestic production of energy/feed crops at the expense of production of other crops, this can lead to a decrease in export of other crops exports and/or an increase in imports of other crops.

A. Biofuels

⇨ *Demand for 1st generation biofuels in the world is doubled compared to the 2030 projections*

First generation biofuels can be produced from oil and sugar. In the model, bioethanol can be produced from corn, sugarcane and wheat while biodiesel can be produced from oil palm, rapeseed, and soybean. Although we expect energy conversion efficiency of first generation biofuels to improve in the next decades due to technological improvements, in the model we assume it remains constant over the period 2000-2030. Even if we make the assumption that there is no trade in biofuels, biofuel feedstock can be traded.

In 2030, in the baseline, ethanol represents two thirds of total biofuel production. It is mainly produced from sugarcane and corn. The other third comes from rapeseed biodiesel and palm oil biodiesel and is mainly used in Europe. Most of the imported palm oil comes from South East Asia. After the shock, the processed quantities of sugarcane, corn, palm oil, and rapeseed are respectively multiplied by 1.6, 1.9, 2, and 1.5 globally compared to their baseline levels. This is achieved through an increase in production of 20% for sugarcane, 16% for corn (maize), 28% for rapeseed and 35% for palm oil.

Production of energy crops takes place mainly in the US, Europe, South America and South East Asia. In the Congo basin, as we have seen earlier, only a small portion of energy crops produced are exported. In this scenario, Congo basin palm oil exports increase by 20%, but quantities remain low, so only 1% of initial production is needed to supply this market. When biofuel feedstocks are produced in regions where cropland expansion is not possible (Europe, US), the only ways to increase production are to increase crop productivity and/or to replace other crops on existing cropland. We observe a reduction in the global production of several crops. The most important fall is for barley (-13%), mainly because of substitution away from this crop to produce rapeseed in Europe. Quantities produced also decrease for chickpeas, cotton, groundnut, millet, and rice while, at the same time, production of cassava and sorghum increase by 7% and 8% respectively. This indicates that, due to a reduction in export of cereals from the main producing regions, importing regions have to increase their own food production, leading to additional land use change. In the Congo basin, if the production of biofuel feedstock is marginal, the indirect effect throughreduction of imports plays a significant role. We see that corn (maize) imports are reduced to zero and wheat, sugarcane and rice imports also decrease significantly (Figure 15). To compensate, local production increases for all food crops, especially cassava, corn, dry beans and sugarcane (Figure 16).

Figure 15 : Crop Imports in the Congo Basin (1000 T)

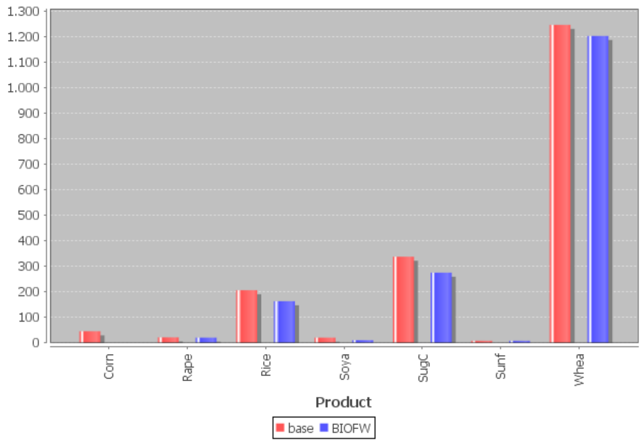
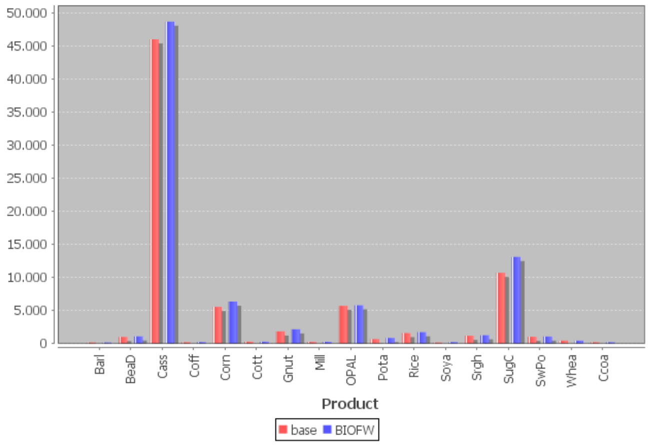


Figure 16 : Crop Supply in the Congo Basin (1000 T)



The total deforested area over the period 2020-2030 increases from 10 Million ha per year in the baseline to 14.8 million ha in this scenario. In the Congo Basin, the area deforested because of cropland expansion increases from 0.3 to 0.44 million ha per year (+50%). This is due to an increase in local food production that offsets the reduced food imports.

B. Meat

- Increase in global meat consumption by 15%

In this version of the model, the meat is represented by a composite good,"animal calories". There is no direct link with pasture area, so that the only way to increase meat production is to increase feeding based on crops. There is no substitution between different crops in animal feeding: feed ratios are fixed at the level observed in 2000 in each region.

In 2030, in the baseline most meat is produced in South America (30%), in China (21%), Europe (10%), India (9%) and the USA (7%). In most regions, the traded quantities represent a small share of total consumption. The prominent exporting regions are South America and Australia-New Zealand while the main importing regions are China and Middle East-North Africa. Globally, corn, sugarcane, soybeans, cassava, and wheat are the crops most in demand for animal feed. After implementation of the 15% increase in meat demand, we observe a large increase in meat production in South America, where animal feed is based on sugarcane, corn and soybeans. Consequently, the strongest global increase in feed demand is observed for sugarcane (+ 16%), corn (maize) (+9%) and soybeans (+9%). Even if the quantities used for feed are smaller, rice demand increases by more than 10% globally, leading to a rise in its price. The Congo basin reduces its imports of corn, sugarcane, rice and soybeans. The higher world price of meat also stimulates production in the Congo basin, causing it to increase by 50%. Even though the Congo basin remains a very small actor on the international meat market, its exports are multiplied by four.

In order to compensate the reduction of food imports and to increase local meat production, the Congo basis increases production of mostcrops, resulting in additional deforestation of 0.09 million ha per year over the period 2020-2030.

6.3 Internal drivers

Except for the scenario of reduced fuel wood demand, the other scenarios on internal drivers of deforestation in Congo Basin reduce unit costs of production for agriculture and forestry products.

Cost per ton = (Cost of production per hectare+ other costs per hectare)/yield
+ Internal transportation cost

Yields differ by crop, management system and simulation unit. Internal transportation costs differ by simulation unit but are uniform across crops and management systems. Costs of production differ by crop and by management system.

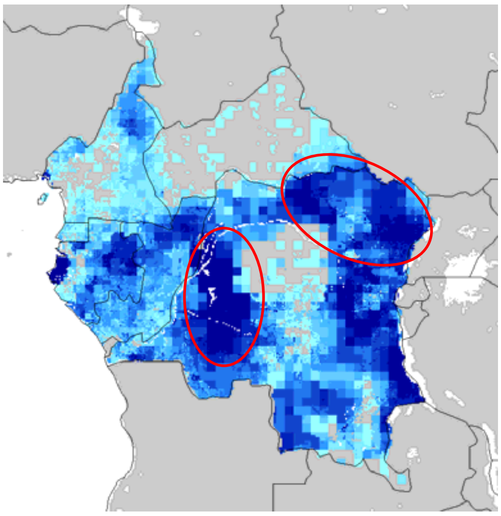
In equilibrium, in each simulation unit where production takes place, cost per unit is equal to the benefit per unit i.e. to the price.

A. Transportation Infrastructure

- ⇨ Infrastructure improvements already planned and funded in Congo Basin

In average, considering the infrastructure that existed in the year 2000, internal transportation costs are lowest in Cameroon, and highest in DRC, where they can lead to a doubling of initial production costs. Figure 17 shows for each simulation unit the difference between internal transportation costs with existing infrastructure and internal transportation costs after implementation of planned improvements to infrastructure. The places with the highest reduction in internal transportation costs appear in dark blue on the map and we notice that most of them are located in RDC.

Figure 17 : Internal transportation cost reduction from infrastructure improvements



(light blue=small transportation cost reduction, dark blue=high transportation cost reduction)

After the reduction of internal transportation costs, output can be sold at a lower price, and since it is cheaper, consumers want to buy more. Consequently, producer prices net of transport costs are going up, which encourages producers to increase their production. Typically, a new equilibrium will be reached with a larger volume and lower price compared to the initial situation. We observe a 12% increase in the total volume of crops produced and a decrease in the price index for local crops following infrastructure improvements in the Congo Basin.

However, the effects vary for the different crops. Infrastructure improvement is especially beneficial for crops with high yields in remote areas. Since transportation costs depend on the volume, not the value of a crop, the lower the unit price of a crop, the higher the share of the internal transportation costs in total production costs. This is especially true in the case of cassava and sugarcane. We can see on the following maps that the highest yields occur in DRC for those two crops, contrary to corn (maize) where the highest yields are achieved in the Northern part of the region, in CAR and North Cameroon (Figures 18 to 20).

Figure 18 : Sugarcane yield, high input (red= low, blue= high)

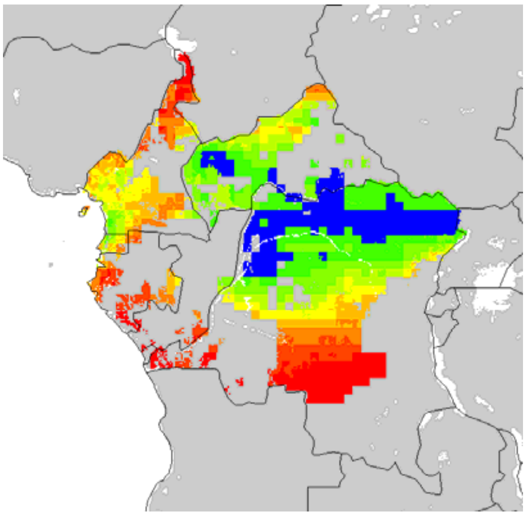


Figure 19 : Cassava yield, low input (red = low, blue= high)

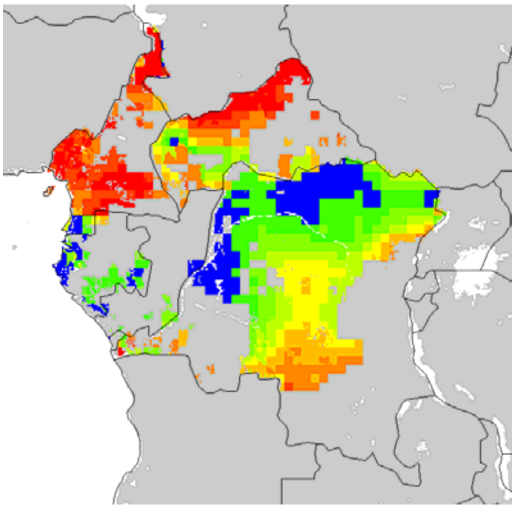


Figure 20 : Corn yield, low input

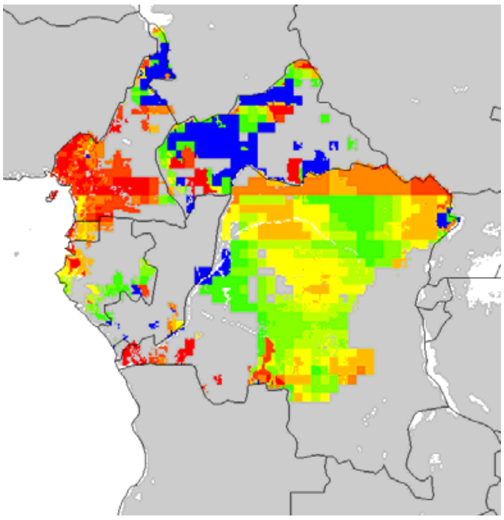
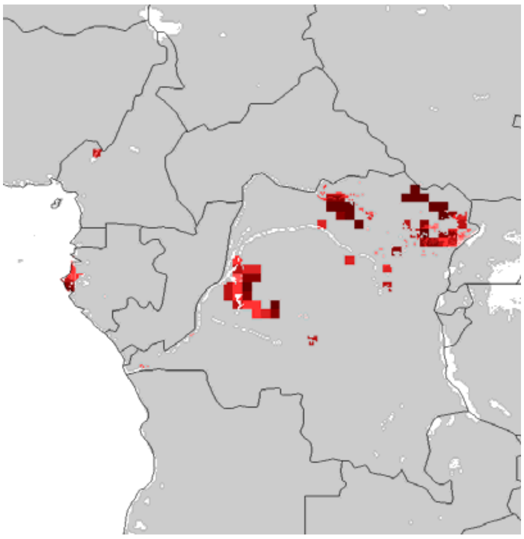


Figure 21 : Areas of deforestation due to cropland expansion following improvement of infrastructure



Demand for animal feed shows the largest change, which implies that the reduction of crop prices benefit most the livestock sector in the Congo basin. This happens because prices decrease most for crops such as cassava and sugarcane that are main components in livestock feed. Since feed ratios are fixed, to produce more meat, feed demand increases proportionally for each of the crops used for animal feed. For crops such as corn (maize), which are used for animal feed but do not benefit from significant reductions in internal transportation costs, the additional feed demand can lead to higher prices. Local food demand increases strongly for cassava (+6%), palm oil (+9%), sugarcane (+15%) and sweet potatoes (+15%) but decreases for corn (maize). On average, food calorie intake improves slightly in the Congo Basin.

The reduction of domestic transportation costs also improves the international competitiveness of agricultural and forestry products. The Congo Basin exports more sugarcane and more palm oil. Moreover, the area of managed forests increases from 47 to 62 million hectares for a total increase of 30% in production of logs. In the model, the new harvested areas are assumed to be sustainably managed, so they do not contribute to deforestation. However, these results show that improvements to transportation infrastructure will also increase the incentives for illegal logging in the region.

Transportation infrastructure improvement has positive effects on the development of the agricultural and forestry sector and could benefit development of the region. However, it increases the threat to Congo Basin forests. In our projections the total deforested area becomes three times as large and total emissions more than 4 times as large, because most of deforestation now occurs in dense forest.

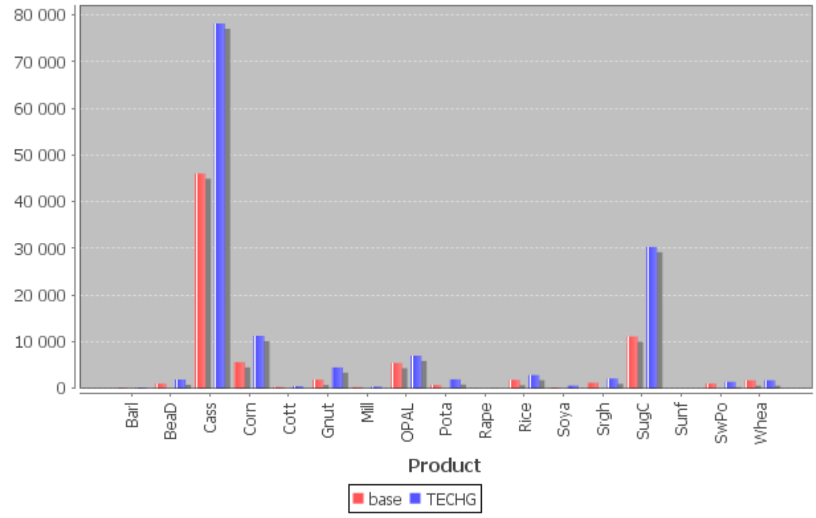
B. Technological Change

⇨ Yield increases of 30% for coffee and cocoa and 100% for other crops

Subsistence agriculture is dominant in the Congo Basin, which explains why average yields are much lower there than in other tropical regions. If productivity increases, it is possible to obtain more output from the same area. We assume that the yields increase proportionally across management systems and simulation units and do not involve higher production costs. Consequently, the *relative* productivity of areas in the Congo Basin is not affected.

Increased productivity leads to a fall in producer prices, which stimulates local purchases (Figure 22). The daily consumption per capita of calories increases by 30% to 2613 kcal from 2067 kcal, bringing consumption closer to the world average of2953 kcal. Food demand for cassava jumps from 42 million tons without productivity improvements to 55 million tons and food demand for other locally produced crops increases for the most part between 16% and 50%. Demand for animal feed also increases and the livestock sector is stimulated. Exports of palm oil, sugarcane and meat increase.

Figure 22 : Total Demand for crops in the Congo Basin



Despite the increased consumption, productivity gains allow much lower domestic prices. The crop price index is reduced by 40% in Congo Basin. However, the impact of this scenario is not uniform across crops consumed in the Congo Basin. For instance, the yields increase for cash crops is more moderate than for other food crops so that their relative cost increases (Figure 23). This leads to substitution of food crops for cash crops in the more intensive systems which are more costly and/or in the most productive areas. Consequently, some crops experience a yield increase even higher than the exogenous yield shock while other crops such as cocoa experience on average a yield increase lower than the exogenous yield shock.

Figure 23 : Comparison of crop prices for baseline and the technological change in the Congo Basin (USD/Ton)

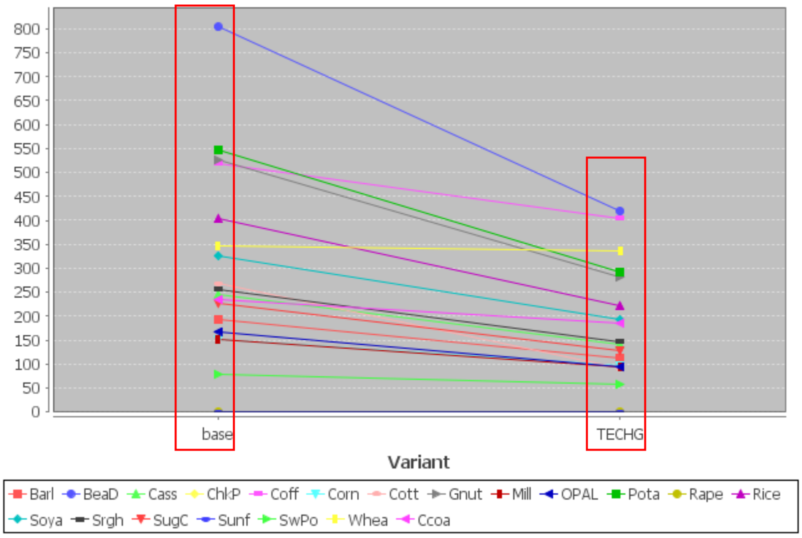
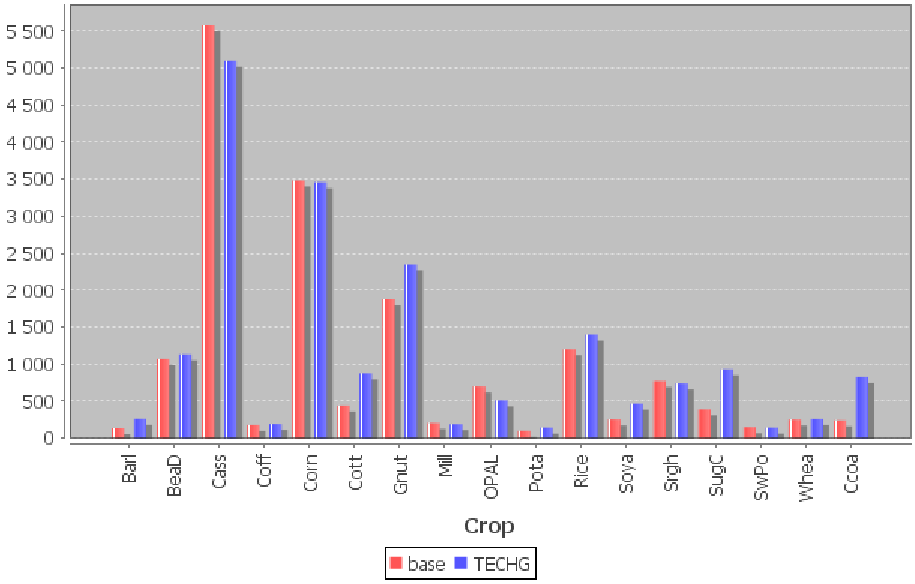


Figure 24 : Comparison of crop area for baseline and the technological change scenario in the Congo Basin (1000 ha)



Increased agricultural productivity leads also to additional deforestation of some 0.2 million hectares per year over the period 2020-2030 as compared to the baseline case. Increased deforestation is due to the reduction in unit production cost which more than compensates for the cost of converting forests into cropland. Local consumption for agricultural products, stimulated by lower prices, increases above the level which can be reached only by the increase in productivity.

C. *Fuel wood*

⇨ Decrease of fuel wood use from 1m3 to 0,8m3/capita/year

The total demand for fuel wood declines from more than 83 million m3 to 66 million m3 (protected and concession areas excluded). The decrease in fuel wood consumption has an immediate impact on deforestation especially in densely populated regions. The rate of deforestation is reduced more than 20%, from 0.11 million ha per year to 0.09 million ha.

D. Cash crops

- ⇨ Decrease of production costs by 25% for coffee and cocoa

A production cost decrease of 25% allows producers of Congo Basin to sell their coffee and cocoa at lower prices. For coffee and cocoa, regional demand is determined exogenously (as a function of the size of the population) so it does not vary with changes in prices. However, lower production costs will improve the competitiveness of the Congo Basin compared to other Sub Saharan regions in the markets of developed countries. Congo Basin coffee exports increase by 14% and cocoa exports by 55%.

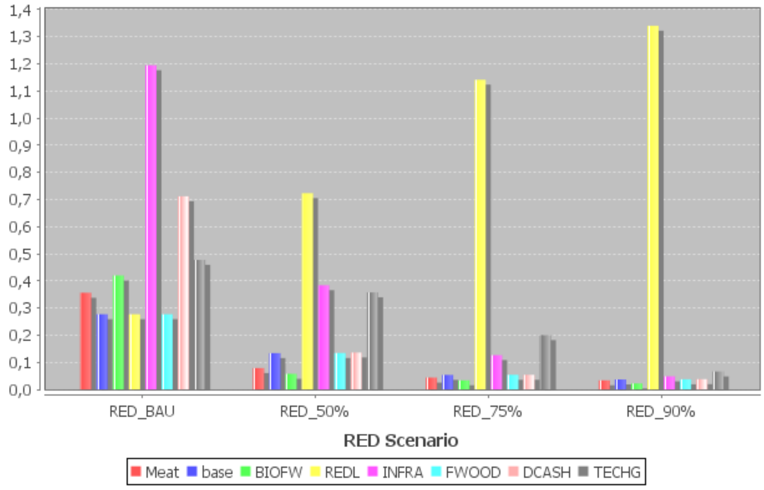
The possibilities to increase productivity are much more limited for coffee and cocoa than for the other crops. First of all, coffee and cocoa are produced not in all of the Congo Basin, but only in approximately one fifth of the simulation units where there is some cropland. It is thus difficult to reallocate production to more productive areas. Also, for some production areas, reported yields are very low, so that a large additional area of cropland is needed to achieve even a slight increase in production. Finally, yields for cocoa and coffee are not estimated by EPIC but based instead on crop distribution maps of IFPRI. This means that we have information on yields only when there is recorded production in 2000. For cocoa, almost all the production of Congo Basin is regarded as low input management by IFPRI. The possibility of increasing productivity by changing the management system is very limited.

No substitution is allowed in demand for coffee and cocoa (exogenously determined), so a decrease in cocoa and coffee prices does not affect demand for the other crops. We observe that coffee and cocoa do not really replace other crops on existing cropland: the area used to grow food crops decreases less than 1% in this scenario. It is more costly to cease producing some food crops domestically than to increase deforestation.

Consequently, this scenario leads to important deforestation in Congo Basin: the total additional area required to increase coffee and cocoa production exceeds 4 million hectares, leading to two times more deforestation than in the baseline.

7 REDD: Results

Figure 25 : Deforested Area due to cropland expansion in the Congo Basin during 2020-2030 (Mha/year)



7.1 Participation of Congo Basin

⇨ Global CO2 emissions from deforestation are reduced over the period 2020-2030 compared to the baseline level

The global limitation of CO2 emissions from deforestation is equivalent to introducing a uniform deforestation tax in regions participating in REDD. The more constraining the reduction in emissions, the higher the corresponding deforestation tax. In the model, we assume that there is no deforestation in the OECD countries of Europe, North America, Former USSR, China, Japan, Pacific Islands and Australia-New Zealand. In these regions, costs are not affected by REDD.

The efforts to reduce deforestation are not uniform among regions. Since it is more costly to deforest with REDD, avoided deforestation occurs in regions with high production costs and low productivity while deforestation continues in regions which are the most competitive, i.e. where agricultural production remains profitable with the additional cost of deforestation.

In the Congo Basin, a large part of the production rise is achieved through cropland expansion. An increase in the cost of deforestation leads to a significant increase in total production costs. Consequently, in the baseline the deforested area due to cropland expansion in the Congo Basin decreases more than proportionally to the global target (Figure 25). Production decreases for all crops: corn (maize) production decreases by 25%, cassava production by 8%, and sugarcane by 30%.

The surge in food prices and an increased substitution of imports to local production raises the issue of the impact of REDD on food security. We see that domestic food prices increase between 20% and 60% compared to their level without REDD in Congo Basin when the raise in the rest of the world is limited to 30% (Figure 26). After REDD implementation, it is rational to produce less food domestically and to import more. Imports increase dramatically for rice, corn, wheat, and sugar (Figure 27). This is in total contradiction with food security policies that are implemented in Congo Basin countries which try to encourage the local food production. Therefore, the cost of REDD is not limited to the value of the forest but it also encompasses the consequences on agricultural markets.

Figure 26 : Evolution of crop price index with baseline assumptions and REDD (1= 2000 prices)

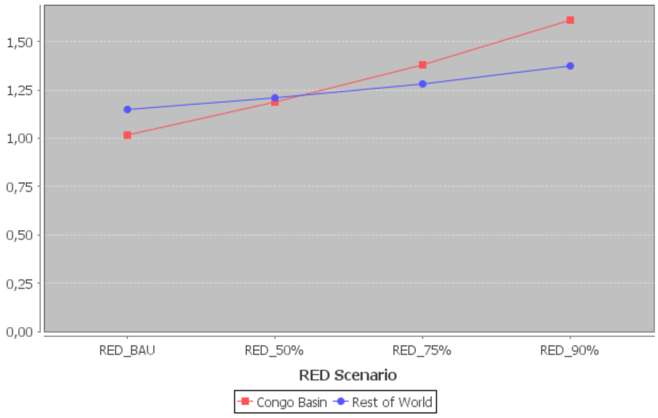
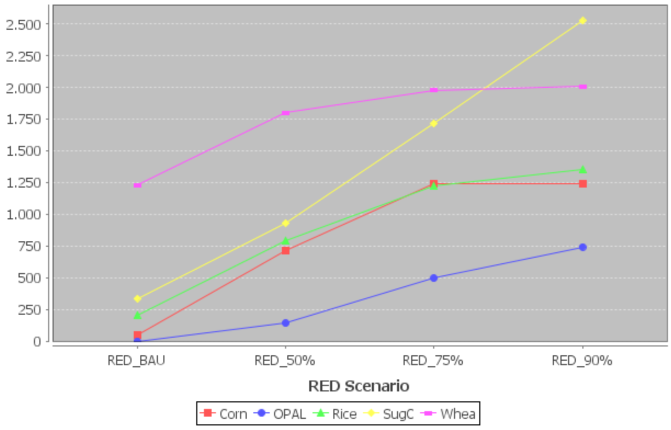


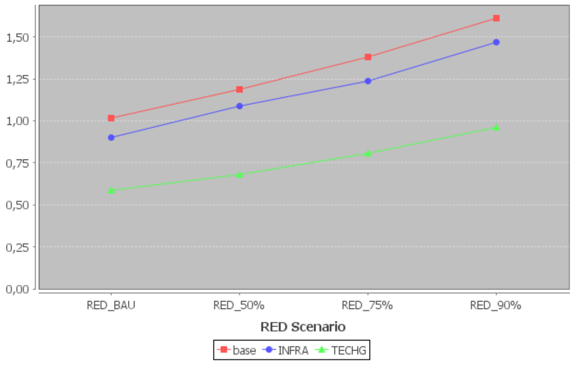
Figure 27 : Main imports in the Congo Basin with baseline assumptions and REDD (1000 T)



If the REDD limitations are the same across all scenarios, the impact differs in terms of reduction of emissions from deforestation in the Congo Basin. We have seen that the scenarios on external drivers of deforestation increase the global demand for crops and leads to increased deforestation compared to the baseline projection. These scenarios lead to a higher equivalent deforestation tax of the REDD policy compared to the baseline, without changing production costs of the regions, so deforestation will be reduced even more in less competitive regions compared to the baseline. High internal transportation costs and low yields compared to the other regions make production in the Congo basin less competitive, with the result that avoided deforestation happens there first. Although deforestation in the Congo Basin is higher in the meat and biofuel scenarios than in the baseline, implementation of REDD leads to a larger cut in deforestation in these two scenarios than in the baseline in the Congo Basin (Figure 25).

The scenarios on infrastructure improvement, technological change and reduction of per hectare cash crop production costs improve the competitive position of the Congo Basin relative to the rest of the world. This explains why, despite a cap on global emissions from deforestation at 50% of their base level, deforestation increases more in the Congo Basin from the 2030 baseline level without REDD. With reduction of internal transportation costs and with technological change, average annual deforestation during the period 2020-2030 reaches 0.38 and 0.36 million ha per year respectively, compared to 0.28 Mha in the baseline without REDD (Figure 25). This implies that improvement of Congo basin competitiveness more than offsets the cost of REDD, so it is profitable to increase deforestation in the Congo Basin. Deforestation begins to fall below the 2030 baseline level with infrastructure improvement or with technological change when we impose a global limit of 25% of total GHG emissions from deforestation. Then, deforestation is equal to the 2030 base level divided respectively by 2 and by 1.4. However, these scenarios limit the surge in food prices (Figure 28) and the substitution of local production for imports.

Figure 28 : Crop price index in the Congo Basin according to different scenarios and REDD



We notice that the reduction in coffee and cocoa production costs is less than the cost of additional deforestation. In this scenario the implementation of REDD offsets the reduction in production costs so that the deforestation level is no different than without the shock, already with a reduction of 50% in global emissions (Figure 25).

7.2 REDD without Congo Basin

- ➪ The Congo Basin refuses to participate in REDD while CO2 emissions from deforestation are limited in the other regions

The reduction of GHG emissions will be particularly hard to achieve if not all countries are involved in the process. In this scenario, the Congo Basin has a trading advantage because REDD increases the cost of deforestation in all the other regions, while it remains constant in the Congo Basin, which is not involved in REDD. This is also known as the carbon leakage effect. The more stringent the constraints on GHG emissions in other regions, the higher their cost of additional deforestation and the greater the competitive advantage of the Congo Basin. Imports are replaced by local production in the Congo Basin, and the Congo Basin also increases its agricultural exports to the rest of the world, which leads to more deforestation in the Congo Basin (Figure 25, scenario REDL). Finally, the reduction in GHG emissions in other regions is offset partially at the global level by the increase in GHG emissions from deforestation in the Congo Basin.

8 DISCUSSION OF THE RESULTS AND INFORMATION GAPS

Future deforestation in Congo Basin will result from the interaction of several factors. The total impact of drivers on deforestation will not result from the simple sum of the isolated impact of each driver. For instance productivity improvement in agriculture will lead to higher deforestation but it can help reducing the total deforestation with infrastructure improvement. Furthermore, in a scenario of effective avoided deforestation policies, infrastructure improvement and technological improvement can be seen as means to enhance economic development of the total land use sector.

Despite of its relatively low exposure to global markets, the economic evolution and forest policy changes in the other regions are expected to significantly influence future deforestation patterns in the Congo Basin. Connectivity to international markets and patterns of relative competitiveness are strongly policy dependent. For instance, the productivity gap between Congo Basin and most of the other regions is currently high so that even a slow increase in productivity in other regions could offset the effects of a large productivity increase in Congo Basin. Thus, the impact of productivity improvements in the agricultural sector and their impact on deforestation need to be assessed in terms of their relative competitiveness.

Food demand is represented at the regional level which means that we assume that all the consumers in a region pay the same price and that they have the same preferences (food patterns and price elasticity). This assumption implies that markets are integrated across the countries of the region (no trade barriers). Consequently, at this stage, the analysis is more relevant at the regional level than at the country level. It also implies that markets are integrated between rural and urban areas. In the reality, self consumption is widespread in rural areas of Congo Basin and implies that the opportunity cost of the land is not well reflected in market prices. However, self consumption is not yet represented in the model.

Fuel wood demand is an important driver of deforestation in the Congo Basin. We have made a first attempt to represent the impact of fuel wood demand on deforestation and forest degradation in Congo Basin using a geographic explicitly approach. However, this representation has several limits. Due to the lack of better information, we do not yet differentiate the impact of fuel wood extraction between rural and in urban areas. Despite the fact that the use of fuel wood seems to be higher in rural areas the damages on the forest can be expected to be lower since fuel wood is harvested in a more selective manner. More generally this issue is related to the impact of shifting agriculture on forests for which there is currently a lack of information. The scenario on a decrease of fuel wood consumption is not yet fully informative and will necessitate improve consumption data. First of all, if alternative energies replace a larger share of fuel wood consumption in the future in Congo Basin, the total impact on GHG emissions should be considered carefully. Some local stakeholders also consider that the trend in fuel wood consumption is toward an increase in fuel wood consumption and not a decrease considering the increase in prices of the other energy sources.

REDD constraint has been considered with a cap and trade approach i.e. reduction of CO2 emissions from deforestation is given and production is reallocated according to the new constraint. In fact, other approaches for REDD are currently discussed. Another approach could be to subsidize local governments efforts compared to a predetermined level. Then, REDD would be more flexible on the deforestation level and the target would be fixed at the country level. In terms of results, that could limit the surge in crop prices in Congo Basin but increase more food prices globally. This would also limit the concentration of deforestation reduction in less competitive areas globally.

Congo Basin countries have put particular emphasis on the need to include forest degradation in REDD. However, reliable information on degradation and more importantly degradation drivers is still sparse. There is crucial need for Congo Basin countries to collect information on degradation drivers, the state of degradation in existing forests and on the impact of improved forest management on emissions.

Finally, the development of the mining industry is expected to be a significant driver of deforestation in the next decades in the region. The development of the mining industry is not yet fully represented in the model. However, some of the planned infrastructure projects which have been included can be related to the exploitation of new mining concessions. Additional effects of mining industry on deforestation through wood use (mining props) and fuel wood consumption for mining operations have not been assessed in this study.

9 CONCLUSION

So far the Congo Basin countries have experienced relatively little deforestation. The analysis presented in this report shows that as the Congo basin countries become more exposed to international markets and due to strong population growth this situation is most likely to change. CO2 emissions from deforestation in Congo Basin vary between 6% and 20% of the global CO2 emissions from deforestation according to the different scenarios. The deforestation increases in Congo Basin region when: 1) import prices increase more than domestic prices so that local consumers shift a part of their consumption from imports to local production; 2) lower domestic prices stimulate the demand for local products; 3) Congo Basin improves its competitiveness on international markets and increase its exports.

The scenarios with the highest negative impact on forest cover in Congo Basin are the improvement of transportation infrastructure, the reduction of production costs of coffee and cocoa and the technological change i.e. the internal drivers of deforestation. We have shown that international drivers such as expansion of biofuels or changes in food consumption pattern are likely to trigger additional deforestation in the Congo Basin. However, without any change in the unit cost of production in Congo Basin, their impact is limited to a higher substitution of imports with local production since Congo Basin is not competitive to take advantage of the new opportunities on international agricultural markets.

This highlights the fact that Congo Basin has been quite isolated from international markets so far due to important internal handicaps. This is one reason of the low historical rate of deforestation in the region compared to other tropical regions which have become major exporters of agricultural products during the last decades. Future deforestation in Congo Basin depends critically on the national strategies that are going to be implemented in the next years and on local investments. Agro-industrial plantations, mining industry, expansion of the transportation network: a lot of projects are currently under study in Congo Basin but international community is still skeptical about their effective realization and success in a region which is often associated with political instability and high level of corruption.

The methodology presented in this report can be used to quantitatively inform development adjustment for baseline deforestation rates. The methodology enables to compute globally consistent baseline scenarios for the Congo Basin. Model results suggest significant potential for leakage of global REDD actions to the Congo Basin region in a scenario where the region is not part of a global REDD deal.

REDD+ finance has a great potential to effectively and efficiently reduce deforestation. The marginal abatement costs were estimated to be competitive in comparison to other tropical deforestation regions. There are a number of preconditions that need to be met. First the effectiveness of REDD implementation will crucially depend on governance. Many deforestation drivers such as small holder agriculture or fuel wood production are spatially diffuse activities many carried out in the informal sector. Thus, under poor governance transaction costs of REDD measures, such as agricultural intensification, would turn out to be excessive and might even lead to rebound effects. Second, one of the main concerns from local stakeholders regarding REDD is related to fewer opportunities for development (Dkamela et al., 2009). The implementation of REDD measures may contain the development of the agricultural and bioenergy sector and lead to higher domestic food prices.

There are still a number of information challenges to be tackled to develop more robust assessment of deforestation and REDD in the region: (1) There is a need to improve basic land use information (2) A comprehensive compilation of driver information is not yet fully developed (3) a comprehensive capacity assessment for REDD implementation in a multi-sector environment. Finally, evidence from other regions (e.g. Brazil) shows that good governance in the entire land-use sector is a precondition for effective REDD implementation.

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APPENDIX 1: Input Data

PARAMETER	SOURCE	YEAR
Land characteristics	Skalsky et al. (2008), FAO, USGS, NASA, CRU UEA, JRC, IFRPI, IFA, WISE, etc.	
Soil Classes	ISRIC	
Slope Classes		
Altitude Classses	SRTM 90m Digital Elevation Data (http://srtm.csi.cgiar.org)	
Country Boundaries		
Aridity Index	ICRAF, Zomer at al. (2009)	
Temperature threshold	European Centre for Medium Range Weather Forecasting (ECMWF)	
Protected area	FORAF	
Land cover	Global Land Cover (GLC 2000)- Institute for Environment and Sustainability	2000
Agriculture		
Area		
Cropland area (1000 ha)	Global Land Cover (GLC 2000)- Institute for Environment and Sustainability	2000
EPIC crop area (1000 ha)	IFPRI- You and Wood (2006)	2000
Cash crop area (1000 ha)	IFPRI- You, Wood, Wood-Sichra (2007)	2000
Irrigated area (1000 ha)	FAO	average 1998-2002
Yield		
EPIC crop yield (T/ha)	BOKU, Erwin Schmid	
Cash crop yield (T/ha)	IFPRI- You, Wood, Wood-Sichra (2007)	2000
Average regional yield (T/ha)	FAO	average 1998-2002
Input use		
Quantity of nitrogen (FTN) (kg/ha)	BOKU, Erwin Schmid	
Quantity of phosphorous (FTP)(kg/ha)	BOKU, Erwin Schmid	
Quantity of water (1000 m3/ha)	BOKU, Erwin Schmid	
Fertilizer application rates	IFA (1992)	
Fertilizer application rates	FAOSTAT	
Costs for 4 irrigation systems	Sauer et al. (2008)	
Production		
Crop production (1000 T)	FAO	average 1998-2002
Livestock production	FAO	average 1998-2002
Prices		
Crops (USD/T)	FAO	average 1998-2002

Fertilizer price (USD/kg)	USDA (http://www.ers.usda.gov/Data/FertilizerUse/)	average 2001-2005
Forestry		
Area under concessions in Congo Basin (1000 ha)	FORAF	
Maximum share of saw logs in the mean annual increment (m3/ha/year)	Kinderman et al. (2006)	
Harvestable wood for pulp production (m3/ha/year)	Kinderman et al. (2006)	
Mean annual increment (m3/ha/year)	Kinderman et al. (2008) based on the Global Forest Resources Assessment (FAO, 2006a)	
Biomass and Wood production (m3 or 1000 T)	FAO	2000
Harvesting costs	Kinderman et al. (2006)	
Short rotation plantation	Havlik et al. (2010)	
Suitable area (1000 ha)	Zomer at al. (2008)	2010
Maximum Annual Increment (m3 per ha)	Alig et al., 2000; Chiba and Nagata, 1987; FAO, 2006b; Mitchell, 2000; Stanturf et al., 2002; Uri et al., 2002; Wadsworth, 1997; Webb et al., 1984	
Potential NPP	Cramer et al. (1999	
Potentials for biomass plantations	Zomer at al. (2008	
Sapling cost for manual planting	(Carpentieri et al., 1993; Herzogbaum GmbH, 2008).	
Labour requirements for plantation establishment	Jurvélius (1997),	
Average wages	ILO (2007).	
Unit cost of harvesting equipment and labour	FPP, 1999; Jiroušek et al., 2007; Stokes et al., 1986; Wang et al., 2004	
Slope factor	Hartsough et al., 2001	
Ratio of mean PPP adjustment	Heston et al., 2006	
GHG emissions		
N2O emissions from application of synthetic fertilizers (kg CO2/ha)	IPCC Guidelines, 1996	
Fertilizer application rates	IFA, 1992	
CO_2 savings/emission coefficients	CONCAWE/JRC/EUCAR (2007) , Renewable Fuels Agency (2008)	
Above and below-ground living biomass in forests[tCO2eq per ha]	Kindermann et al. (2008)	
Above and below ground living biomass in grassland and other natural land [tCO2eq per ha]	Ruesch and Gibbs (2008) (http://cdiac.ornl.gov/epubs/ndp/global_carbon/carbon_documentation.html)	
Total Non-Carbon Emissions (Million Metric	EPA, 2006	

CO2-Equivalent)		
Crop Carbon Dioxide Emissions (Tons CO2 / hectare)	EPA, 2006	
GHG sequestration in SRP (tCO2/ha)	Chiba and Nagata, 1987;	
International Trade		
MacMap database	Bouet et al., 2005	
BACI (based on COMTRADE)	Gaulier and Zignago, 2009	
International freight costs	Hummels et al., 2001	
Infrastructure		
Existing infrastructure	CIRCA 2000; WRI; Referentiel Geographique Commun (DRC)	
Planned infrastructure	National statistics from Cameroon, CAR, and Gabon and AICD (World Bank) for DRC and Congo	
Process		
Conversion coefficients for sawn wood	4DSM model - Rametsteiner et al. (2007)	
Conversion coefficients for wood pulp	4DSM model - Rametsteiner et al. (2007)	
Conversion coefficients and costs for energy	Biomass Technology Group, 2005; Hamelinck and Faaij, 2001; Leduc et al., 2008; Sørensen, 2005	
Conversion coefficients and costs for Ethanol	Hermann and Patel (2008)	
Conversion coefficients and costs for Biodiesel	Haas et al. (2007)	
Production costs for sawn wood and wood pulp	internal IIASA database and RISI database (http://www.risiinfo.com)	
Population		
Population per country (1000 hab)	JRC Sevilla, POLES, Russ et al. (2007) *updated*	average 1999-2001
Estimated total population per region every ten years between 2000 and 2100 (1000 hab)	GGI Scenario Database (2007)- Grubler et al.	
0.5 degree grid	GGI Scenario Database (2007)- Grubler et al.	
Population density	CIESIN (2005).	
Demand		
Initial food demand for crops (1000 T)	FBS data - FAO	average 1998-2002
Initial feed demand for crops (1000 T)	FBS data - FAO	average 1998-2002
Crop requirement per animal calories (T/1 000 000 kcal)	Supply Utilisation Accounts, FAOSTAT	average 1998-2002
Crop energy equivalent	FBS data - FAO	

(kcal/T)		
Relative change in consumption for meat, anim, veg, milk (kcal/capita)	FAO(2006) World agriculture: towards 2030/2050 (Tables: 2.1, 2.7, 2.8)	
Own price elasticity	"International Evidence on Food Consumption Patterns", James Seale, Jr., Anita Regmi, and Jason A. Bernstein, Technical Bulletin No. (TB1904) 70 pp, October 2003	
GDP projections	GGI Scenario Database (2007)	
SUA data for crops (1000 tones)	FAO	
FBS data	FAO	
Bioenergy projections	JRC Sevilla, POLES, Russ et al. (2007) *updated*	
Biomass and Woodconsumption (m3/ha or 1000 T/ha)	FAO	

International Institute for Applied Systems Analysis (IIASA) Forestry Program Schlossplatz 1 A-2361 Laxenburg, Austria Tel: +43 2236 807 0 Fax: +43 2236 71313