Feasibility of industrial charcoal production in the Republic of Congo

An assessment of Congo Carbo Industrie

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Abstract

This report evaluates the technical and economic feasibility of industrial charcoal production in the Republic of Congo. It updates a feasibility study conducted in 2009 in three ways: (1) changing the source of raw materials from wood residues to a self-managed tree plantation, (2) adding the production of charbriquettes from factory by-products and (3) substituting Magnien portable metallic kilns with the Green Mad Retort Kilns. The 22.9-million-euro investment envisaged would produce more than 51,000 tonnes of charcoal and charbriquettes valued at 25.3 million euros (458 euros/tonne) over 8 years, a 10.7% return on investment. The assessment's calculations should be considered a rough appraisal and an upper bound on investment performance. Available data have been provided by project staff, and annual service on debt is not considered because the firm's financing model has not been established. The project has potential for positive social and environment benefits depending on management and implementation. However, detailed social and environment impact assessments are not possible at this time because the location of the factory and the location and size of the land concession and plantation are not known. Without this information, plausible impacts can be discussed only generally. Our assessment nonetheless suggests that there may be an opportunity for industrialization of charcoal production in the Congo, especially under favorable operating conditions, perhaps including tax breaks and reduced land rehabilitation costs. If it is to succeed as a sustainable enterprise, however, future attention must be directed to capacity development for the establishment and operation of carbonization technologies and of the plantation, as well as to the social and environmental impacts of the project.

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Contents

Acronyms

ADB	African Development Bank
AFD	Agence Française de Développement
CCAFS	Climate Change, Agriculture and Food Security
CCI	Congo Carbo Industrie
CEDEV	Congo Environment and Development
CH_4	Methane
CO	Carbon monoxide
CO_2	Carbon dioxide
CSR	Corporate social responsibility
CTCN	Climate Technology Center and Network
EFC	Eucalyptus et Fibres du Congo
FAO	United Nations Food and Agriculture Organization
FCPF	Forest Carbon Partnership Facility
FIP	Forest Investment Program
FRA	Forest Resource Assessment
GHG	Greenhouse Gas Emissions
GIS	Geographic Information System
GMDR	Green Mad Retort Kiln
ICRAF	World Agroforestry Center
ICS	Improved cooking stove
INDC	Intended National Determined Contribution
NGO	Non-governmental organization
REDD	Reduction of Emissions from Deforestation and Forest Degradation

SDG	Sustainable Development Goals
SSA	sub-Saharan Africa

Introduction

[1] **The number of people who rely on wood as a source of fuel is large and growing, especially in less-developed parts of the world.** In sub-Saharan Africa (SSA) more than 80% of households rely on wood or charcoal for cooking, and the numbers will increase in coming decades because of population growth and urbanization and the lack of alternatives. Urbanization leads to higher demand for woodfuels (especially charcoal) because of smaller household size, more frequent cooking and increased consumption by businesses such as restaurants and public institutions like hospitals.

[2] **The societal impacts of woodfuels are mixed. Traditional wood stoves emit smoke and gases that cause long-term respiratory health problems.** This indoor air pollution accounts for an estimated 10% of disease-related deaths in Africa and disproportionately affects women (Köhlin et al. 2011, Giles et al. 2011). But fuelwood also offers clear economic benefits. In contrast to imported fossil-fuel energy, wood-based biomass can be the source for value-added local products, supporting economic development and reducing poverty. In most SSA countries, the wood-based biomass sector employs a significant workforce. To take just two examples: in Kenya an estimated 700,000 people work in the charcoal sector, while in Ghana that sector employs about 3 million people, of whom 65% are women (Sepp 2008).

[3] **Woodfuel's dangers to the environment have been overstated.** Although fuelwood is often still associated with forest degradation (Hiemstra-van der Horst and Hovorka 2009), local realities are more complicated. Fuelwood consumption by rural households is no longer considered a principal cause of forest degradation or deforestation, especially when compared to other drivers such as agriculture (Bailis et al. 2017).

[4] **Given the continued importance of wood-based biomass energy supply and use to health, natural resource management and economic development in SSA, a sustainably designed and operated sector could help countries attain the United Nations Sustainable Development Goals (SDGs).** It could create economic opportunities for rural households (SDG1), ensure access to sustainable energy (SDG7), create jobs and build economic wealth of communities (SDG8), combat climate change (SDG13) and manage natural resources (SDG15) through reduction of deforestation and forest degradation.

[5] **Congo Carbo Industrie (CCI) aims to establish among the first industrial-scale supply chain for charcoal and associated products in sub-Saharan Africa.** The goal is to raise the efficiency of production and stabilize supply. This will produce economic, climatic, environmental, social and industrial impacts. Ambitiously, the project intends to provide households more ready access to a renewable energy source that is efficient, less polluting and well suited to local and international culinary culture.

[6] **The Republic of Congo ('Congo' hereafter) is an ideal case to examine the potential of industrial charcoal production[1].** Roughly 85% of the population burns woodfuels for energy. As in other African countries, the woodfuel sector employs tens of thousands of people and is a significant driver of economic activity in rural areas. Unlike other countries in SSA, the Congo also has extensive forests, which means it is well positioned to satisfy charcoal demand in a sustainable way. At the moment, however, the sector relies largely on unimproved, inefficient carbonization technology. Given the high demand and extensive forest resources, CCI aims to modernize the charcoal sector and position it to meet the Congo's energy needs in a sustainable way, while also giving a boost to the country's economy. With rising urbanization across the continent, future markets for charcoal for much of Central Africa will resemble that of the Congo today. A sustainable, economically viable and modernized charcoal industry in the Congo could serve as a model for similar projects in other countries in the region and indeed globally.

[7] **This document reports on the feasibility of the CCI project.** The main body of the report details analysis of the technical and economic outlook of creating an industrial charcoal supply chain in the Congo, as well as its possible impacts and potential risks to its success. Then a brief impact statement of economic, social (including gender) and environment issues is presented. Besides technical and economic review, this document describes the supply chain, market size and mitigation impact.

[1] Industrial charcoal production uses capital investments in materials and unit processes to modify the carbonization process which can: improve yield of charcoal from wood, increase rate of carbonization, use alternative raw materials (e.g., sawmill residues), recover chemicals and energy from unit processes and reduce environmental pollution.

1. Strategic context

1.1. Country context

[8] **Republic of Congo's economy has been weakening in the recent past.** The gross domestic product of the Congo, a lower-middle income country, was 7.83 billion USD in 2016, declining at an annual rate of -1.9% per year. Six years earlier, in 2010, GDP exceeded 12 billion USD and was growing at 8.8% (World Bank 2018a).

[9] **The forestry sector accounts for approximately 5% of the country's GDP and export revenue (Moise 2014) due to timber extraction.** In 2017 forests covered approximately 223,300 km^2 (65%) of the country's surface areas (figure 1). Forest area has been declining at a relatively slow rate in Congo by comparison to other tropical countries, about 0.1% year per year since 1990, when the country had 227,300 km^2 of forests. Information on the extent of forest degradation, a common issue with fuelwood extraction, is not available.

[10] **Republic of Congo has the highest rate of urbanization (65.7%) of any country in sub-Saharan Africa (World Bank 2018b)**. Of Congo's total population of 5.13 million, approximately 3.4 million people live in urban centers, with the vast majority living in only four cities: Pointe-Noire, Brazzaville, Dolisie and Nkayi. The urban population continues to grow, expanding by 3.2% in 2016.

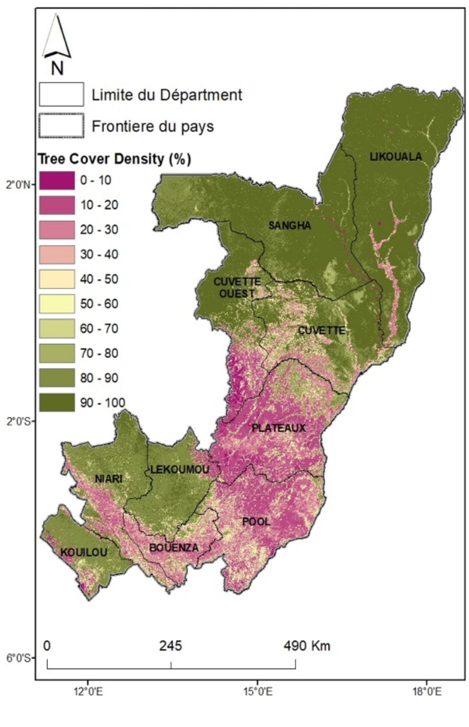


Figure 1.Tree cover in the Republic of Congo. Data derived from Atlas of Congo Basin (WRI, 2014).

[11] **There are a number of existing laws that relate to wood energy in the Congo,** including environment protection (n°003/91, 23 April 1991); forest management and ecological, social and economic sustainability (n°16/2000, 20 November 2000); land tenure (n°17/2000, 31 December 2000); extent of public domain (n°10/2004, 24 March 2004); and indigenous people and the recognition of tenure and rights (n°5/2011, 25 February 2011).

1.2. Woodfuel demand

[12] **Roughly 85% of the people in the Congo burn woodfuels (firewood or charcoal) to satisfy basic energy needs.** The dependence on wood-based energy sources varies by department, ranging from 49–99% of the department's population (Boundzanga 2014). Departments that include urban areas, with at least some access to oil and gas, have lower relative dependence on woodfuels but higher overall demand on wood resources because of population size and extensive use of charcoal. Even in cities, wood energy dominates the energy mix: Pointe-Noire relies on 48% wood energy, 40% gas, 9% oil and 3% other; in Brazzaville the figures are 67%, 21%, 10% and 2%, respectively.

[13] **Woodfuel demand in the Congo is about 1.5 million tonnes of wood annually, including at least 0.3 million tonnes of firewood and 1.2 million tonnes of wood converted into 150,000 tonnes of charcoal** (Boundzanga 2014)**.** By the FAO's estimate, Congo produced 1.45 million tonnes of woodfuels in 2016, a 25% increase since 2001 (FAOSTAT 2018). The high per capita consumption is roughly similar to that of some other African countries.

[14] **The relative mix of woodfuel demand has shifted from firewood to charcoal, a trend likely to accelerate in the future due to urbanization.** In 2014 average consumption of woodfuels was 0.21 and 0.12 kg^{-1} person day^{-1} for firewood and charcoal, respectively, vs. 0.79 and 0.15 kg^{-1} person day^{-1} 20 years prior. (Boundzanga 2014). Firewood is usually used in rural areas, while charcoal is more prevalent in urban areas, typically because of transport and other costs. Projected trends in population and urbanization would suggest that demand for charcoal, relative to firewood, will continue to increase.

1.3. Charcoal supply chain

[15] **Extrapolating from research in other sub-Saharan African countries, the woodfuel supply chain in the Congo likely employs tens of thousands of people as producers, transporters, gross sellers and retailers, oftentimes providing the only cash and labour opportunities in rural areas.** It is not possible to estimate precisely the number of jobs in this supply chain as most of it occurs in the informal economy. Estimates of job creation in the woodfuel supply chains of countries with larger populations such as Kenya, Tanzania, Malawi and Ghana range from 90,000 to more

than 700,000. Due to the Congo's lower overall population, as well as its high rates of urbanization, the proportion of the population involved in the woodfuel sector is likely considerably lower than that of these other countries. Even so, the numbers suggest woodfuels are a significant driver of rural economic activity.

[16] **The supply chains for firewood and wood-derived products (such as charcoal and charbriquettes) differ, with implications for competitiveness and the feasibility of industrial production.** A rule of thumb is that the relative length of the supply chain (i.e., the number of production steps) increases price and therefore affects economic feasibility. Generally, the biomass type with the shortest supply chain has a logistical advantage because each step represents effort, cost and complications.

[17] **Because woodfuel in the Congo is principally sourced from forests near major markets (i.e., areas of higher population density), it continues to cause localized deforestation and forest degradation.** Although woodfuel was long thought to be a driver of widespread forest loss, recent research suggests it is not the proximate cause of deforestation (Bailis et al. 2017). Given low population levels and significant forest cover in the Congo, it is entirely possible for woodfuels to be sustainably harvested, below the point of non-renewable biomass.

[18] **Market price for charcoal varies based on location—i.e., proximity to production—and ranges from 4,800–6,000 FCFA per 30 kg bag (Pointe-Noire) to 6,600–7,500 FCFA per 30 kg bag (Brazzaville).** In general, costs of production are borne across the supply chain, with 26% for labour of logging and assembling; 21% each for kiln preparation, cooling and sealing, and purchase of empty bags; and 9% for transport to the roadside. The result is that the producer, transporter, gross seller and retailer make 2,200, 500, 1,000 and 1,500 CFA bag^{-1}, respectively (annex 1).

[19] **The current charcoal supply chain in the Congo relies almost exclusively on unimproved mound kilns, with carbonization rates of less than 15%.** Carbonization is the conversion of wood into charcoal (more generally, the conversion of an organic substance into a carbon-containing residue). The efficiency of the process is highly dependent upon the temperature of the kiln, the type of biomass and the moisture content of the biomass. Unimproved kilns yield rates of carbonization in the high single digits to low teens (e.g., 8–13%). By contrast, improved kilns can reach 40% or higher (Iiyama et al. 2014, annex 2).

1.4. Higher-level objectives

[20] **Industrial charcoal production contributes to a range of higher-level objectives.** It has the potential to help the Congo attain the Sustainable Development Goals (SDGs). Specifically, it can help end poverty (SD1) because charcoal production and supply provides economic opportunities for rural households. It can help ensure access to affordable, reliable and sustainable energy (SD7) by improving the supply and reducing costs. Industrial charcoal production can create decent jobs and enhance economic wealth of communities by providing more productive equipment (SDG8). It can help combat climate change (SD13) by reducing deforestation and forest degradation and helping to balance emissions from burning woodfuels with natural regrowth. Finally, it can help sustainably manage natural terrestrial resources (SDG15) by developing economically viable and environmentally sound forestry practices.

[21] **Industrial charcoal production can serve as an example for other supply chains throughout Central Africa and beyond**. The vast majority of persons (more than 90%) in Central Africa rely on woodfuels for cooking needs. Because of the high rate of urban demand, future markets for charcoal for much of Central Africa will resemble that of the Congo today. Therefore, economically viable industrial-scale charcoal production in the Congo could serve as a model for similar projects in other countries in the region. Development of a financially viable enterprise could have cascading impacts on private sector development in value chains throughout the continent.

[22] **Industrial charcoal production contributes to the Congo's development strategy, Congo National Development Plan 2018-2022 and climate change goals stated in the country's REDD+ and NDC documents.** Industrial charcoal production would meet many pillars of the National Development Plan, including transformation of the economy, development of economic and social infrastructure, development of human resources, and sustainable development. This activity would further aim to increase revenue from forests, a key goal of the overall National Development Plan and Wood and Forestry Plan. In addition, Congo has stated goals toward climate change mitigation and forest management in its Reducing Emissions from Deforestation and forest Degradation (REDD+) and Nationally Determined Contribution (NDC) documents, which the project would help to meet.

2. Congo Carbo Industrie

2.1. Objective

[23] The goal of the Congo Carbo Industrie is to establish the first industrial production of charcoal and associated products in the Congo and among the first in SSA. Industrial production differs from the current techniques in the amount of charcoal being produced, the technology used to create charcoal, and in some cases the organization of the supply chain. The aim of CCI is to increase the efficiency of production and stabilize supply by using improved technologies and formalizing part of the charcoal supply chain. The premise is that doing so will lead to ambitious economic, climatic, environmental, social and industrial impacts.

[24] The project intends to provide households ready access to a renewable energy source that is efficient, less polluting and well suited to local and international culinary culture. Specifically, CCI aims to: (i) make use of planted private forest and sawmill waste by producing charcoal and charbriquettes; (ii) increase forest cover and improve living conditions for populations living close to forests; (iii) contribute to clean industrialization in the forestry sector; (iv) contribute to the development of national strategies for REDD+; and (v) contribute to achieving the NDC goals. The installation of a fully-fledged industrial supply chain for the use of forest biomass obtained from planted private forests and sawmill waste will reduce pressure on protected (and unprotected) natural forests, which will help conserve biodiversity, create several hundred jobs across the country and reduce poverty.

[25] CCI plans to develop an industrial-scale charcoal production and distribution operation. The project would source charcoal feedstocks from plantations of existing and newly planted *Eucalyptus* and other fast-growing species. Improved production technologies will include brick kilns, a carbonization plant and development of charcoal briquetting capability, all of which will improve the efficiency of carbonization and the scale of production. Production activities will then be integrated with carbonization processes, transport and, potentially, exports. Because of the scale and approach, CCI

would transform a considerable part—the stated plan represents 10% but the ambition is 30%—of the Congolese charcoal supply chain. This will have impacts on the existing supply chain and the people who are currently active within it (see section 5).

2.2. Technologies

[26] CCI will use new carbonization technologies to improve quality and increase quantity of charcoal production. Advanced kilns will increase the efficiency of carbonization, doubling it by comparison to the traditional mound kilns and unimproved kilns commonly used in the Congo today. Here we describe the three technologies that CCI will use, none of which are currently in use in the Congo.

Green Mad Retort (GMDR)

[27] The Green Mad Retort Kiln (GMDR) is a semi-industrial brick retort kiln. It was initially developed in Madagascar to produce charcoal from *Eucalyptus* wood harvested in local plantations—the same use as proposed by the CCI project. The GMDR consists of three parts: (i) an external combustion chamber, where lower-quality wood or other biomass may be used, (ii) a charcoal chamber, and (iii) a chimney that includes a simple system that allows the post-combustion of the gases generated by the carbonization. The GMDR has double walls that ensure an airtight seal during the cooling phase. This carbonization technique produces up to 35% charcoal yields, by mass, when used with wood at the appropriate moisture content (Temmerman, ECO consult, pers. comm.).

[28] Through a thermal gas-cleaning system, this brick kiln enables combustion of the methane generated by the pyrolysis before it is released into the atmosphere. Although the heat from this combustion is not recovered or reused, the combustion system makes GMDR one of the cleanest technologies for producing charcoal. Less than 1 kg CH_4 is emitted in producing one tonne of charcoal. By comparison, the production of one tonne of charcoal in a traditional mound kiln generates around 40 kg of CH_4, and the production of one tonne of charcoal with an Adam retort kiln generates 20 kg (Sparrevik et al. 2015). The Adam kiln, named after its inventor, is highlighted because it was probably the first brick kiln designed to allow the combustion of

methane—a greenhouse gas with an effect on the atmosphere 25 times greater than that of carbon dioxide—emitted during the carbonization process.

[29] The key advantages of the GMDR is that it involves only a moderate investment yet produces high yields of carbonization (30–35%) via the retort principle, in which pyrolysis gases are combusted and the generated flue gas are used to heat up the wood load (Temmerman, ECO consult 2016). The GMDR is relatively easy to construct and produces high-quality charcoal. The primary disadvantages are that skilled craftsmen are required for design and installation, and that the kiln is of fixed capacity.

CML process with Industrial Retort Kiln

[30] Industrial production plants using the CML process consist of a standardized unit comprising 4 or 12 cylindrical retorts kilns that are all connected together to a post-combustion furnace prior to the chimney. It uses the heat produced by the combustion of the pyrolysis gases for drying purposes (e.g., of fuelwood) or to produce electricity. The CML unit allows the carbonization of all types of wood, including deciduous and resinous, providing significant flexibility in woodstock. The carbonization efficiency (in yield and productivity) is directly linked to the quality and characteristics of the raw material used (particle size, humidity, cleanliness, etc.).

[31] Charcoal is produced in cylindrical retorts fitted with a lid at the top and a discharge hatch in the base. Entry of air is controlled by valves positioned at the base and around the lower sides of each retort. Retorts are filled from the top using a forklift truck fitted with a bucket. Later they are discharged cold using a common central bottom hatch. Under each retort, the charcoal is channelled directly to the extinguishing pans. These pans pass along a service ditch running between the two lines of retorts by means of a trolley on rails. A lifting mechanism at one end then pulls them out of the ditch.

[32] Industrial retort kilns have the advantage of a continuous process, and they produce a consistent, high-quality charcoal. A complete production cycle of loading, carbonization, cooling and discharge may be completed within 24 hours for each of the kilns. For example, using oak or beech with moisture content of 20–25%, the daily production capacity for 12 kilns is about 8.75 tonnes of charcoal. Under optimal conditions, a 12-retort CML plant can produce over 3,000 tonnes of charcoal year per year from 15,000 tonnes of wood. Due to the combustion of the pyrolysis gases, this process of charcoal production is climate friendly, producing no CH_4 emissions.

[33] In short, the CML process provides precise control over production and has significant lifespan. It is a flexible system that allows installation of from 4 to 12 kilns to match needs and capacity. There are very few GHG emissions due to the recovery and combustion of pyrolysis gases. The disadvantage is that there is a very significant investment cost. Establishment, kiln manufacture and operations require skilled labour and significant logistical consideration.

Charcoal briquettes

[34] Charcoal briquettes ('charbriquettes') are combustible briquettes made of carbonized biomass material. Dust particles of charcoal, known as 'fines', are bound together and compressed. Charbriquettes require a binding agent, usually starch from maize, manioc or rice, which accounts for 5–10% of unit weight. Charbriquettes behave and burn very similarly to charcoal, requiring users to change neither stove nor practices. Their main advantages compared to charcoal are that they have a longer burning time, do not produce sparks, are somewhat less polluting and offer consistent quality.

[35] Most plants worldwide produce charbriquettes through compaction of carbonized materials. This approach is suitable for developing countries because investment costs are relatively low and briquettes can be made with recycled, often wasted materials. The main challenge with charbriquettes is to keep costs as low as possible because in the marketplace they compete with charcoal, which is cheap. Few successful businesses producing renewable charbriquette have emerged. When they have proven viable on domestic markets such as in Kenya (e.g., Chardust Ltd., http://chardust.com/) and Cambodia (Sustainable Green Fuel Enterprise, http://www.itasean.org/wp-content/uploads/2016/09/Sustainable-Green-Fuel-Enterprise-EN.pdf), charbriquette businesses typically use charcoal dust, instead of other biomass residues, as the main raw material because of its lower costs.

2.3. Design principles

[36] **Stable raw material supply.** Availability and cost of raw materials are two of the most significant risks to large-scale charcoal production. The project takes two actions to maintain continuity in supply of raw materials. First, it relies on wood sourced

from its own plantation of *Eucalyptus* and other fast-growing species. This provides CCI greater control over supply, though the sustainability of the resource will require appropriate planning. Second, dust materials (fines) for charbriquettes will be collected from by-products of CCI produced charcoal (rather than from other providers). Binding agents for charbriquettes, such as manioc, are in sufficient supply in the project area.

[37] **Consistency for quality.** Carbonization and charcoal quality are sensitive to the characteristics of the raw material, such as wood moisture content and particle size. The CCI project must pay strict attention to the wood preparation before carbonization: moisture content must not exceed 25% to ensure yield and quality while minimizing the need of fuelwood for carbonization and keeping maintenance costs of kilns low.

[38] **Market diversification.** Sorting and sieving of charcoal will be conducted to produce high-quality and consistent products. The planned centralized sorting plant has the advantage of allowing better quality control. However, the trade-offs are that it requires additional investment (i.e., for a machine sieve), storage space and higher labour costs. Yet the quality of the charcoal must meet a range of local, national and perhaps international market standards. Quality-control measures that start with kiln building and maintenance will need to be put in place. A dedicated team in charge of building GMDR kilns will be appointed and trained.

[39] **Social and environmental safeguards.** Wood plantations and land concessions will be the main source of renewable raw material and energy. The size of plantation is intended to be significant and will ensure and sustain an industrial-scale business (see estimates in annex 3). However, the greater the scale of production, the greater the potential for negative social and environmental impacts. Downside risks include environmental degradation and pollution and diminished livelihood options for local peoples. Potential concerns are discussed further in section 5, but a full impact assessment is needed to address concerns and ensure positive outcomes.

[40] **Adaptive management.** Congo Carbo Industrie intends to be underpinned by a solid monitoring and evaluation system that supports evidence-based decision-making and reinforces adaptive management in business practices. The tracking system will monitor production activities, processes, inputs and outputs to track achievements against targets, emphasizing use of the data to improve efficiencies and lower costs. Rigorous social and environmental assessments will need to be made at the start to measure the ancillary impacts (positive and negative), with updates at necessary intervals.

[41] **A cooperative approach.** CCI intends to have a wide network of traditional charcoal makers using the GMDR group of kilns. The company will apply the same requirement in quality standards as for the inhouse products and these charcoal makers will be fully integrated in the CCI network of product suppliers. This will enhance the volume of CCI charcoal and create an inclusive business model. Charcoal provided by this source is not included in this model.

2.4. Project design

[42] Congo Carbo Industrie will produce charcoal at a large scale and with industrial processes. The CCI will implement a combination of three technologies: industrial retort kilns using the CML process, GMDR and charbriquettes. The project is designed to combine a centralized carbonization factory (CML) and decentralized kilns (GMDR) in order to use the two tools in complementary ways to maximize production. The modelled pace of technological establishment and start of production is ambitious and feasible only with strict coordination and appropriate human resources.

[43] Originally designed in 2009, the project planned to use CML and Magnien portable metallic kiln technologies to process residues from sawmills. Processing wood residues, a by-product, into a product with high added value would have improved the overall efficiency of the forest exploitation. Success of the business model relied on long-term accessibility and availability of wood residues. Recently, the Congo's Ministry of Forest Economy approved to provide the project a land concession of 100,000 ha to establish a tree plantation instead of recycling materials from sawmills[2]. This strategic change in business operations would reduce logistic costs, increase control over prices and make a significant amount of wood readily available for exploitation.

[44] Industrial charcoal production has a higher capacity as a consequence of the addition of an industrial technology with higher potential profits. However, it also presents greater risks in terms of operations and finance. Because of that, CCI will use a combination of technologies, which have a high level of resilience to technical malfunctions, to mitigate risks: GMDR, CML and charbriquetting.

[45] Production with GMDR will be implemented in a phased approach. It will start through a pilot project of twenty GMDR kilns during the six months (5 in the first year),

[2] An emphyteotic bail based on 100.000 ha is intended to be signed probably during January 2019 according to CCI.

and then target 200 kilns (in total) at the fifth year. Starting with the initial pilot project, CCI will internalize the expertise of kilns construction, maintenance and training within a dedicated staff. Consistent charcoal quality requires that all kilns are built, operated and maintained with minimal disruptions. Attention will need to focus on quality, targeted production capacity and control of costs.

[46] CCI will deploy CML technology. A factory will be implemented at year four, with the ability to produce 80% of capacity during the following year and reach full capacity in year five. This schedule can be broken into five components, detailed below.

[47] About 15% of charcoal is lost due to inefficiency of factory operations, especially during unloading and handling. Dust and small pieces are often wasted. Charbriquette production would enable reuse of about 10% of the dust normally lost, thus increasing effective capacity at year six. Charbriquette production will expand over three years.

[48] Component 1: Development and implementation of sustainable tree-energy plantation. This component will finance the development of a sustainable source of raw materials to feed the charcoal kilns. Its three subcomponents pertain to the initial period of planning and the establishment of the plantation, and then the management of the plantation over time. The importance of this component cannot be overstated because sustainability and economic feasibility are based on appropriate management of raw materials supply.

[49] Subcomponent 1.1: Establishing of productive and sustainable *Eucalyptus, Acacia* and *Cacia* plantation. This subcomponent will include the establishment and initial investment in the tree plantation. It will finance project planning and implementation related to the development of a plantation management plan, including an in-depth impact assessment and planting and felling of the first trees. The plantation management plan will translate the estimates provided in this document into concrete actions and targets and examine the social and environmental impacts from industrial-scale charcoal production around Pointe-Noire. This will include but not be limited to impacts on gender and vulnerable populations and impacts on soil, water and climate. This subcomponent will also include the first year of plantation management, such as planting of trees. If the concession includes existing *Eucalyptus* plantations, which this assessment assumes it does, this subcomponent also includes felling of an initial source of wood materials. The annual plantation need is 327 ha (see annex 3). But because of

the rotational management, the entire area (2,602 ha) is needed from the first year of the project.

[50] Subcomponent 1.2: Managing an environmentally sound and economically viable tree-energy plantation. This subcomponent will finance the operational costs for management of the plantation. This includes every activity from reforestation through harvesting to maintain the quality and quantity of source materials for the charcoal production. It will provide for cost of equipment, imported materials, etc. Lastly and importantly, it includes the cost of labour and the costs of reforestation (currently planned to be conducted under the supervision of the National Service of Reforestation (SNR)) and the conducting of the social and environmental impact assessments.

[51] Subcomponent 1.3: CCI will develop evidence of the project's contribution to REDD+[3] ambition of the country. Details will be delivered in an additional document. However, in brief, CCI covers the five main activities types involved in REDD+: (1) avoiding deforestation by restoring cleared lands by planting forests, (2) avoiding rainforest exploitation, (3) allow the conservation of a biomass (only 30,000 of the 100,000 ha will be development for production; the additional 70,000 ha will be protected as a conservation scheme), (4) sustainable management of forests through strict practice that maintains ecosystem services such as reduced impact harvest, and (5) enhancing carbon stocks by planting or restoring degraded lands. In short, the CCI will orient itself toward business models that deliver emission reductions and contribute to forest conservation objectives.

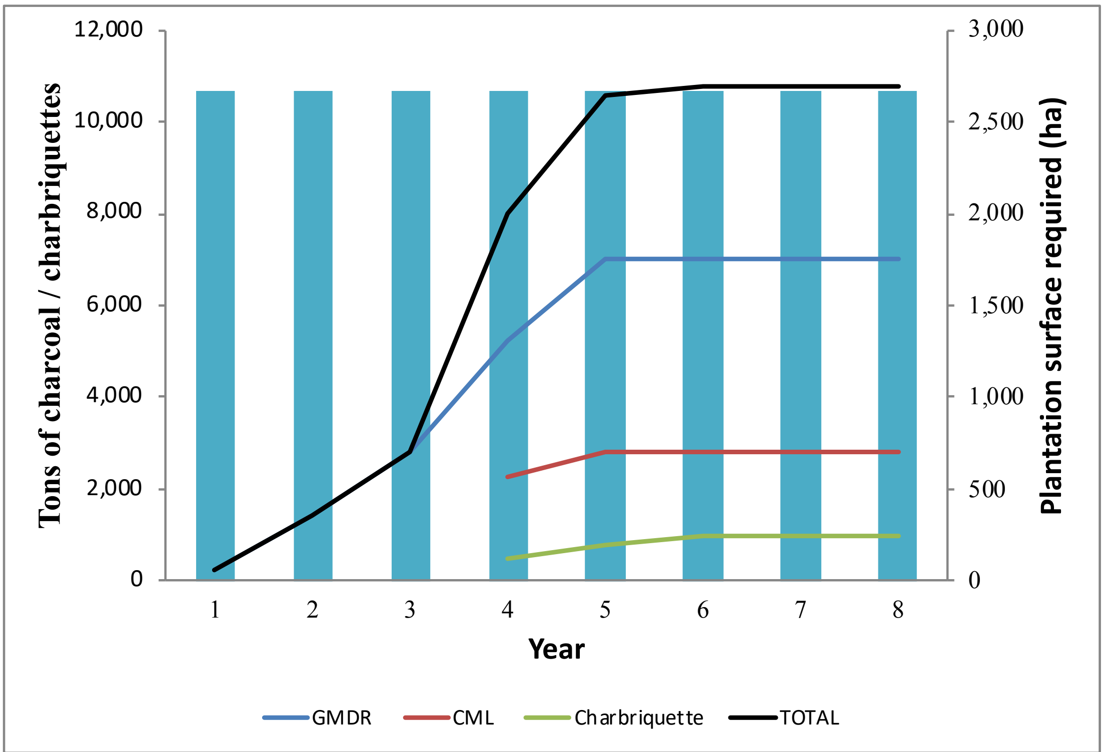
[52] Component 2: Development and management of large-scale charcoal enterprise using multiple production processes. This component will support the establishment and management of industrial-scale charcoal production using the three technologies previously outlined: retort kilns with GMDR kilns (subcomponent 2.1), CML process (subcomponent 2.2), and charbriquettes (subcomponent 2.3). It should be noted that current figures take into account an initial wood moisture content of 40%, which will be lowered to 20–25% by using natural passive drying. A storage space large enough for six months of operation is required. However, the CML technology can be combined with a heat exchanger to provide hot air for wood-drying. This would reduce significantly the surface dedicated to raw material supply. With GMDR technology, it

[3] Dec. 1/CP.16, paragraph 70 of the Cancun Agreement *"encourages developing country Parties to contribute to mitigation actions in the forest sector"*.

also would be possible to use a simple heat exchanger to use the heat from combustion of outlet gases from the kilns.

[53] Subcomponent 2.1: Establishing the capacities (human and material) to develop and operate 200 GMDR kilns. This subcomponent will finance the piloting and establishment of a network of GMDR kilns. In the first year, there will be a pilot of the kilns, with insights from the ECO-Consult team from Germany, to perfect and provide training in their manufacture (ECO-Consult has years of experience with the GMDR in Madagascar). This will require only five kilns to be operational in the first half of the first year. Additional kilns will be constructed over the next five years, increasing to 20, 60, 100 and 140 in years two through five, with a target of 200 GMDR kilns in operation starting in year six. The nominal production capacity of 200 kilns will be 7,000 tonnes of charcoal per year.

Figure 4. Evolution of charcoal and charbriquette production and plantation surface area (bars) over 8 years.



[54] Subcomponent 2.2: Developing the system of retort kilns using the CML process. This subcomponent will support the development of retort kilns using the CML process. This includes all assets and investment for centralized charcoal-making, including assets and labour. The CML technology would be constructed in year four of

the project, following the establishment of plantation production practices and the consolidation of the CCI technical team, with technical assistance from French technical partners (LCRB Development, www.lrcb-development.fr). Installation of 12-kiln units will require approximately one year for order, manufacture, importation and establishment. Once production of the kilns has started, it should be possible to reach nominal capacity at the end of the first year (3,500 tonnes per year if moisture content of wood is less than 20%, or 2,800 tonnes if the moisture content is 18–25% (a likely scenario). Maintenance costs are believed to be greater than those for GMDR brick kilns due to the amount of metal involved and possible tar accumulation, especially if wood moisture content is greater than 20%. Thus, in year six of the project, the CML process will produce only at 80% of nominal production rate (2,240). At peak load, the CML factory will produce approximately 33% of the charcoal, with the other 66% derived from the GMDR kilns.

[55] Subcomponent 2.3: Establishment of charbriquette operation to recycle charcoal fine dust. This subcomponent will build the institutional and technical capacity to recycle charcoal dust into charbriquettes. Deployment of capacity will begin in the fourth year of the project. Charbriquetting is delayed in order to allow focus on the other subcomponents and to wait for the level of charcoal production by-products to be sufficient to support the process. At full capacity, 880 tonnes of charbriquettes will be produced each year. Because of the simplicity of the process, it is expected that full capacity will be reached in the third year of production (the sixth year overall), with 440 and 740 tonnes of briquettes produced in years four and five of implementation.

3. Economic feasibility

[55] The economic and financial analysis follows best practices for feasibility assessment and reflects evidence from similar assessments on the topic in the Republic of Congo, Central Africa and other locations globally. The economic analysis evaluates the project's benefits and costs over an eight-year period. Asset costs are amortized at variable rates (e.g., between 5% for buildings and 33% for trucks). The economic projections aggregate net benefits from application of the three technologies and the production of charcoal and charbriquettes along the evolution of production, as detailed in the previous section. The economic analysis does not attempt to include the monetary benefits of avoided carbon dioxide emissions from engaging in carbon markets, although this is an area of active interest (annex 5). Tax on profits was included at 30%. It is important to note that while financial outcomes presented here include amortization of assets, they do not include any annual interest to banks or financial partners. These costs could not be included because the source of financing for the project has not been established. Therefore, the estimates presented here can be considered an upper bound on potential profits and will need to be reduced accordingly as planning moves forward.

[56] A summary of the economic analysis can be found in table 1 and full details in annex 7. The analysis estimates an investment cost of approximately 4.6 million euros and operations costs of 0.5-3.3 million euros per year, depending on the stage of development and activities. The resulting return of 25.3-million-euro investment is about 2.4 million euro, or 10.7% over eight years. The economic analysis suggests the enterprise could turn a profit after the fourth year, after the fourth year, assuming a selling price of charcoal at 300 FCFA per kg charcoal and purchasing price of wood of 40 euros (26,500 FCFA) per tonne.

Table 1. Summary of economic feasibility of industrial charcoal production.

Industrial enterprise	Unit	Value
Production		
Charcoal	tonnes	51,110
Charbriquettes	tonnes	4,214
Initial investment		
CML factory	euro	2,564,685
GMDR &charbriquettes	euro	2,075,686

Operations		
Fixed costs	euro	4,083,963
Variable costs	euro	18,230,265
Performance		
Revenue[1]	euro	25,309,193
Period until profitable	years	4
Return on investment[2]	%	10.7%
Cost-benefit ratio		1.1
Co-benefits		
Forest conserved	ha	unquantified
Greenhouse gas emissions avoided[3]	tCO_2-eq	72,000
Jobs created	Person	700

[1]Assumes sale price of 300 FCFA kg charcoal and charbriquette. [2]After eight years, calculated as the ratio of profit to investments plus operating costs. Does not include interest on loans. [3]See Annex 7.

[57] There are clear opportunities to improve the financial performance of the enterprise, based simply on relative costs to other operations and expert judgement. To begin with, management of the plantation and rehabilitation is estimated to be 5,000 euros per ha, nearly double similar estimates in other parts of the world. In total, reforestation costs represent about 25% of annual operations costs. Whether these operations can be conducted through a group of NGOs, the community or another more cost-effective mechanism needs to be explored. In addition, the CML and GMDR processes produce high-quality charcoal, assuming wood moisture and particle size are appropriate. High-quality 'green' charcoal presents an opportunity to target a different, perhaps global, market segment that is willing to pay a premium for sustainable Congolese charcoal. Moreover, though production of charbriquettes is predicted to be only 10% of charcoal sales at nominal capacity (~0.4 m tonnes of a total of 4 m tonnes), it accounts for nearly 50% of profits over the eight years. This is because the investment costs are relatively low while the market price is similar to that of charcoal. Charcoal dust, the main raw material for briquettes production, costs very little as it is a waste product from charcoal production. CCI may explore to start producing charbriquettes as soon as the raw materials are available in sufficient quantities. Lastly, CCI may consider the use of agroforestry practices (integration of trees with crops and livestock) to diversify and increase the productivity of the land concession. This could help offset part of the large upfront costs and reduce the initial payback period. In addition, multipurpose plantations, which integrate other species grown in the understory, could

serve local communities. Successful models of agroforestry systems designed to produce fuelwood have been running in neighbouring Democratic Republic of Congo for many years. None of these options have yet to be integrated into the financial models presented here.

Assumptions

[58] This assessment is based on a series of assumptions about the source of raw material, operational efficiency and market size. Under different assumptions, the feasibility—technical and economic—would change. To begin with, the envisaged supply chain depends on the immediate availability of feedstock for rapid production (annex 6). This feedstock would presumably be sourced from the requested 30,000 ha forest concession. The intended concession near Malolo would include 3,000 ha of 3-year-old *Eucalyptus* plantations, providing the necessary feedstock. Without the concession and the availability of a mature plantation, there would be a greater time lag before production and therefore reduced near-term revenue projections.

[59] Such a scenario would not necessarily invalidate the feasibility of CCI or industrial charcoal production, because alternative sources of wood may be available and alternative supply-chain organization could be realized. For example, it may be possible to work with existing supply chains from large-scale timber operations and artisanal suppliers, as CCI originally intended, though this would involve much greater transaction time to establish, as well as increased risk in securing a high-quality supply of raw materials. Initially, the project targeted wood residues from sawmills in the Department of Kouilou near Pointe-Noire and the harvest of forest residues from the Eucalyptus and Fiber Congo (EFC) company. However, the availability and consistency of this resource is unclear. Residues are likely available in large quantities but are already subject to commercialisation. Many households use sawmills residues as a source of energy for cooking. The potential for residue sources was not investigated in depth here given the new CCI approach of using farmed trees. Further investigation about wood residues from sawmills would be necessary to examine the feasibility of that approach. However, the former feasibility study of CCI did focus on this topic and provides a first assessment.

[60] A second assumption refers to the rate of construction and utilization of the new technology introduced, including GMDR and CML kilns and charbriquetting techniques. CCI is still at the concept phase, and there is limited experience in-country

for installation and operation of these technologies. However, actual conditions may vary significantly from those proposed and analysed here, depending on human and institutional capacity. Early and significant engagement with technology partners (ECO-Consult (Germany) for GMDR and LRCB Development (France) for CML Process) will be required. The pilot implementation of the GMDR is forecasted to start soon and to last for six months, which may mitigate some concerns (box 1, annex 8) and comply with technology transfer framework under the CTCN technical assistance process.

[61] A third assumption is the market price of charcoal. Average charcoal prices seen on the domestic market (January 2018) range from 160–200 FCFA/kg in Pointe-Noire and from 220–250 FCFA/kg in Brazzaville. Experience shows that even with higher quality, it takes time to sell a new charcoal product at significantly higher price than traditionally charged. In the meantime, it will be strategic from a marketing point of view to increase its price as rarely as possible, thus setting a price that anticipates future increases is advisable. A price of 300 FCFA/kg for 'green' charcoal or charbriquettes would serves as a maximum.

Uncertainties

[62] This assessment relies on information and data extracted from available documents, key informant interviews and the initial business plan elaborated by CCI in 2009 (see annex 7). Data related to specific parameters of the economic model have some unquantifiable level of uncertainty associated with the methods used to collect them. As much as possible, data were crosschecked with key informants. However, many of the variable and fixed-cost expenses in the model were provided by CCI itself.

Box 1: GMDR in Madagascar: feasibility and lessons learned

In 1996, GIZ initiated the German–Malagasy Environmental Programme. Its immediate target was to increase the percentage of sustainably produced charcoal through wood energy plantations to supply the city of Antsiranana, Madagascar. As in the Congo, most kilns being used in Madagascar at the time had a low rate of carbonization (10–12%) and a high rate of waste. The program's fast-growing plantations, managed with short rotation cycles, yield large quantities of wood. This supported the development of technologically advanced kilns that were more efficient and produced fewer emissions. Kilns developed by the project, such as the stationary Green Mad Dome Retort, have an efficiency rate of more than 30%, triple that of the commonly used kilns. New kilns with methane recycling cut the carbonization time from 7 days to 72 hours and recycle flue gases that normally would be emitted into the atmosphere. The internal rate of return of such an investment (4,500 euros/unit) exceeds 40%. And since the global warming potential of methane is 25 times that of CO_2, the technology significantly reduces climate impacts.

Modernizing the value chain in an integrated manner meant assisting both plantation owners and charcoal burners to organize themselves as groups of shareholders. Groups averaged 40–50 members. They gained market access by creating registered micro-enterprises to invest in and run the retort and commercialize the product, including certified proof of origin. Each company's business plan is based on the exploitation plan of the respective plantation area (in general, 300–400 ha per company). Companies pay duties to the commune and taxes to the region. In order to create a 'green' value chain, some of the rural companies joined forces and established an urban charcoal market in Antsiranana, thus facilitating the product's traceability and increasing transportation efficiency. This increased shareholders' economic returns by 30%.

Source: Hannes Etter, Steve Sepp, Klaus Ackermann, Daniel Plugge and Mark Schauer, ETFRN News

4. Project risks

[63] The overall risk to the project is not trivial. The key risks and challenges include: (i) political instability in key market areas, (ii) limited institutional capacity and technical knowledge for implementation of new technologies and marketing, (iii) fiduciary risk in terms of a lack of historical information on procurement and accounting and good business practices, and (iv) the potential to disrupt the environmental and social systems with both the land concession and the production of charcoal on a significant scale (table 2). CCI has suggested ways it will mitigate such risks.

[64] **Political instability.** After years of civil unrest, the Congo is experiencing a period of relative political stability. By the World Bank's measure of political stability, the Congo has been near or above -0.5 in the 10 years since 2009 (2016 value = -0.57)[4]. Recently, however, new instability has emerged, especially in the Department of Pool, where a military rebellion has led to energy shortages (of gas, oil and charcoal) coming from southern Congo.

[65] **Institutional capacity.** CCI is still at the concept phase and has limited experience yet in kiln, charbriquetting and tree plantation activities at commercial scale. The project promoter has experience in charcoal processing gained in various trainee periods at Charbon Aggouni (France); in addition to a network of collaborators in the French charcoal industry and biomass energy researchers. More time, however, is needed to acquire control over the overall project specificities. Furthermore, marketing of charcoal products will require development of an alternative supply chain. Time also will be needed to consolidate actors and move processes forward. These risks may be mitigated with a reasonably paced growth strategy starting with the pilot stage of GMDR operation as planned, and collaboration with more experienced institutions. For example, CCI signed a strategic partnership with the owner and manager of an industrial charcoal plant in France (Charbon AGGOUNI). According to the existing agreement, the owner of Charbon AGGOUNI will stand as the next chief operational officer at CCI.

Table 2. SWOT analysis for Congo Carbo Industrie

[4] World Bank Political Stability Index ranges from -2.5 to 2.5. Data from https://www.theglobaleconomy.com/Republic-of-the-Congo/wb_political_stability/.

Strengths	Weaknesses
Efficiency and quality: Centralized plant enables better control of production practices. **Operations:** GMDR technology is simple and reliable, with all construction materials and expertise available locally. Operation and maintenance costs are low. No need of electricity. Kilns can be implemented in several batteries in several spots of the plantation. **Resilience:** Production model relies on 200 kilns, so any trouble or required maintenance has a small impact on global production (i.e., high level of resilience). **Environmental impact:** CML and GMDR technology greatly reduces smoke released during carbonization and methane emissions. **Product differentiation:** Charbriquette production is well suited to charcoal enterprises since it increases business efficiency by minimizing waste and maximizing incomes. **Realistic but ambitious pace of technology transfer:** Business strategy based on realistic pace of technology transfer. Twelve-month period for the pilot phase in order to ensure a successful technology transfer process for GMDR. More complex technologies come in later in the project. **Raw materials:** Wood is sourced from self-managed plantation.	**Costs**: High investment cost for CML technology with moderate ratio of production capacity to investment costs. Also, GMDR kiln is a small single unit duplicated to reach large scales. **Capacity demands**: GMDR technology relies on a semi-decentralized production model and requires higher costs for training, quality control and maintenance. **Unintended consequences**: Potential for social and environmental impacts due to land concessions and change in supply chain. **Operations**: CML is sensitive to wood conditions that may be difficult to control **Social and environmental impacts**: Tree plantation over large land concession requires proper social and environmental impact assessment since it might have a negative social impact. The plantation also increases costs.

Opportunities	Threats
Market: Significant domestic market, relatively near to an urban centre (Pointe-Noire), and potential for meeting global demand. **Source of wood:** CCI will receive a land concession from Ministry of Forest Economy and ProNAR, on which 3,000 ha of *Eucalyptus* is already growing. **Environmental:** Centralized production can reduce impact from deforestation and reduce emissions during production. **Land:** CCI is in the process of accessing a large land concession of around 100,000 ha (99 years of emphyteotic bail with support from the Ministry of Forest Economy and ProNAR). **Environmental impact:** Positive environmental impact on deforestation. **Climate change:** Contribute to NDC implementation, and the afforestation will address the adaptation need while remaining one of the country's mitigation actions.	**Competition**: CCI charcoal will compete with artisanal charcoal, and thus cost is critical. **Supply chain**: Require significant shifts in aggregation, which may increase transaction costs. **Business model**: Somewhat ambitous pace of technology development and dissemination after pilot. **Political stability**: Recent political instability in key area, the Department of Pool. **Distribution**: Transport cost is high in Congo. **Marketing**: Introduction of new product (charbriquettes) will require development of new market. **Price**: CCI charcoal is direct competitor to traditional charcoal and cannot be more expensive on domestic market if it is to meet goals

[66] **Fiduciary**. There are significant unquantifiable fiduciary risks for CCI. It is unquantifiable because the company is only emerging. It has yet to establish a detailed financial plan, so it is not possible to evaluate fiduciary risks at this time. A financial management document must clearly elaborate financial management controls, procurement policies, documentation of expenditures, management oversight and monitoring systems.

[67] **Environmental and social**. CCI represents a transformative change to the charcoal industry in the Congo. These changes will almost certainly have both positive and negative impacts for the environment around the plantation and factory, for participants in the supply chain and for customers of the product. A discussion of potential impacts is elaborated in the next section but needs to be made in more detail once the project has started and the location of the plantation and industry is known. It should be noted that CCI intends to use a corporate social responsibility (CSR) program to help mitigate and minimize downside consequences. Discussion between CCI and potential partners in CSR are ongoing and will help to mitigate negative consequences to people and planet.

5. Impact assessment

[68] It is too early to clearly state whether the project will have definitive positive or negative social and environmental impacts. This is largely because economic articulation with charcoal producers or employees is still unknown (see draft in annex 8) and the exact location of plantations concession has not yet been identified. The direction (positive or negative) and magnitude of impacts will depend on the management practices implemented during production. A revision of the forest code is foreseen. All of these factors further increase the uncertainty around social and environmental impacts. Because of these limitations, this section is limited to describing impacts needing consideration and suggests that a detailed impact assessment will need to be conducted during the next phase of project establishment.

[69] **Economic.** Implementation of CCI will have direct economic impacts on the revenue of charcoal producers through at least two possible mechanisms. Charcoal producers may be hired to work on the plantation or in the production of charcoal. The nature of the work—daily wage or contract—has social implications that will need to be considered. Artisanal producers may either (i) have a contract with CCI to get paid on a daily or weekly basis, which means that such labour costs would not be internal CCI salaries; or (ii) work as independent producers using the carbonization kilns provided by CCI and selling a share of the charcoal produced to CCI at a set price. CCI might give preference to the latter scenario, which follows the concept of contract farming. Discussions and negotiations between CCI and charcoal producers about possible arrangements related to production, sourcing and price of charcoal are forthcoming with the support of the Ministry of Forestry Economy, which is in favour of the latter option. Either way, a new supply chain using industrial procedures will be created and have cascading impacts on countrywide rural employment.

[70] **Gender.** Women are typically marginal actors in the Congolese charcoal supply chain, according to key informants interviewed for this report. Traditionally, women are primarily involved in the trade of charcoal. It is expected that because of the volume of production, CCI will require an aggregation of supply-chain actors, which may unintentionally marginalize the roles of women. This scenario is very speculative at this time given that there are no practical examples upon which to base this conclusion, but it nonetheless must be considered. An alternative scenario in which CCI creates opportunities for rural female employment through more formal means, perhaps as part of the charbriquetting operations, is also possible. Special attention will be needed to

create the space for employment of women if CCI and its investors see this as an important outcome of establishment. According to the CCI promoter, CCI will target jobs for women, including administration, sale and packaging staff.

[71] Availability of charcoal may positively affect women's workload. Though no data are available for the country, women's workload related to firewood and cooking in the Congo is believed to be similar to that of other African countries. Women spend a disproportionately large amount of time on woodfuel-related tasks. For example, women in Guinea spend nearly seven times the amount of time on firewood collection per day than men and 33 times more time cooking; in Tanzania the figures are 2 times and 9 times, respectively. The greater availability of charcoal may reduce the time dedicated to these tasks and allow redistribution of time to other demands.

[72] Land tenure. The development of industrial plantations over 100,000 ha (30,000 ha plantation and 70,000 reserve) may have a significant impact on the local population. It is unknown how many people live in or around the possible concession. Impacts may include restricted access to lands used for grazing, hunting, foraging, etc. Availability of water resources are also unknown in the area, and conflicts over water resources may emerge. Once granted, it is unclear what operations will be allowed inside the boundaries of the concession. In some cases, establishment of the concession may lead to land tenure conflicts and to displacement of villages. Land tenure concerns may be mitigated to some extent because the land let to CCI is secured through the Government's ProNAR, which takes as its mission to avoid land tenure conflicts which could impact local populations. At minimum it will require radical shifts in the livelihood strategies of local populations. Any plantation model of such size must be discussed and negotiated with local communities following the principle of free, informed and early consent.

[73] **Health.** A note must be made about the working conditions. Handling charcoal generates large amounts of dust, which is suspended in the air and might be inhaled by the workers. Masks need to be provided to the staff, but this individual protective equipment should be complemented by vacuum and/or air filtration systems. CCI plans to implement HACCP principles to better ensure the health and safety of workers.

[74] Women are the most vulnerable population to burning poor-quality charcoal during cooking (because of the impact on indoor air quality, risk of fire and sparking, etc.). Allocating additional quantities of high-quality charcoal produced by CCI in the Congo will help limit the health impacts related to the national cooking sector.

[75] **Environmental.** The land concession is not delimited yet. Without clear demarcation, it is not possible to estimate the future impact on water and soil resources. Large-scale *Eucalyptus* plantations are known to generate non-trivial environmental impacts (box 2). Concerns relate to soil health, water quantity and quality and biodiversity and other effects. The final size of the plantation and the conditions of use will ultimately determine the extent of impact.

[76] The environmental impact of carbonization gas is threefold: carbon monoxide (CO) is toxic and therefore has a direct effect on human health. Acid emissions (acetic, formic, propionic, etc.) and polycyclic aromatic hydrocarbons have effects at the environmental local scale (acid deposition, for example). Gases such as CO_2 and CH_4 are greenhouse gases, and CH_4 has a radiative forcing equivalent 25 times that of CO_2. The GMDR kiln enables the combustion of carbonization gas, and field testing carried out in Madagascar and Namibia indicates that only 0.2% of the carbon emitted is CH_4. In this case, the use of a GMDR saves 1.75 tonnes of CO_2 equivalent per produced tonne of charcoal. CML technology emits practically no GHGs. Thus, conversion to advanced kilns has the potential to avoid a significant number of GHGs.

[77] More generally, improvements in the conversion of biomass to charcoal in sub-Saharan Africa shows a substantial potential for reductions in GHG emissions. The mitigation potential could be around 100 Mt CO_2-equivalent per year in this region alone. It consists not only in limiting emissions in the combustion process, but also in avoided consumption of non-sustainable biomass. In Africa, over 20 Mt of charcoal are consumed per year, and the growing demand for charcoal fuel is an important cause of deforestation and continued GHG emissions. CCI could create a model that could improve the charcoal industry across the region, with substantial benefits in climate change mitigation.

Box 2: Environmental impacts of *Eucalyptus* production around Pointe-Noire

Commercial plantations of *Eucalyptus* have been planted on tens of thousands of hectares of native savannah around Pointe-Noire since the 1970s. Managed on six to eight year rotations, productivity averages about 20 m^3/ha/year for a seven year old plantation generating significant resources on otherwise mostly unutilized land (Laclau et al. 2000). The environmental impact of producing fast growing trees species has long been of concern, however (Shi et al. 2012; Grace et al. 2014). Conversion of natural ecosystems and management of existing stands affect nutrient dynamics, water quantity, and biodiversity. The magnitude and direction, positive or negative, of change depends on the scale, location, design and management of the plantation(s) (McKay 2011). This box details potential environmental impacts of *Eucalyptus* plantations using data collected, almost exclusively, under Congolese conditions and assumed to be similar to those that will likely be used by Congo Carbo Industrie (CCI). It is critical to point out, however, that the natural process and human actions that regulate environmental impacts can vary significantly over small spatial scales and between locations. Therefore, this discussion is simply indicative. Future work based on specific site characteristics and management plans is needed to more accurately predict environmental impacts and plan mitigation activities.

Soil health

Native savannah soils are typically of poor quality. They are sandy, acidic and have only small reserves of nutrients. For example, a well-studied experimental site near Kondi has a sandy texture with greater than 90% sand to a depth of least 2.8 m, a pH less than 5 and total carbon and nitrogen of less than 0.9 and 0.07%, respectively (Bouillet et al. 1999). This improvised initial state suggests a vulnerability to physical degradation such as erosion during weathering and compaction during cultivation and chemical degradation when nutrient reserves are exported offsite in biomass or leached down through the soil profile.

Nutrient ‘budgets’ use accounting approaches to quantify inputs and outputs of nutrients from production systems, such as nitrogen (N), phosphorus (P) and micronutrients, as a diagnostic tool for sustainability (Ranger and Turpault 1999). Like a bank account, if the balance is positive, the resource pool is growing. When negative, nutrient budgets indicate a debt. With the first rotation, upwards of 144 kg N/ha are removed (Laclau et al. 2005). This represents roughly 7% of the total N available in the upper half meter of soil. Deficits of other nutrients are less extreme than for N, however also decline with production (table B2-1) and also decline over sequential rotations.

Losses, however, can be reduced with appropriate management decisions. For example, nearly 50% of the P, K, Ca and Mg is accumulated in aboveground foliage and thus can be conserved if residues, bark, leaves and branches in field site (De Dieu Nzila et al. 2002), though different harvesting

Box 2 continued

methods will conserve nutrients to different levels (table B2-1). Moreover, ecologically sound use of fertilizers or reestablishment of biologically nitrogen fixing species as understory or in companion planting may also help balance the nutrient budgets, especially N (Voigtlaender et al. 2012; De Dieu Nzila et al. 2002). Changes in silviculture however increases production costs and thus there can be trade-offs among environmental sustainability and economic profitability.

Table B2-1. Nutrient budgets under different harvest technique (kg/ha). Negative value represent an export of nutrients offsite. Values in parentheses are the reduction of nutrient mining (%) with the use of alternative harvest management technique by comparison to whole tree harvesting, the common practice. Adpated from Laclau et al. (2005).

Harvesting method	Nitrogen	Phosphorus	Potassium	Calcium	Magnesium
Whole tree	-274	-35	-41	-39	-37
Debarked pulpwood	-94 (66)	-10 (71)	17 (142)	15 (139)	-5 (87)
Debarked pulpwood and firewood	-144 (47)	-19 (44)	-4 (90)	7 (117)	13 (64)
Pulpwood with bark removed	-126 (54)	-19 (44)	-6 (85)	-15 (61)	-22 (41)

Water quantity

Afforestation and production of *Eucalyptus* may alter hydrologic cycles. This is caused by shifts in distribution and characteristics of above and belowground biomass associated with trees versus savannah vegetation (Laclau et al. 2001; Bouillet et al. 2002). In short, *Eucalyptus* increases evapotranspiration and reduces drainage by comparison to savannah ecosystems (table B2-2). Overall trees capture nearly 97% of annual precipitation while savannah only 60% (Bouillet et al. 1999). Greater water capture under *Eucalyptus* has been shown to reduce streamflow in some grassland ecosystems of South Africa (Scott and Smith 1997). Estimates from Southern Congo suggest that *Eucalyptus* did not endanger the water table even though there is 20% less deep drainage than in savannah systems (Laclau et al. 2005). However, concerns over increase capture and reduced flows may be particularly acute during years of low precipitation. Drainage out of the native savannah was 357 mm greater than a *Eucalyptus* plantation over three years suggesting reduced recharge and local availability (Nizinski et al. 2011).

Increased evapotranspiration has potential to alter additional aspects of regional hydrological cycles as well. Much of the rainfall that falls across equatorial Africa is recycled. Trees act as pumps transporting water back into the atmosphere through evapotranspiration (van Noordwijk et al. 2014). It is estimated that the rain will be recycled 2.7 times. *Eucalyptus*, by comparison to native

Box 2 continued

savannah, increases actual evaportranspiration by 13% on average over three years (Laclau et al. 2005), with potentially greater differences during years receiving less precipitation (Nizinski et al. 2011). The potential for relatively thirsty *Eucalyptus* to disrupt and contribute regional water cycling remains a question however (Johansson et al. 2016).

Table B2-2. Average annual water fluxes (mm) in Congolese *Eucalyptus* plantations vs native savannahs (adapted from Laclau et al. 2005).

Flux	***Eucalyptus* plantation**	**Native savannah**	**Ratio**
Precipitation	1518	1532	0.99
Through fall	1380	1355	1.02
Stemflow	14	-	-
Interception	125	177	0.71
Surface runoff	25	5	5.0
Evapotranspiration	1024	907	1.13
Deep drainage	507	603	0.84

* m.a.p = mean annual precipitation

The magnitude of effect of *Eucalyptus* on river, lakes or groundwater bodies is dependent on scale, location and forest design and management, with scale being the most important issue. As its footprint increase, so does its impact relative to that of other land uses. CCI can reduce risks with extensive planting, separate parcels rather than a single large plantations. Studies generally show that it is very difficult to identify any water impacts against natural background variation when less than 20% of a catchment is subject to woodland creation or removal (McKay 2011).

Biodiversity

Plantations increase above and belowground biodiversity as measured by species richness when understory vegetation develops. Increases in the numbers of species results from reduction of the human-created fires that burn savannahs annually but are not set in plantations and the consequential microclimate modification of *Eucalyptus* stands. Species composition found in the new understory neither mirrors the savannah or the nearby forest but is unique (Bernhard-Reversat 2001). Diversity, wood cover area and basal area of this vegetation continues to increase as *Eucalyptus* age. The added litter accumulation have additional knock-on effects on belowground biodiversity, where the branches, leaves, etc provide a diverse diet of organic materials that control the abundance and nature of soil fauna (Bernhard-Reversat 2001). These changes take time and develop after 7-10 years of production, and only start when soil organic matter increases, and thus suggests importance of increased litter of trees as a key mechanism. It should also be noted that *Eucalyptus* does produce an allelopathic effect, depressing

1. Viability & sustainability

[78] The CCI industrial charcoal production project is relevant to the pressing issue of development of the wood-energy sector in the Congo, the region and sub-Saharan Africa generally. Congo Carbo Industrie or a similar industrial project could be a model for industrial charcoal production in the region. The initial financial analysis (based on the best available information at the time) indicates that CCI *may* be financially viable within the period analysed, though as stated the projections are optimistic given the scope of technology application and the lack of interest payments on the financial model. However, the necessary initial investments for the implementation (more than 4.5 million euros) may limit investor interest.

[79] That being said, CCI presents an opportunity to improve livelihoods and environmental outcomes and to capture a unique market. If a significant share of the 'green' charcoal produced is allocated to the domestic market, this will benefit the health of those using charcoal and the forest. If CCI is able to create high-quality green charcoal, its ability to meet European demand would be significant, opening up new opportunities for development in the Congo. Currently, CCI marketing policy is set to address local market needs and to consider supplying to international customers later, not before the sixth year. It is likely there will be a shifting share of charcoal divided between national and international markets (with an average of 80% national, 20% international). Indeed, such apportionment may be especially appropriate given that various production techniques will generate different levels of quality.

[80] Considering the technological feasibility, the kiln technologies selected are relevant. Green Mad Retort Kilns and charbriquetting are appropriate technologies that have already been implemented in similar contexts, such as in Madagascar (see box 1). It should be noted that while several private enterprises producing charbriquettes do exist, very few projects have demonstrated viability and sustainability in producing densified briquettes for domestic markets due to high production costs, low price of firewood, lack of demand and inappropriate designs of stoves and kilns. CML technology will be more challenging to implement technologically. However, it is still

relevant given the design of the CCI project and the source and availability of raw materials. Although the main barrier to implementation of CML is its cost, the technological challenges should not be underestimated.

[81] Perhaps the most significant foreseen difficulty with CCI lies in the pace of dissemination of technologies. Establishment and operations at the scale envisaged will require time to achieve optimal performance. This is relevant for all charcoal technologies, irrespective of location. Technology transfer in developing countries requires time (for recruitment, capacity building, training, logistics, monitoring, etc.) Internally, CCI will need time to acquire new capacities in a new field of activities (recruitment, capacity building and training, carbon finance, etc.). CCI targets and the feasibility assessment are based on a fast pace of dissemination and establishment. This requires not only sufficient capital and well-functioning teams but also the availability of technical expertise at the appropriate time. There is a chance that the pace of change will be slower than that presented.

[82] It is worth repeating that industrial plantations require a substantial investment. The reforestation costs, plus the exploitation costs five years later, represent a significant part in the overall expense of the project. The cost of wood makes it more difficult to be competitive with the informal charcoal sector, which sources its wood from natural forests. But reforestation cost could be further negotiated, making prices more competitive.

[83] The Republic of Congo has recently experienced scandals related to an industrial plantations project (ATAMA). Risks of land grabbing and deforestation are often linked to land concessions, not only in the Congo but worldwide. Congolese laws and regulations must of course be respected, and the principles of impact assessment, compensation and cooperation, and free, informed and early consent must be applied.

2. Conclusions

[84] Our assessment suggests that, despite challenges, there is an opportunity to industrialize charcoal production in the Republic of Congo and generate economic and

environmental benefits. Indeed, the projected revenues generated and return on investment are encouraging. However, more detail is needed. Specifically, there is a need to (1) develop a full risk assessment of social and environmental concerns once the location of the concession and the factory are demarcated and management plans have been developed and in addition, (2) the economic model needs to include service on debt, which can only be determined when the funding instruments (e.g., grants, loans, etc.) are known. Because of these unknowns, this assessment can best be thought of as a significant step toward appraising the revised CCI plans.

[85] There are management interventions CCI might take to improve feasibility further. This type of project presents many challenges due to large scale, high investment, potential environmental degradation, local social benefits and potential conflicts, fiduciary risks, etc. CCI might mitigate risks by adopting a modest pace of technology transfer, staggering technology implementation or reducing the number of technologies used. CCI has already started to adopt some of these measures by prioritizing the use of GMDR kilns during the first five years or more and starting with a pilot phase to consolidate project operations: raw material supply, costs, production and technologies, profitability, logistics, human resources, capacity development, building, etc. Adaptive management and learning by doing will provide the necessary foundation for a sustainable larger-scale production.

[86] Congo Carbo Industrie presents an ambitious plan to modernize charcoal production in the Congo. If successful, the project will have impacts that may extend far beyond the communities working in the plantation and factory, the enterprise or even the Congo. However, the technical challenges and economic risks should not be underestimated. Once financing, operation plans and concession location and condition are determined, the additional details will be in available to gain precision of feasibility.

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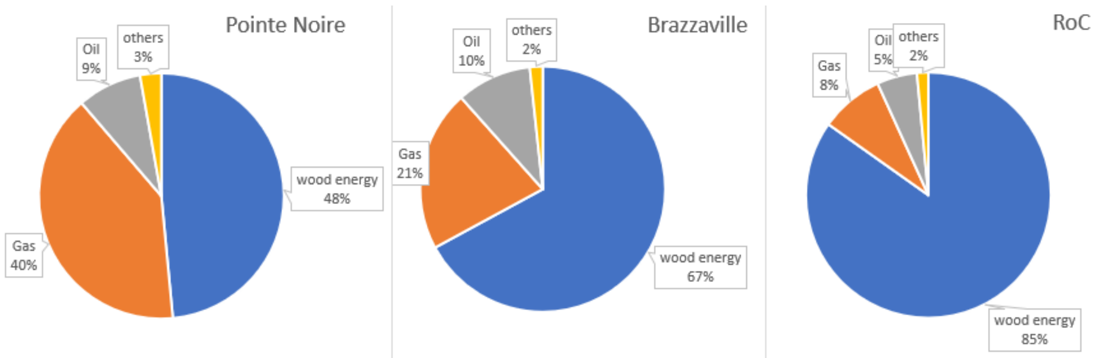
Annex 1: The size of the market

The market

Our market analysis focused on (i) domestic energy sources, (ii) national demand and (iii) individual consumption. Wood energy accounts for 85% of the total energy use in Congo, though that figure is approximately 60% in urban centres, where more than 65% of the population lives (figure A4.1).

Figure A1.1: Domestic energy sources in major urban centres of the Republic of Congo (Source: Boundzanga 2014).



National demand for woodfuels ranges between 1.5 and 1.7 million Mg per year. This includes 300,000 Mg of fuelwood and 1.2 million Mg of wood that has been converted into 150,000 Mg of charcoal. These estimates are consistent with the historical trends that suggest an increase from 941,904 m^3 demand in 1990 to 1,463,312 m^3 in 2010 (FAO and PNUD 2004), a 55% increase in the 20 intervening years, or 2.8% growth in demand $year^{-1}$. Assuming a conversion rate of 1.25 between m^3 and Mg of wood, the 2010 figure indicates a demand of 1,170,649 Mg. At 2.8% $year^{-1}$, 2017 demand would be 1,750,121 Mg of wood.

Although national consumption of woodfuels has also been increasing, individual consumption is decreasing. For example, in 1994 fuelwood consumption was 0.79 kg $person^{-1}$ day^{-1} nationally, while in 2014 it had decreased to 0.21 kg $person^{-1}$ day^{-1}. Similarly, charcoal consumption dropped from 0.15 to 0.12 kg $person^{-1}$ day^{-1} over the same time period. While individual consumption is dropping, total demand continues to increase due to population growth.

The relative demand for wood-based fuels depends on location. Charcoal is much more often demanded in urban areas, typically due to transport logistics (table A4.1). By comparison, woodfuels are used in more rural areas.

Table A1.1: Estimation of total annual wood demand by department. A conversion rate of 8 kg of wood required to produce 1 kg of charcoal is used to convert the consumption of charcoal into consumption of wood equivalent (column 3 to 4).

District	Ind. wood cons. (kg)[1]	Ind. char. cons. (kg)	Ind. char-wood equiv. (kg)	Total wood-equiv. cons. (kg/year)	Population	% of pop.[2]	Total wood equivalent consumption (Kt)
Bouenza	69.9	30.5	253.3	323.3	385,318	92	114.3
Cuvette	67.8	26.0	215.8	283.6	194,538	91	50.2
Cuvette-Ouest	80.9	23.5	195.3	276.2	91,007	93	23.3
Kouilou	97.4	62.7	520.7	618.1	114,639	87	61.4
Lékoumou	69.3	28.7	238.4	307.6	120,172	98	36.2
Likouala	128.8	21.7	180.3	309.0	192,133	99	58.5
Niari	101.9	52.9	438.8	540.8	288,322	79	123.6
Plateaux	69.7	27.1	225.0	294.7	217,661	87	55.7
Pool	96.9	28.2	233.9	330.8	294,960	88	85.6
Sangha	83.5	57.1	473.8	557.3	106,889	89	53.3
Pointe-Noire	61.1	45.2	375.3	436.4	891,799	49	188.8
Brazzaville	72.4	57.6	478.1	550.5	1,712,179	67	632.5
Total Congo	76.2	45.5	377.9	454.0	4,609,617	85	1,768.6

[1]Abbreviations: 'Ind.' = individual, 'cons.'=consumed, 'equiv.'=equivalent, 'pop.'=population

[2]% of pop. indicates the relative percentage of the population using woodfuels.

Lastly, the current price of charcoal was analysed. Based on conversations and data collection, the price of charcoal in Pointe-Noire and Brazzaville was determined in 2017. Prices in Brazzaville were higher, 220–250 FCFA per kg, while prices in Pointe-Noire were 160–220 FCFA.

Annex 2: Comparison of kiln technologies

Table A2.1. Efficiencies, advantages and disadvantages from various charcoal kiln technologies. Efficiencies based on review by Ilyuma et al. (2014). Advantages and disadvantages are authors' perspectives.

Kiln	Efficiency (%)	Advantages	Disadvantage
Traditional (pit, mound, casamance)	8–12	- No investment, requires labour force only - Can be built almost anywhere - Adjustable size	- Difficulty over process control, permanent monitoring - Highly dependent on the skills of charcoal makers - Long process - Low-quality charcoal - Low yield, variable; partly combusted wood load process - Poor sanitary working conditions - High level of GHG emissions
Masonry	28–35	- Moderate investment - Good control over production process, easier to conduct - Short and regular carbonization process - High yield of carbonization (30%–35%); retort principle - Consistent, good-quality charcoal -Very limited GHG emission thanks to the combustion of pyrolysis gas	- To date, no heat recovery from the combustion of pyrolysis gas; however, this could be possible after further development - Significant lifespan due to construction material (bricks) - Kiln manufacture requires skilled craftsmen - Fixed capacity of the kiln
Metal	25–38	- Transportable kiln - Better control over production process; easier to conduct - Short and regular carbonization process - Quality of charcoal improved but variable, also depending on state of kiln (which is subject to deformation over time) - Moderate investment	- Yield improved but still low and variable; partly combusted wood load process - Sanitary working conditions improved thanks to the use of chimney but still poor (because of low height); also depends on the state of the kiln - High level of GHG emission - Limited lifespan due to construction material (metal) and frequent moving - Kiln manufacture requires skilled craftsmen - Fixed capacity of the kiln

Retort	30–40	- Accurate control over production process, easy to conduct - Significant lifespan due to good quality construction material (imported) - Almost no GHG emission thanks to the combustion of pyrolysis gas - Possible heat recovery from the combustion of pyrolysis gas - Short and regular carbonization process - Regular and high-quality charcoal - Flexible installation: from 4 to 12 retorts in plant to match production target	- High investment - Imported plant - Kiln manufacture requires skilled craftsmen - Operations require significant logistical means and machines - Moderate yield of carbonization

Annex 3: Estimation of wood demand

Reforestation and productivity simulation

The project aims at producing large quantities of charcoal, which requires even larger quantities of wood. A simulation of *Eucalyptus* plantations[5] is given here as an example. The expected productivity ranges from 25 to 40 m^3 per ha per year. Rotation is assumed to be five years, with three rotations possible before it is necessary to uproot and renew the plot. After the first rotation, the plantation would be managed as a coppice system. Spacing starts at 2 x 2 m. The need for wood supply is associated with the increasing number of kilns installed and the carbonisation plant constructed by the project. The following tables provide calculations for the amount of area demanded based on assumptions about productivity, moisture content and drying.

Table A3.1. The productivity of one (1) ha of *Eucalyptus*. An average of 105 tonnes of wet wood per ha is used in later calculations.

	Productivity (m^3/ha/year)	Rotation (years)	Wood supply (m^3)	Wood supply (wet t)	Wood supply (dry t)
Low productivity	25	5	125	81.3	69
High productivity	40	5	200	130.0	111

Table A3.2. Dry wood needed to produce tonne of charcoal.

Annual charcoal target (t/year)	Wood-charcoal conversion rate	Annual wood target (dry t/year)	Loss of weight (%)	Annual wood target (wet t/year)	Ignition wood (%)	Annual wet wood target + ignition wood (t/year)
1	0.35	2.9	15	3.3	10	36

[5]Other species of interest would be *Acacia*, teak, *Gmelina*, *Gliricidia*, *Cassia* and others.

Given the productivity and conversion hypothesis above, we assume every hectare can generate 105 tonnes of wet wood that will produce around 30 tonnes of charcoal (105 / 3.6). We can then calculate the need of plantations to supply project source wood needs based on the evolution of construction of the carbonization technologies. The charbriquetting is not taken into consideration in the plantations requirements as it deals with residues. The tables below summarize the calculations.

Table A3.3: Production ramp-up over eight years for GMDR and CML technologies.

Variable	Year							
	1	2	3	4	5	6	7	8
GMDR production slope (%)	3	20	40	50	75	100	100	100
Kilns (#)	6	40	80	100	150	200	200	200
Charcoal production (tonnes/year)	210	1,400	2,800	5,250	7,000	7,000	7,000	7,000
CML production slope (%)				80	100	100	100	100
Production tonnes/year				2,240	2,800	2,800	2,800	2,800
Total industrial (tonnes/year)	210	1,400	2,800	7,490	9,800	9,800	9,800	9,800

The next step is the calculation of plantation area. As the plantations' rotation is 5 years, the tree planting on year N will supply the need of wood in year N+6. The following table shows that there is no ramp-up for plantations. Indeed, on year 6 the charcoal production is already expected to reach its full capacity. Thus, on year 1, the project needs to plan enough plantations to expect enough wood in the future. The annual plantations need is 327 ha. On a five-year basis, it will need 1,635 ha.

Table A3.4: Plantation area needed for each scenario (ha).

	Year	

	1	2	3	4	5	6	7	8	**Total**
Plantation	327	327	327	327	327	327	327	327	2,616

In terms of investment need, CCI will need to secure 1.63 million euros annually (5,000 euros/ha[6]), or a total of 13.08 million euros over eight years (table A5.5), assuming a unit cost of 5000 euros per ha.

Table A3.5: Investment required (millions of euros, assuming costs of 5,000 euros per ha)

	Year								
	1	2	3	4	5	6	7	8	**Total**
Plantation	1.635	1.635	1.635	1.635	1.635	1.635	1.635	1.635	13.08

[6]Planting is planned to be subcontracted to SNR. The cost of reforestation is 2,300 euros/ha without maintenance costs of plantation (e.g., weeding, fire breaks, etc). Logging costs are around the same. Thus, the total cost of 1 ha is estimated to be 5,000 euros.

Annex 4: Economics of Congo Carbo Industrie

The following tables provide detailed calculations for the economic feasibility assessment presented in section 2.5

Table A4.1: Charcoal and charbriquette production over eight years.

	Year								
PRODUCTION DATA	1	2	3	4	5	6	7	8	Total
GMDR									
Production Slope (%)	3	20	40	50	75	100	100	100	
Kiln (#)	6	40	80	100	150	200	200	200	
Charcoal production (tonnes / year)	210	1,400	2,800	5,250	7,000	7,000	7,000	7,000	37,660
CML									
Production slope				80	100	100	100	100	
Production tonnes / year				2,240	2,800	2,800	2,800	2,800	13,440
Charbriquetting									
Production slope				50	80	100	100	100	
Production tonnes / year				490	784	980	980	980	4,217
Charcoal & charbriquette price (euros / tonne)	458	458	458	458	458	458	458	458	
Sales in 1,000s euros	96	641	1,282	3,654	4,847	4,937	4,937	4,937	25,335

Table A4.2: Initial investment costs (euros) and amortization.

1. Investments	GMDR kiln + charbriquetting	CML factory	Amortization (%)
1.1. Administration fees	22,878	22,878	
1.1.a. Study costs and research	540,296		
1.1.b. GMDR pilot	200,000		
1.2. Ground	0	0	
1.3. Infrastructure (access roads)	91,511	91,511	10
1.4. Buildings and civil engineering	191,860	447,673	5
1.5. Hardware and operating tools			
GMDR kilns / ovens + CML technology	400,000	135,000	20
Generators	16,777	33,554	20
Materials extraction	4,000	45,000	
Materials clean-up	0	30,000	
Used screening	4,000	149,055	
Charbriquetting unit (5 tonnes / day)	150,000	30,000	
Semiautomatic line	0	69,358	
Bridge	0	90,000	
Logistics import fees	0	50,000	
Installation / transfer of technology	34,679	70,000	
Other facilities	4,000	124,670	
Subtotal	682,782	826,636	
1.6. Transportation equipment			
3 4x4 Vehicles	61,007	122,015	25
2 Pick up 4x4	97,612	0	25
crane	0	76,259	20
2 forestry tractors	67,108	67,108	25
2 Trucks	61,007	61,007	33.33
1 Manitou (Maniscopique)	0	50,026	15
1 Small manitous	40,021	40,021	15
1 BELL T22D Timber truck	0	292,702	25
1 BELL 225A Debarker	0	117,653	25
1 BELL 220A Versalift	0	74,084	15
1 BELL 1010D Forwarder	0	271,300	25
Subtotal	326,755	1,172,174	
1.7. Office equipment and furniture			
Office furniture	3,813	3,813	25
Hardware	15,792	0	25

Other	0	0	25
Subtotal	19,605	3,813	
TOTAL INVESTMENT	2,075,686	2,564,685	

Table A4.3: Operating expenses (in euros) over eight years. Green are variable expenses, beige is fixed costs, and blue are financial costs.

	Years							
OPERATING DATA	1	2	3	4	5	6	7	8
1. Commodities Local								
Wood plantations (reforestation, including exploitation)	24,090	80,300	240,900	401,500	562,100	803,000	803,000	803,000
Logistics, transportation & processing	8,236	27,453	82,360	342,251	448,404	530,764	530,764	530,764
2. Other purchases of imported materials								
Empty bags (imported)	7,920	26,400	79,200	132,000	184,800	264,000	264,000	264,000
Empty pallets (imported)	1,904	6,348	19,044	31,740	44,436	72,790	72,790	72,790
Stretchable film (imported)	103	342	1,026	1,710	2,394	3,922	3,922	3,922
Sewing thread (imported)	68	228	684	1,140	1,596	2,614	2,614	2,614
3. Energy	1,665	5,550	16,650	27,750	38,850	63,640	63,640	63,640
4. Maintenance and caretaking								
Local maintenance								
Maintenance supplies	171	570	1,710	2,850	3,990	6,536	6,536	6,536
Maintenance, imported								
Spare parts	857	2,856	8,568	14,280	19,992	32,749	32,749	32,749
Guarding facilities	1,114	3,714	11,142	18,570	25,998	42,587	42,587	42,587
5. Transport consumed								
Travel purchases	50	168	504	840	1,176	1,926	1,926	1,926
Travel sales	747	2,490	2,864	1,494	3,237	5,354	4,358	4,731
Personal transport	34	114	342	570	798	1,307	1,307	1,307
Transport folds	16	54	162	270	378	619	619	619
Travel and trips	32,791	16,396	16,396	16,396	16,396	16,396	16,396	16,396
6. Rents								
Offices	40,500	15,120	15,120	36,720	36,720	28,836	26,503	28,780
Other rents	64,800	21,600	21,600	21,600	30,240	31,968	25,402	26,162
7. Training costs (0.5% of payroll)	6,069	6,069	6,069	6,069	6,069	9,942	9,942	9,942
8. Marketing and communication (2% of sales)	1,647	5,491	16,472	51,978	51,978	51,978	51,978	51,978
9. Overhead								
Workwear & consumable (local)	513	1,710	5,130	8,550	11,970	19,608	19,608	19,608
Other purchases (local)	684	2,280	6,840	11,400	15,960	26,144	26,144	26,144
10. Consumed services	0	0	0	0	0	0	0	0

11. Taxes and duties	47,291	47,291	48,191	48,191	49,656	49,656	49,656	49,656
12. Other charges	8,236	8,236	24,708	77,967	105,750	132,874	132,874	132,874
13. Internal staff costs	121,380	121,380	121,380	121,380	121,380	198,832	198,832	198,832
Chimney sweepers, jobbers	16,200	54,000	162,000	270,000	378,000	540,000	540,000	540,000
14. Financial expenses	4,576	4,576	4,576	4,576	4,576	4,576	4,576	4,576
TOTAL OPERATING EXPENSES	**486,306**	**832,107**	**1,342,342**	**2,517,453**	**3,215,575**	**3,286,314**	**3,273,348**	**3,276,820**

Table A4.4: Balance sheet for industrial charcoal production.

PROJECTED INCOME STATEMENT	1	2	3	4	5	6	7	8	Total
Charcoal	96,087	640,577	1,281,154	3,427,086	4,484,038	4,484,038	4,484,038	4,484,038	23,381,056
Charbriquettes	0	0	0	224,202	358,723	448,404	448,404	448,404	1,928,136
TOTAL products	96,087	640,577	1,281,154	3,651,288	4,842,761	4,932,442	4,932,442	4,932,442	25,309,193
Variable expenses	103,835	490,018	958,266	1,977,420	2,618,370	2,656,496	2,652,429	2,652,864	14,109,697
Fixed charges	377,895	337,513	379,500	535,458	592,630	625,243	616,344	619,380	4,083,963
Financial expenses	4,576	4,576	4,576	4,576	4,576	4,576	4,576	4,576	36,604
Total operating expenses	486,306	832,107	1,342,342	2,517,453	3,215,575	3,286,314	3,273,348	3,276,820	18,230,265
Budget surplus operating GROSS	-390,219	-191,530	-61,188	1,133,835	1,627,186	1,646,128	1,659,094	1,655,622	7,078,928
Depreciation and amortization >> GMDR kilns	250,474	250,474	250,474	250,474	250,474	250,474	250,474	250,474	2,003,794
Depreciation and amortization >> CML factory	475,715	475,715	475,715	475,715	475,715	475,715	475,715	475,715	3,805,718
Operating result	-1,116,408	-917,719	-787,377	407,646	900,997	919,939	932,905	929,433	1,269,417
Interest on medium- and long-term loans									
Net result before tax	-1,116,408	-917,719	-787,377	407,646	900,997	919,939	932,905	929,433	1,269,417
Taxes on profits				122,294	270,299	275,982	279,872	278,830	1,227,276
NET PROFIT	-1,116,408	-917,719	-787,377	285,352	630,698	643,957	653,034	650,603	2,863,645

Annex 5: Mitigation options

Greenhouse gas emissions from deforestation and forest degradation are the main source of emissions in the Congo, with 19.2 MtCO_2-eq per year in 2015 (PI REDD–11). The main drivers of deforestation and forest degradation are slash-and-burn agriculture, timber exploitation and wood energy. Improvements in the conversion of biomass to charcoal can reduce the associated GHG emissions. It is estimated that the mitigation potential could be around 100 Mt CO_2-eq per year in Central Africa alone (CDM Standard CA–11). Mitigation potential is derived from both avoided consumption of non-sustainable biomass and mitigation of CH_4 emissions during the carbonization process. Here we estimate the avoided emission based on the GMDR baseline data.

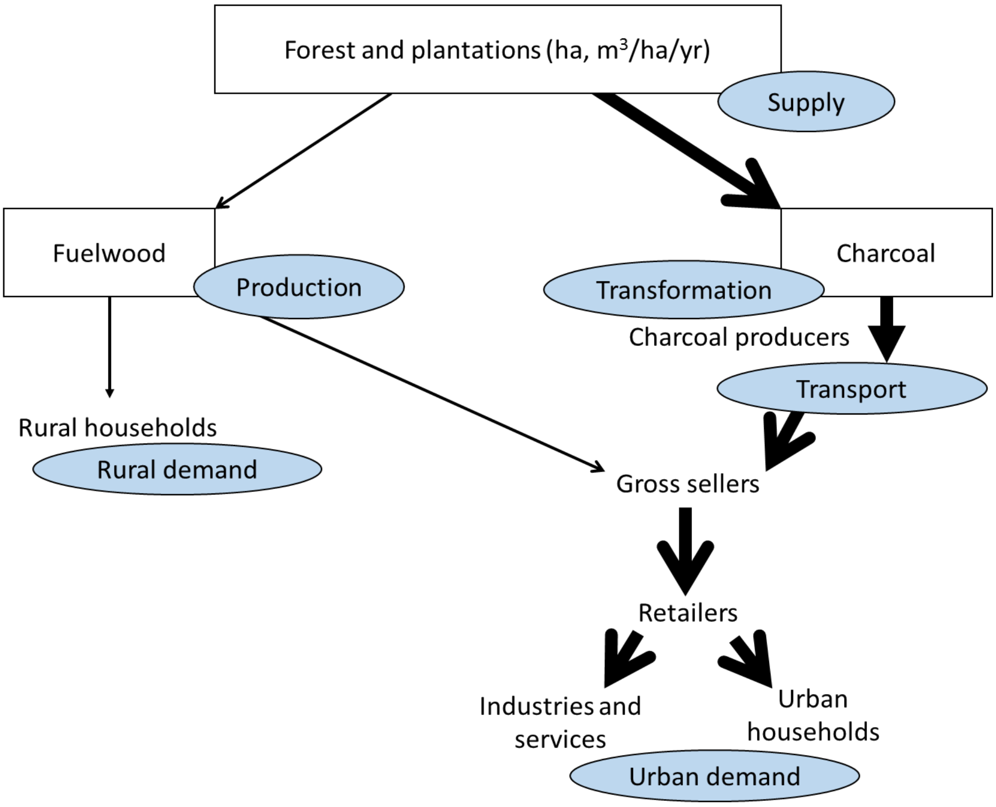
Table A5.1: Avoided Mg CO_2eq emissions for each scenario based on 1.75 Mg CO_2 eq Mg^{-1} of charcoal produced–GMDR baseline (Temmerman 2016).

Year	Semi-industrial	Industrial
1	315	315
2	1,050	1,050
3	3,150	3,150
4	5,250	9,940
5	7,350	13,482
6	11,550	16,940
7	11,550	16,940
8	11,550	16,940
Total	51,765	78,757

Annex 6: The supply chain

Currently in the Congo, the main actors involved in the charcoal supply chain are producers, transporters, gross sellers, retailers and consumers (figure A4.2). Producers are either temporary or permanent. Temporary producers (45% of total) usually work on a seasonal basis. Permanent producers (55%) are composed of unemployed and/or poor people. Some rural people use charcoal production as the sole source of income and make a living from it.

Figure A6.1: The current woodfuels supply chain



Producers can be differentiated according to their production capacity. Large producers use 4–5 times the area, perhaps working on contract and using chainsaws. Small producers are family-owned operations relying on hand tools. It is conventional wisdom that most of the wood resource is not sustainably managed, as producers take what is available, considering access and costs but not regeneration. Transporters can also be divided into 2 groups: those who rent vehicles to transport their own charcoal, and those who own vehicles and buy charcoal from producers. Depending on vehicle size, renting a vehicle costs from 200 to 500,000 FCFA. The biggest truck can load up to 20 m^3 or 100–150 30 kg bags of charcoal.

Gross sellers buy large quantities of charcoal from transporters. Depending on the trust between them, the payment is either immediate or delayed. Retailers buy from gross sellers a much smaller quantity of charcoal (on average 3–5 bags). This charcoal is then sold to consumers per kilo or small pack. Retailers sell charcoal in marketplaces or by passing in the streets as mobile vendors. Urban consumers can be divided into two groups. Small users are labourers, artisans and poor people using 6–18 bags per year. Larger consumers (middle class, government workers, restaurants, etc.) can use up to 180 bags per year.

Charcoal production is typical performed by males, though is sometime performed by women, because of the physical strength and endurance required to prepare and move the wood and bags. Women sometimes assist in supplying water and food to the site. Women and children also are sometimes involved in light tasks such as filling and sealing bags. Recently, however, women and children have become more visible on sites because of increasing poverty.

Annex 7: Methods and data collection

This feasibility assessment was based on a technical review of documents and key informant interviews. Documents including Boundzanga et al. (2004, 2014a, 2014b) provided the most up-to-date information on households' consumption, supply-chain descriptions and charcoal prices. Other documents, detailed in the bibliography, were also reviewed to provide information on technologies, efficiencies and other key input parameters. In addition to the document review, non-structured interviews of key informants were undertaken over a 10-day period in December 2017 in Brazzaville. Key informants included government representatives, donors and civil society.

Table A7.1. Key informants interviewed.

Name	Entity	Position
Isaac MOUSSA	United States Forest Service (USFS)	National Coordinator, Republic of Congo
Joseph BADEVOKILA	Congo Carbo Industrie	Project initiator and promoter
S.E. Madame Rosalie MATONDO	Ministry of Forest Economics	Ministre de l'EconomieForestière
Todd ROSENSTOCK	World Agroforestry Centre (ICRAF)	National Coordinator, Democratic Republic of Congo
Fulgence ITSOUA	Congo Environnement et Développement (ONG CEDEV)	
Julien PETITJEAN	ID	Responsable programme filières cuiseurs économes
Aurélie ROSSIGNOL	Banque Mondiale	Forest Program Officer
Maylis BORELLI	AFD	
Georges BOUNDZANGA		National Coordinator for REDD+
Jean-Parfait AMPALI, M. Filippini	United Nations Food and Agriculture Organization	
	BDEAC	
Cédric SEPULCRE	WWF	Congo conservation advisor
Lambert IMBALO	ProNAR	National Coordinator
Tsiba MOUAYA	Ministry of Forestry Economy	Advisor in charge of Afforestation and Forest planting
Mathieu Auger-SCHWARTZENBERG	FSC	Programme manager