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BioTrade2020plus

Supporting a Sustainable European Bioenergy Trade Strategy

Intelligent Energy Europe
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Deliverable WP 3

Progress report on WP 3 case studies Colombia

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The BioTrade2020plus Project

Objectives

The main aim of BioTrade2020plus is to provide guidelines for the development of a **European Bioenergy Trade Strategy for 2020 and beyond** ensuring that imported biomass feedstock is sustainably sourced and used in an efficient way, while avoiding distortion of other (non-energy) markets. This will be accomplished by analyzing the potentials (technical, economical and sustainable) and assessing key sustainability risks of current and future lignocellulosic biomass and bioenergy carriers. Focus will be placed on wood chips, pellets, torrefied biomass and pyrolysis oil from current and potential future major sourcing regions of the world (Canada, US, Russia, Ukraine, Latin America, Asia and Sub-Saharan Africa).

BioTrade2020plus will thus provide support to the use of stable, sustainable, competitively priced and resource-efficient flows of imported biomass feedstock to the EU – a necessary pre-requisite for the development of the bio-based economy in Europe.

In order to achieve this objective close cooperation will be ensured with current international initiatives such as IEA Bioenergy Task 40 on “Sustainable International Bioenergy Trade - Securing Supply and Demand” and European projects such as Biomass Policies, S2BIOM, Biomass Trade Centers, DIA-CORE, and PELLCERT.

Activities

The following main activities are implemented in the framework of the BioTrade2020plus project:

- Assessment of **sustainable potentials of lignocellulosic biomass** in the main sourcing regions outside the EU
- Definition and application of sustainability criteria and indicators
- Analysis of the **main economic and market issues of biomass/bioenergy imports** to the EU from the target regions
- Development of a dedicated and **user friendly web-based GIS-tool** on lignocellulosic biomass resources from target regions
- **Information to European industries** to identify, quantify and mobilize sustainable lignocellulosic biomass resources from export regions
- **Policy advice on long-term strategies** to include sustainable biomass imports in European bioenergy markets
- **Involvement of stakeholders** through consultations and dedicated workshops

More information is available at the BioTrade2020plus website: **www.biotrade2020plus.eu**

About this document

This report is a progress update of one of the six case studies to be developed under WP3 of the BioTrade2020+ project

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List of Abbreviations and units

CMS	Carbon molecular sieve
CPO	Crude palm oil
CSR	Corporate social responsibility
EFB	Empty fruit bunches
EU	European Union
FFB	Fresh fruit bunches
Ha	Hectare
MDF	Medium density fiberboard
PKS	Palm kernel shell
PO	Palm oil
POME	Palm oil mill effluent
POR	Palm oil residues
RPR	Residue to product ratio
Tonne	Metric ton equivalent to 1000 kg

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1. Introduction

1.1 General Introduction

The main objective of WP3 is to analyse the main economic and market issues concerning biomass/bioenergy imports to the EU from each of the six selected sourcing regions. Main elements are the analysis of current and future production and consumption volumes of biomass, identification of on-going and possible future trade routes and delivered costs, and potential risks of competition with other industries (both local and not) utilizing the investigated feedstocks per region.

In this work package, methodology to determine a net sustainable export potential of biomass and related cost and GHG supply curves will be applied and tested to six different country case studies: Brazil, Colombia, Kenya, Indonesia, Ukraine and the USA. For these six case studies, various potentials (technical, sustainable, market, etc.) will be determined.

The aim of this progress report is to highlight the status of the data collection and analysis until June 2015. In section 2, a summary of the methodology is presented. In section 3, the general case study description is presented (based on Deliverable 2.1). In section 4, a summary of the data collected and thus far and an overview of preliminary results are presented. Finally, in section 5, a short outlook on the further work and completion of the case study is given.

1.2 General BioTrade2020plus methodological approach

The methodology chosen for the selection of the regions followed the overall general methodology (See the general report on methodology). The methodology is divided in three main areas: the selection of the regions, the considerations for the theoretical potential in each region according to selected feedstock and the overall background information of the regions.

The focus regions include the US, Ukraine, Brazil, Colombia, Indonesia and Kenya. The feedstocks that will be considered are those which can produce different carriers such as wood chips, pellets, and torrefied biomass and pyrolysis oil.
The theoretical potential was calculated according to the availability of the selected feedstock and the residue production ratio identified in the literature as well as already calculated ratios and residues available.

The overall methodology is illustrated in **¡Error! No se encuentra el origen de la referencia.** according to the general methodology the selection of case studies and their assessment include the technological, and market potential, sustainable potential (see report on methodology Mai-Moulin et al, 2015).

The background information for the selected countries helped to identify the regions in each country that were more promising for the availability of the feedstock but also that included some of the technological facilities (including transportation and other logistics). The information provided from the Advisory Board (AB) also contributed to better select the particular regions. **¡Error! No se encuentra el origen de la referencia.**Figure 1 shows the methodology and information followed in this report.

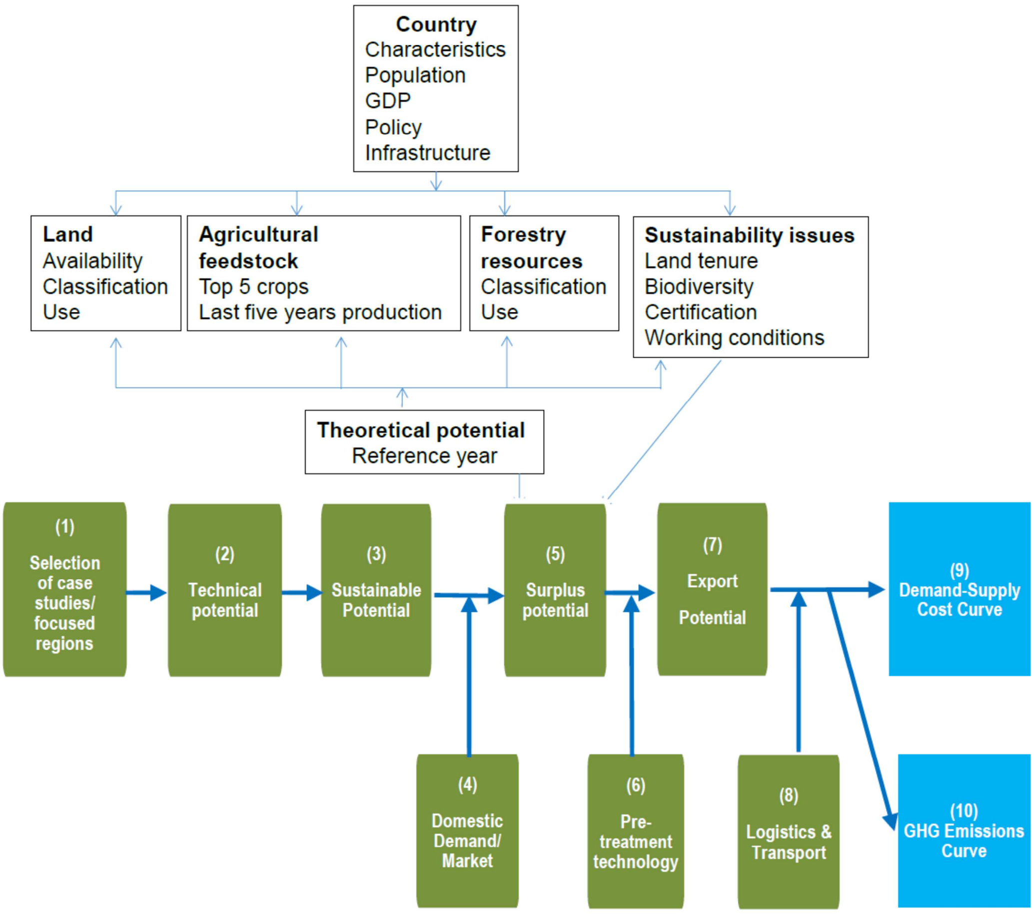

Figure 1. Methodology for selected countries and regions

The following section presents the information collected for the selected countries and regions. This was based in literature review, partners' previous work in the selected countries and information provided by the Advisory board members.

The detailed information and technical, sustainability and market potentials along with scenarios, is included in the specific case studies as the information needed requires more detail and in some cases field work provided mainly by students working in the regions.

Additional socio-economic issues such as the willingness to harvest and the management of the forests, in terms of the use of the resources (e.g. recreational, conservation, market) are not discussed in this report but considered in the specific case studies.

The summary of the countries and feedstock potential presented in this report is shown in Table 1

Table 1. Summary of countries and feedstock potential

Country	**Feedstock**				
	Forest residues	*Agricultural residues*	*Forest plantations*	*Biomass crops*	*New forest plantations*
Brazil		√		√	√

Colombia		√		√	
Kenya		√	√	√	
Indonesia		√			
United States	√		√		√
Ukraine	√	√		√	

2. Case study: Colombia[1]

2.1 Overview of the country

Population & Economy

Colombia had a population at 48.32 million in 2013 with a 1.3% annual growth (World Bank, 2013). Its GDP in 2013 was USD$378.1 billion with a 4.1% 5-year average growth. The country is heavily dependent on its rich natural resources such as petroleum, coal, natural gas and a variety of precious metals such as gold and platinum (Paiyi, 2009). The country is divided in 32 departments (Figure 2) and one capital district, Bogotá. Bogotá is also the capital of the department of Cundinamarca (Fields, 1980).

Figure 2. Map of the 32 departments in Colombia. (Source: Wikipedia)

Land Use

Colombia is a large country with diversified characteristics in terms of climate, soil, geology, topography, vegetation cover and current land use which forms the basis for six regions. It has a total area of 114 million ha, of which approximately 50% is covered with forest (Castiblanco et al, 2013), as shown in Figure 3. Colombia is one of the most mega-diverse countries worldwide (Dias, 2003). With only 0.77% of the world's land area it contains 10% of its known species (IDEAM, 2004). About 90% of its non-agricultural land is protected area. The main agricultural activities of Colombia are coffee, dairy, sugar, bananas, flowers, cotton and cattle (NL Agency, 2013). However, Only 9.6% or 4.1 million ha of agricultural land is used for crops. Annual crops represented 33% of the cultivated area, whereas permanent crops and plantations accounts for 59%, the rest 8% was fallow land (Figure 4). The most extensive land use is cattle grazing which accounts for over 70% of the agricultural land, usually exhibiting low productivity levels (McAlpine et al., 2009).

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[1] This section is based on Deliverable 2.1

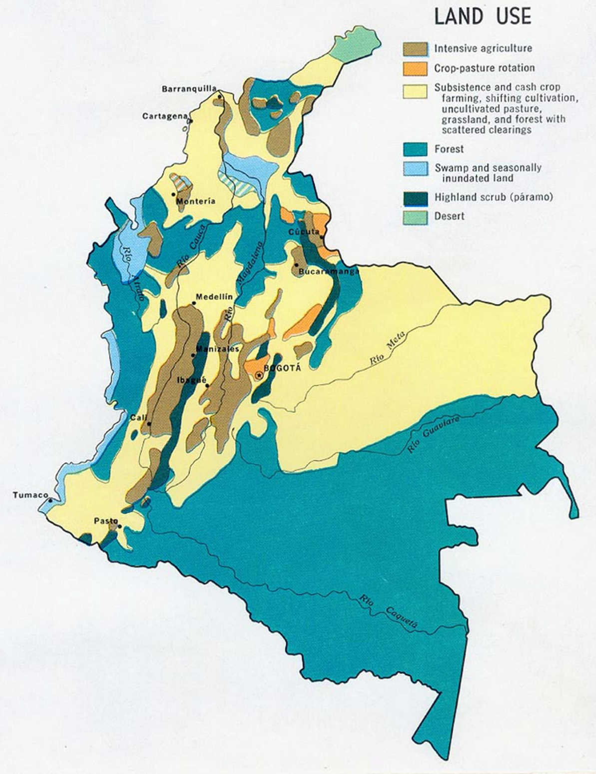

Figure 3. Land use in Colombia (Source: Colombia Environmental Ministry, 2014)

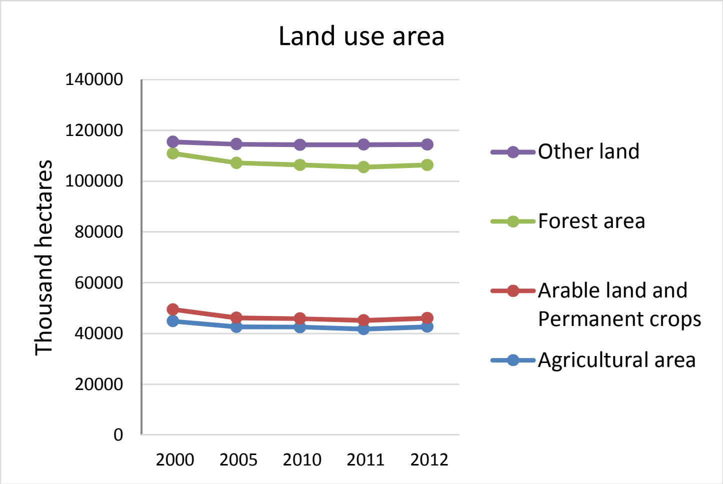

Figure 4. Land use area of Colombia. Source: FAOstat, 2015.

Energy Sector

The power market is liberalized in Colombia. In 2012, Colombia’s energy capacities installed, which is shown in Figure 5 consists of 64% large hydroelectricity, 17% natural gas, 7% oil, 7% coal and 5% renewables. In the remote areas, where conventional power generation is more expensive, many diesel 'mini-grids’ are under operation, which aims at an increase in renewable energy usage to 20% by 2015, and 30% by 2020 locally. On the other hand, as a country rich in fossil fuel resources, Colombia also exports large amount of net power, including coal, oil and natural gas to countries worldwide.

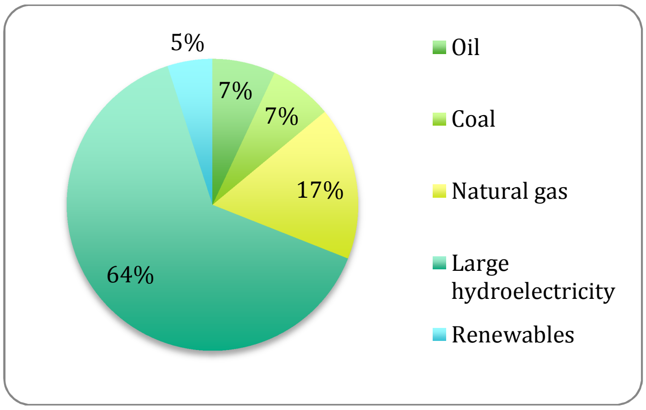

Figure 5. Energy sources in Colombia, 2012 (Source: BNEF)

2.2 Bioenergy and Biomass

Colombia is among the region's leading biofuels producers, it produced 324.7 million litres of ethanol and 173,043 tonnes of biodiesel in 2009 using sugar cane and palm oil as their main feedstock (NL Agency, 2013). The biofuel industry generates an estimated 24,000 direct and 48,000 indirect jobs (NL Agency, 2013). Sugarcane and palm oil were commercially introduced to Colombia since the early 1900s. As one of the countries with highest yield in the world, each of the crops contributes to approximately 4% of the GDP in the agricultural sector. Furthermore, current land use for bio-ethanol production only accounts of 405,737 ha (FOA stats, 2014) whereas the Ministry of Agriculture and Rural Development (MARD) estimates the area with potential for sugarcane production at 3.9 million ha. Hence, solid biomass residues produced from the sugarcane and palm oil processing industry, along with other agricultural and forestry residues present a great potential for domestic energy generation and export. Table 2 shows the main agricultural and forestry residues produced in Colombia and their feedstock will be assessed further. Banana and plantain residues could also mentioned here but they are unlikely to be converted into an exportable biomass product at a reasonable price due to the fact that the residues are produced in the field and have a high moisture content. The field residues also contain large amounts of minerals (mainly K) which represent a considerable value in the plantation and will lead to low quality biomass.

Table 2. Main biomass feedstock available in Colombia (MARD, 2014)

Type of feedstock	Residues
Oil Palm	EFB, fibres, shells
Sugarcane	Bagasse, leaves
Rice	Husk, straws
Coffee	Husk, stalk
Livestock	Manure
Forestry	Residues, fuel wood,

The National Interconnected System (SIN) features a total installed capacity of 15,465.25 MW: 206 MW correspond to cogeneration from sugar cane bagasse (Ministerio de Minas y Energia, 2015).
The types of sources that provide energy to the SIN are listed in the following Figure 6.

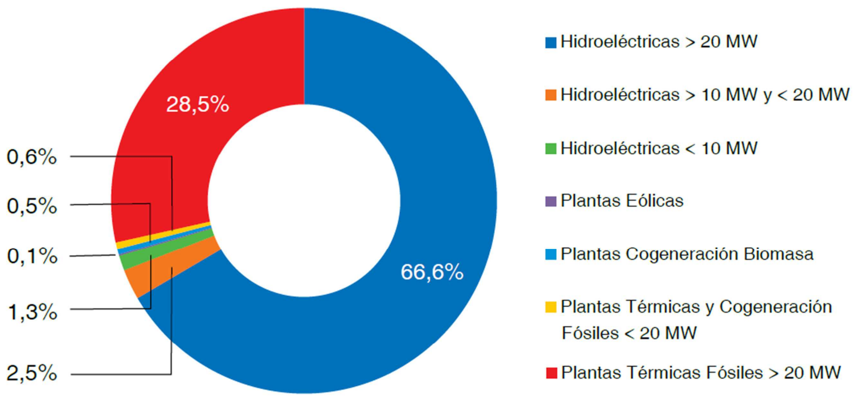

Figure 6. Total installed capacity: 15.645 MWSource: (Ministerio de Minas y Energia, 2015).

The National Energy Balance (BEN, for its acronym in Spanish) shows that natural gas is the main energy resource used by the Colombian industry. Pellets have been proposed as a future source of energy (Table 3)

Table 3. Energy resources in the National Energy Balance. Source: After Ministerio Minas y Energia. 2015.

Class	**Renewable/non renewable**	**Type**	**2010 %**	**2011 %**	**2012 %**
Primary	100% non renewable	Natural gas	39.87	33.68	39.64
		coal	12.17	28.66	16.37
		oil	5.49	0	0
	100% renewable	bagasse	9.97	8.02	8.59
		wood	0.19	0.14	0.18
		residues	3.15	2.15	2.83
Secondary	100% renewable	Charcoal	0.18	0.41	0.09
		BioDiesel	0	0	0
		Ethanol	0	0	0
		Ethanol	0	0	0
New energy fuels					
Secondary	100% Renewables	Biomass residues	2.83	1.94	2.55
		Biogas	0	0	0
		Pellets	0	0	0

Apart from its palm oil and sugarcane production which generate together the majority of agricultural residues in terms of volumes, Colombia also has large plantation areas for bananas, rice and coffee, of which their residues can be used as biomass for energy generation.

Both rice and coffee residues have high cellulose and hemicellulose content and low moisture content. For every ton of coffee beans produced, approximately 1 ton of husks are generated during their drying process, whereas for wet and semi-wet processing this residue amounts to more than 2 ton (Saenger et. al., 2001) (Table 4).

For rice husk, every ton of paddy produced, generates about 750 kg of rice straw and 250kg husk (Gadde et al, 2009). Hence, in 2013, 2,434,853 tonnes of rice were produced with 1,217,426 tonnes of rice residues, whereas 464,640 tonnes of coffee beans were produced with an estimation of same amount of husk (Table 4).

Table 4. Total production of rice, rice residues, coffee and coffee residues in 2013. *total straw available excluding the 2/3 left on land as soil fertilizer (European standard). (Gadde et al, 2009).

Rice paddy (tonnes)	Rice straw (tonnes)	Rice husk (tonnes)	Coffee beans (tonnes)	Coffee husk (dry tonnes)
2,434,853	1,826,139	608,713	464,640	464,640
Total residue	1,217,426 tonnes*		464,640 tonnes	

A summary of the residues from feedstocks with possibilities to be used for carriers to export to Europe is presented in Table 5. The Atlas produced in Colombia focuses on three different types of residues: agriculture, livestock and urban waste. Figure 7 shows the yearly production of agricultural residues by municipality.

Table 5. Summary of selected agricultural residues produced in Colombia: Source: Escalante et al, ny based on pre 2007 data.

Crop	**Yield (ton/year)**	**Type of residue**	**Origin of residue (C/I)**	**Residue factor**	**Yield of residue (ton/year)**	**Energy potential (TJ/year)**
Oil palm	872,117	shell	I	0.22	189,074	2627.44
		fibre		0.63	546,381	6778.89
		empty fruit bunch		1.06	924,618	6607.31
Sugar cane	2615,251	trash	C	3.26	8,525,718	41,707.22
		bagasse	I	2.68	7,008,873	76,871.65
Molasses sugar cane	1514,878	bagasse	I	2.53	5,680,790	62,305.56
		leaves	C	3.75	3,832,640	18,749.81
Coffee	942,327	pulp	I	2.13	2,008,192	7,206.79
		husk	I	0.21	193,460	3,338.57
		branches/stalk	C	3.02	2,849,596	38,561.52
Rice	2,463,689	Straw	C	2.35	492,738	20,699.41
		husk	I	0.2	1,878,194	7,136.53

C: crop harvest; I: Industrial

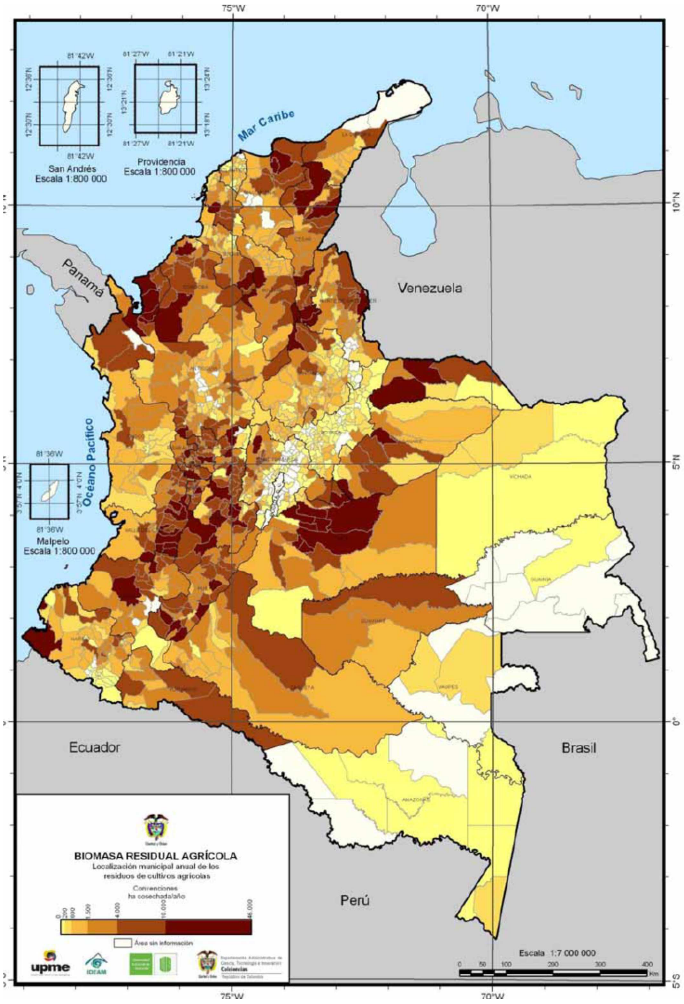

Figure 7. Municipalities with agricultural residues production per year (MARD, 2014)[2]

From Table 5, it becomes clear that the largest amount of residues, in terms of total biomass and per hectare volume, is produced in sugar cane, particularly the industrial sugar cane. In addition, industrial sugar cane also has the advantage of large spatial concentration in the Cauca valley (see Figure 8) which makes the logistical handling of the residues more efficient, also in relation to the location of harbours on the pacific coast.

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[2] Maps can be accessed in the MARD (2009) Biomass Atlas http://www1.upme.gov.co/sites/default/files/article/1768/files/Atlas%20de%20Biomasa%20Residual%20Colombia__.pdf

Figure 8. Municipalities’ annual production of residues of sugar cane (MARD, 2014).

The advantage of large spatial concentration also applies to oil palm residues (Figure 9) which have the largest production areas in the East and North of the country. Especially the eastern region has the potential for exports given the relative location near the Caribbean coastal port cities of Buenaventura and Cartagena. In the next further details are given.

Figure 9 Municipalities’ annual production of residues of oil palm (MARD, 2014)

Overall it can be concluded that of all agricultural residues sugar cane and palm oil have the best possibilities for providing relatively unused residues at relatively high spatial concentrations situated in regions at relatively near distance to sea-ports.

Forestry

Although more than half of the country's land is covered by forests, most of them are protected areas with diversity of animal and plant species. Hence, Colombia presents limited potential for forestry biomass compared to other types of biomass. The amount of forest residues and products produced in 2013 is presented in Table 6. It shows that chips and particles and charcoal are the main products in the country.

Table 6. The amount of different type of forestry products produced in Colombia, 2013 (MARD, 2014).

Type of forestry products	Amount
Chips and particles (m3)	227,000
Wood Fuel(C)(m3)	2,236,000
Wood Fuel (NC)(m3)	6,068,000
Wood Residues (m3)	61,000
Wood Charcoal (m3)	315,805

Another alternative in Colombia is the residues of bamboo. Although bamboo is present in forms of forests, in Colombia it is managed in the Environmental Ministry rather than in the Agriculture and Forestry Ministry. A report by ECN (Daza et al, 2013) estimated the residual guadua-biomass potential in Colombia (Table 7). Although the potential is considerable, torrefaction would need to be implemented to produce pellets as carriers rather than chips. This could be a possibility after 2020.

Table 7. Residual guadua-biomass potential

Natural stands	Hectares	kton/year	MWth
National	51,000	765	480
Coffee axis	28,000	420	260

Apart from the exploitation of *G. angustifolia* stands, an alternative scenario is the establishment of bamboo plantations as dedicated bioenergy crops. As for the coffee axis, when the total area with potential for high productivity is considered (125,000 ha).

2.3 Biomass potentials of oil palm and sugar cane

The main biofuel crops/products identified having potential for exports from Colombia are palm oil and sugarcane. The production of palm oil has been increasing in the last five years, demonstrating that the total sowed area is distributed in two stages: in production and in development.

3. Oil Palm

The milling process of the oil palm fruit in Colombia is one of the most important generators of biomass per cultivated hectare comparing to other oil or bioenergy type crops. In 2014, with its 62 extractor plants of palm oil and a productive area of 450.131 ha around the country, Colombia produced about 5 million tonnes of fresh fruit bunches (FFB) at a yield of around 19 tonnes fresh per ha, although the yields vary per region . It generates around 1mln tons of crude palm oil and around 250,000 tons of kernel. In addition, in the last couple of years there is a large expansion. Around 100,000 ha of additional land were cultivated for palm oil between 2008 and 2013. These additional palm oil areas came mostly at the expense of pastures, croplands and lands with natural vegetation (McAlpine et al., 2009). In 2010 the oil palm sector generated 2.6% of the agricultural GDP while its plantation area only occupied less than 1% of the total agricultural land area (FEDEPALMA, 2011) (Figure 10)..

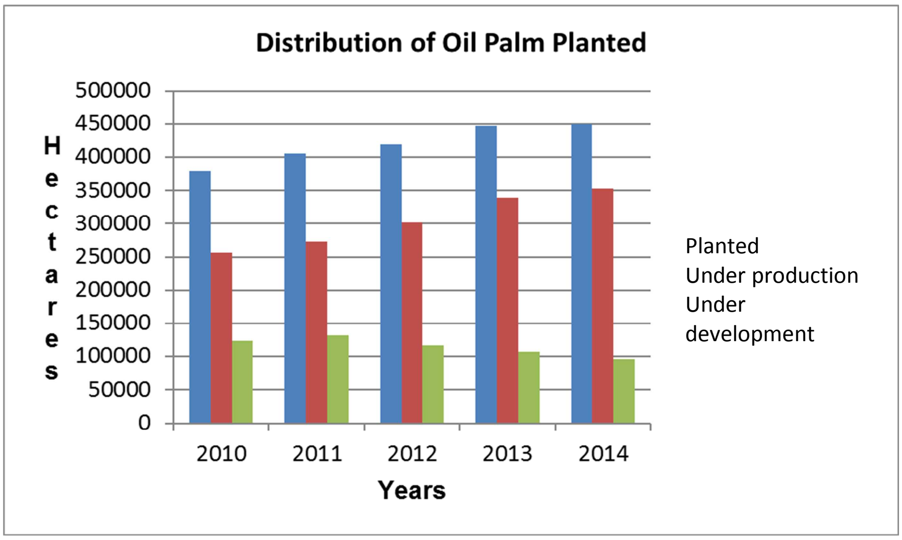


Figure 10. Planted area. Source: Statistical Yearbook: The Oil Palm Agroindustry in Colombia and the World 2010-2014.2015.

Palm oil plantations are located in four zones in 2014, north, central, east and the south-west zones, shown in Figure 11 and Figure 12. The East zone has the most plantations, which contributes to 39 % of total plantation area, followed by 32 % in central 26 % north and 4 % in south- west zones. The plantation area in the south-western zone mainly coincides with areas which were previously forested (Seeboldt and Salinas, 2010). Especially the palm oil production in the south-western zone has been lagging behind as compared to other zones because of poor infrastructure, armed conflicts, and the existence of collective territories of Afro- Colombian communities (See Boldt and Salinas, 2010; BID-MME, 2012) and more recently disease problems.

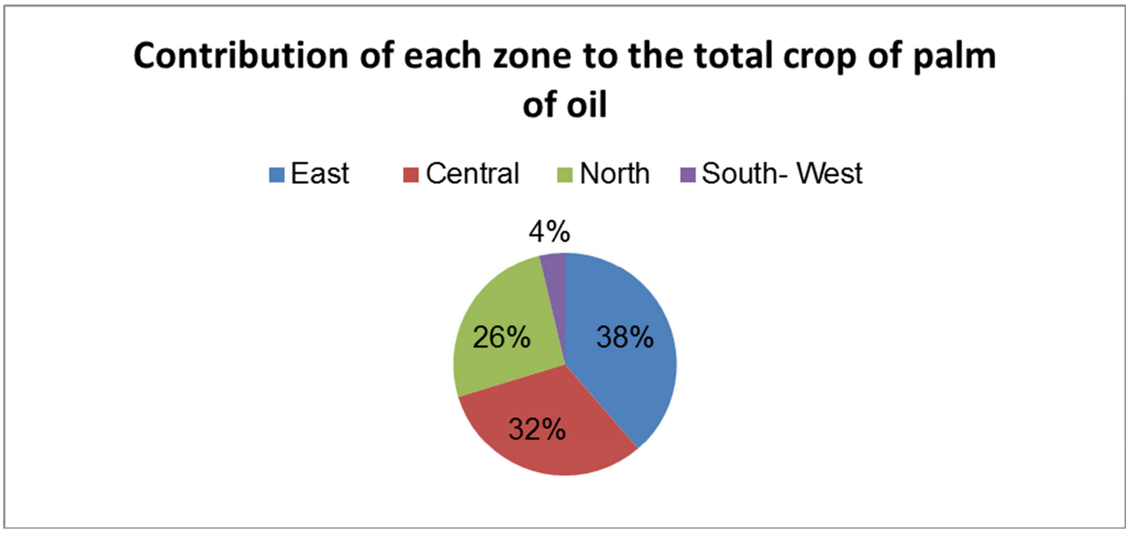


Figure 11. Oil palm production by region.

Figure 12. Crops of palm of oil in Colombia 2014 by FEDEPALMA (2011).

Given the increase in palm oil plantation and production, availability of considerable amounts of by-products of high energy value such as Fibre, Shell and EFB, (and POME) means that the oil palm industry has a possibility of generating electricity in isolated regions and/or exporting its biomass as energy sources (Garcia et al, 2010).

3.1 Technical potential

There are approximately 62 palm oil mills operating in Colombia. Most of the mills generate the combined heat and power from fibers, EFB and husks, making their operation self-sufficient in energy. Nevertheless, the use of residues of palm of oil can still be optimized in more energy efficient systems. Figure 13 shows the mills in Colombia.

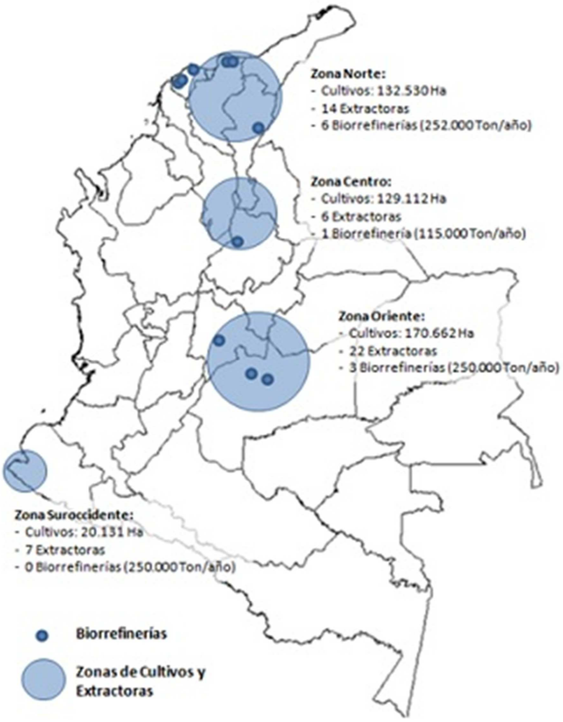


Figure 13. Production areas and locations of palm oil mills in Colombia (FEDEPALMA, 2015)

The production of cluster of fresh fruit generates residues in mainly two places: on the plantation and the extractor plants. The residues produced in the plantation consist of trunks and leaves. As plantations are relatively new in Colombia trunks are not considered and leaves are used as compost.

Oil Palm residues: Empty Fruit bunch, Fibre, Shell and POME

The types of residue generated by the industry of palm of oil include the 'tusa' or empty bunches of fruit (EFB), the Fiber ('fibra'), the Husk ('cuesco') and POME ('effluentes) as a potential source of fuel or biogas. The residues mentioned previously are generated in the extractor plants of palm of oil. The process used for generation of electric power from biomass and biogas is presented in Figure 14.

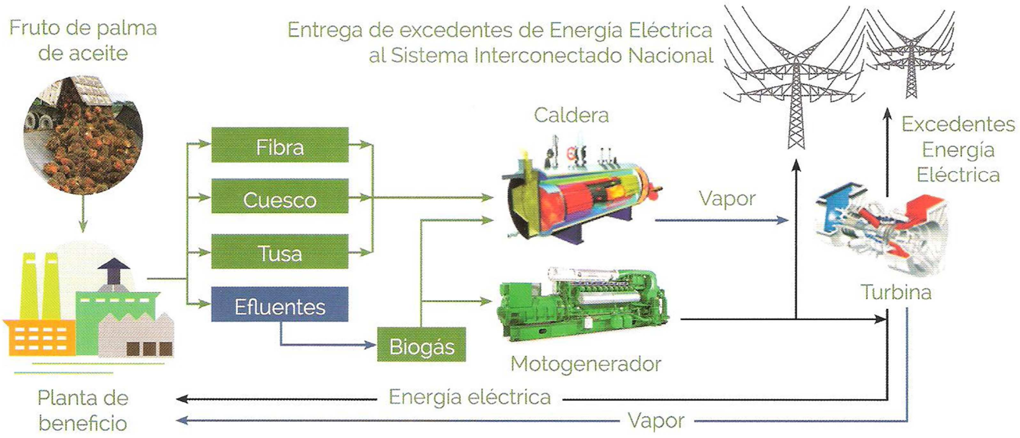


Figure 14. Energy generation from oil palm. Source: FEDEPALMA.2015.

The effluent POME, which is generated in the process of extraction is a liquid biomass, is characterized for having high loads of organic matter, residues of the produced oil, pH acid and contents of nitrogen, phosphorus and potassium. Anaerobic digestion of POME is being adopted to produce biogas (55-65 % of gas methane and carbon dioxide), which can be used as fuel. Solid residues EFB, shell and fiber have the potential to be converted to pellets and potentially be (partially) used for exports to EU.

Future developments in palm oil residues

In the future this status quo may change given land suitable for establishment of new plantations and former trends in oil palm plantation areas and yield developments. The land suitability for extension of oil palm plantations was assessed in a study by BID (2012) (see Figure 15). In this study a spatially explicit assessment was done of land availability for extension of oil palm plantations excluding the following categories of land:

1) protected areas and other areas of high biodiversity
2) low productive lands and land of high carbon stocks where conversion to palm oil would lead to high LUC and ILUC -GHG emissions and therefore not reaching a 40% GHG mitigation (as compared to fossil-diesel) if the palm oil would be used for biodiesel production
3) existing agricultural lands
4) land with large bio-physical limitations (marginal lands)
5) land that is inaccessible/remotely located away from road and other transport lines,

Based on the BID (2012) study it could be determined per department how much extra land in the suitable and moderately suitable category would be available for future development without adversely affecting biodiversity and the environment. According to these BID figures assumptions in this study were made about the future growth of palm oil production areas

Therefore area increase is only possible in regions where palm oil plantations already occur and where enough land for sustainable growth is available according to the BID study (2012) (see Table 8).

Table 8. Land suitability for oil palm towards according to the BID land suitability assessment (2012).

	Areas suitable for expansion (BID, 2012 study)			**total planted area, 2013 (Estadistica, Colombia)**
Region	**Moderately suitability**	**Suitability**	**total**	
ANTIOQUIA	350,000	50,000	400,000	1,104
ATLANTICO			-	357
BOLIVAR	70,000	-	70,000	27,287
CAQUETA	350,000	380,000	730,000	785
CASANARE			-	43,524
CAUCA			-	624
CESAR	80,000	-	80,000	72,896
CHOCO			-	5,137
CORDOBA	350,000	-	350,000	311
CUNDINAMARCA			-	8,574
LA GUAJIRA			-	1,375
MAGDALENA	400,000	-	400,000	66,864
META	800,000	600,000	1,400,000	178,303
NARIÑO			-	32,057
NORTE DE SANTANDER			-	24,281

	Areas suitable for expansion (BID, 2012 study)			**total planted area, 2013 (Estadistica, Colombia)**
Region	**Moderately suitability**	**Suitability**	**total**	
SANTANDER	10,000		10,000	102,635
SUCRE	40,000	-	40,000	50
TOLIMA	10,000		10,000	
VICHADA			-	130

3.2 Determining the sustainable potential of oil palm residues

For the sustainable potential the following issues were taken into account:

1) maintenance of soil organic carbon (SOC) and fertility
2) no use of high biodiversity areas (covered by BID study)
3) no use of high carbon stock lands with high LUC and ILUC GHG emissions when converted to palm oil plantations

The first criterion is covered by excluding the field residues, the trunks and leaves, as these are completely returned to the soil. Maybe more important. We estimate that the cost of collection is for now too high to be of interest.

The avoidance of the use of biodiversity rich and high carbon areas is covered in the BID (2012) study that excluded these areas from the surface suitable for extension of palm oil plantations.

3.3 Availability of palm oil residues form the Northern and the Central regions.

In Colombia there are 4 palm oil growing regions. The south western region is small and currently in crisis due to disease problems. The eastern region is large and expanding but is also relatively isolated behind the Andes mountain range. This makes export to a harbour very expensive for a relatively low value product such as pellets or pyrolysis oil made from residues. The cost of transporting one ton of biomass pellets from the eastern region to a harbour would cost more than $ 50 per ton.

This leaves the Central and Northern regions which may be able to export biomass residue products in the short to medium term.

We use the recent assessment by Ramírez et al (2015) as a basis for the biomass availability assessment. They assessed the production and current use of palm oil mill residues in 2013 in Colombia.

The lignocellulosic mill residues include the empty fruit bunch (EFB), the mesocarp fibre and the shell. On top of this palm oil mill effluent (POME) is produced which is increasingly used for anaerobic digestion followed by energy production. The fibre is used mostly for energy (stream and electricity) generation for the mill. Some is used for composting and a small portion is returned to the field without processing. The shell is used for energy generation (stream and electricity) and 21% is sold for different purposes including carbon black production. Some shell is also used as local road cover. A small portion is returned to the field (Table 9).

If shells are sold, the price paid (at the plant) is reported to be between $USD 15 (30.000 Colombian Peso) and $USD 26 (52.200 Colombian Peso) per ton (14% moisture) according to Ramírez et al (2015). Empty Fruit Bunch (EFB) has few uses except for composting.

Table 9. The current uses of palm oil mill residues in Colombia according to Ramírez et al (2015) for the year 2013.

Current uses:	**For mill energy generation**	**Compost**	**Other**	**To the field**
EFB	0.0%	24.8%	11.4%	63.8%
Fibre	73.9%	5.7%	3.5%	16.9%
Shell	71.7%	0.0%	24.6%	3.7%

The cost of returning EFB residues to the field is estimated at between 0.55 $USD per ton (1.100 Colombian pesos) for 5 km and 29 $USD per ton (58.000 Colombian pesos) for 60 km distance from mill to field. Considering that the DM content of EFB is between 30 and 50% this can be a considerable cost per ton of DM. In many cases the EFB is pressed to remove oil (2% extra) and to reduce weight and volume making transport less costly.

Due to high transport costs, residues are often distributed to fields close to the mill which may then receive too much residue, leading to over fertilization. In some areas the fly *Stomoxys calcitrans* uses EFB to breed leading to local pest problems for cattle and humans. Overall, the benefits of returning EFB to the field are less as the distance from mill to field increases.

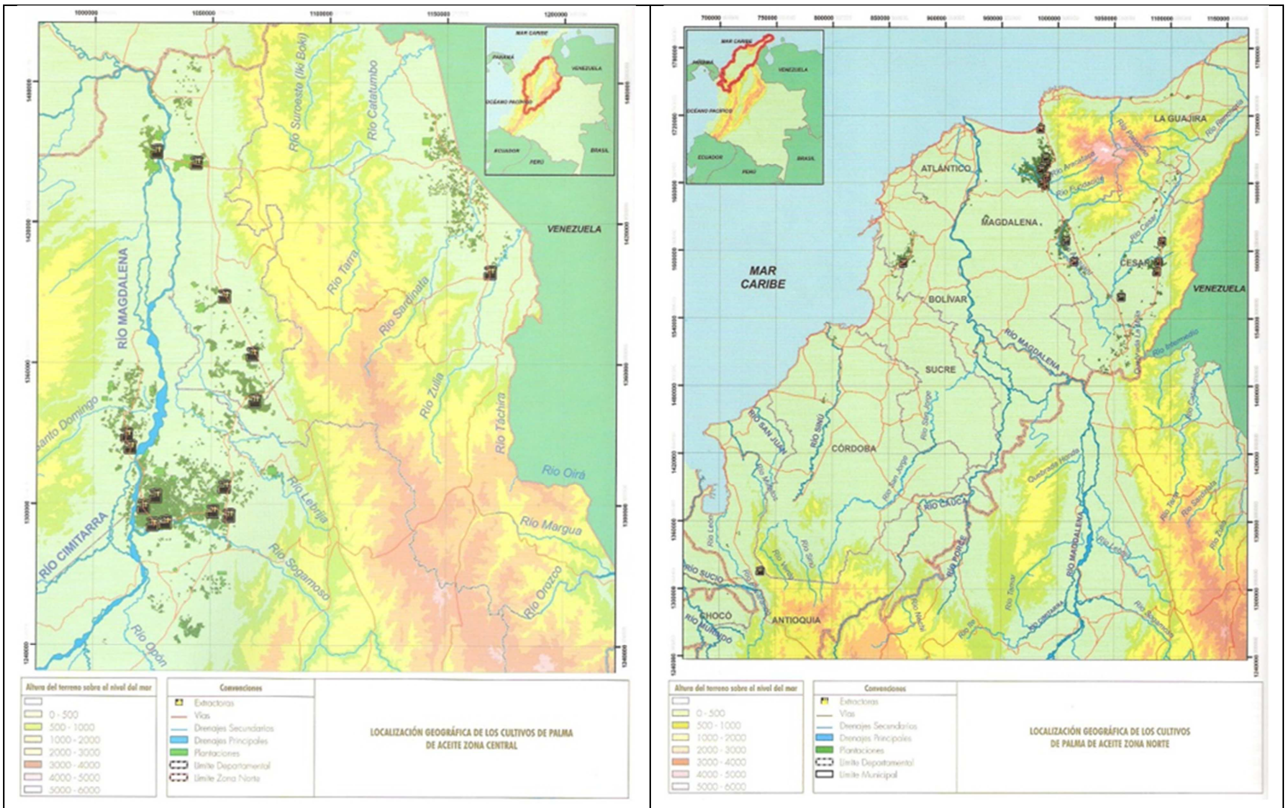
In the analysis by Ramírez et al (2015) the biomass that is returned to the field is considered available for other purposes. This is due to the costs and due to the fact that returning biomass to the field can lead to hygiene or emission problems (Table 10).

Table 10. Total palm oil mill residue production and current availability according to Ramírez et al (2015) for the year 2013.

5 million tons FFB production		**Characteristics**		**---- Total production ---**		**--------- Available for new uses -----------**		
	% of FFB	DM %	HHV (MJ/kg)	FW (ton)	DM (ton)	% of FFB	FW (ton)	DM (ton)
EFB	20.22%	35%	17.9	1,011,000	353,850	15.21%	760,500	266,175
Fibre	13.65%	65%	19.2	682,500	443,625	2.78%	139,000	90,350
Shell	5.63%	86%	21.5	281,500	242,090	1.59%	79,500	68,370
Total:	**39.50%**			**1,975,000**	**1,039,565**		**979,000**	**424,895**

Export potential

The average distance to harbour facilities in the Northern region is just over 100 km. The average distance to harbour facilities for the Central region is some 500 km, but there are options to lower transport cost if ship transport is used to Buenaventura harbour via the Magdalena river. Figure 15 shows the geographic distribution of palm oil plantations in the North and Central areas and the distance to the ports.



a) Central palm oil region

b) Northern palm oil region

Figure 15. Geographic distribution of oil palm plantations and mills in the Northern and Central palm oil regions of Colombia. Source: Fedepalma,2015.

To estimate the residue production and export potential we must know the current production in these areas and the expansion in production for 2020 and 2030 and the expected yield increases and the expected local use of the biomass to assess the availability for export in 2020 and 2030.

Palm oil expansion rate.

As described above the historical expansion rate of palm oil has been 6.5% per year in Colombia, though the expansion rate appears to be decreasing. Still, more than 20% of the area is under development, which takes only a few years to realize. The available land for expansion is also considerable in Colombia especially for the eastern zone which will not be considered for export here. The provinces in the Eastern and Northern zones are shown in Table 11. We see that here considerable expansion is possible.

Table 11. Land area suitable for palm oil for the different Colombian departments as assessed by BID[3] land suitability assessment.

	Areas suitable for expansion (BID, 2012 study)			total planted area, 2013 (Estadistica, Colombia)
Region	**Moderately suitable**	**Suitable**	**total**	
ANTIOQUIA	350,000	50,000	400,000	1,104
ATLANTICO			-	357
BOLIVAR	70,000	-	70,000	27,287
CAQUETA	350,000	380,000	730,000	785
CASANARE			-	43,524
CAUCA			-	624
CESAR	80,000	-	80,000	72,896
CHOCO			-	5,137
CORDOBA	350,000	-	350,000	311
CUNDINAMARCA			-	8,574
LA GUAJIRA			-	1,375
MAGDALENA	400,000	-	400,000	66,864
META	800,000	600,000	1,400,000	178,303
NARIÑO			-	32,057
NORTE DE SANTANDER			-	24,281
SANTANDER	10,000		10,000	102,635
SUCRE	40,000	-	40,000	50
TOLIMA	10,000		10,000	
VICHADA			-	130

Yellow = Northern region ; Blue = Central region

As shown in Table 12, the total palm oil plantation area is 450.000 ha of which 97.000 ha is under development. The current productivity per hectare is 15 tons FFB per hectare given that 5 million ton FFB is produced per years (Ramírez and Garcia-Nunez, 2015).

Table 12. The current production area in the Northern and Central Palm oil zones of Colombia.

Hectares	Northern zone	Central zone
Planted	173.861	142.493
In production	138.457	112.732
Under development	35.404	29.761

Table 133 shows the total residue availability for the Northern palm oil zone. We assume that under BAU the area under development is under production and that area expansion slows to 2.5 % between 2020 and 2030. For the HE scenario area expansion is 5% per year, which is still less than it has been over the last decade.

The FFB production is assumed to be 15 ton FFB per hectare on average. Keep in mind that relatively young stand in expanding areas have lower average productivity which increases over time.

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[3] BID-MME, 2012. Evaluacion del ciclo de vida de la cadena de produccion de biocombustibles en Colombia. Resumen Ejecutivo. Available at: www.fedebiocombustibles.com (accessed 20.03.2012).

We assume an increase in productivity of 1% under BAU en 2% under the HE scenario for whereby maximum productivity is reached in 2030 for the HE scenario of 20.6 tons of FFB per hectare.
Overall the yield will increase from 2 million tons FFB to 3.9 and 7.8 million tons of FFB per year under the two scenarios. For the residue production we assume that the production per ton of FFB stays the same expressed as % of FFB.

The availability of mill residues changes over time. Under BAU, more EFB will be used for compost production. Compost production will take off to improve soil quality, maintain soil moisture and nutrient recycling. Fibre and shell are less suited as a source for compost. EFB contains more nutrients and is less attractive as a feedstock for other purposes. Under the HE scenario EFB use for compost is maintained or increases slightly. EFB availability for export is between 10 and 15% (of FFB)

Elbersen et al (2013) showed that almost 100% of fibre and shell could be made available for other uses if energy efficiency is increased at the mill and if POME anaerobic digesters supply a large part of the mill energy needs. Fibre availability thereby increases from 2.78% now to 10% (of % FFB). For shells mill energy application can also be reduced considerably especially under the HE scenario.

Overall the availability of mill residues will increase from 176,489 ton DM now, as assessed by Ramírez and Garcia-Nunez (2015), to between 306,000 tons DM under the BAU scenario and 1.18 million tons under the HE scenario in 2030. Equivalent to between 5.8 and 22.9 PJ HHV per year (Table 13).

Table 13. Total production area and mill residue production for export in the Northern palm oil zone of Colombia under a Business As Usual and a High Export scenario for 2020 and 2030.

Northern zone		**Current**	**BAU**	**HE**	**BAU**	**HE**
Year:		2015	2020	2020	2030	2030
Area increase per year		-----	-----	5.0%	2.5%	5.0%
Area	ha	138,457	173,861	202,028	222,557	379,235
Yield increase per year	%		1.0%	2.0%	1.0%	2.0%
Yield	ton FFB/ha	**15.0**	15.9	16.9	17.6	20.6
FFB production	ton FFB per year	**2,076,855**	2,768,354	3,412,753	3,914,480	7,809,130
Total all (technical potential)	**ton DW**	**431,805**	**575,577**	**709,556**	**813,871**	**1,623,620**
Sustainable potential	**ton DW**	**395,388**	**476,553**	**647,205**	**673,850**	**1,480,947**
Mill residues exp potential	**ton DM**	**176,489**	**198,491**	**422,499**	**306,112**	**1,186,207**
Total all (technical potential)	HHV (GJ)	**8,330,249**	**11,103,848**	**13,688,526**	**15,700,948**	**31,322,359**
Sustainable potential	HHV (GJ)	**7,677,281**	**9,328,347**	**12,570,572**	**13,190,373**	**28,764,236**
Mill residues export potential	HHV (GJ)	**3,312,075**	**3,795,109**	**8,082,542**	**5,854,848**	**22,858,924**

Central palm oil zone.

The scenarios for the Central palm oil zone were similar to the Northern zone except for the growth rates. Based on the IBD study we assumed that less land will become available limiting the expansion rate to 1.5% per year for the BAU scenario and 2.5% for the HE scenario.
Overall the availability of mill residues will increase from 143,698 ton DM now, as assessed by Ramírez and Garcia-Nunez (2015) to between 250,884 tons DM under the BAU scenario and 769,711 tons DM under the HE scenario. Equivalent to between 4.8 and 14.8 PJ HHV per year (Table 14).

Table 14. Total production area and mill residue production for export in the Central palm oil zone of Colombia under a Business As Usual and a High Export scenario for 2020 and 2030.

Central zone		Current	BAU	HE	BAU	HE
Year:		2015	2020	2020	2030	2030
Area increase per year		-----		2.5%	1.5%	2.5%
Area	ha	112,732	142,493	151,072	182,403	246,080
Yield increase per year	%		1.0%	2.0%	1.0%	2.0%
Yield	ton FFB/ha	15.0	15.9	16.9	17.6	20.6
FFB production	ton FFB per year	1,690,980	2,268,888	2,551,968	3,208,229	5,067,223
Total all (technical potential)	**ton DW**	**351,577**	**471,731**	**530,587**	**667,033**	**1,053,542**
Sustainable potential	**ton DW**	**321,925**	**390,573**	**483,963**	**552,274**	**960,963**
Mill residues export potential	**ton DM**	**143,698**	**162,679**	**315,934**	**250,884**	**769,711**
Total all (technical potential)	HHV (GJ)	**6,782,508**	**9,100,492**	**10,235,925**	**12,868,183**	**20,324,591**
Sustainable potential	HHV (GJ)	**6,250,859**	**7,645,326**	**9,399,949**	**10,810,566**	**18,664,665**
Mill residues export potential	HHV (GJ)	**2,696,699**	**3,110,396**	**6,043,916**	**4,798,517**	**14,832,800**

3.4 Palm residue pellet production cost assessment

In the previous section the availability of palm residues has been assessed. The results show that currently there is available up to 176,000 ton DM in the Northern zone and 143,000 ton DM in the Central zone. In each of the zones there are clusters of mills that together could provide sufficient biomass to supply a medium sized pellet plant of 50.000 tons DM per year. Over time much more biomass could be sources in the regions.

A first assessment of the production and delivery of EFB pellets is presented with similar assumptions as for sugar cane pellets. The estimated cost is €118 per tonne delivered or €6.5 per GJ.

The largest uncertainties lie in the cost of acquiring the pressed EFB and in the cost of cleaning the EFB. Though the price of EFB may now be considered negative the cost of contracting a secure supply over a longer period may require paying a significant price. Also the cost of cleaning the EFB to make a pellet that has a certain quality that will fetch a price that lies close to the price of wood pellets has not been assessed. The procedure will require repeated leaching steps with clean water followed by pressing of the EFB. The estimate given here of € 10 per tonne DM is very preliminary. The cost of pellet production is the most important factor.

The transport cost assumes that a bulk carries is used, which assumes large loads of up to 50.000 ton. Clearly a certain scale is needed to be able to fill such a ship regularly. The price of wood pellets can be as high as €150 in Europe. It is important to consider that wood quality cannot easily be achieved. So the pellets will have to be sold at a lower price and this price is uncertain (Table 15).

Table 15. Cost assessment of EFB pellet production and delivery from the **Northern palm** oil growing zone of Colombia to Rotterdam.

Item	value	Explanation
Moisture content of pressed EFB	50%	
Price of pressed EFB	€ 2.5	€/tonne FW

Price of EFB?	€ 5.0	€/tonne DM
Cost of cleaning EFB	€ 10.0	€/tonne DM
Cost of transport to plant	€ 4.0	€/tonne DM
Energy content of pressed EFB	18.0	GJ/ton LHV
Energy cost of drying	15%	%
Cost of EFB including washing	€ 21.25	€/tonne DM
Pelletizing:	€ 50	€/tonne DM pellet
Loading 1.5 €/ton	€ 1.5	€/ton
Transport to harbour	€10	€/ton
Harbour cost (incl storage and loading)	€20	€/ton
Transport to Santa Marta or Baranquilla:	€ 11.0	$12.41 per track truck, similar to Cali to Buenaventura cost
Transport by ship Buenaventura to Rotterdam	€ 15.0	Panamax bulk, current prices
Cost per ton pellet delivered	**€ 117.75**	**€/tonne pellet delivered at Rotterdam**
Cost per GJ	€ 6.54	**GJ/ton LHV**

If a similar plant is placed in the Central zone similar cost apply albeit with higher transport costs. Based on INVIAS (2015) data, transport to a harbour in Colombia over a distance of 600 km could cost $ USD 45- per tonne (= € 40 per tonne). The total cost would then be €148 per tonne delivered or €8.2 per GJ. This could still be acceptable if the quality is sufficient. Inland transport by ship over the Magdalena river may reduce the cost.

3.5 Cost supply curves for Palm oil residue pellets

The cost supply curves are given in Table 16 it is assumed that for the two regions the cost for buying the residues increases from €2.5 to € 10 for each 1/3 of the available residue.

Table 16. Cost supply information

Region	Fraction used	Amount	Residue cost	Trucking cost per ton pellet	Cost of pellet delivered to Rotterdam FOB	
		Ton DM	Ton FW	per ton pellet	per ton	per GJ
Palm North	1/3	58,830	€ 2.5	€10	**€ 117.75**	**€ 6.54**
	2/3	58,830	€ 5.0	€10	€ 123.50	**€ 6.86**
	3/3	58,830	€ 10.0	€10	€ 135.00	**€ 7.50**
Palm Central	1/3	47,899	€ 2.5	€40	€ 147.75	€ 8.21
	2/3	47,899	€ 5.0	€40	€ 153.50	**€ 8.53**
	3/3	47,899	€ 10.0	€40	€ 165.00	**€ 9.17**

The different scenarios are summarized in Figure 16.

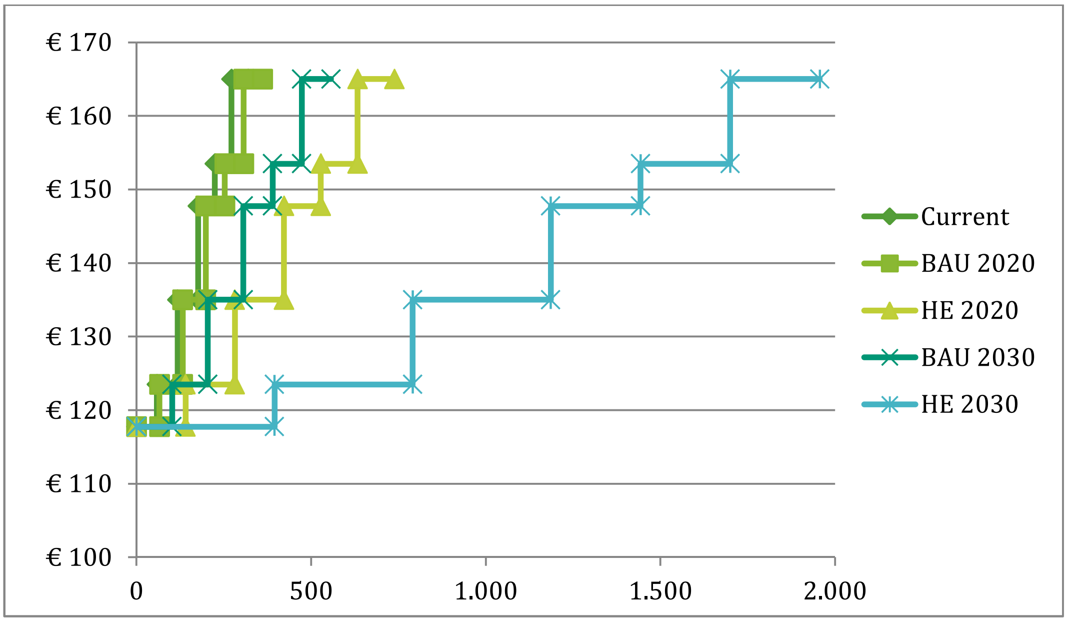

Figure 16. *Cost supply curve for palm oil mill residue delivery from Colombia to Rotterdam (FOB)*

4. SUGAR CANE

4.1 Sugar cane biomass potential

In the Cauca river valley, spanning some 200 km between the eastern and central Andes ranges of Colombia, virtually all sugar cane for large scale processing is grown in Colombia (Figure 17). Close to 50% of the area is covered with 220,000 ha of sugar cane which is processed at 12 factories into sugar and ethanol. Ethanol is used for blending with gasoline in transport. Sugar is used for local consumption and a large part is also exported (OECD, 2015). The Cauca valley, with an altitude of 1200 m above sea level, has excellent conditions for sugar cane growing, leading to sugar cane yields of 120 tons per ha per year and year round harvesting, making efficient use of factory facilities possible. Climate conditions can reduce yield considerably, as has happened in 2013 during flooding caused by "la Niña".

Figure 17. Cauca Valley sugar cane region indicating the sugar cane area and the sugar cane mills.

Based on Hasuani et al. (2005) we estimate the amount of residues produced at 140 kg DM of bagasse originating at the mill and 140 kg DM of trash per ton of sugar cane harvested in the field. Trash consists of the brown leaves, green leaves and the green tops which are all left in the field during (mechanical) harvest. In mechanical harvesting some of the trash is not removed during mechanical harvesting. These leaves are later processed and end up with the bagasse or they are removed and converted into compost together with some other residues at the mill (pers. comm. From Cenicana and mill personnel).

Current use of sugar cane residues:

Bagasse is currently used for co-generation at the mill producing energy for the sugar and ethanol production process and for electricity production using high pressure boilers. Cogeneration capacity of the mills is set to increase from 187 MW in 2013 to 360 in 2017, with a 300 days per year availability (Presentation by Johan Martinez, Asocana). In total 80% of bagasse is used for energy generation. The remainder, 20% of the bagasse, is sold for pulp production. The price is equivalent (on an energy basis) to coal. Actually, bagasse is sold in exchange for coal (pers. comm. Johan Martinez, Asocana). Trash is generally left the field and arranged into rows manually as to not cover the new sprouts.

Alternative uses of sugar cane biomass

Alternative uses of sugar cane residues are being discussed and developed in Colombia currently. The national oil company of Colombia, Ecopetrol, has been developing second generation ethanol production using from bagasse and EFB (Palm empty fruit bunch) over the last years. A pilot plant with a one ton (input?) capacity per hour has been implemented.

Expansion of electricity production is also an option. Recently the new law, “no 1714”, was passed that aims to support renewable electricity production. It is currently not clear if this will also lead to substantial more use of sugar cane residues for this purpose.

Sugar cane production development

The capacity to expand sugar cane production is virtually absent in the Cauca River Valley where some 50% of the area is covered with 225.000 ha of sugar cane, which is almost the total area that can be planted (USDA, 2014) There has actually not been any expansion in sugar cane production area in the Cauca River Valley in the past years. In other areas sugar cane is expanding in Colombia. Especially in the Llanos area, east of the Andes, where a large unused supply of land is considered available. Conversion of extensively used cattle pastures into cash crops like sugar cane and oil palm is taking place (Figure 18). The geographic conditions and lack of transport infrastructure make export unrealistic in the years to come. Therefore focus for biomass export should be on the Cauca River Valley which is separated by a lower range of the Andes and some 100 km from the port of Barranquilla.

Higher productivity per hectare is still possible and likely is happen, assuming that investments in better varieties and production systems are made. For now we can assume a 1% production increase per year.

Figure 18. Photos of mechanical harvesting of sugar cane and view of trash in the field after harvesting which is put on rows to permit regrowth of sprouts.

In Table 17 the production and availability of sugar cane trash is shown together the relevant assumptions. An important assumption is that trash availability is 50% of the trash currently left in the field, after mechanical harvesting. This value should depend on the cost of removal and the need for maintaining soil quality. A 50% availability is also assumed by other (Pippo et al., 2011)
The current (2015) availability of trash is therefore estimated at 840.000 tons DM per year. If there is some economic demand for the trash, and expansion of mechanical harvesting, we may assume that in 2020 field burning could be reduced to 40 % and to 25% in 2030. Higher productivity and better agronomic practise should make it possible to increase trash removal to 75% by 2030 and a 1% yield increase is assumed, trash availability would amount to 1.2 million tons DM 2020 and 2.2 million tons DM in 2030.
We can conclude that there is room for several medium scale pellet plants in the Cauca river valley. One average size mill could accommodate a pellet mill with a capacity of 50.000 to 100.000 tons per year.

Table 17. Sugar cane trash availability in the Cauca river valley.

		Current	**BAU**	**HE**	**BAU**	**HE**
Year:		2015	2020	2020	2030	2030
Area	ha	200000	200000	200000	200000	200000
yield increase per year			0.5%	1.0%	0.5%	1.0%
Sucar cane production	Ton per hectare	120	123	126	129	146
Bagasse per ton of cane		140	140	140	140	140
Trash per ton cane	kg DM	140	140	140	140	140
Machanical harvest	%	50%	50%	60%	60%	75%
Harvestable %		50%	50%	55%	60%	70%
Local use		0%	5%	10%	20%	10%
Technical potential (trash + bagasse)		5,040,000	5,167,266	5,650,230	5,793,622	7,174,717
Technical Trash potential	ton DM per year	1,680,000	1,722,422	2,118,836	2,172,608	3,074,879
Sustainable potential	ton DM per year	840,000	861,211	1,165,360	1,303,565	2,152,415
Export potential	**ton DM per year**	**840,000**	**775,090**	**953,476**	**869,043**	**1,844,927**
Technical potential (trash + bagasse)	GJ per year	90,384,000	92,666,309	101,139,118	103,705,841	128,119,954
Technical Trash potential	GJ per year	29,232,000	29,970,145	36,867,751	37,803,386	53,502,893
Sustainable potential	GJ per year	14,616,000	14,985,072	20,277,263	22,682,032	37,452,025
Export potential	**GJ per year**	**14,616,000**	**13,486,565**	**16,590,488**	**15,121,354**	**32,101,736**

Quality of trash and bagasse

Table 18 gives an indication of the quality characteristics of sugar cane trash and bagasse. As expected the ash content is lower for bagasse at 4% compared to 7.7% for trash. The energy content is also lower at 17.4 for trash vs 18.2 MJ/ kg daf for bagasse. A more dramatic difference is the 10x lower Cl content of bagasse and the much higher ash melting temperature 1272 °C compared to 1025 °C for trash. Part of the ash content may be from contamination. This means that with good management the ash content could be lower.

Table 18. Median quality characteristics of sugar cane trash and bagasse (from the ECN Phyllis database).

		Trash	**Bagasse**
Ash	% dry	7.72	3.99
LHV	MJ/kg daf*	17.38	18.17
HHV	MJ/kg daf	18.69	19.37
C	wt% (daf)	47.49	49.03
H	wt% (daf)	6.09	5.98
N	wt% (daf)	0.54	0.46
S	wt% (daf)	0.09	0.07
O	wt% (daf)	45.81	44.47
Cl	mg/kg (daf)	3596	368.9
IDT	°C	1025	1272
SOT	°C	1200	1321

*daf = dry and ash free

Hasuani et al (2005) show similar data, albeit the ash content is lower than reported from the Phyllis database. They also show the difference in composition between the 3 trash components: dry leaves, green leaves and tops. The main quality characteristics for thermal conversion such as Cl, K, N, and total ash are all lower in bagasse than in trash. Within the trash, the brown leaves have much better characteristics than green leaves and especially the green tops. Hasuani also estimated the DM weight per hectare of the dry leaves, green leaves and tops (Table 19).

Table 19. Trash and bagasse composition data from Hasuani et al 2005

	---------------------------- **Trash** ----------------------------------			**Bagasse**
	Dry leaves	Green leaves	Tops	
	------------------------------------ % of DM weight --			
Ton DM per hectare	11.8	1.6	0.3	
Moisture content	13.5	67.7	82.3	50.2
Ash	3.9	3.7	4.3	2.2
Fixed carbon	11.6	15.7	16.4	18.0
Volatile matter	84.5	80.6	79.3	79.9
C	46.2	45.7	43.9	44.6
H	6.2	6.2	6.1	5.8
N	0.5	1.0	0.8	0.6
O	43.0	42.8	44.0	44.5
S	0.1	0.1	0.1	0.1
Cl	0.1	0.4	0.7	0.02
	--- g/kg DM --			
P2O5	0.5	2.0	2.5	0.5
K2O	2.7	13.3	29.5	1.7
CaO	4.7	3.9	2.6	0.7
MgO	2.1	2.2	2.5	0.5
Fe2O3	0.9	0.5	0.2	2.3
Al2O3	3.5	1.4	0.5	2.3

Franco et al (2013) distinguished only green tops and dry leaves and determined the weight and composition of each as described in Table 20.

Table 20. Composition of green tops and dry leaves according to Franco et al (2013).

	Fresh Matter	Dry Matter	Moisture	N	K	P	Ca	Mg	S
	------------ ton/ha --------------		------%----	------------------- g/kg DM ---------------------					
Tops	12.8	4.9	62	7.5	12.4	0.86	6.8	1.7	1.5
Dry Leaves	6.3	5.8	9.2	3.4	1.8	0.17	5.3	2.5	1.5

Options for sugar cane trash or bagasse delivery for pellet or pyrolysis oil production

Currently trash has no uses apart from soil amendment. As a soil amendment it does have a value which is however hard to calculate. The nutrient content can be calculate and converted into a value. The biomass/carbon also has a value which is much harder to express. As discussed above, we assume that using 50% of the trash should be acceptable. We anticipate a system in which the green tops would be left in the field and the lower/brown leaves (more than 50% of the trash) would be transported to the mill for processing, as has also been proposed by Franco et al (2013). They estimate that the tops contain 80% of the N, P and K. Thereby decreasing fertilizer cost and increasing biomass quality for thermal conversion.

Two options for biomass mobilisation for pellet production should exist:

Option1: Trash harvest for pellet production

Option 1 is to remove 50% of trash per harvest cycle and use it for pellet production after a washing and drying and grinding procedure. It would be logical to harvest the old leaves and leave the green tops behind. This will ensure that most of the nutrients are left behind and a significant part of the biomass (50%). This will increase the thermal conversion quality of the trash and require less washing and perhaps lower losses during the washing steps. At this moment few data can be found to estimate the cost of trash harvesting and transport to the mill. Also the cost of trash washing has to estimate. Hassuani et al (2005) tested 3 trash recovery systems and estimated the total cost of delivery of trash to the mill between $13,70 to $31,12 per dry ton delivered. The recovery of trash varied between 50 and 66%. The cost included cost of negative soil effects.

Option 2: Bagasse for pellet and trash for boiler fuel replacing bagasse.

Option 2 is to make pellets from bagasse and use trash as a replacement for the bagasse in the high pressure boilers. Bagasse generally has 50% moisture and 80% is used for energy production in efficient high boilers for the mill and for electricity production for the grid. 20% is used for pulp production. The value of the bagasse when traded is equivalent to the cost of coal, which replaces bagasse. Making bagasse pellets for export is hardly an option because it will be replaced by coal. The purpose of pellet use in the EU is to replace coal and other fossil fuel use in order to reduce GHG emissions. If however, mills would agree to replace bagasse by trash for energy production this could be a sustainable option. This could therefore be a fall-back option if production of trash pellets is not a viable option. The question would then be if the mills would be willing to replace bagasse by trash and at what cost that would be. It seems likely that the efficient high pressure boilers at the sugar mill would also require washed trash to increase quality. This cost would then have to be added to the price of bagasse. For now we assume a 30% premium over the cost of coal.

For the preliminary cost estimation we used typical values derived from Ehrig et al 2014 and own estimates. The energy content of coal is 25GJ/ton (LHV) we assume a price for local delivery of coal of $42 per ton (Table 21).

Table 21. Cost estimate of bagasse pellet production at approximately 100.000 ton pellets per year in Colombia and transport by sea to Rotterdam, with trash replacing bagasse as a boiler fuel.

Cost item	Value	Dimension
Delivered price of coal in Colombia:	€ 42	€ per ton
Energy content of coal	25	MJ/kg
Energy content of bagasse	8	MJ/kg as is
Moisture content of bagasse	50%	
Cost of bagasse (based on price of coal)	€ 13.44	€/ton wet
Cost of bagasse?	€ 26.88	€/ton DM
Premium if bagasse is replaced by trash:	20%	Premium increases from 20% to 40% to 60%.
Energy content of pellets	17.5	€/ton DM
Biomass cost incl. cleaning of trash	€ 32	€/ton DM pellet
Price of bagasse including premium	€ 32.26	€/tonne DM pellet
Pelletizing	€ 50.00	€/ton pellet
Loading	€ 1.50	€/ton
Transport to Buenaventura:	€ 10.00	$12.41 per track truck
Harbour cost, incl. storage and unloading/loading	€ 20.00	€/ton
Transport by ship Buenaventura to Rotterdam	€ 20.00	**€/ton** Transport 5194 nautical miles including Panama Canal.
Cost per GJ	**€ 133.76**	**€/tonne pellet delivered at Rotterdam**
Cost per GJ	**€ 7.64**	**€/GJ**

A first estimate shows that bagasse pellets could be delivered to Rotterdam at a cost of approximately €134 per ton equivalent to €7.6 per GJ (Table 22).

Table 22. Summary of costs.

Fraction used	Amount	Residue cost	Cost of pellet delivered to Rotterdam FOB	
	Ton DM	Ton FW	per ton	per GJ
1/3	280,000	€ 35	€ 134	€ 7.6
2/3	280,000	€ 38	€ 139	€ 8.0
3/3	280,000	€ 43	€ 144.5	€ 8.3

Cost supply curves for sugar cane bagasse pellets

The cost supply curves under current, BAU 2020/2030 and HE (high export) scenarios are shown in Figure 19.

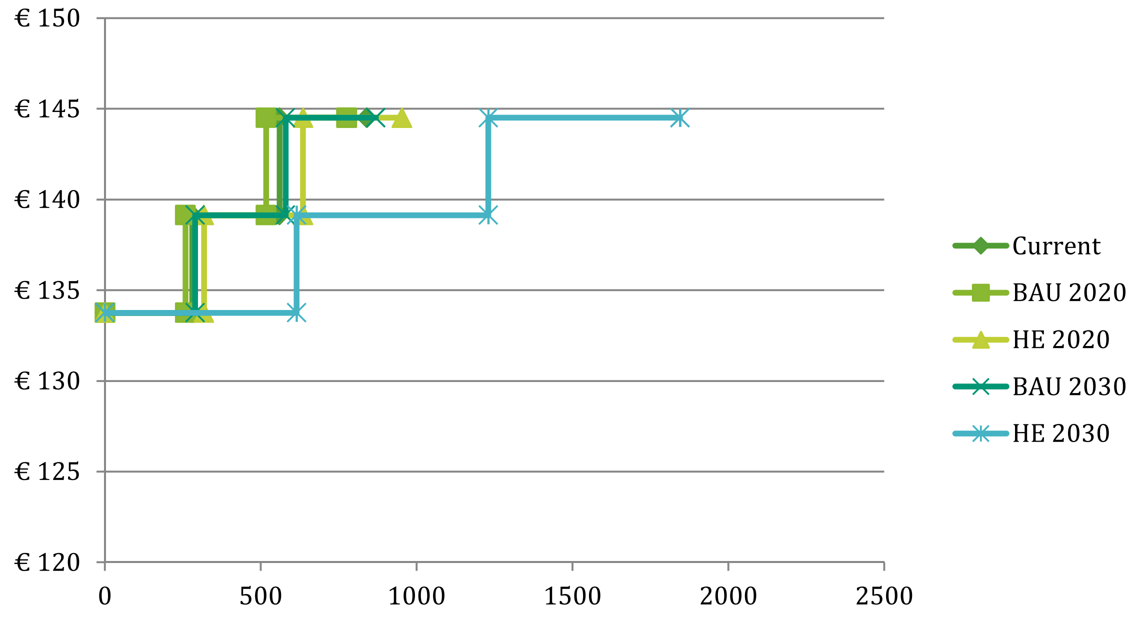

Figure 19. Cost supply curves for sugar cane bagasse pellets.

Overall cost supply curves

Figure 20 summarises the cost supply curves of sugar cane and palm oil residues for current and for the 2020 and 2030 scenario's expressed in tons and GJ per year.

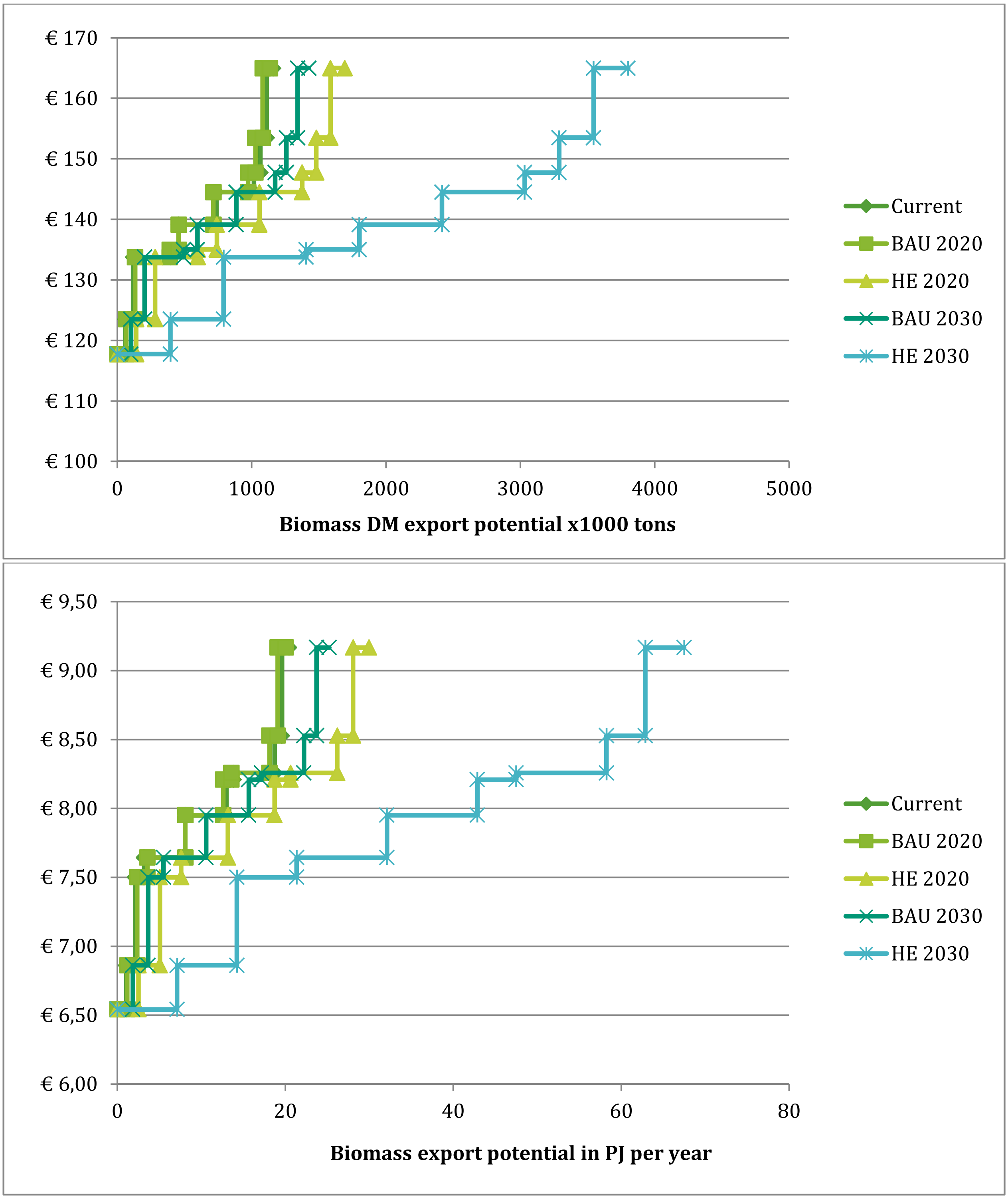

Figure 20a and b. Cost supply curves for current and 2020 and 2030 sugar cane residue pellet supply under Business as usual and high export (HE) scenarios for the Colombian Cauca Valley.

5. GHG balance of palm oil residue and sugar cane residue pellet delivery to Rotterdam

The greenhouse gases (GHG) emission of production and delivery of palm oil residue pellets has been estimated based on the following assumptions:

The pellet mill with a capacity of 50.000 to 100.000 tons per year is situated next to a palm oil extraction mill supplying 1/5 (DM) of the residues (EFB + fibre + shell).
The remaining residue is supplied from nearby mills at a an average distance of 20 km (local transport), the remaining feedstock is supplied from the adjacent palm oil mill

For sugar cane trash the pellets mill is located adjacent to a sugar mill which supplies energy for pre-treatment and pellet making using biomass residue. The trash is supplied from nearby mills at a an average distance of 20 km (local transport),

The palm mill residues are pretreated to upgrade the quality. Pretreatment involves size reduction followed by countercurrent washing with water. The water containing nutrients is then recycled for use in the plantation system. This is followed by the extraction with removing 70% of K, 50% of P and 20% of N. To calculate the loss of nutrients we use the contents as given in Elbersen et al (2013).

For sugar cane trash we assume that the dry yellow leaves which have a lower nutrient content, are used.

Table 23. Typical composition characteristics of palm oil Empty Fruit Bunches (EFB), mesocarp fibre, and shells.

		EFB	Fibre	Shells
Nutrient composition				
N	% dw	0.7	0.4	0.4
P	% dw	0.08	0.07	0.01
K	% dw	2.37	1.18	0.15

Table 24. For GHG impact calculation we use the following assumptions (provided by UU)

Fertilizer		CO2	CH4	N2O	CO2-eq.
N	kg/t	3680.00	7.49	2.35	4566
P2O5	kg/t	1112.11	1.92	0.05	1169
K2O	kg/t	588.71	1.72	0.01	629

The energy (electricity and heat) for pre-treatment, drying and pelleting is supplied by the boiler of the adjacent pellet or sugar mill burning residues. We assume that there is a financial cost, but no relevant GHG emissions of drying and electricity production.

No specific GHG emissions for truck transport were identified we therefore used average numbers from different sources. The GHG emission of local transport of residues is assumed to be double that of long distance truck transport due to higher moisture content and lower efficiency due to smaller scale.

Table 25. GHG emissions per mode of transport used based on a short survey of data.

	$CO2_{kg}$/t-km
Local truck	0.240
Long distance truck	0.120
Ship	0.015

The overall calculation of GHG emissions for residues of palm oil and sugar cane of the specific regions are presented in Table 26.

Table 26. GHG emissions for palm oil residue and sugar cane trash delivered to Rotterdam FOB.

Region		Total feedstock emissions (CO2kg/ton)	Feedstock emissions delivered (CO2kg/GJ)
Northern palm oil region	EFB	177.86	9.92
	Fibre	164.06	8.54
	Shell	160.91	7.50
Central palm oil region	EFB	234.26	13.06
	Fibre	220.46	11.48
	Shell	217.31	10.13
Cauca Valley sugar cane region	Trash	184.18	10.52

6. SUMMARY OF FINDINGS

This report presents an assessment of the sustainable potential of biomass and export potentials for Colombia to the EU. The main biomass potentials in Colombia consist of crop residues. The potential to use these residues at regional or national level is very limited due to the fact that many of the residues are generated in the field and/or have a high moisture content and/or a high mineral content and/or are dispersed and/or cannot be mobilised due to a lack of infrastructure to transport the biomass at a reasonable cost to a sea harbour.

Favourable conditions for export do exist, however the export potentials for residues from the Northern and Central palm oil zones and for the Cauca Valley sugar cane zone range from one million tons DM (pellets) currently to 4 million pellets in 2030 under high export conditions. The cost for export to the EU starts at €118 per ton pellet delivered.

The sustainable potential was calculated focusing in the main regions in Colombia that have the sugar cane and palm oil production, that are close enough to a harbour to make export feasible. In the case of Colombia, it shows a high theoretical potential but one of the main impediments is related to the logistics for transport. Nevertheless, as demonstrated in the cost analysis and the current uses, the production of pellets from sugar cane from the Valley of Cauca are a possible source of biomass export to the European Union (Figure 21).

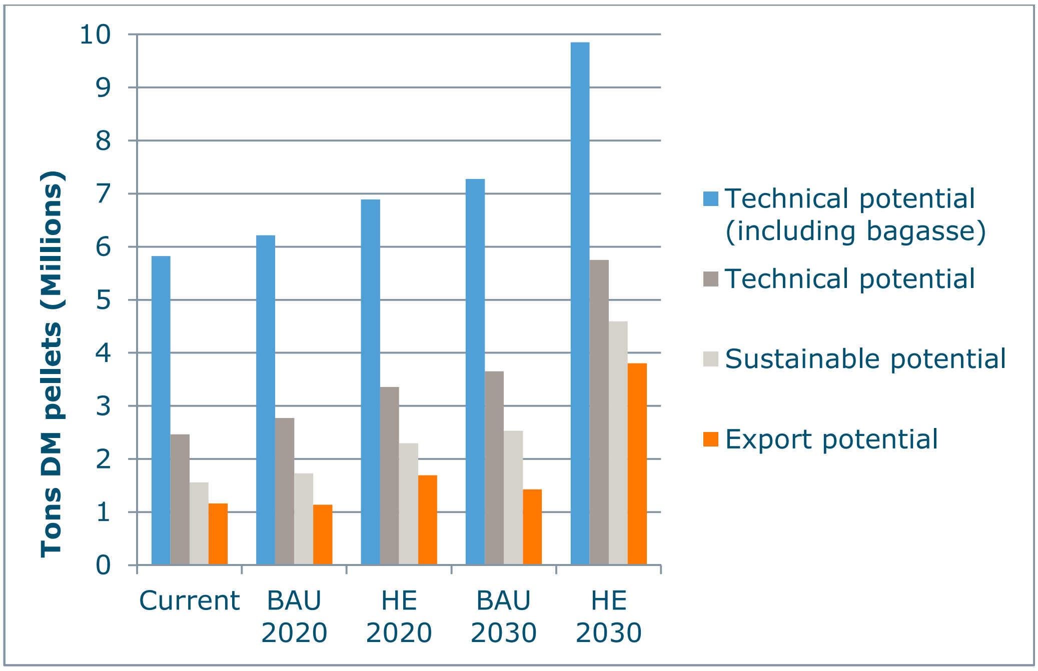

Figure 21. Sugar cane and palm oil sustainable export potential

Finally, Table 27 presents a summary of the characteristics of how pellets should be considered to be a commodity that can expand the market.

Table 27. Summary of characteristics of the pellets of residues to be considered a commodity from Colombia.

A FULL COMMODITY	NOT A COMMODITY
Easily transportable and storable → ➢ high energy content, low moisture, ➢ low volume **Quality standardized** **Fungible** (= "exchangeable") ➢ Standard transport, contracting, ➢ insurance, safety, etc. ➢ Standard processing, etc. **Functioning market** ➢ Trade system → Price formation ➢ Financial instruments (futures, etc.) ➢ High "tradability" **Sustainability** ➢ Standard certification systems exist	**Not easily transportable or storable** **No standards** (quality, sustainability, safety, etc.) **No exchange markets** ➢ No market price ➢ No financial instruments (futures) **No sustainability standards** **Transaction costs higher** **Security of supply becomes very important/difficult** **Long term relationships needed** ➢ One on One and Case by Case ➢ relations **Vertical chain integration needed**

From this point of view there are still several considerations to be included in the production of the pellets to be exportable to the EU and enlarge the market. If these conditions can be overcome then a more sustainable market for export of biomass can be achieved.

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