Project No: 603502

DACCIWA

"Dynamics-aerosol-chemistry-cloud interactions in West Africa"

Deliverable

D2.1 Emission inventories

Due date of deliverable:	31/05/2016		
Completion date of deliverable:	02/12/2016		
Start date of DACCIWA project:	1st December 2013	**Project duration:**	60 months
Version:	[V1.0]		
File name:	[D2.1_Emission_inventories_DACCIWA_1.0.pdf]		
Work Package Number:	**2**		
Task Number:	**2.1**		
Responsible partner for deliverable:	**UPS**		
Contributing partners:			
Project coordinator name:	Prof. Dr. Peter Knippertz		
Project coordinator organisation name:	Karlsruher Institut für Technologie		

The DACCIWA Project is funded by the European Union's Seventh Framework Programme for research, technological development and demonstration under grant agreement no 603502.

Dissemination level		
PU	Public	**x**
PP	Restricted to other programme participants (including the Commission Services)	
RE	Restricted to a group specified by the consortium (including the Commission Services)	
CO	Confidential, only for members of the consortium (including the Commission Services)	

Nature of Deliverable		
R	Report	
P	Prototype	
D	Demonstrator	
O	Other	**x**

DOCUMENT INFO

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Changes with respect to the DoW

Issue	Comments
Delay of the deliverable	As agreed on with the PO this deliverable was postponed by 6 months due to necessary tests of the inventory during and after the field campaign in summer 2016. Conversation with PO: Ares(2016)1156355 - DACCIWA (603502)

Dissemination and uptake

Target group addressed	Project internal / external
Scientific	Internal and external

Document Control

Document version #	Date	Changes Made/Comments
0.1	05.10.2016	First version with general structure
0.2	22.11.2016	Version for approval by the GA
1.0	02.12.2016	Version approved by the GA

Table of Contents

African Anthropogenic Emissions Inventory for gases and particles from 1990 to 2013 (UPS-Liousse et al.). 5
1 Abstract 5
2 Introduction 5
3 Methodology 5
3.1 Method for biofuel and fossil fuel emissions 5
3.1.1 Fuel consumption database (FC) 5
3.1.2 Emission factors (EF) 6
3.1.3 Spatial allocation 6
3.2 Method for open waste burning emissions 7
3.3 Method for flaring emissions 8
4 Results 9
4.1 Spatial distribution 9
4.2 Sectors and country contributions 10
4.3 Emission trends 11
5 Comparison with previous emission inventories 12
6 Availability of the data 12
7 Conclusion 12
References 12

African Anthropogenic Emissions Inventory for gases and particles from 1990 to 2013 (UPS-Liousse et al.).

1 Abstract

This deliverable in the framework of WP2-DACCIWA consists in the first version of African fossil fuel (FF), biofuel (BF), gas flaring and waste burning emission inventories for the 1990-2013 period for the major atmospheric compounds (gases and particles). It is important to note tests on these inventories are ongoing in Regional Climate Model (RegCM) at the African scale for 2005 and 2010. This work resulting from a collaboration between Laboratoire d'Aérologie, France and Laboratoire de Physique de l'Atmosphère (LAPA) of UFHB, Côte d'Ivoire, provides up to date emission fields at 0.125° x 0.125° spatial resolution and yearly temporal resolution that can be used to model atmospheric composition and impacts over West Africa. These data are available on the website of ECCAD (Emissions of atmospheric Compounds and Compilation of Ancillary Data, http://eccad.aeris-data.fr/) for DACCIWA users.

2 Introduction

Presently, there is one African regional inventory dealing with biofuel and fossil fuel emissions (Liousse et al., 2014) and only global emission inventories including Africa. Developing a regional inventory for gases and particles is not an easy task: the DACCIWA project has allowed to organize a framework suitable for this development through regrouping several investigators. The aim conducted through the PhD of S. KEITA, University Felix Houphouet Boigny and Laboratoire d'aérologie is to set an African database on fuel consumption and new emission factor measurements. Note that the only existing African inventory (Liousse et al., 2014) did not take into account other sources of pollution than biofuel and fossil fuel such as flaring and waste burning yet not negligible in Africa. The inclusion of these sources in the new inventory and also new emissions factor measurements will reduce the uncertainties on anthropogenic emissions in Africa. Moreover, Liousse et al. (2014) is for 2005 and 2030 whereas our work will allow to take into account temporal variability of emissions from 1990 to 2013.

3 Methodology

3.1 Method for biofuel and fossil fuel emissions

Briefly, biofuel and fossil fuel emission inventories for the years 1990 to 2013 used a bottom-up methodology, based on the relationship EM = FC x (EF) where FC are fuel consumption data and EF is the emission factor (in g of species/kg of consumed fuel). Figure 1 resumes the process used to build our emissions inventory.

3.1.1 Fuel consumption database (FC)

FC are fuel consumption data given by United Nations organization (UN). UN database for fuel consumption is provided in details for 54 African countries for the years 1990 to 2013.

This FC database is for 22 different fuels and is available by country and by fuel following 5 sectors: domestic (residential combustion sources), industry, power plant, traffic and other sectors. In this work traffic sector is disaggregated into 4 sub sectors (road, rail, domestic navigation and aviation). Emission factors are fuel, activity and technology dependent. Consequently, they are also country dependent as technology performance are not the same in all countries. Due to a lack of emission factors as a function of countries/fuels/activity/technology/norms combinations in Africa, our methodology is based on a "lumping" procedure designed to manage with available experimental data and to account for main factors of variability.

As technologies and norms are considered to be country dependent, the 54 African countries have been classified into three groups (developed, semi-developed and developing countries) following their GDP products, for which different EFs are applied.

3.1.2 Emission factors (EF)

This regional inventory is for particles (BC, OC) and gases (NOx, CO, $NMVOC_{tot}$ (Non-methane volatile organic compound), $NMVOC_{C5\text{-}C10}$, SO2). In order to improve the only existing regional inventory, we conducted several emission factor measurement campaigns for traffic sources, domestic fires and dump open burning.

Table 1 displays values thus obtained for BC, OC and NMVOC. Note that our NMVOC measurements only include C5 to C10 species whereas NMVOC in Liousse et al. (2014) include all C species. The other values of emission factors are provided by literature. There are some differences between our values and those of literature. Generally, for the particles our EF values are slightly higher than those of Liousse et al., (2014) except for charcoal. A paper is in preparation to deal with results of these experiments.

Table 1 Emission factor from our measurements and literature values

	EF(g/kg dm)	BC	OC	NMVOC	TPM
Gasoline car	THIS WORK	**0,52**	**0,91**	**23,40**	**6,1**
Gasoline car	Liousse et al., 2014	**0,15**	**0,73**	**34**	
Diesel truck	THIS WORK	2,7	3	7,8	38,7
Diesel gbaka	THIS WORK	2	1,5		19,2
Diesel bus	THIS WORK	1,8	2,1	0,4	23,5
Diesel taxi & car	THIS WORK	5,8	4,3	2	66
DIESEL ROAD	THIS WORK	**4,5**	**3,5**	**2,6**	**52**
DIESEL ROAD	Liousse et al., 2014	**5**	**2,5**	**10,9**	
TwoWheel 2stroke	THIS WORK	4,3	302	880	684
TwoWheel 4stroke	THIS WORK	2	65	39	251
TW ROAD	THIS WORK	**2,5**	**124**	**249**	**359**
TW ROAD	Liousse et al., 2014	**2,3**	**30,6**	**312**	
FuelWood-D	THIS WORK	**2**	**14**	**1,6**	
FuelWood-D	Liousse et al., 2014	**0,9**	**2,7**	**8,8**	
Charcoal-D	THIS WORK	**0,57**	**1,4**	**3,5**	**12,7**
Charcoal-D	Liousse et al., 2014/ Roden and Bond, 2006	**0,75 / 0,2**	**2,3 / 1,5**	**4,9**	
Charcoal making	THIS WORK	**1,1**	**4,2**	**1,8**	**100,3**
Charcoal making	Brocard, 1996 / Liousse et al., 2014	**0,4 / 0,5**	**3,6 / 4,8**	**12**	
Waste burning	THIS WORK	**2**	**6,4**	**20,4**	**87,9**
Waste burning	Christian et al., 2010	**0,7**	**5,3**	**22,6**	

3.1.3 Spatial allocation

Finally, from 1990 to 2013, gas and particle emissions were spatially allocated to a 0.125° x 0.125° horizontal grid from 2010 population density given by CIESIN (Gridded Population of the World Future Estimate: GPWFE). The next step will be to use traffic lines and geographical location of point sources such as power plant.

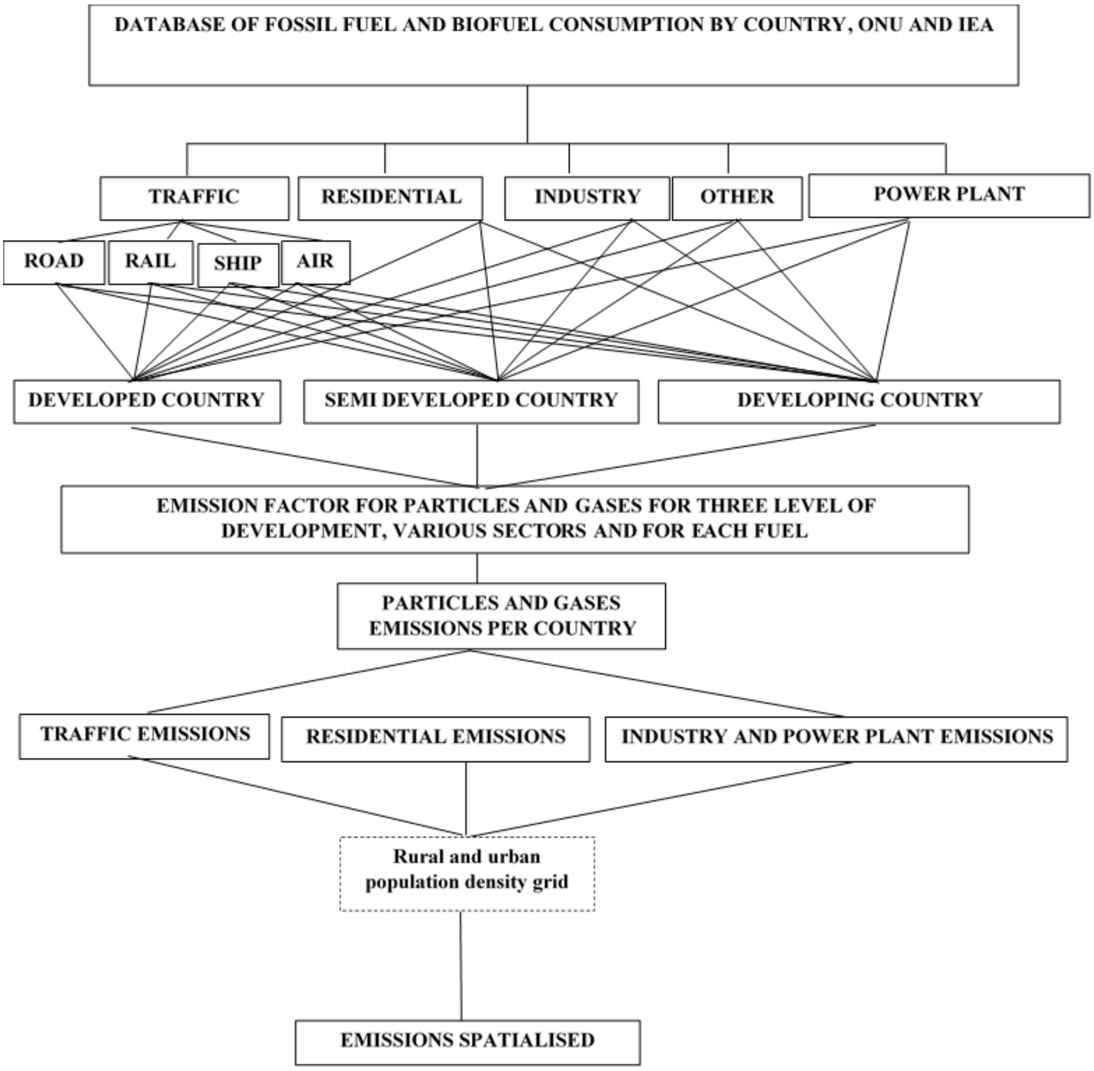

Figure 1: Emission inventory algorithm

3.2 Method for open waste burning emissions

An open waste burning emission inventory was built following the IPCC guideline for estimation of GHG inventory that include open residential and dump waste burning. In this context, the following expression was used: $E_i = WB * EF_i$ in which:

WB is the amount of solid waste that is burned residentially and in uncontrolled dump, EF_i is the emission factor of pollutant i. In our inventory our EF measurements were used for BC, OC, NMVOC EF whereas from literature for other pollutants studied (NOx, CO and SO2). The total amount of waste burned (WB) is equal to the sum of the amount of domestic waste that is burned at individual residences openly near the residence and the amount of waste burned at dumps. WB does not include waste that is burned in incinerators or modern combustion systems and already taken into account in the industrial sector.
For each African country, the amount of waste burned (WB) is estimated using the general guidelines from section 5.3.2 in the 2006 IPCC Guidelines for National GHG Inventories:

$WB = P \times MSWp \times Pfrac \times Bfrac$

where P is the national population, MSWp is the mass of annual per capita waste production, Pfrac is the fraction of the population assumed to burn some of their waste and Bfrac is the fraction of waste available to be burned that is actually burned. Values for MSWp and Pfrac used for the calculations here are taken from Wiedinmyer et al., 2014. In this paper, note that the fraction of a country's population that is assumed to burn their waste (Pfrac) is assumed to be based on national income status, urban versus rural population, and waste collection practices. For example, in developing countries, Pfrac is estimated as the fraction of total population whose waste is not collected plus the fraction of the population whose waste is collected and disposed in open dumps that are burned. In our study, all rural populations are assumed not to have waste collection. Therefore, Pfrac is assumed to be equal to 100%. In urban areas, waste that is not collected is assumed to be burnable near the individual residences. Fractions of waste collection are country-dependent (for example the fractions of waste uncollected are 0.77, 0.3, 0.4, and 0.76 respectively for Benin, Ivory Coast, Ghana and Nigeria (Wiedinmyer et al., 2014)). Moreover, collected wastes are available for burning in open dumps. For Bfrac, 0.6, the default value recommended by IPCC, was used.

Urban and Rural populations used for these calculations are provided by the World Bank database (http://data.worldbank.org/indicator, accessed 02 November 2016). Country-level economic status (“developed” versus “developing”) was assigned to each country based on the income levels assigned by the World Bank (http://data.worldbank.org/country). The countries with income levels assigned as “Low Income” (LI), “Lower Middle Income” (LMI), and “Upper Middle Income” (UMI) are classified as developing countries (Wiedinmyer et al., 2014). All other countries (HIC) are assigned as developed. In this context, all African country are classified as developing countries. Open waste burning gas and particles emissions were spatially allocated to 0.125° x 0.125° horizontal grid from 2010 population density given by CIESIN (Gridded Population of the World Future Estimate: GPWFE).

3.3 Method for flaring emissions

We have developed flaring emission inventory for the years 1994 to 2010 (other years are not available), based on the nighttime light data (Avg_x_pct) provided by the U.S Defense Meteorological Satellite Program satellite (DMSP), combined with the regional volumes of gas flared available from the National Oceanic and Atmospheric Administration (NOAA) (Doumbia et al. 2016, submitted). The methodology consists to overlap layers of maps including “Avg_x_pct” images, gas flare areas, world maritime boundaries, total gas flares per country and gridded file based on Geographic Information System (ArcGIS software). This method has been validated over Nigeria. The emissions were predicted using the following equation:

$$X_{flaring} = GF_{volume} * X_{EF} * d_f$$

where $X_{flaring}$ is the emission rate of a pollutant X (kiloton), GF_{volume} is the volume of gas flared in billion of cubic meter (bcm). X_{EF} is the emission factor (EF) in g of X per kg of fuel gas and d_f is the density of the fuel gas. Typically, the density of the fuel (natural gas) varies between 0.75 and 1.2 kg/m^3 depending on the fraction of heavy hydrocarbons constituent of the fuel (US Standard Atmosphere, 1976). In this inventory, we assumed a gas density of 1.0 kg/m^3 used for converting volume of associated gas to mass (E&P Forum, 1994). EFs for various species (CO, NO_x, NMVOC, SO_2, OC and BC) are provided by the literature. Table 2 shows a large range of particles and gases emission factors provided by the literature review. To face this problem (large range of EF) a minimum and a maximum emission inventory have been set up using the minimum and the maximum EF values. Note that other flaring emission inventories have been developed using VIRRS satellite data by Deetz et al. (2016, in review) for June-July 2014 and 2015.

Table 2: Review of the literature EF (g/kg) for industrial flares for different species.

EF (g/kg, this study)	CO_2	CH_4	BC	CO	NOx	SO2	NMVOC	OC
Min	1980	2.5	0.14	5.95	1.05	0.013	3.0	0.15
Max	3366	45	3.2	18	3.7	0.13	12.3	0.15
Mean	2794	19	1.3	8.83	1.77	0.07	7.32	0.15

4 Results

4.1 Spatial distribution

Figure 2 shows BC spatial distributions (yearly emissions of 1.57 Tg C), CO (84.7 Tg C), $NMVOC_{tot}$ (10.29 Tg $NMVOC_{to}$), $NMVOC_{C5-C10}$ (4.2 Tg $NMVOC_{C5-C10}$) and NOx (7.05 Tg NOx) for African fossil fuel (FF) and biofuel (BF) emissions. BF and FF emissions for BC roughly contribute to 71% of total anthropogenic BC emissions, whereas 27% are due to open waste burning emissions and 2% to gas flaring in 2010. In these BC emissions, due to BF and FF, BF contributes to 83 % against 17 % for FF, 10% of which was attributed to diesel.

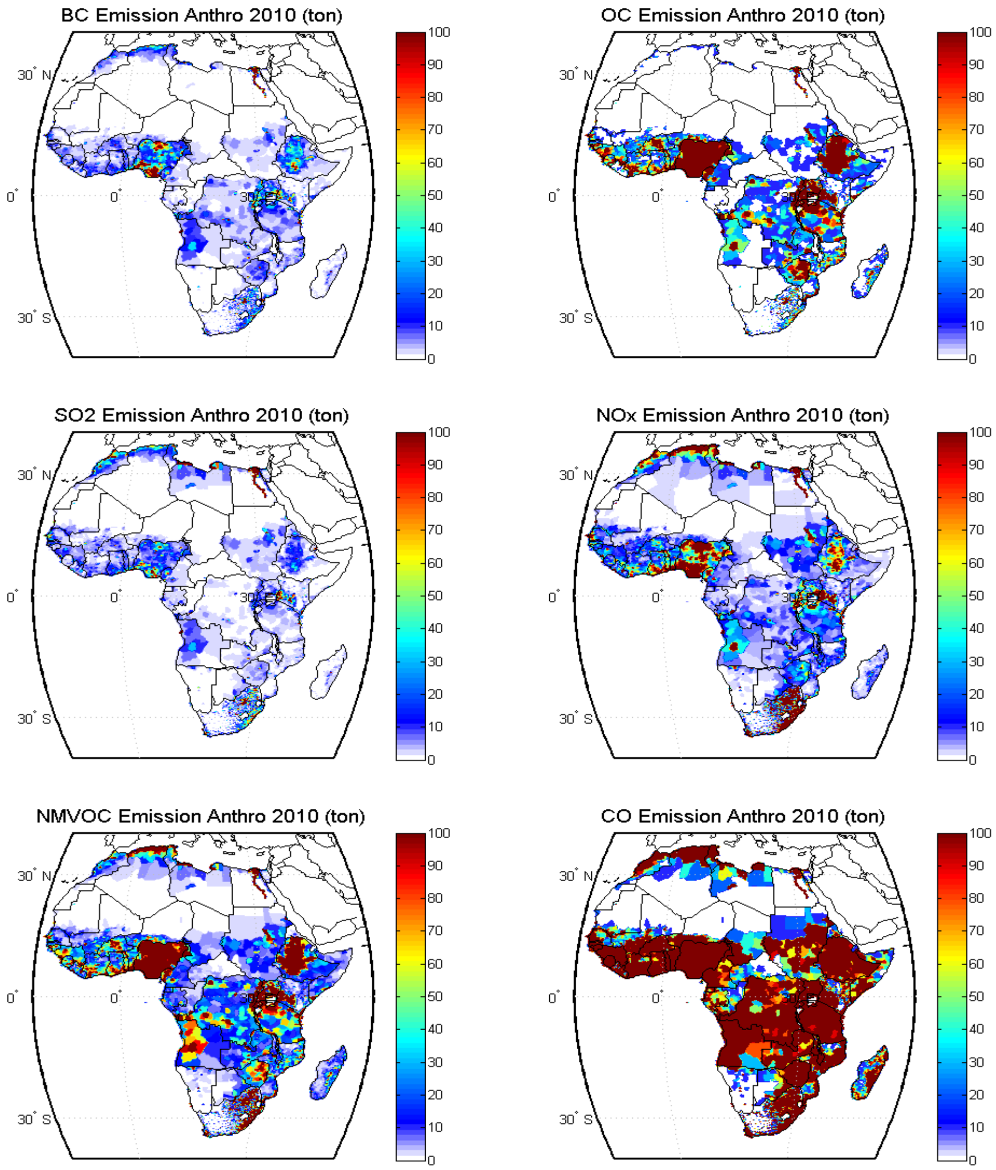

Figure 2: Spatial distributions of BC, CO, NMVOCC5-C10, SO2 and NOx fossil fuel and biofuel emissions over Africa at 0.125° x 0.125° resolution.

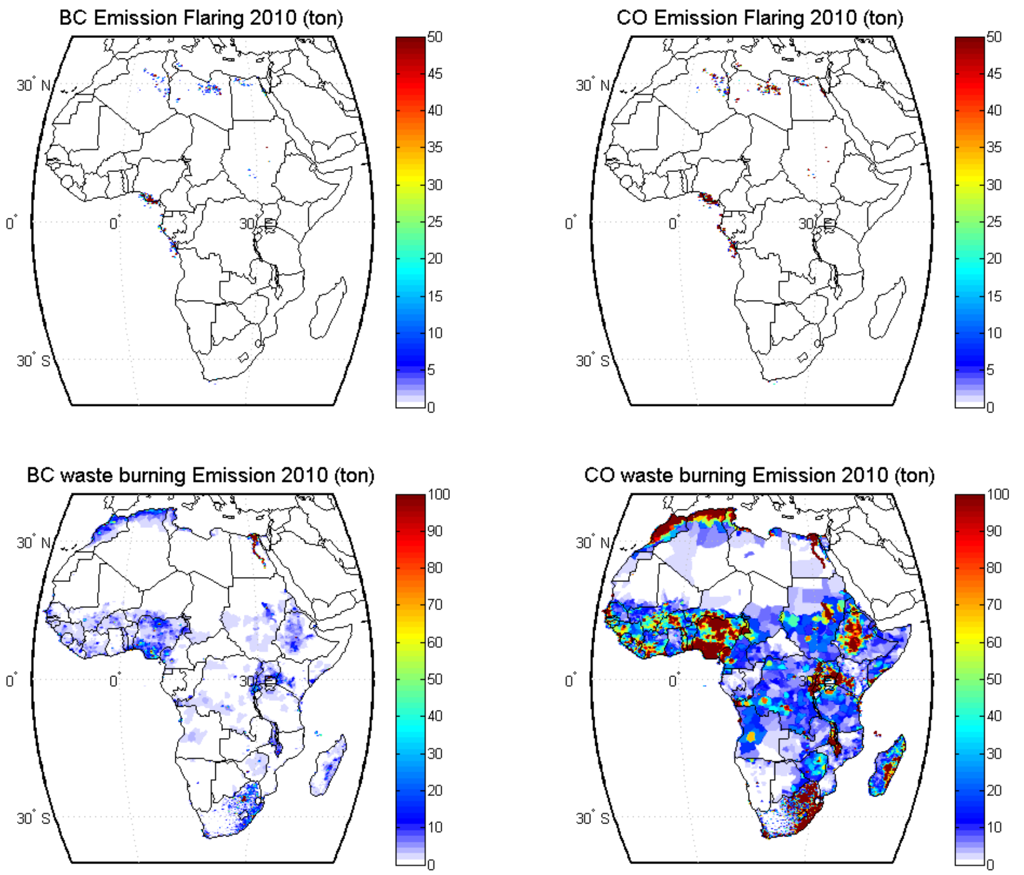

Figure 3: Spatial distributions of BC and CO emissions from open waste burning and gas flaring in 2010 for Africa.

Figure 3 presents BC flaring and open waste burning emissions for 2010 for African countries. We can see that the relative importance of Nigeria is predominant in both inventories.

4.2 Sectors and country contributions

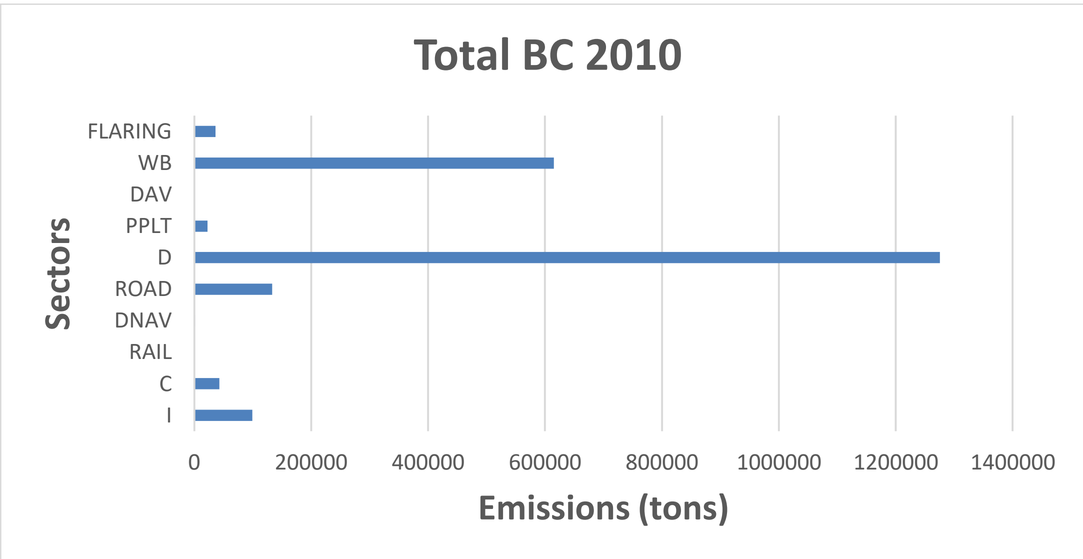

Figure 4: BC emissions in tons/year from FF, BF for the different sector (traffic (road, rail, domestic aviation and navigation), residential, industrial and power plant), WB and Flaring.

Figure 4 shows the relative predominance of domestic activities (57.2 %) in 2010 in the total Africa BC anthropogenic emissions followed respectively by open waste burning (27.6%), road traffic (6.0%), industry (4.4%) and gas flaring (1.6%). Figure 6 shows these results for some countries of Southern West Africa (SWA).

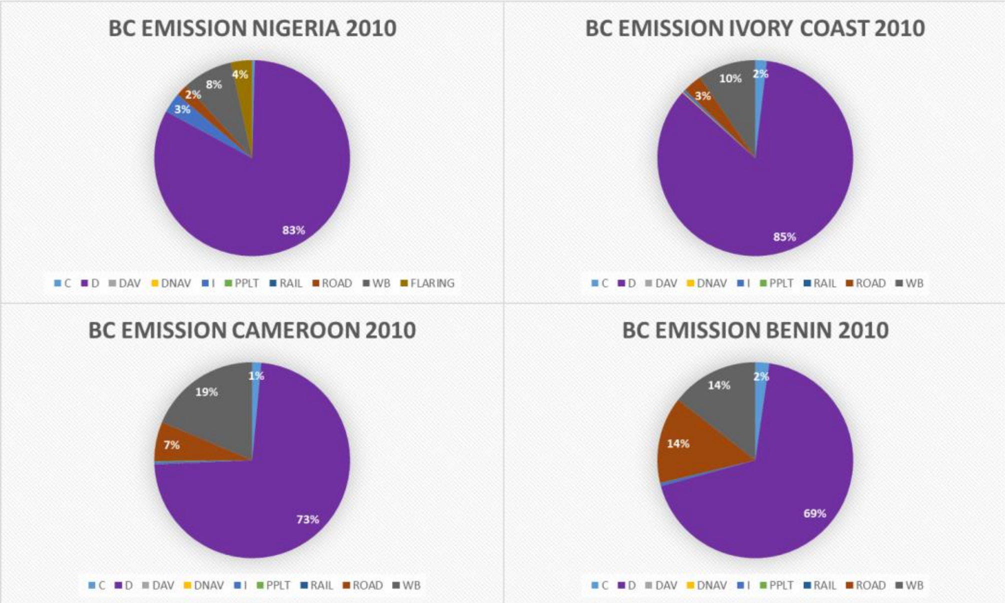

Figure 5: BC emissions in tons/year of some SWA countries with sector contribution (D: domestic, PPLT: power plants, I: industry, WB: open waste burning, ROAD: road traffic, RAIL: rail traffic, DNAV: domestic ship navigation, FLARING: gas flaring, C: another sector)

At country level the domestic sector is also relatively more important than other sources followed by WB and then the others, whose ranks differ from one country to another. Note that Benin and Cameroon as well as Nigeria and Côte d'Ivoire present similar patterns.

4.3 Emission trends

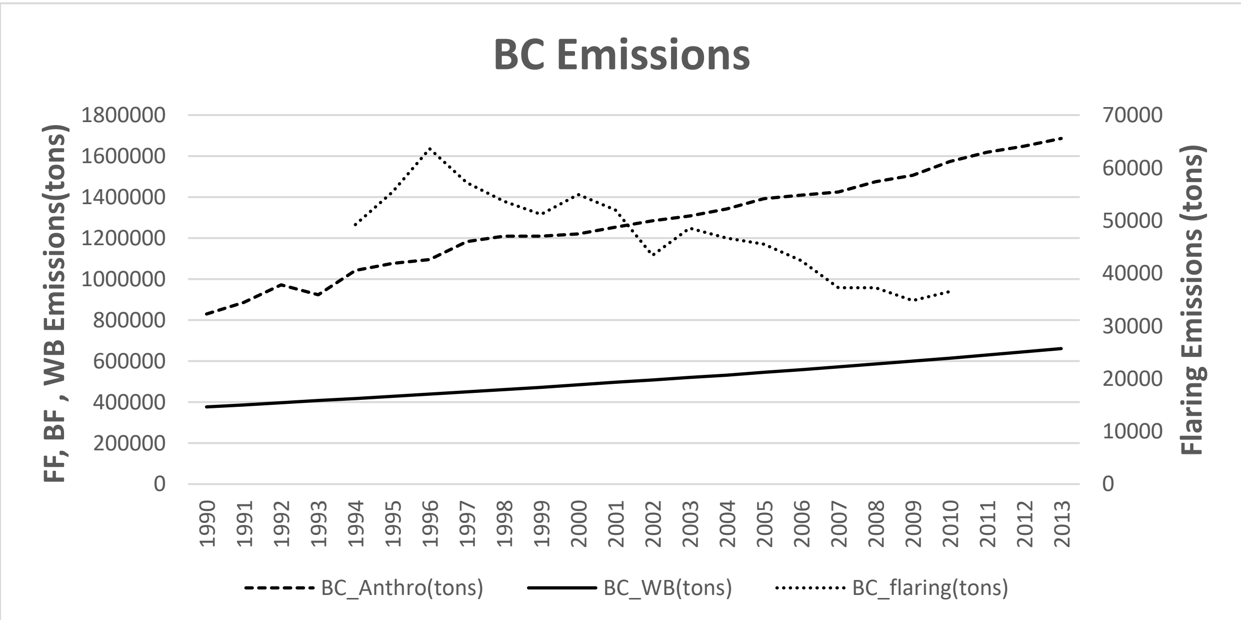

Figure 6: BC emissions in tons/year from 1990 to 2013 for Africa.

In this section, we show the trend of BC emissions in Africa for all sectors from 1990 to 2013 (Figure 6).

This figure shows an increase in BC emissions for fossil fuel (FF), biofuel (BF) and open waste burning (WB) from 1990 to 2013. Unlike FF, BF and WB, BC emissions from flaring are decreasing.

5 Comparison with previous emission inventories

The comparison of our emission inventory and the previous African emission inventory by Liousse et al. (2014) for the year 2005 shows that our FF and BF emissions are more important than in Liousse et al., 2014 for BC (0.68 to 1.57) and CO (58.6 to 70.76). This can be explained by the updating of fuel consumption data base and also by the use of new emission factors. $NMVOC_{C5-C10}$ value is lower than in Liousse et al. (2014) since our measurements were done for the C5 to C10 species.

6 Availability of the data

Practically, the data files for BC, OC, CO, $NMVOC_{tot}$, $NMVOC_{C5-C10}$, SO2 and NOx fossil fuel, biofuel, open waste burning and flaring emission inventories for the year 1990 to 2013 and provided at a spatial resolution of 0.125° x 0.125° are available on ECCAD website (http://eccad.aeris-data.fr/) for DACCIWA users.

7 Conclusion

In the framework of DACCIWA-WP2, a new African emission inventory was developed for fossil fuel, biofuel, open waste burning and gas flaring for the years 1990-2013. New values of EF were proposed providing from new EF measurements on African pollution sources. A few improvements or additions, interesting for the users are on going. They will be documented and included as new versions of DACCIWA-WP2 inventories in the ECCAD database. These improvements deal with:

- focus at Cote d'Ivoire level with improvements of ancillary data: use of local fuel consumption for BF, FF and open waste burning, spatial distribution of roads for traffic mapping …,
- propose an inventory based on IEA fuel consumption database
- include new species such as NH_3 and CH_4,
- extrapolate this inventory to the year 2016 from 1990-2013 trends,
- propose scenarios of emissions for the years 2030 and 2050.

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