Transportation is a crucial vector for urban insertion since it gives access to economic activity, facilitates family life and helps in spinning social networks. It links the different spaces of the city on which an individual/a family has to implement his/its tri-dimensional strategy of life (family, work, residence). So urban mobility is at the heart of the challenges faced by any city-dweller. The World Bank Urban Transport Sector Strategy for Sub Saharan Africa has raised these concerns particularly for the urban poor and the socially disadvantaged groups (women, young and elderly people) and, therefore, selected as one of its three objectives, “the understanding of the nature and the significance of urban poverty and the extent to which, and ways in which, transport policies can contribute to poverty reduction” (SSATP 1999b). However, transportation can also induce important social costs, i.e. those caused by dysfunction or transport externalities such as accident-related costs, environmental costs (noise and air pollution), costs caused by congestion, and finally health costs. Therefore, the formulation of new policies targeted to improving the access of the poor people to transportation systems, has also to account for the air quality issues, such groups of people being also the most exposed to air pollution. Evaluating and allocating these costs, determining the main factors involved in their formation, are important steps on the road towards the improvement of «decision support» for the selection of environmentally friendly transport systems.

A tentative research program has been set and is being conducted since 1997 along two phases ¹:
- Phase 1 (1997-1999): a case study on the District of Bamako by, firstly, using mainly macro and secondary survey data to generating emissions data and, then, defining and applying an impact assessment model of the household and individuals characteristics;
- Phase 2 (1999-2001): a survey in Ouagadougou on Migrations, Urban Insertion, Transportation systems use and Air Pollution. Together with data on individual daily mobility and on the household's and individuals transportation equipment, a life-cycle

¹ In partnership with the Population Reference Bureau (funding from the Mac Arthur Foundation) for the Bamako case, and with the Department of Demography, Montreal University, and, for the survey in Ouagadougou, with the Unité d’Études et de Recherche Démographiques, Université de Ouagadougou.
approach has been followed to collect near persons of 21 years of age and up, individual events histories on study/work, family formation and evolution, residential mobility and access and actual possession of specified means of transportation (motorized and non motorized).

This paper presents the results of the Bamako case-study, highlights some of the main achievements and weaknesses, and, finally, raises the objectives and the issues being tackled through the Ouagadougou survey.

1. The Context

During the last decade, the worsening quality of the air has become a famous characteristic of the majority of the capital-cities in West Africa, namely Bamako, Dakar or Ouagadougou. Natural dust combines its effects to those of smokes and gases emanating from wood and charcoal or gasoline combustion, industries and informal sectors burning of materials. Respiratory illnesses, acute eyes and skin irritations are then common complaints. Above the benign irritations and respiratory discomforts, one knows that more serious diseases may result from the accumulation of dust in the lungs. Indoor and atmospheric pollutant emissions are indeed causal factors.

At the sub-regional level, a first attempt to estimating air pollution from motor vehicles through two studies has been made, for the SSATP/World Bank, by Tractebel in Dakar and in Ouagadougou, respectively in 1998 and 1999. Based on mobility data prior to the 1994 CFA F. devaluation, these studies used traffic counting data and a standard dispersion model (EMME2) to generate the first set of emissions for these capital-cities (SSATP 1999a, SSATP 1999b). There is not yet any air quality index for the District of Bamako, and research institutions have just begun to investigate the area through qualitative studies raising the seriousness of air quality issues (Coulibaly Y., 1995; Sidibe, S., 1993). Some other studies have been devoted to quantifying specific stressors like lead or suspended particulate matter (PM10) levels in the air of the District. In the framework of Kyoto preparation, the first National inventory of Greenhouse Gas (GHG) emissions in Mali has been conducted in 1996/97 (see CNRST, 1998) (For a detailed evaluation of these studies, see Wane 2001).

In its three (3) pages section on «Quality of life and pollution in urban setting», the volume 1 «Environmental diagnosis» of the National Environmental Action Plan (PNAE) is mostly devoted to solid waste, water pollution and sanitation issues. Combustion of solid wastes and plastics on one side, and industry emissions on the other, are the recognized factors in the two paragraphs on air pollution. But the threats that they constitute for health are just mentioned (PNAE / PAN-CID, 1998, Volume 1: 39-42). As waste management and sanitation are considered as the main environmental problems by the District technical and administrative authorities, the draft of regional action program is focused on waste management (PNAE / PAN-CID, 1998, Volume 3: 46-50). However, it appeared that automotive air pollution is a general concern of the population. The national forum for the validation of the PNAE action draft plan and programs, held in May 1998 in Bamako, urged the authorities to extend the environmental policy to this issue and to tackle it in the framework of the priority program.
There is not yet any expression of a civil organization on that issues. Individual parties are mostly noticeable among motorcyclists and merely consist in such feeble means as work masks or turbans. If they can be efficient against the dust to some extent, these defenses do not impede the inhalation of micro particles and gases or the fixation of heavy metals on parts of the human body. The recourse to air conditioner system by the wealthiest preserves the private cars users from ambient pollution. However, it contributes to the pollution by the additional fuel related emissions and by the ozone production by the cooling outlet.

2. **The Objectives of the study**

There is indeed a real need of a low-cost and replicable methodology for the: 1) setting of accurate standards of emissions and the assessment of the nature and of the levels of emissions from the personal use of both public and private transportation systems; 2) evaluation of the impacts on air pollution of socio-economic factors of the household and of the individuals’ mobility through their access and use of the current transportation systems.

This case-study has a twofold objective: 1) to generate, for the first time, a set of emissions resulting from the personal use of motor vehicles in the urban district of Bamako for both sectors of transportation; 2) to measure and analyze the impact on air pollution of the daily mobility of the household’s members. It aims to examine and test the extent to which a low cost approach combining, indirect measurements of emissions, on one side, and, on the other side, a model based on household transportation expenditures, can yield valuable information for policies targeted to mitigating urban air pollution.

3. **The Methods**

3.1. **Estimating the emissions**

The method consists in generating emissions by sector of transportation and, for the impact assessment, transforming them in emissions at the micro household level.

Macro-level data are estimates of emissions in specific pollutants by the two types of transportation systems: private and public.

Faiz and others have set a general formula for estimating a specific pollutant emission by a given class of motorized transportation vehicle (see Faiz, A., Weaver, C. S., Walsh, M. P. 1996). It stands that a vehicle emissions (VE) is a function of estimates of the kilometer-vehicle (KV) and of estimates of specific emission factors (EF).

The first set of research activities consisted in estimating the KV, i.e. the mean distance traveled. Following the calculations of the EF, the third deals with the estimation of total emissions and, finally, emissions by the household are estimated.

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2 The most recent data source on household transportation expenditures was the *EMCES94 (Enquête Malienne de Conjoncture Economique et Sociale 1994)*, with information on the expenditures in public transportation and, unfortunately, not on gasoline purchasing. It belongs to the priority surveys of the World Bank program on Social Dimensions of Adjustment.
3.1.1. Estimation of the Kilometer-Vehicle

Kilometer-Vehicle (KV) was estimated through two tasks: i) the setting of a coherent database on the vehicles and motorcycles 1996 fleet by using the NDT records and extrapolated data from EBC 89 and EMCES 94; ii) through experts and operators’ panels (Delphi Technique-like), the calculations of usage data (kilometer-vehicle) according to the sector of transportation for all motorcycles and classes of vehicles in both sectors of transportation.

Assuming that we could get good estimates of the mean Kilometer Vehicle (KV) from users, operators, scientists, and managers, separate panels were organized to generate data for private and for public transportation.

The methodology was a Delphi Technique-like. Usually this method is applied to try to value a particular good by a group of experts through an iterative process. It was adapted to get the fleet usage data through two panels organized in the form of separate workshops with:

?? experts, technicians and managers for passenger cars, motorcycles, buses and other heavy duty vehicles;
?? drivers and gasoline retailers for public transportation vehicles. The latter category has been targeted to counterbalancing the tendency of the drivers to inflate their daily declaration in gasoline consumption. The amount of the owner’s daily receipts is, in principle, the daily cash-flow minus the daily gasoline expenditures in the charge of the driver.

It is assumed that the 1996/97 estimated mean distance by category of vehicle was the same as of 1994.

3.1.2. Estimation of Emission Factors (EF): the use of COPERT II Model

Most of the local fleet is from Europe or from Japan. So, the Computer Programme to Calculate Emissions from Road Transport (COPERT II Model) was used to derive emissions factors estimates (EF) for different stressors. This model has been parameterized with own speed and correction factors for the local driving or commuting patterns and for infrastructure factors assumed to having a significant impact on the levels of the emissions. Such correction factors have then been incorporated mainly for public transportation.

3.2. The Assessment of the Impact of the Household’s Mobility on the Emissions

It has been conducted through: the transformation of the macro-data into emissions at the household level; the setting of an operational model in which the household’s emissions (by stressor and total) are the dependant variable and a set of explanatory (independent) variables characterizes the head of the household (gender, age), the household’s composition (dependency ratio), its socio-economic status (number of actual pupils/students, motorcycle ownership, formal versus non formal sector of employment of its members), its poverty status (poverty-gap). Robust

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least squares models are run along a household-type variable, which is used to collapsing, into one single intermediate variable, the combined effects of the size of the household, its composition and level of motorization (car ownership). So four models are considered: Model 1: Large family and Car owner; Model 2: Large Family and No car; Model 3: Nuclear Family and Car owner; Model 4: Nuclear Family and No Car.

4. The Results

4.1. Estimation of the Kilometer-Vehicle

The synthesized result on Kilometer-Vehicle by category of vehicles, in 1994, is presented in table 1 below.

Table 1. Estimates of Total kilometer–vehicle (km/day) in the District of Bamako according to the categories of vehicle, 1994

<table>
<thead>
<tr>
<th>Category</th>
<th>Gasoline</th>
<th>Diesel</th>
<th>Total</th>
<th>%</th>
</tr>
</thead>
<tbody>
<tr>
<td>Passenger Cars</td>
<td>2695152</td>
<td>442288</td>
<td>3137440</td>
<td>53.42</td>
</tr>
<tr>
<td>Motorcycles</td>
<td>1475899</td>
<td></td>
<td>1475899</td>
<td>25.12</td>
</tr>
<tr>
<td>Public Transportation</td>
<td>525664</td>
<td>735240</td>
<td>1260904</td>
<td>21.46</td>
</tr>
<tr>
<td>Total</td>
<td>4696715</td>
<td>1177528</td>
<td>5874243</td>
<td>100.00</td>
</tr>
</tbody>
</table>

Source: own calculations, May 1997

Every day, on the average in 1994, motorized trips are made on 5.9 millions km. Private cars make more than half of the total distance traveled, motorcycles 25 % and the public transportation sector the remaining 20 %. The corresponding figures for the daily motorized trips (about 1.6 millions) are higher than the level found in Ouagadougou (1.4 millions) by a survey on mobility in 1992. The commuting patterns and the modal split of two urban populations equally sized and mobile (on the average, 1.8 motorized trips daily) are likely to make a real difference. Mutatis mutandis, the conclusion of a comparative study of Ouagadougou and Dakar applies also in this case: «the difference in capacity between a public transportation vehicle and a motorized two-wheels explains easily that, in Dakar, 3 millions daily trips generate a daily traveled distance of 2.8 millions km (of which 65 % of the distance in private cars against 35 % in public transportation), while 1.4 millions of trips in Ouagadougou are responsible for more than 4 millions km (of which 81 % on 2-wheels)» (Luc Vertongen in World Bank SSATP 1999b). In Bamako, the sprawled configuration of the city and the centrality of the trips are factors that enhance trips length (on the average, 3.715 km against 2.857 in Ouagadougou). Finally, the system of «continuous working day» – from 7.30 to 15.30, reduces the number of work and business related trips, and hence the total distance traveled.
4.2. The Emissions at the Macro and at the Sectors Levels

The estimates of emission factors for the District of Bamako have been summarized in a detailed table. The pollutants covered are: CO, CO\textsubscript{2}, Nox, SOx, HC, VOC, CH\textsubscript{4}, N\textsubscript{2}O, NH\textsubscript{3}, PM10, NH3, Heavy Metals\textsuperscript{5}. Nearly 560000 tons of pollutants have been discharged in the atmosphere, in 1996, through the households’ use of transportation systems (table 2). If CO\textsubscript{2} – which represents 83.6 \% of that mass, is not accounted for, then the remaining 95500 tons yield about 984,4 kg of pollutants per household and 119 kg per inhabitant yearly in the District area. These figures are to be compared to 1279 kg and 360.6 kg respectively in the Metropolitan Area of Mexico City in 1994 (Lezama et al 1997). On the average, between 1994 and 1996, the total emissions increased yearly by 19.5 \% (a 3.5 years of doubling time).

<table>
<thead>
<tr>
<th>Stressors</th>
<th>1994</th>
<th>1996</th>
</tr>
</thead>
<tbody>
<tr>
<td>CO\textsubscript{2}</td>
<td>307178</td>
<td>462651</td>
</tr>
<tr>
<td>CO</td>
<td>39834</td>
<td>64519</td>
</tr>
<tr>
<td>HC</td>
<td>9537</td>
<td>12600</td>
</tr>
<tr>
<td>NMVOC</td>
<td>3179</td>
<td>6181</td>
</tr>
<tr>
<td>Nox</td>
<td>5726</td>
<td>7881</td>
</tr>
<tr>
<td>Sox</td>
<td>1182</td>
<td>1521</td>
</tr>
<tr>
<td>PM10</td>
<td>532</td>
<td>856</td>
</tr>
<tr>
<td>CH\textsubscript{4}</td>
<td>262</td>
<td>555</td>
</tr>
<tr>
<td>Pb</td>
<td>117</td>
<td>195</td>
</tr>
<tr>
<td>Total</td>
<td>367547</td>
<td>558179</td>
</tr>
</tbody>
</table>

Source: own calculations

About 90 \% of these stressors constituted by major exhausts (CO: 68 \%, HC: 13 \%, Nox: 9) while represents less than 2 \% and PM10 hardly 1 \% of the total (Graph 3.1). Less than .25 \% of the mass is made of lead.

\textsuperscript{5}namely Cadmium, Copper, Chromium, Nickel, Selenium, Zinc.
4.3. **Emissions according to sources**

Private transportation contributes four times more than the public system to the total pollution – respectively 80 % and 20 % of the total mass, as well as to the specific emissions. As shown on graph 3.2, nearly 60 % of daily CO emissions are from the cars and less than half of that level (26 %) are from motorcycles since the private cars, which are at 90 % gasoline-fueled, are primarily very high emitters of CO. If all the motorcycles and the mopeds had been registered, the two-wheeled sub-sector would probably had ranked first in CO emission.

The motorcycles generated half of the HC while the public transportation vehicles emitted one third of the total. Once again, the full registration of the two-wheeled engines would have worsened the record of HC as in Ouagadougou where they made 95 % of the HC emissions (World Bank SSATP 1999).

The public transportation sector is the main contributor to two other exhaust emissions (Nox: 71 %, SO2: 84 %), and to NMVOC (53 %). It discharges in the atmosphere about the same percentage (42 %) of the total PM10 as the private cars (44 %). One knows that diesel-fueled transportation vehicles are mostly reproved for their high unit emissions in Nox, SO2 and PM10 (lead content) (Faiz et al. 1996; Joumard and others 1990). The minibuses, which represent 80 % of the fleet for public transportation, run on diesel in a proportion of 90 %.

With the graph 3.3, let us consider emissions by the public transportation system only, in Exhaust are prevailing with CO (43 Nox (31 %) and HC/NMVOCC (18 Sulfur dioxide is also relatively important, total particulate representing a marginal contribution (1 %).

Beyond the actual level of a specific pollutant, the crucial point is the conjunction of its trends and the way its likely interactions with other emissions may be harmful in the local context. This issue is not discussed here. In the following section, we will look at the recent trends in the emissions.
4.4. **Trends in the emissions**

The graph 3.4 illustrates the growth rate of the emissions, between 1994 and 1996, and their respective doubling time period. On the average, the emissions increased yearly by 19.5, a growth rate that raises a doubling time of about 3.5 years.

Some pollutants followed the dominant trend (Nox, CO, PM10) while the underestimated HC and SO2 registered the lowest growth rates but still at a very high level. Their emissions would double every 6.5 and 4.5 years respectively. Regarding VOC and CH4, their volume would double every two years against 3.2 years for Lead.

4.5. **Behavioral causes of pollutants emissions through the Public Transportation System**

Whatever the case, the models show very strong correlations (from 37.3 percent to 70.5 percent) between mostly socio-economic factors of household mobility and the emissions through the public transportation. Indeed, there is no significant influence of the demographic factors on the polluting behavior of the households but for the age of the head of the household (HHD) in the model 4 (nuclear and no-car family). In that case, each year of increase in the age of the HHD, generates, yearly, an additional emission of 3.260 kg of pollutants at he household level.

Moreover, there is no direct relation between the size and the complexity of the household’s structure, on one side, and the explanatory power of the models, on the other side. If more than 70 per cent of the variation in the level of emissions could be explained in model 1 (large and car-owner), this proportion is as high as 53.3 in model 4, i.e. more than in the two last models; 48.5 percent (model 2) and 37.3 percent (model 3). Hence, it seems that neither demographic factors per se – i.e. the size and the structure of the household, nor its motorization status – namely car ownership and use, have a significant impact on its mobility through public transportation.

The dependency ratio impacts the mobility, and hence the emissions, in the two types of large family. Whatever their ownership of at least one car, every increase of the ratio of the elderly and of the younger (less than 14 years) to the other members, induces, yearly, 2.250 kg and a half kilogram (.574) more in model 1 and model 2 respectively.

As an expected outcome, owning motorcycle makes a big difference only in the nuclear no-car family (model 4). In that case, this factor reduces, yearly, the emissions by nearly 70 kg.
One of the basic insertion strategies of families in the urban centers, is to distribute the members of the household within both sectors of employment (formal wage-earning and informal). More than half (53.4 percent) of the households have such successful strategies. With respect to the households that have their members only in the informal sector, their better access to the public transportation is reflected also in a significantly higher contribution to the emissions as much as 85 kg yearly.

A household poverty gap has been defined and its annual decrease (in 100 000 CFA F) feed the models as independent variable. This factor appears to be the strongest in the impacting variables. The explanatory power of the whole model depends strongly on it, from 80 percent (models 1 and 4) to 89 percent (model 3) and as much as 97 percent in model 2. This factor significantly increases the variation of the emissions in all the models, the lowest being for the nuclear car-owner household (nearly 11 kg), the highest being for the large car-owner (about 49 kg) with an intermediate level of 36 kg for the two other types of family. This also mean that if the poor households have actually the least access to public transportation, an improvement of their access through a reduction of the poverty gap, would also induce an increased contribution to the formation of the emissions in the context of the different types of family.

5. Conclusions

- Quick and low cost approach to generating plausible and valuable data on mobility and emissions by stressor for each category of vehicle and source sector;

- Conclusive test of transformation of these macro-emissions (that are more disaggregated than Inventory data) and household expenditures data into household level emissions to feed an impact assessment model linking emissions by sector of transportation to household’s and individual factors of mobility. But necessity to disentangle poverty indicator to specific socio-economic and policy relevant factors as those dealt through the new Strategic Framework Against Poverty.

- Necessity to get more accurate and systematic data for: 1) calculating daily km-passengers and km-vehicle according to public and private means of transportation and purpose of trips; 2) calculating associated costs (gasoline and public transportation expenditures, purchasing, operating and maintenance costs); 3) setting an O/D matrix to capturing traffic congestion and to building, for each individual or household, his/its Mobility, Energy, Environment Budget; 4) an history of all the means of transportation ever possessed by the adults (21 years and up) with their main characteristics.

These issues are being tackled in the framework of the Ouagadougou survey (January – August 2000), the data of which have been just processed. Two main outcomes are expected from this new research: 1) a replication of the Bamako case with, however, a larger analytical perspective (both sectors of transportation, fine tuned policy-orientation, congestion and health issues); 2) a prospective of mobility and emissions raising the environmental transitions to come and their underlying factors.

6 The so-called “Budget Energie, Environnement des Déplacements” built by a team of INRETS researchers for Agence française pour la Maîtrise de l’Energie (ADEME).