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Transport environmental impacts in cities and sustainability : Martinique island case study, French West Indies

Master of Science Thesis in the Master Degree Programme, Industrial Ecology, for a Sustainable Society

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Gothenburg, Sweden, 2012
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Cover: Traffic congestion on a highway stretch linking the capital city Fort de France to the west and south regions of Martinique island, French West Indies. ADUAM picture, taken in the morning in 2011.

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SUMMARY

This Master Thesis work has been done to assess the unsustainability of the transport policy defined for years in urbanised areas to answer to the increasing demand of people for mobility. The chosen case study is Martinique island, based in French West Indies, a small territory divided upon three association of metropolitan areas, not so much densely crowded, but encountering worrying environmental impacts and high traffic congestion issues. An assumption is to consider the island as one single urbanised area as major economic and residential poles are concentrated in the island center. Sustainable transport principles have been used to assess the transport policy current situation. People are indeed favoring the use of private car mean of transport partly because the other existing alternatives, especially public buses transports networks, are not efficiently functioning to compete with private cars. Lack of communication among the different transport organising authorities leads to the difficulty in achieving inter modality, while most inhabitants are daily evolving on at least two out of the three metropolitan areas. In practice many improvements are to be done, from ticket fare homogenization to punctuality, but it is also necessary to stop the rivalry between public buses and taxicos, two major road public transports. Eventually, one displacement leading to main traffic congestion issues has been especially studied: commuting to work. For that purpose a flow model has been defined, calculating carbon dioxide emissions as well as fuel consumption with current situation. From this model three scenarios of alternative mobility systems have been set up to demonstrate that a diversified transport system was achieving best environmental impacts reductions compared with current situation. Besides, the comparison of these scenarios revealed that an efficient use of private cars, i.e with a high occupancy rate, was achieving better results than with public transports, which raises the question of the private car place in a city policy transport. A more precise model is yet to be defined to more deeply assess the environmental impacts of all people's displacements in Martinique island, denying or supporting this Master Thesis findings.

The report is written in English.

Keywords: Martinique island, sustainable transport, city, environmental impacts

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Contents

Chapter 1

Introduction

This project is conducted to validate a Master of Science thesis done at Chalmers University of Technology in the field "Industrial Ecology - for a sustainable society". I was very much interested in studying to which extent current urbanized areas were for most of them following a similar unsustainable path despite geographical and historical differences, especially in terms of mobility.

Today and for the first time in history, the urbanized proportion of the global population sur-passed 50%. At the same time, urban areas are responsible for a large majority of impacts on the environment: they overexploit natural resources, generate too much waste with no closed loop system and they are also causing to some extent climate change. All these facts are at variance with the principles of sustainability. This project is not a trial to study a city in its entirely, it rather aims at focusing on an aspect required in any city functioning: people's mobility. To transport city-dwellers in a sustainable way is indeed a key challenge in urban areas, and today it is not successfully achieved, leading to many impacts among other traffic congestion, natural resource inefficient use and high pollution.

The thesis is divided into two major parts. At first, principles for a sustainable transport will be used to analyse the policy transport set up in the studied urban area, and a special focus will be done on commuting to work displacements, explaining how serious the situation is and for which reasons such a situation is encountered. Secondly, results of a flow model modeling people's habits to commute to work will be given to assess the potential environmental impacts reduction in the transport sector. Different associated transport related flows will be calculated as carbon dioxide emissions and fossil fuel consumption. Three different mobility scenarios, based on current situation, will then be set up with the same flow model and analysed to define which transport policy would achieve the most environmental impacts reduction. The chosen urban area is spread to

a whole island, Martinique island, based in the French West Indies. This rather small territory, not so much crowded, is currently saturated in terms of transport and it was providing a good support of study for this project.

1.1 Purpose

The purpose of this project is to use sustainability principles knowledge to assess the transport policy sustainability set up in Martinique island territory, and to come up with solutions to the mobility issue encountered there. It will also be used to describe and generate a transport flows model of people commuting to work and related flows model of the studied Martinique island urban area. This flow model will then help showing which outlined mobility alternatives would achieve the most environmental impacts reduction, above all the less carbon intensive mobility system. More generally, this project provides accurate data on Martinique island that can be the support for new future studies on it and it also can inspire people who want to study another city affected by the same issue.

1.2 Scope

A first approximation is done regarding the system boundary: a whole island, Martinique island, is considered as a single urban area, while in reality they do exist separated small cities revolving around the capital city Fort-de-France, and countryside parts. However, the geographical proximity and the many interconnections between these small cities and their capital city enable to validate this hypothesis. Then, only flows of people are considered in this project, and therefore flows of goods and merchandise are totally ignored. Besides, the model of simulation developed in the second part of the thesis only considers commuting times and working population. Results in this study may also be usable for other cities, as Martinique island urban development can be compared with other cities. Therefore the conclusions of this project might be transposable to any other urban area inasmuch as the latter gets the same development framework as Martinique island urban area.

1.3 Limitations

In only considering transportation flows associated with people's transport in this study, many city environmental impacts are not described and tackled. Other studies are required to fully describe city environmental impacts, but as they are usually complex,

it may be preferable to study separately each aspect of the city generating impacts to produce a precise and less muddled work. This project thus only highlights one source of city environmental impacts. A drawback of this approach is that results given by potential different studies might not suit once brought together.
Another limitation is that only transportation flows of people is considered in this study, therefore everything coming from transportation of goods and merchandise is neglected in the flow model. Two reasons justify this choice: first it aims at simplifying the model of simulation and secondly the results might have been different between goods and people. Another study only considering transportation flow of goods and merchandise should be done to achieve a comprehensive study.
Since the second part of the project is based on a model describing transportation flows of people commuting to work and transport related flows of Martinique island, the accuracy of this model will directly impact the precision of the analysis and results. This model will besides be defined quite simply as studying transportation flows and its related ones in an urban area might be quite difficult as they are numerous, and that available data is not necessary comprehensive. However, major flows are usually sufficient to expose global solutions, and in this project this lack of precision may not disrupt the conclusions. Despite the emission of different gases from exhausted pipes of vehicles, only carbon dioxide emissions will be representative of vehicles pollution in the developed model.
Also, provided results may not be valid for any other city and urban area due to these approximations, and in that sense conclusions may not be direclty transposable to another urban area. Still, the project will offer an approach and a methodology that can latter be used for similar studies.
Eventually, when exposing different alternatives of transport for people commuting to work, the evolution of direct and indirect city environmental impacts resulting in people's mobility within the urban area may not be precisely described for all of them as it will be difficult to quantify their evolution.

Chapter 2

Theory: Industrial Ecology and city environmental impacts in literature

This chapter provides an overview of significant scientific literature published by researchers on the topics of city environmental impacts and mobility aspects. It helps the reader to immerse himself in the context in which the thesis is written and at the same time it provides the main notions required to further understand the project.

2.1 Cities environmental impacts are increasing but not enough studied

There is a lot to learn about the way city must develop to become sustainable. Christopher Kennedy & Co. defined in their study a sustainable city as *an urban region for which the in flows of materials and energy and the disposal of wastes do not exceed the capacity of its hinterlands*[12]. Yet, the synthesis of several studies by Christopher Kennedy and Co. indicates so far that *the metabolism of city is increasing*: wastewater flows as well as the energy inputs increase, and the city is becoming material intensive, which results among others in materials transported into a city from much further than before, and indirectly this energy input increase contributes to urban heat island effect. Another point is that cities are today organized around the concepts of *growing fast, keeping wealth happy, staying competitive and cleaning up the rest later* [42]. It is thus of the highest importance to make this model evolve towards a strategy that *improves the well-being of the worst off and manages carbon stocks and fluxes important to public health and climate protection* [42].

As a result of the current strategy, cities environmental impacts have grown substantially and pollution has for instance become one of the main issues of authorities. These impacts are today recognized as being occurring at multiple levels, from local to

regional and global [84], this being reinforced by the fact that cities are today representing the majority urban concentration and that emissions are closely tied to anthropogenic energy emissions. Effects of urban areas on the environment expand therefore much further than cities boundaries. One of the most obvious example may be air pollutants, originating in a city and transported outside of its limits. However, it remains difficult to tackle global impacts at a local level of a city. Eventually, an important point to be mentioned is the fact that each step of city development generates environmental issues: only the source of them remains different, going from poverty-related to industrial pollution related to lifestyle related [84].

Yet, industrial ecologists have not much published about cities and the role of human settlements in the biosphere evolution and in global carbon cycling [31] and the too few studies result today in a lack of knowledge in this field. To date one knows that cities account for a high percentage of CO2 emissions [31], and still much more studies are found on the carbon cycle of land. But cities do not only release high concentrations of CO2, many of them also encounter chronic episodes of above-standard ambient PM 2.5 and PM10 [42], leading to human and environmental impacts more or less known and correlated. However, city studies could learn a lot from the study of its flows. A city is dynamic, in a sense that it is the place of evolution of many different types of flows, materials, humans, energy, emissions that are all to some extent correlated and linked. Studying them in parallel to city studies would enable to optimize urban form in a way to achieve at the best the circulation of these flows, the latter reflecting the city own activities.

2.2 Traffic and city form: an unsustainable and complex historical pattern

If models in industrial ecology are not as well adapted to study carbon balance of city, there seems however to be a real interest according to Xuemei Bai to make urban scholars and industrial ecologists work together. One can quite easily observe methodological similarities between studying urban ecosystems and industrial ecosystems, as well as spatial and functional linkages between them [84]. The reason is that urban form is a product of history [42], cities and industries being closely linked to their development, people choosing to settle where firms have never been established. Over time, these first settlements have shaped cities so that their current urban form can be explained by history.

As one has previously pointed out that people and industries settlements had always been linked over time, mobility appears to represent a key point in city development,

its first application being indeed to transport employees from dwellings to work. A city successful development depends thus on its ability to provide efficient mobility but mobility is among others function of local needs. It is therefore of paramount importance to develop a mean of transport that is adapted to urban form. Yet, here again, not much study has been carried out about the connections between urban metabolism and people displacement. Little attention has also been provided to transport logistics in terms of urban development and energy use, whereas it could be influenced by the role carried by a city in its region.

If one considers history, it comes out that one specific pattern has been massively repeated whatever the city considered: cities have grown from *linear transit cities to sprawling automobile cities* [12]. Personal mobility is therefore today still increasingly met through private vehicles, the *road-based radial-centric development patterns* in cities added to the will to settle as far as possible from industrial sites leading to a lot of traffic in city centers [42]. Also, an interesting point to mention is that the largest category of people moving by non motorized transport remains the poorest one. Therefore, the current city model does not enable everybody to get a good access to mobility.

As mentioned earlier, people have always purchased new parcels of land as far as possible from brownfield sites generated by industry. The city growing fast and more complex, people' s displacement has also increased over time, but as said by Miller and Ibrahim (1998), this may more be the distance from the central business district and other employment center that has more contributed to explaining transportation demand than population in itself. Still, with the automobile pattern and the incapacity of authorities to anticipate needs for mobility, huge problems of traffic congestion have come out in many urban areas [84]. City centers are particularly concerned because urban scholars have not anticipated that a sprawling urban form would likely force people to go through it to reach their destination. Ring roads have thus been built to release town centers, but the issue has only been moved and at best delayed. Consequently, average trips length has increased as well as the average commuting times to work, and it has indirectly lead to inefficient fuel use and local build-up of pollutants [42]. All these assessments show that it is necessary to study more deeply transportation flows to be better prepared in anticipating changes in mobility within cities.

Traffic congestion is not the only visible effect of a poorly managed mobility. Air quality and transport issues were also showed to be correlated, transport sector accounting for a high percentage of energy utilization and consumption, and therefore emission release. This relationship between transportation energy demand and urban form has been widely studied, still various conclusions have emerged, among others the fact that transportation demand, energy consumption, and urban spatial structure were linked and that per capita transportation energy consumption decreased as pop-

ulation density increased (Newman and Kenworthy 1991). This pollution and energy consumption pattern is however not likely to stop if the adopted model remains the one of employment in firms far away from homes with the use of private cars as means of transport. That is why air quality and transport issues must be included in policy agendas to come up with sustainable solutions but before that, more studies on people mobility need to be conducted to learn more about these connections.

2.3 Industrial Ecology can help re-defining a sustainable mobility form

To curb this issue, two ways of thinking exist. First, one could try to reduce people' s mobility, but it seems unlikely to achieve making people work at home rather than in firms despite democratization of computer technology and communications, and moreover, people do not only use their car to go from home to work but also to do business and shopping (Jarvis 2003; Mokhtarian 2002). This could at best only be part of the solution. Therefore, the remaining solution would be to change the way people are moving by offering less carbon-intensive mobility systems. Banister argues that *massive investment would be required in changing production processes for the new superefficient cars, in sourcing for instance substantial quantities of alternative fuels, and in giving incentives to industry and individuals to use these new vehicles*. But if increasing the amount of superefficient vehicles on the roads could decrease air pollution and weaken the pressure on fossil fuels, they are not likely to solve problems of traffic congestion and inefficient fuel-use. Mobility form needs to be totally reinvented in a way that fulfills people' s demand for mobility in a sustainable way.

Still, the new mobility form must absolutely come up from pilot-studies that will have been previously carried out on cities. If current urban form has generally a similar frame as previously said, each city has some random particularities, which are necessary to be included in the study to define its most suitable mobility form. With that in mind, existing studies about the subject have converged to the fact that the remaining most likely possibility would be to shape in a different way urban areas by integrating multimodal mobility systems via the use of mass public transit technologies. The required investments could partly come from multilateral financial institutions that are today too much oriented towards *conventional road building* and that are investing a lot more for private vehicles than public mass transit system [42]. In parallel it is required to increase safety and security for non motorized transport as well as providing good connections to public transport infrastructure. As mentioned earlier, people do not indeed only work and major facilities such as education, core retail or entertainment must

permanently be close to aboveground motorized service. Once again, all these parameters can be evaluated as soon as people' s mobility demand is well known.
Eventually, as urban land remains a lot desired, it is of paramount importance to better coordinate urban land-use and transport infrastructure, to achieve the best way urban form rezoning and reconfiguring. Existing studies on that subject have shown that the size of a city influences its choice in terms of public mass transit system: smaller cities will favor bus-oriented systems while larger and higher density cities will adopt rail-based mass transit systems [42].

Some factors can however slow down and limit in the implementation of a mass public transit system in a city. First, in some areas, city administrations and organizations have difficulties in implementing a public transport system because many people have developed their own public transport self- company [42]. It results in a detrimental competition, an unquantifiable loss of market by public authorities and a service quality that is below user' s expectation because self- companies do not set themselves any constraint in terms of time schedule, punctuality or road map... Fares can also be unequal and unstable because self-companies are often undeclared and they are not subjected to welfare costs as public transport companies do. It is important to continue studying cities that encounter such type of public transport self-company in order to define the best way to integrate them in global mobility form. Then, the implementation of such a public transport system would compete with the interests of the automobile industry and the companies mandated to build roads, and it is few to say that lobbyists in the automobile industry are numerous. It is important to consider everything that is at stake in order to get the best chance of success. Eventually, there must foremost be a will and a deep involvement from authorities to make things evolve. However, these factors are function of persuasion, while it is essential to first know people' s mobility habits, which remain the fundament of a successful public mass transit system.

As a conclusion of this theoretical introduction, one can write that some piece of information exists about cities, traffic and carbon. Some studies have showed that their evolution was linked and correlated. Traffic influences urban form and the way city is developed leads to special mobility pattern and more or less emissions. Carbon cycle is therefore known to be disrupted by city related flows of emissions, among them transport related flows of emissions, but to which extent remains uncertain. In fact scholars recognize that current mobility pattern and city form are unsustainable and that change needs to be undertaken. Yet they have much uncertainty about the way to proceed the change towards sustainability. What also comes out from studies is that authorities have neglected people's demand for mobility. Not enough studies have been conducted to better know people's habits in terms of mobility and settlement and that

partly explains current traffic congestion issues and pollution peaks in cities. To come up with an efficient and sustainable transportation system, it is necessary to be fully informed of people's displacements, so that flows of people to be at best connected with different transportation systems. Yet, every city being different from one another, it appears difficult to come up with one unique and universal solution to solve the issue linking cities, traffic and carbon, even if general patterns exist. That is why new cities must keep being studied to get deeper knowledge of patterns and behaviors regarding transport related flows of people in order to achieve sustainable passenger mobility in urban areas. This thesis project therefore continues on the lines of the undertaken research.

Chapter 3

Methodology

In this chapter, the reader is explained how relevant data for the thesis have been found and collected, and how they have been used to proceed the project.It also provides at its end a brief description of the remaining chapters.

3.1 Data collection

A deep work of documentation has been made about everything dealing with transportation of people in Martinique island. It was important to get an overview of this topic and from different point of views in order to get the most comprehensive image of current transportation situation on the island. Some of these data provide general information to introduce transportation context in Martinique island, while most of them support evidences of an unsustainable transportation system of people.

Data were collected thanks to several websites of agencies, one of the most important being the INSEE, literally the French National Institute for Statistics and Economic Studies, which concentrates data from many years and which has helped getting a trend of the situation over years until nowadays. However, data available were still limited and thus to better understand how the transportation issue of people was tackled on the island, it was required to meet the different local organisations and protagonists working in that field. Therefore a long work of contacts and meetings of the concerned people working in that field have been done. Among them the ADEME Martinique, Energy Control and Environment Agency in Martinique island, the ADEM, Martinique Economical Development Agency, the ADUAM, Martinique Development and Urbanism Agency, and the Regional Council establishments can be quoted. Also, the three associations of metropolitan areas have been contacted: the CCNM, Communauté de Communes du Nord de la Martinique, the CACEM, Communauté d'Agglomération du CEntre de la Martinique and CAESM Communauté d'Agglomération de l'Espace Sud

Martinique[1]. This enabled to get comprehensive data as well as getting the internal point of view of Martinique transportation organisations and agencies regarding people's mobility.

Then, to get this time the inhabitants point of view regarding transportation in Martinique island, an internal survey was conducted in a company, C.C.I.E car dealer company, set up in Lamentin city, therefore in the main economic activity pole of the island and located in the island center. The importance of localisation comes from the fact that it enabled having a good sample of people living in different parts of the island and at different distances. 25 people have answered to the questionnaire. Workers of this company, from white collars to mechanic workers have been asked some questions about transportation. I was given information about how personally inhabitants of Martinique island were considering the transportation issue. Specific questions have been asked concerning the employees habits in terms of mobility when commuting to work. This survey has also been useful for the developed model of simulation presented in the second part of the thesis. Results of this survey are presented in the Appendix B.

Eventually to get some information about related environmental impacts of transportation in Martinique island, qualitative description has been made for some of them through the analysis of various environmental studies done on the island. Concerning vehicles emissions of pollutants, all data come from Madininair association approved by the Sea, Sustainable Development, Ecology and Environment French Ministry, and which has kept the air quality into surveillance since 1998 in Martinique island.

All these data being collected, the current transport system of Martinique island has been assessed: three main principles defining a sustainable transport system have been used in order to demonstrate the unsustainability of the current transport policy. Then, the study sought to show that people's commuting to work displacement is largely responsible for some impacts in the island. Eventually, the analysis of several scenarios developed to make the working population commuting to work in a different way than current situation has been done to reveal that a transport policy based on diversified means of transport achieves best impacts reduction. The concerned scenarios have been simulated thanks to the model of simulation presented in the next section.

[1]More information available in Section 4.2

3.2 Flow model

To provide suggestions and piece of solutions to the transportation issue in Martinique island, a flow model has been created with Microsoft EXCEL software. This model aims at modeling working population commuting to work and it calculates the related flows of carbon dioxide emissions and of fuel consumption. Results are given per day or per year, for all working population or just one worker and per category of transportation mode (diesel / gasoline private car, public transport, two-wheeler). People commuting to work per feet or with none transportation mode are also put in the model but just to remember them as one assumes that their carbon dioxide emissions and fuel consumption are inexistent. Figures used in this model come from 2008 data because that year enabled to collect most of the required figures to run the model. To chose a more recent data but from different years may have create more uncertainties and mistakes.

Several assumptions have been made to design the model. The following figure 3.1 presents the different values and constants that have been used to run this model. The given assumptions are justified following the order in the next figure. Diesel and gasoline average fuel consumptions have been estimated with these statements: inhabitants of Martinique island have rather powerful engines in their private cars, as 50% of new vehicles in 2007 are engines with more than 6 fiscal horse powers[2], the studied urban area represents a city between 2000 and 49000 inhabitants [39], therefore private vehicles are considered to evolve in urban cycle conditions and most vehicles in the island automobile fleet are less than 5 years old because climate conditions accelerate the fleet turnover [39]. Then, the distribution in percentage of working population transportation modes comes from the ADUAM study from 2008 data [27]. The estimations of the number of diesel and gasoline cars in total car fleet are besides provided through the assumption of a 7% annual growth. It represents a linear interpolation of 2002 (20% diesel, 80% gasoline) [35] and 2005 (44% diesel and 56% gasoline) [15] data. It has been furthermore assumed that all working population commuting to work by car has the same pattern than car fleet, i.e 65% of them are commuting to work with a diesel car while 35% commutes to work with a gasoline car. The average commuting distance to work is based upon the ADEME study in metropolitan France and from the survey done at CCIE car dealer company. It may be a little above the real value. The next value in the table estimates by 10% the increase of fuel consumption with traffic. Of course this extra fuel consumption is function of many parameters, among others the type of vehicle, the length of traffic jams and the climate conditions but this mean value still seems reasonable. The number of persons in one car to commute to work is said to

[2]See Table 4.4

be equal to one: on average and according to ADEME Martinique agency, the average number of people in a car reaches 1.4 people in Martinique island. However, as this model is only considering commuting trips to work, it may be more realistic to suppose only one person per car.

In the second "Unchanged parameters" table, also seen in figure 3.1, most data are basic constants. Yet, the working population figure is from 2008 [27] and one considers that in the model these people represent all working people of Martinique island. It is therefore the studied sample for the calculations. The amount of worked days in a year theoretically is 220 but in reality due to people illness, death or maternity this value falls to 210 on average in France [39]. An important remark is that the carbon dioxide emission value calculated per person and driven kilometer in an urban area by bus has been directly taken from the NTM calculator (Network for Transport and Environment) available on the webpage of the NTM non profit organisation[3]. The only assumptions made are that buses are evolving in an urban area and that the given value is a synthesis of the different values one gets with several types of bus (minibus, urban bus...), as it can be found in Martinique island public transport systems.

Further assumptions and comments on the flow model are given below: public transport vehicles are only running with diesel fuel as only buses are used, public transports do not have enough independent lanes to avoid traffic jams, therefore calculations are both run with and without traffic jams assumptions. Two-wheelers are considered on average with middle engines (between 25cc and 950cc) [36] all running with gasoline fuel. Besides, no extra fuel consumption due to traffic jams is added to two-wheelers as it is irrelevant for them. Eventually, to provide comparable and summarised data, results in tons of diesel or tons of gasoline have also been converted in pet (petroleum equivalent tons).

3.3 Scenarios

Three scenarios have been developed as an alternative to current transportation situation. They are shortly presented in the following paragraph. Others could have been set but these three ones are representative of real and significant improvement in terms of transportation environmental impacts in cities.

[3] http://www.ntmcalc.org/index.html

CONSTANT AND VARIABLE PARAMETERS

Parameters that can be changed in the model

		Unit
Diesel average fuel consumption	0,067	L/km
Gasoline average fuel consumption	0,079	L/km
Working population only taking their car	0,8	80%
Working population only taking public transport	0,1	10%
Working population only taking a two-wheeler	0,01	1%
Working people only going by feet	0,06	6%
Working people not using any transportation mode	0,03	3%
Percentage of diesel cars in total car fleet	0,65	65%
Percentage of gasoline cars in total car fleet	0,35	35%
Average commuting distance to work (return trip)	36	km
Traffic jams = +10% fuel consumption	1,1	-
Number of persons in one car to commute to work	1	person
Gasoline fuel consumption of a two-wheeler engine	0,045	L/km

Unchanged parameters

		Unit
Carbon content of diesel	0,0202	kg/MJ
Carbon content of gasoline	0,02	kg/MJ
Energy content of diesel	41	MJ/L
Energy content of gasoline	34,6	MJ/L
Diesel density	0,85	kg/L
Gasoline density	0,765	kg/L
Working population more than 15 and having a job	134557	person
Worked days in a year	210	day
Molar mass ratio between C and CO2	3,66666667	44/12
Bus CO2 emissions per person and driven km in an urban area	0,06	kg/person.km
Equivalence 1 pet	41,855	GJ

Figure 3.1: Constant and variables parameters in the model of simulation

Scenario 1: car pooling is developed

In this first scenario, organisations in charge of transportation have done a great work on developing facilities such as car parks and on increasing public awareness to this alternative transportation mode. The number of people per vehicle has thus increased, assuming that people are massively using car pooling solution to commute to work. The assumption in the model of simulation is that there are necessarily 2 people in each car. The remaining parameters are unchanged. There are therefore less than 54 000 cars on the roads from people commuting to work each day.

Scenario 2: public transport is better organised and more developed

In this second scenario, organisations in charge of public transport in the three associations of metropolitan areas have successfully achieved coordinating their respective public buses networks and time schedules according to people's mobility. People are thus massively using them instead of their private car to commute to work. One assumes that all people that have been doing car pooling in Scenario 1 are now taking public transport: it means that out of 80% taking initially their car, 40% of them are now taking public transport. They are therefore now more than 50% using public transport every working day. The remaining transportation modes distribution are unchanged. One besides assumes that the remaining people taking their private car to commute to work are alone in their vehicle, which means that as for in Scenario 1, there are less than 54 000 cars on the roads from people commuting to work each day.

Scenario 3: Scenario 1 and Scenario 2 are combined

In this third and last scenario, the last two precedent ones are combined. It means that 50% of people are commuting to work with public transport, and that the remaining 40% of them taking their private car are doing car pooling. It means that less than 27000 cars from people commuting to work each day are found on the roads. The remaining parameters are unchanged.

3.4 Outline of the thesis

The remaining chapters of this thesis are divided as following.

Chapter 4 provides general background on worldwide transportation. It also briefly

introduces Martinique island main features. Eventually, the reader is presented the policy transport that has been defined in the island through the description of the different existing means of transport. It helps him to immerse himself in the island local context.

Chapter 5 gets deeper into the description of Martinique island transport modes of people and it provides key elements and results that are relevant for the analysis of the policy transport that will be done in Chapter 6. Each result is associated with one principle of sustainable transport. It helps the reader in understanding why such results are given.

Chapter 6 analyses the unsustainability of the transport policy according to the three principles of sustainable transport. Then the particular commuting to work displacement is analysed through the study of the flow model results. It determines which scenario achieves best results in terms of environmental impacts reduction.

Chapter 7 eventually draws the different conclusions along with the suggested further investigations.

Chapter 4

Background : global and local scales

This section deals with the transport mode that has been adopted by all developed countries and that is currently slowly but undoubtedly growing in under development countries, reaching today a success without precedent. It states in figures the current weight of cars worldwide and in Martinique island local territory. Other means of transport existing in Martinique island are also introduced. Eventually, a short presentation of the main features of Martinique island is also provided to get the reader a general picture of the urban area case study.

4.1 Global scale : the automobile and other modes of transport weight

The importance of motion has tremendously grown the past decade. Two different types of transport have expanded differently. They can be grouped into two categories : public and private transports. Private transport is transportation service which is not available for use by the general public, while public transport is a shared passenger transportation service which is available for use by the general public [83].

Private motorized transport mainly represents private car with internal combustion engine technology, alternative technological solutions, especially with the electric engine, being still at its marketing beginnings. On the contrary, many technological solutions have been used for a longer time in public transport. Among buses, tramway, trains, or subways and taxis, the panel is wide. The choice of fuel is also diversified, not restricted to the use of diesel or gasoline as for cars (the other fuels more being at the experimental phase than commercial phase), but including among others natural gas or electricity.

So far, private transport has been as a majority favored, and its expansion has been fast and worldwide. The figure 4.1 showing graphically the evolution of worldwide

production of private vehicles between 1898 and 2010 is the main evidence to support this statement.

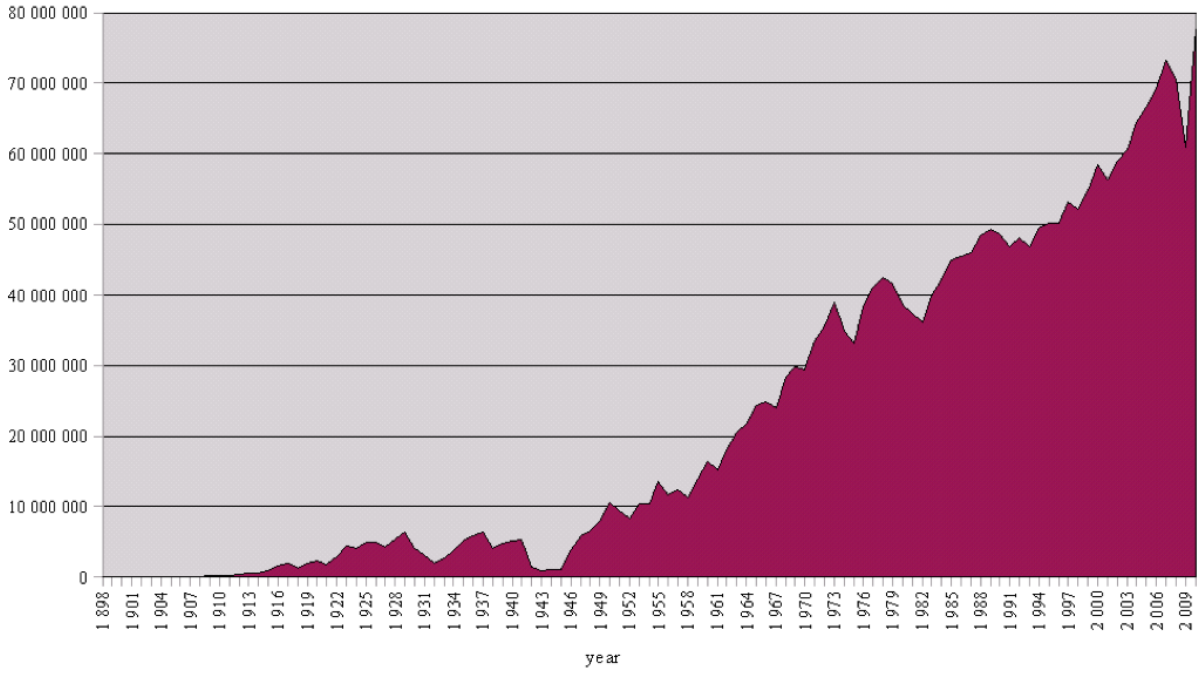

Figure 4.1: Worldwide Automobile Production, 1898-2010 *Source [43] : Freyssenet M.*

One can see that the automobile production growth has been slow until the end of World War Two, and it has then grown fast. Between 1950 and 2007, the production of vehicles went from 10 millions to 70 millions. Two categories of vehicles are included in the worldwide production : private and commercial cars. As a majority, private customers are the first target of car dealers, as private cars sales are usually twice higher than for commercial cars, as shown on the figure 4.2 on the period 2000-2009.

To be more precise, one can see that the production of private vehicles has gone from 29.7 millions in 1980 to 58.4 millions in 2010, hence an increase of almost 100% in 30 years [2]. Yet, with the worldwide economical crisis, private vehicles production has for the first time decreased in 2007, going from 53.2 millions to 52.0 millions. This decrease has gone on, with a 10% decrease in 2009, reaching 47.7 millions of private cars produced. But in 2010 the production has raised once again to a level of production never reached before, with 58.4 millions of private cars produced [2]. These trends are presented on figure 4.3.

Another indicator to characterize the worldwide automobile expansion is to consider the number of cars per thousand inhabitants evolution with time, as given on the figure 4.4 for the main countries in the world. France reaches for instance 599 cars per thousand inhabitants in 2010, hence an increase of almost 40% in 25 years. Under

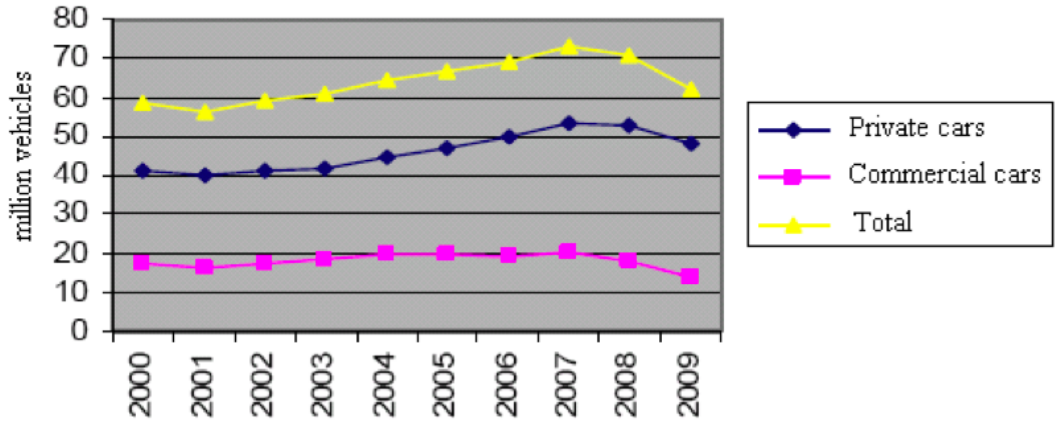

Figure 4.2: Worldwide Automobile Production, 2000-2009 *Source [2] : CCFA*

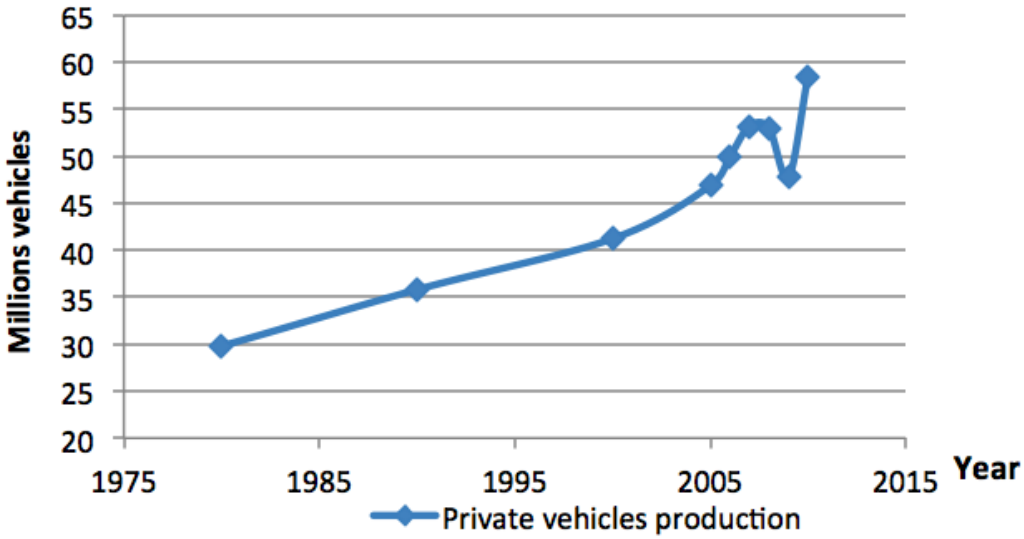

Figure 4.3: Worldwide private vehicles production, *Source [2] : CCFA*

developed countries have the lowest figures, but they are considered as having the most commercial potential for the coming years. The fact that in developed countries, the amount of cars per thousand inhabitants has kept increased - except in Germany for the 2010 year - leads to the conclusion that private cars have an important weight in society and that unless a long and global crisis, the demand in the automobile sector is likely tol keep growing in the coming years, in developed countries, but mainly in under development ones.

Not surprisingly, distance covered by people has also tremendously increased among years, the demand for mobility being more granted than anything with the use of private cars. Worldwide, this distance went from 1800 km per year and per inhabitant in 1960 to 4400 km per year and per inhabitant in 1990, hence an increase by 144% [33]. In

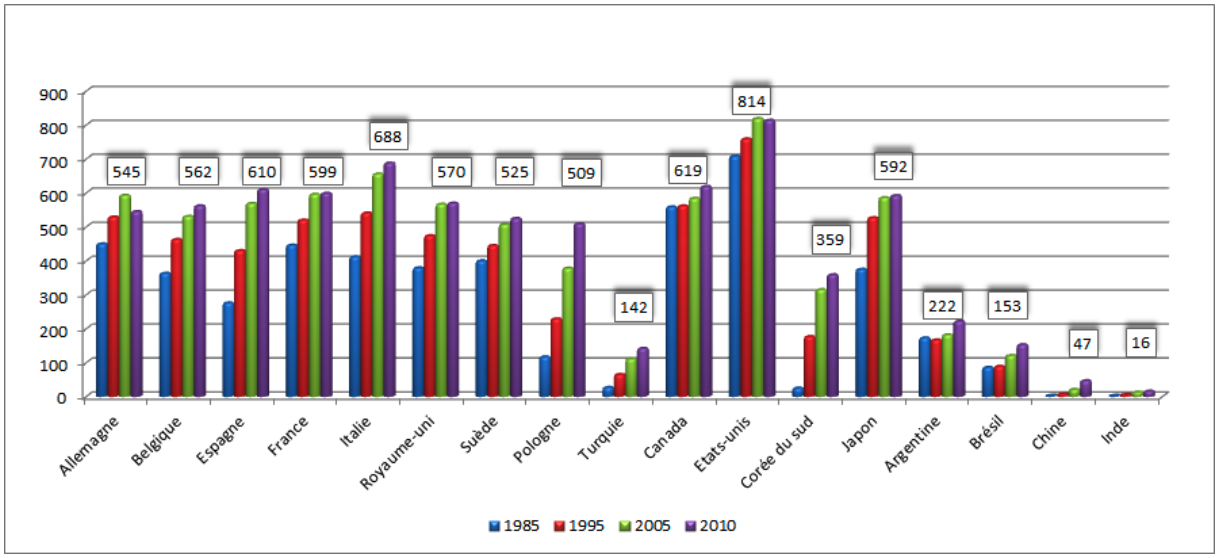

Figure 4.4: Cars per thousand inhabitants evolution, *Source [28] : Actualitix*

France for instance, the distance covered by private cars has increased by 28% between 1990 and 2010 [23].

To compare with, this scenario is different for public modes of transport, which weight is less important than private cars. As it is shown in figure 5.3, between 1960 and 1990, the use of automobile as mean of transport went from 55% worldwide to 52%, while bus transport went from 22% to 29%, and rail transport from 20% in 1960 to 10% in 1990 [33]. Public modes of transport remain far away from cars, even if bus share has increased by 7% in 30 years. If a tiny decrease in the world[1] use of private cars is seen on the graphic, this is due to a difference of population growth between developed and under development countries, but when each part of the world is considered, car share has increased, except in America.

On average, less than 20% of population in any city uses everyday a public transport system [22]. Public services are not developed in the same way depending of the concerned urban areas : private means of transportation will rise in poor densely areas detrimental to public services while high densely areas will develop public means of transportation to meet people's demand for mobility.

[1]"Monde" in figure 5.3

	1960				1990			
	Voiture	Bus	Rail	Air	Voiture	Bus	Rail	Air
OCDE	73	10	14	3	75	7	6	12
OCDE Amérique	88	5	3	3	82	3	1	14
OCDE Europe	54	20	24	3	72	12	7	9
OCDE Pacifique	23	16	60	2	54	8	22	16
PECO et ex URSS	5	21	70	4	28	31	29	12
PED	18	61	20	1	27	59	9	4
Monde	55	22	20	3	52	29	10	9

Figure 4.5: Evolution of the use of motorized transportation modes between 1960 and 1990, *Source [33] : Schafer*

4.2 Local scale : a short introduction of Martinique island main features

Martinique island case study presentation

Martinique island, with an area of 1128 km^2 is located in the archipelago of the Lesser Antilles. It represents 0.25% of the Swedish area. As it can be seen on the figure 4.6, Martinique island is characterized by a diversified relief : up in the North a mountainous relief is found (orange color), with the Carbet peaks and a still active volcano, the Pelée Mountain (height 1397m). The island can then be described as a succession of small and middle high hills called ”Morne” (beige color) where main residential areas are to be found. The only existing plain between the hilly landscapes is situated in the center of the island, called Le Lamentin (green color). This is also the place where the international airport has been built. This zone only accounts for 10% of the island area[14].The island is only 24 km wide and 64 km long for the most distant points.

According to this short description, one can already draw some piece of conclusion : the island is quite small, which suggests that space is likely to be one major constraint to any type of development, and that a smart distribution of free land is crucial to get the best access possible to any facility. The usable territory is yet smaller than the island surface due to its hilly relief, and one can think that occupied spaces will concentrate into the plain and medium hills.

Figure 4.6: Martinique reliefs, *Source [1] : Martinique Maps*

If one considers the island urban form history, one can see patterns that support the previous statement. First, under slavery period, urbanized space was following the Master house pattern, with slaves huts in the land and small burgs nearby Master houses. When slavery was abolished in 1848, middle high hills[2] were for the first time parceled out with some individual land-grabbing. Burgs were under development. In the first half of the 20st century, there was a high migration of population in cities, the latter encountering for the first time peripheral neighborhoods, especially for the capital city Fort-de-France. Between the 60s and the 70s, this is more the littoral that have been settled, but always nearby the island center. One needs to wait for the road infrastructures development in the 80s to get the middle high hills settled with the large house concept. Nowadays, free land is getting rare, especially in the island center, and house prices have much increased. Between 1994 and 2004, urban land went from 19 500 ha to 26 400 ha, hence a 35% increase, while population has only increased by 7%

[2]See figure 4.6

over the same period [55].The settlement in middle high hills farther and farther from main economic activities and cities centers has also favored the mobility increase. The next figure 5.8 presents the current cities development alongside the territory : cities are located in the island plain and alongside the coasts, direct result of the historical pattern.

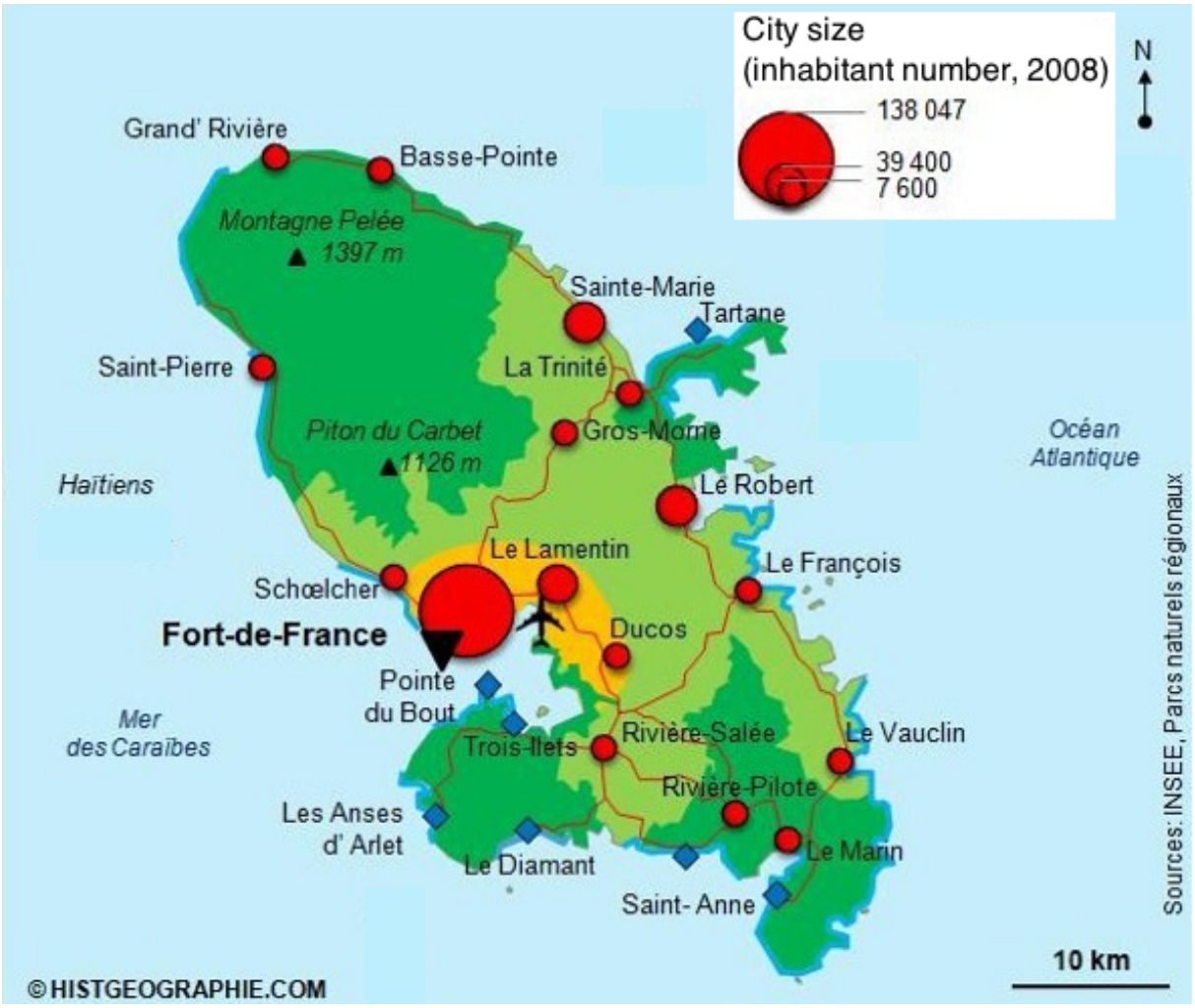

Figure 4.7: Martinique island cities size widespread in flater areas, *Source [19] : Insee & Histgeographie*

The population is therefore unequally widespread alongside the territory, with a rather high density, from 356 inhabitants per km^2 on average, to 2044 inhabitants per km^2 in the capital city Fort-de-France. This population, reaching 403 000 inhabitants according to 2008 data[3] is mainly grouped into 4 main cities, all located nearby : Fort-de-France, the capital city, with 89 794 inhabitants, Le Lamentin, 39 442 inhabitants, Le Robert, 24 068 inhabitants, and Schoelcher, 21 510 inhabitants. These four cities

[3]INSEE figures

alone represent 44% of the entire population. Restrained by its natural environment, population size steadily growths among years, as it is seen on the following figure 4.8.

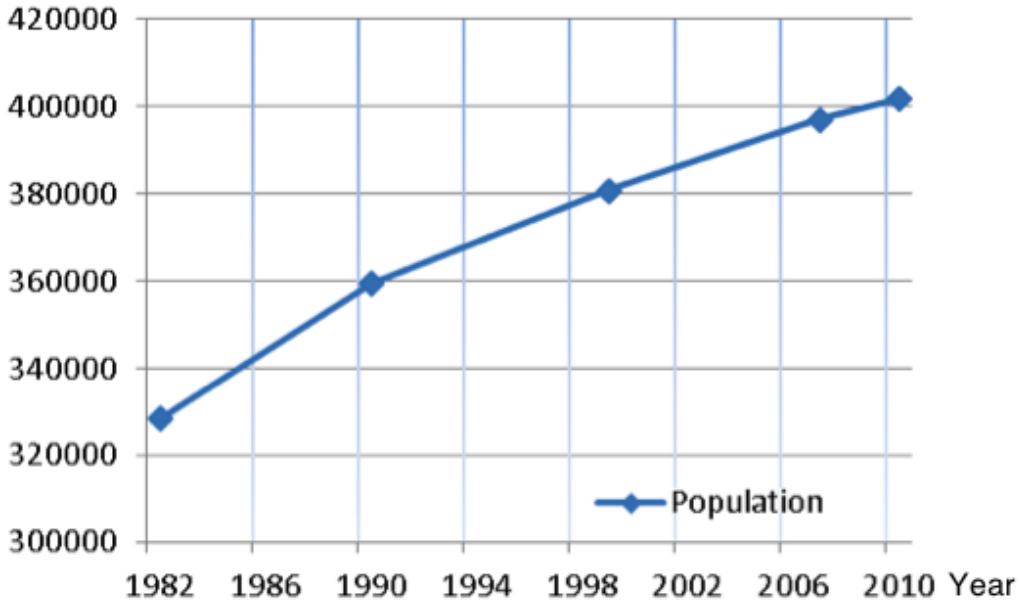

Figure 4.8: Population increase over time, *Source [14] :* INSEE

Cities in Martinique island are not managed by one single public organisation that provides a global urban plan. As it can be seen in figure 4.9, the island is divided into three associations of metropolitan areas according to geographic criteria : the CCNM (Communauté de Communes du Nord de la Martinique), the CACEM, (Communauté d'Agglomération du CEntre de la Martinique) and CAESM (Communauté d'Agglomération de l'Espace Sud Martinique). CCNM is the oldest organization, set up in 1996, while CACEM was set up in 2000 and eventually CAESM in 2005. The mission of these public establishments is to develop partnerships between the main cities of their areas. For instance, CACEM community aims at federating the capital and the three main suburban cities located in the centre of the island : Fort-de-France, Lamentin, Saint-Joseph and Schoelcher. CAESM and CCNM have to federate respectively 12 and 18 suburban cities. Eventually, the three associations of metropolitan areas have to work together at a global level to achieve global urban work on the whole island territory.

Figure 4.9: Geographic associations of metropolitan areas : CCNM, CACEM, CAESM, *Source [67] :* ADUAM

The next figure 4.10 illustrates the inhabitants number per district and sprawling in Martinique island. Population is concentrated in the CACEM territory, among Fort-de-France, Schoelcher, Saint-Joseph and Lamentin cities. Two and half of the population leaves here. However, population in the capital city Fort-de-France has decreased by 6% between 1990 and 1999, while population in surrounding cities have much increased

over the same period. For instance, Rivière Salée, Robert, Lamentin or Trinité districts recorded respectively a demographic growth of +40.2%, 19.9%, 18.1%, and 16.2% within these 10 years.

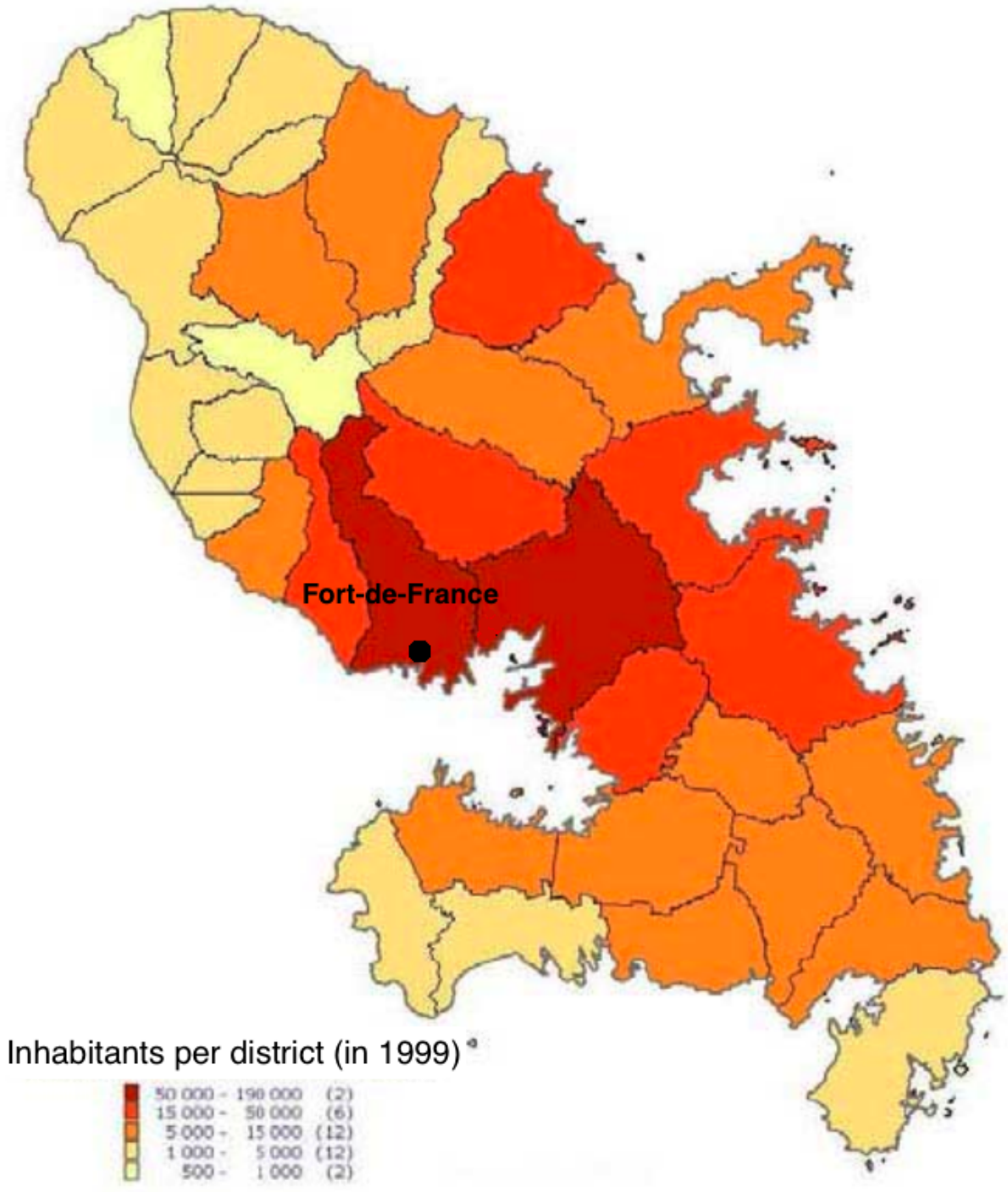

Figure 4.10: Inhabitants per district, 1999, *Source [79] :* IEDOM

This part of the territory (Fort-De-France, Saint-Joseph and Lamentin) also concentrates a large part of economic activities. First, the harbor, the airport and 6 out of 8

island supermarkets are found in this zone. In total, three and half of Martinique population is working within this area [79]. The two figures 4.11 and 4.12 illustrate these facts.

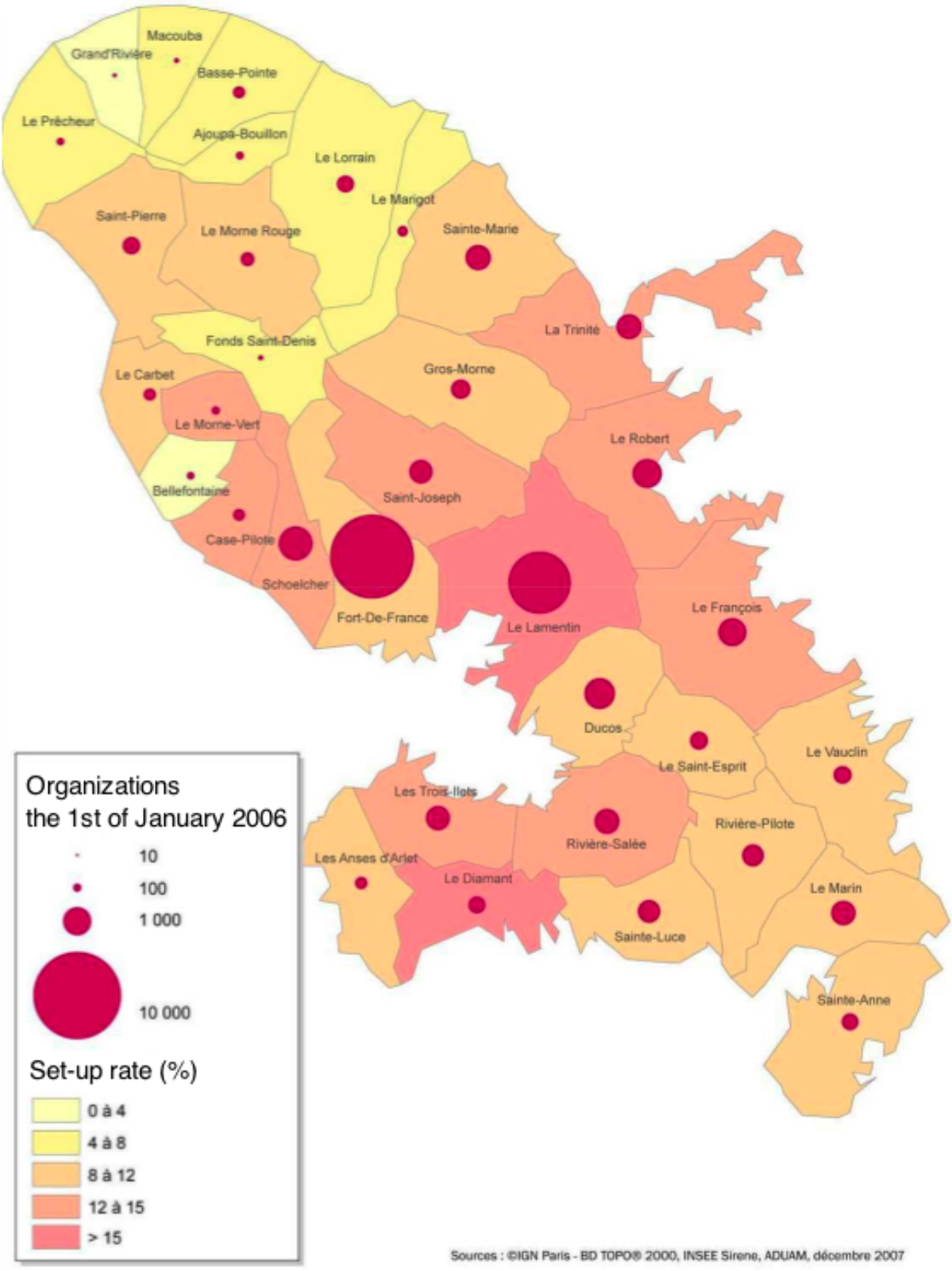

Figure 4.11: Number of organizations and set-up rate, 2006 *Source [24] :* ADUAM

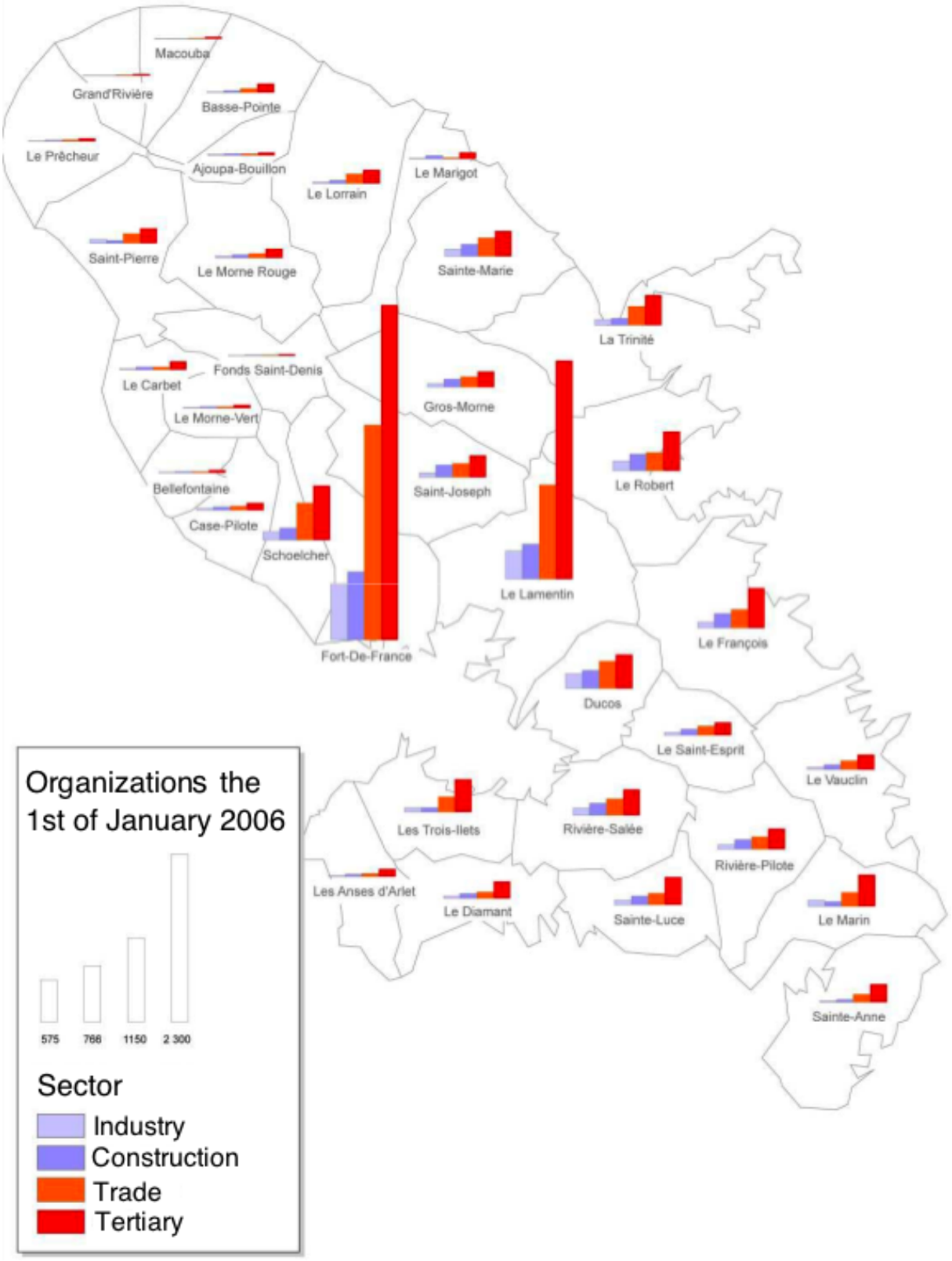

Figure 4.12: Organization classified by sectors, 2006, *Source [24] :* ADUAM

Regarding mobility, Martinique island road network, divided into 4 categories, mainly consists in small roads, as presented in the next table 4.1. Only one small motorway is found, which is in fact the ring road of the capital city Fort-de-France. It is 7 km long, and it has evolved from two-lane road to three-lane road back in the end of 1990. Then, the island has 274 km of trunk road, sometimes two-lane roads, most of time one-lane roads. Eventually there is 630 km of secondary roads, one-lane road, and 2300 km of township roads.

Headed	2002	2008
Length of motorway network, in km	7	7
Length of trunk roads, in km	270	274
Length of secondary roads, in km	600	630
Length of township roads and other, in km	2300	2300

Table 4.1: Road Network, *Source [74] :* DDE

The following figure 4.13 presents roads sharing out on the island. As it is can be seen, all townships are more or less well-served, but partly due to the geographic distribution all roads are converging on the same point : Fort-de-France and its suburbs. The figure only shows main roads.

Figure 4.13: Road cartography of Martinique island *Source [14] :* INSEE

The island climate is also particular. Indeed the island founds itself under the Cancer Tropic and benefits from a warm (26°) and humid (between 80% and 87%) climate. It is also under the influence of the trade winds. Two seasons occurred : the warm and dryer season between March and September, and the warm and more humid one the other part of the year. The diversity of vegetation found on the island leads into the fact that 4 variations of climates can be found, widespread as shown on the next figure 4.14.

- The yellow zone represents a dry tropical climate (1000L/m2 yearly)
- The black zone represents a tropical climate (2000L/m2 yearly)
- The grey zone represents a humid tropical climate (3500L/m2 yearly)
- The blue zone represents a super humid climate (7000L/m2 yearly)

Figure 4.14: Distribution of the four types of climate encountered in Martinique island, *Source [57]: Météo Martinique*

The particular localization of Martinique island results as previously seen in a huge diversity of climates and reliefs, and flora and fauna is also rich. It is of paramount importance to understand the interaction between them and human activities, to produce as little disturbance as possible and manage the wildlife conservation. If Martinique island is a place of specific flora, with more than 3000 plants and 396 trees species the probable most disturbing one is the mangrove swamp. Mangroves are various kinds of trees up to medium height and shrubs that grow in saline coastal sediment habitats in the tropics and subtropics, as shown in figure 4.15. On the island, it has a surface of 1 840ha, which accounts for 6% of total wood area [32](BD TOPO, IGN, 1994). The mangrove is very important for several reasons : it is the living place or reproduction place of many different species, but it also contributes a lot in the cleaning of fresh water before it ends in the sea. Finally, this particular environment, at the border of sea and ground is a good barrier against tsunamis. Yet this considered fragile ecosystem is more and more stressed among others by urban extension, coastal and town planning as well as the pollution that results in human activity. As a consequence, the Ifrecor institution has estimated that the mangrove surface in Martinique island had decreased by 30% in 10 years [61] [51]. Concerning the fauna, more than 400 species have been registered on Martinique island, among them more than 200 birds species. Approximately 10% of these species are endemic species.

Figure 4.15: Mangrove swamp in the Galion Bay, *Source [48] :* ACADÉMIE MARTINIQUE

Protection and control tools of Martinique island wildlife

Because many ecosystems are fragile and more and more of them are threatened by the constant human development, establishments of regulation and of protected areas have come up. The map in figure 4.16 presents the different areas of protected environment, through the setting of various protection tools. The yellow area shows registered/designated natural sites[4], which is a natural site whose interest is high enough to be watched carefully without yet being high enough to be classified. Red areas represent classified/conservation natural sites, which are natural sites whose any transformation requires a special authorization. Eventually, green areas show regional natural Park. This regional Park accounts in itself for 63 500 ha of various types of forests.

[4]French label

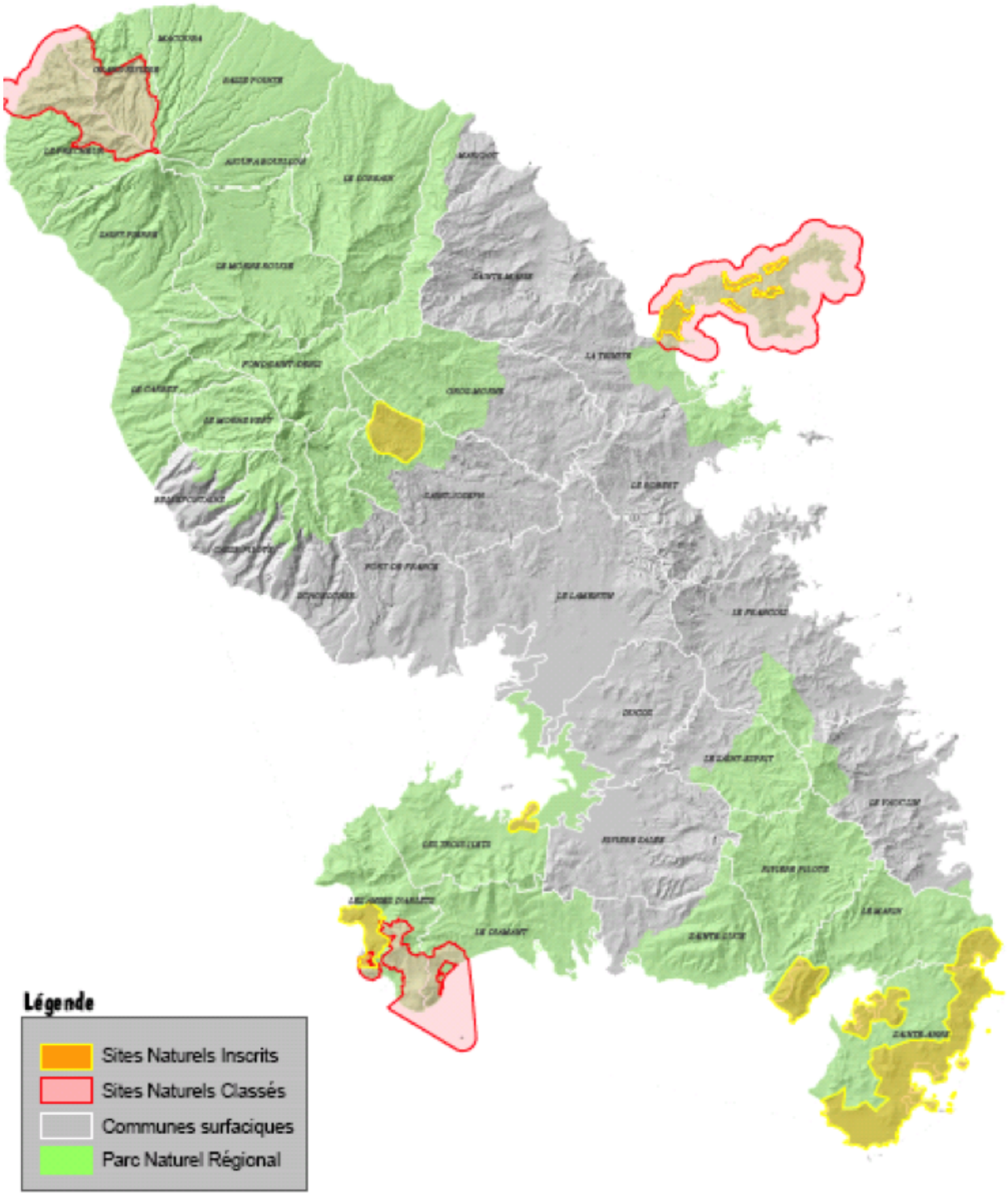

Figure 4.16: Representation of several land protected areas in Martinique island, *Source [75] :* DIREN *Martinique*

Other protection tools, described on the next figure 4.17, have enabled to start protecting this island diversity. One founds the ZNIEFF [5] zoning, which both deals with marine (blue colors) and land (green colors) areas. Eventually, one can quote natural reserves (orange color) and prefectural decrees (green and yellow dots)...

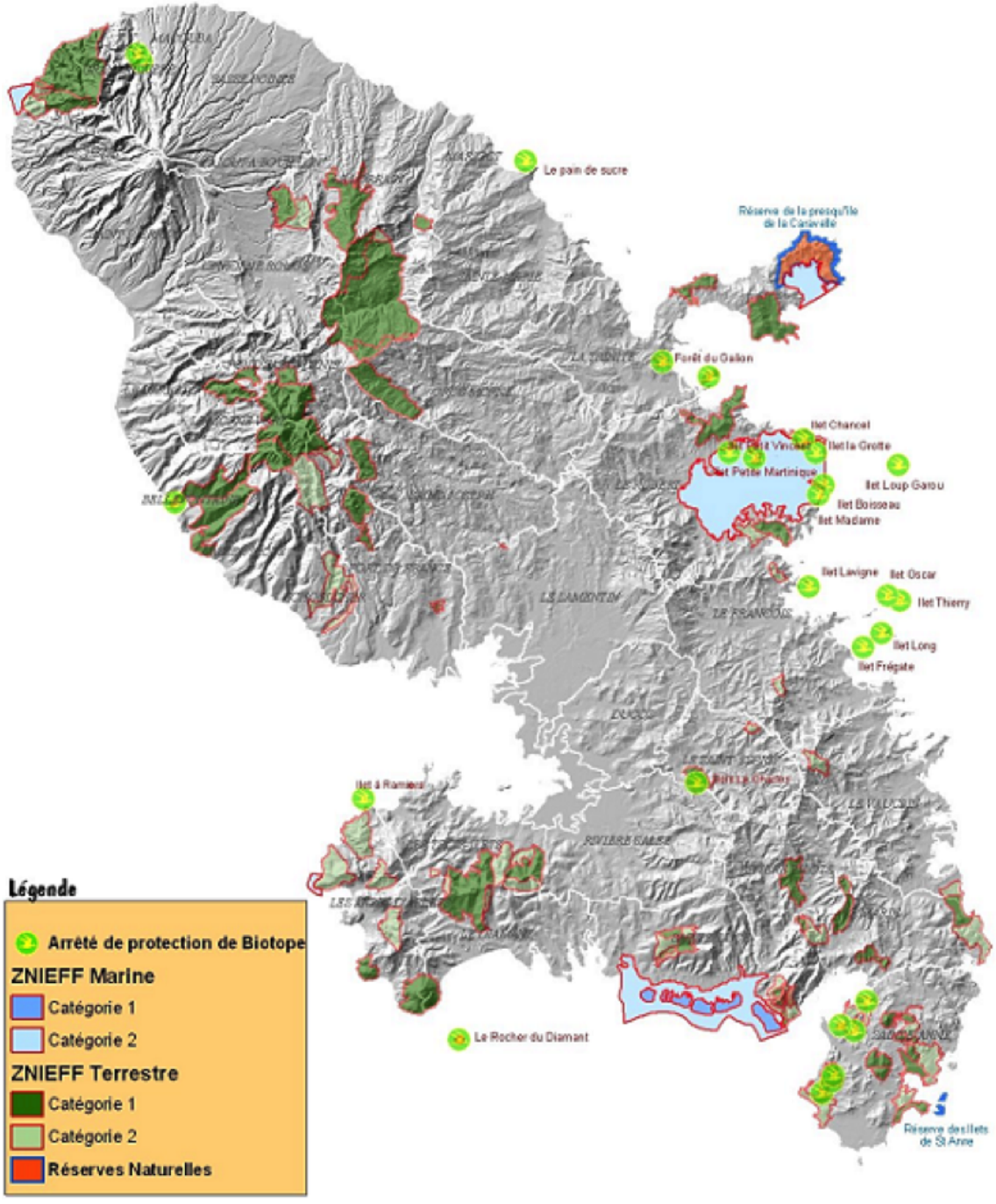

Figure 4.17: Representation of ZNIEFF zoning, natural reserves and prefectural decrees, *Source [75] :* DIREN *Martinique*

[5] ZNIEFF :Natural Zone which presents an Ecological, Faunal and Floral Interest

Air pollution control organisation and regulation

Fauna and flora are not the only one controlled.The natural environment is indeed not the only one to be threatened by city development. Impacts on human health are often under estimated and little known. Despite a strengthening regulation, according to the WHO -World Health Organization-, air pollution is today responsible for two millions premature deaths in the world [60]. Health regulation on air pollution is frequently updated by the French Ministry of Ecology, Sustainable Development, Transport and Accommodation.

In Martinique island, one organization, Madininair, set up in 2001 and authorized by French Ministry of Ecology, Energy, Sustainable Development and Sea is in charge of the air quality monitoring of the island. Cities are indeed releasing emissions of different substances in the air, which need to be measured in order to be controlled. French air law from December 30, 1996 defines air pollution as "the human introduction, directly or indirectly, in the atmosphere and closed spaces, of substances leading to prejudicial consequences that can threaten human health, being harmful for biological resources and ecosystems, influence climate changes, damage material goods and cause excessive olfactory pollution". Two types of pollutants exists : primary emissions, such as diesel particles, and the products of atmospheric transformation, such as ozone and sulfate particles formed from primary pollutants that evolve into a more stable component. Nowadays air quality is more and more studied, especially in cities in order to prevent population from health hazards and taking necessary measures when pollution is too important.

Different thresholds exist with different prevention plans in order to best protect the population. For instance, the information and recommendation threshold is the level of pollution that requires public information to limit an health risk on sensitive population class : it has been fixed to 200 μg/m^3. The warning level, fixed to 400 μg/m^3 requires urgent actions because a short exposition carries a risk for human health and the environment. Eventually, the limit value health protection (200 μg/m^3) is a level that can be reached and overrun during a certain time, fixed according to scientific knowledge to avoid, prevent or reduce harmful effects on public health or on the environment (definitions of Ministry of Ecology, Sustainable Development, Transport and Accommodation, France).

In Martinique island, eight air stations have been widespread along side of Fort-de-France and its suburbs Lamentin and Schoelcher, and two of them are specialized in air traffic : Concorde and Renéville stations. These stations are presented in the next

figure 4.18. They are all located in the CACEM region and close to the capital city Fort-de-France.

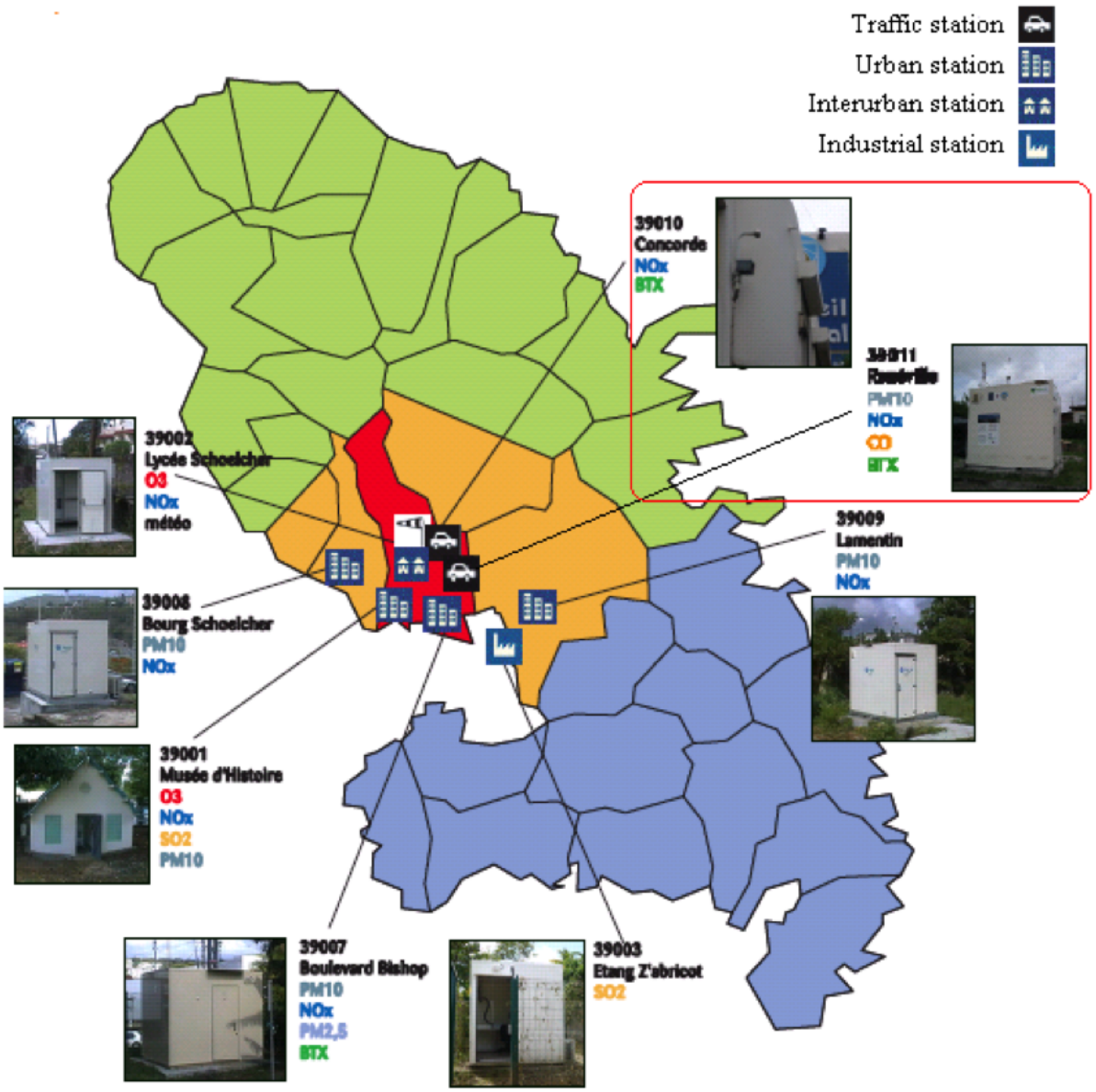

Figure 4.18: Air stations in 2010 in Martinique island, *Source [47] :* M*adininair*

To be more precise, a detailed map is presented below on figure 4.19 : Renéville and Concorde traffic stations are represented, as well as the five other stations. Renéville station is located close to the unique motorway section, while Concorde station is placed on the capital city ring road. These stations measure precisely the emissions from traffic on these road stretches.

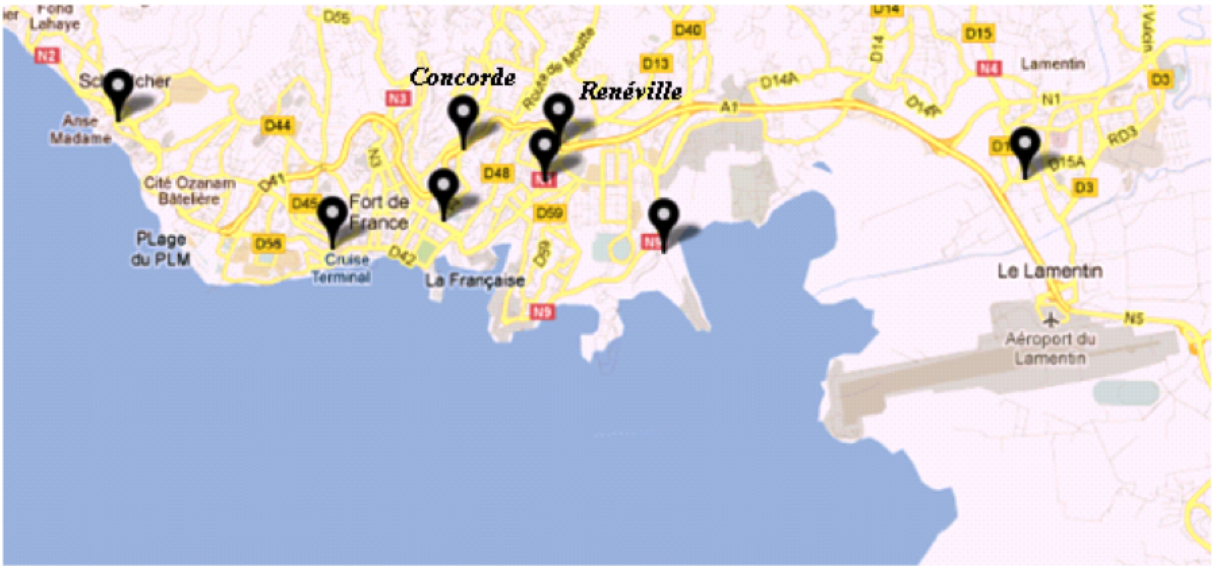

Figure 4.19: Renéville and Concorde traffic stations location, *Source [47] :* M*adininair and Google* M*ap*

The automobile indeed releases many different gases in the air, shortly described in the following paragraph. Air emissions from heat engine vehicle provides from exhausted gases produced through the burning fuel in internal combustion engines. Depending on the burnt fuel, unleaded gasoline or diesel, gases produced are different. Exhausted gas are however different depending on whether the engine is cold or has reached its equilibrium temperature and is thus warm[41]. Studies so far have more focused on emissions when the engine is warm. Besides, these emissions are function of the vehicle characteristics, for instance, the vehicle age, model, but they also are function of the motorist driving or the weather conditions. Among different emitted substances, one finds carbon monoxide, hydrocarbons, dioxide nitrogen, policyclic aromatic hydrocarbons and particles. Particles are however considered as null for unleaded gasoline engines.

4.3 Martinique island mobility : the automobile weight

Economic weight

The likely most representative aspect to consider to determine the automobile importance on the island is to look at its economic weight. If the economy of the island rests itself upon 3 main activities - agriculture (sugarcane, banana and pineapple), tourism, and trading -, the weight of transportation sector in the island economy is quite large. As it is seen on table 4.2, repair shops and automotive business accounts for 24.9% of

the total number of organizations existing the 1st of January 2010, with 9 179 shops.

	Number	%
Total	36801	100.0
Industry	2937	8.0
Construction industry	5012	13.6
Trade, transports, various services	25 547	69.4
Including car trade and repairing	9179	24.9
Public service, health, social action, education	3305	9.0
(trade without agriculture)		

Table 4.2: Number of organizations classified by activity sector the 1st of January 2010, *Source [14] :* INSEE

As one can see in the next table 4.3, during the same year, 1043 shops in relation to the automotive sector have been set up : this represents 21.3% of all new companies set up in 2010. The automobile sector hence keeps being active and dynamic on the island despite a setting-up rate smaller than the other sectors.

	Total	%	Setting-up rate
Total	4886	100.0	14.6
Industry	371	7.6	13.9
Construction industry	612	12.5	12.6
Trade, transports, various services	3445	70.5	15.1
Including car trade and repairing	1043	21.3	13.0
Public service, health, social action, education	460	9.4	14.5
(trade without agriculture)			

Table 4.3: Setting-up of companies according to activity sector in 2010, *Source [14] :* INSEE

With such an activity, cars sales are likely to be important. The evolution of the number of registration plates between 2004 and 2009 given in table 4.4 is representative of this dynamism : 13142 new private vehicles have been sold in 2009 while 21073 are second-hand cars. However, a peak of sales occurred in 2007 and it has then decreased in 2008 and 2009, reaching a 10% decrease in 2009 compared to 2007. This drop in sales is explained by the economical crisis, the vehicles cost as well as the swing of fuel prices. Yet between 13000 and 18000 new cars are sold on average every year, which remains a relatively high figure for such a small territory.

	2004	2005	2006	2007	2008	2009
New vehicles						
Private cars	13613	14749	14132	14666	13679	13142
Including % of diesel private cars	42	41	49	54	57	nd
Including number of private cars with less than 6 HP	nd	7444	7026	7333	nd	nd
Two-wheeler	nd	749	782	978	1117	991
Trucks, vans, specific vehicles	2693	2860	2905	3011	2949	2411
Busses	31	31	94	138	114	66
Second-hand vehicles						
Private cars	21975	22392	24338	24420	24450	21073
Two-wheeler	nd	nd	nd	nd	nd	1079
Trucks, vans, specific vehicles	3006	3201	3432	3375	3481	3101
Busses	62	75	111	98	67	56

Table 4.4: New and Second-hand registered cars since 2004, *Source [81] : Statistical Department of Ministry for Transports and [66]* SOeS

This sector is also likely to be dynamic in terms of employment. The next table 4.5 shows the number of employees working in a car company. The whole automotive sector accounts for 2570 working stations. Compared to the total amount of working stations in all sectors, the automotive and two-wheeler human activity represents 28.6%. The automobile sector is therefore not only a source of economic activity but it also generates much employment, and in a context of high unemployment rate, reaching more than 20% in 2011, hence 35 100 unemployed [14], it remains even more important.

	Figures the 31st of December 2008
Car trade	935
Car repairing and maintenance	844
Car equipment trade	791
Two-wheeler repairing and trade	39

Table 4.5: Employees in the private motorized sector, *Source [14] :* INSEE*, Clap*

Cars fleet and households preferences

If the automobile sector is so dynamic in Martinique island, this is because private car is an important mean of transport developed and used. There were indeed 160 000 vehicles on the roads in 2000, 168 000 in 2002, 204400 in 2009 and 228 000 vehicles are expected in 2015 [85]. It was representing 430 vehicles per thousand inhabitants in 2002 against 515 vehicles in 2008 and 552 vehicles expected in 2015. The 2008 figure is in the mean of all developed countries, as seen in figure 4.4. However, this value is the highest of all French islands and it is even higher than in the metropolitan France, the later having 506 cars per thousand inhabitants the same year. Households get therefore better and better equipped. Between 1999 and 2008, the households' motorization has indeed increased by 33% on the island [27]. As seen in the following table 4.6, more than 70% of the households have at least one car in 2008, which represents 111805 families, whereas there were only 83 701 families in 2002, hence a percentage of 64% [78].

	Until 1st of January 2006	Until 1st of January 2008 (number in %)
Households with at least one car	108726	111 805
Households equipment rate (%)	69.9	70.1
Including households with only one car (%)	49	49.2
Including households with two cars or more (%)	21.2	21.8

Table 4.6: Households automotive equipment the 1st of January 2006 and 2008, *Source [14] :* INSEE, RP2008 *and [77]* IEDOM 2009

Besides, households usually prefer investing in new vehicles. The turnover of vehicles is also high, as on average people in Martinique island change their car every 5 years. Indeed, the island climatic conditions contribute to a large extent to a much faster deterioration of any electronic, metallic good than in other types of climates,

which explains why new vehicles sales usually represent a large share in total sales. However, a new phenomenon is currently occurring : since 2007 [6], new cars sales have been decreasing while second-hand cars sales have been increasing : between 2007 and 2008, one counted a 5% decrease, against 7% decrease between 2008 and 2009 [27]. A decrease in these sales is revealing that the households habits is changing, a probable reason being the difficult economic situation. Another households preference is the power of cars : many bought vehicles have indeed powerful motorization, 50% according to the 2007 figure in table 4.4, one reason of that being the hilly landscape with very steep slopes. Many people also chose a four wheel car because of the bad road surface quality in many places. To finish, another behavior is emerging : more and more diesel cars are sold each year, with a trend showing an increase from 42% of diesel motorization in 2004 to more than 57% in 2009 [14]. This may be explained by the constant increase of fuel price.

The importance of private cars of inhabitants of Martinique island is also seen in the number of people getting their driving license. The next table 4.7 illustrates the amount of delivered driving license between 2005 and 2009. Each year one notices an increase in that number : 4 602 in 2005 to 6 133 in 2008 for private cars, hence an increase of 25% in four years.

(unit : number)	2005	2006	2007	2008
Private cars	4602	5099	5487	6133
Two-wheeler (less than 25KW)	6	1	2	6
Two-wheeler	748	768	737	745
Trucks (higher than 3.5T)	274	353	290	328
Buses (vehicles with more than 8 sits)	95	116	174	163
Trucks with trailer	128	130	146	192
Total	5853	6467	6836	7567

Table 4.7: Number of delivered driving licenses, *Source [40] : Ministry of Ecology, Energy Sustainable Development and town and country planning*

[6] see table 4.4

The island policy regarding the automobile mean of transport

If the automobile is likely to have influence and weight in Martinique island, it is explained by the policy transport which has favored for a long time its development. Indeed, until recently, the more the increase of mobility, the more the extension and the creation of new facilities for cars. A first assessment is that in less than one century, road facilities in Martinique island territory have almost doubled, increasing total roads length from 1200 km to almost 3000 km nowadays.
Besides, with the increasing demand for mobility, roadworks have been undertaken : road lanes have been extended, as for the highway stretch, which was changed from a two lanes road to a three lanes road in the mid 1990 [85]. When Fort-de-France city center has started to become densely taken in the beginning of the 1980s, a ring road was also built. Another section near the airport and before the beginning of the highway is currently under construction to transform the two lanes road into three lanes road.
In parallel to these road constructions, different facilities have favored the use of private cars : many car parks have been built around the capital city center. Currently, Fort-de-France has a capacity of 7 200 parking spaces, but already 4 000 to 5 000 parking places are already taken by people going to work by car [71]. Besides, most of car parks were free of charge until a recent policy, and some malls are even offering free parking as soon as one buys something there. This is the case for the Cour Perrinon one, which was created in 2007 and offers 640 parking places in the capital city center [13]. The following figure 4.20 shows the total parkings places available in Fort-de-France city center, from 2007 data : as one can see the inner city has no restriction to the automobile access at all. Companies and public administrations also provide large private parkings for their employees, with 1 500 parking places available for them.

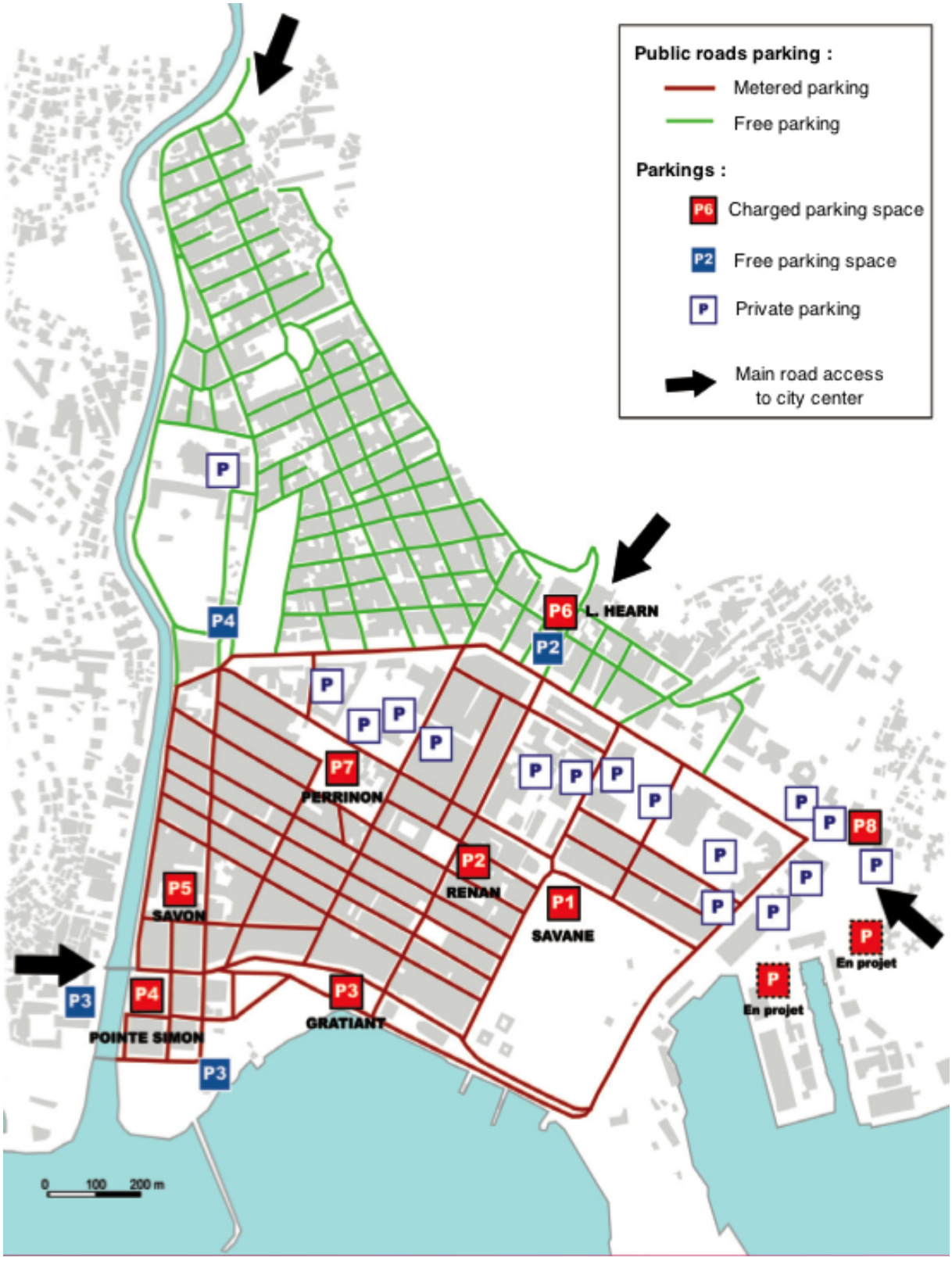

Figure 4.20: Parking places offer in Fort-de-France city center, 2007 data *Source [13] :*

Also, no clear control has been carried out to curb illegal and disturbing parking, and for the rare charged parking, controls were not done. It is therefore easily to come up with the conclusion that all this policy has favored car transport mode.

4.4 Other private means of transport weight

The automobile is not the only existing mean of transport found on Martinique island. This chapter aims first at describing the other means of transport present on the territory, the technological choices that have been made especially regarding public transportation systems.

Walking and Cycling

Walking is a passive mean of transport, which means that it does not require a motorized engine. A study from French Environment and Energy Management Agency[7] shows that in 2001, 17% of people displacements were done by feet in Martinique island. It comes after after cars (66%), but before public transport (14%). Walking weight as mean transport is therefore important.

A second passive mean of transport is the use of bicycle. Cycling is quite a popular sport on Martinique island : in January 2008, there were 1626 members of the national tennis federation, among around 63 000 members, which represent 2.6 % of total recorded. To compare with, in Metropolitan France, cycling only accounts for 0.6 % of total recorded people[8]. This higher figure may be reached on the island because not all metropolitan sports are available on the island. On week-ends, many cyclists are therefore found cycling in pack, mostly in the south of the island because the landscape is flatter and roads are broader and in better state. They are always followed by one or two cars that inform motorists and slow them down. As it will be described in the next chapter 5, the situation is different for any other displacement.

Two-wheeler

The use of two-wheeler mode of transport has emerged quite recently. The next table 4.8 illustrates the number of sales between 2004 and 2009. If the number of new vehicles sold has been decreasing since 2008, the sales of new motorcycles have kept increased since 2005, going from 749 in 2005 to 1117 in 2008, hence an increase of

[7]Source : ADEME survey 2001
[8]Source : INSEE, 2008 data

50%. Yet, one encounters a slight decrease in 2009. This may be explained by the economic crisis. Despite this increase, the use of a two-wheeler mean of transport remains low, reaching only 2% in 2001 [35].

	2004	2005	2006	2007	2008	2009
New vehicles						
Private cars	13613	14749	14132	14666	13679	13142
Two-wheeler	nd	749	782	978	1117	991
Second-hand vehicles						
Private cars	21975	22392	24338	24420	24350	21073
Two-wheeler	nd	nd	nd	nd	nd	1079

Table 4.8: Number of two-wheeler and private cars since 2004, *Source [81] : Département Statistique du Ministère des Transports*

4.5 Public means of transport weight

Several means of public transport have been developed in Martinique island. A certain number of different institutions are responsible for public transport. Four types of organizations are linked to transportation in France : the State, which coordinates interregional buses and trains, the regions, which are in charge of regional, inter or peri-urban trains, and inter-departmental buses, the departments, which must take care of non-urban transport, and eventually, the built-up areas are designed as urban transport authorities when a PTU[9] has been set up [11].
Martinique island, which has been a DOM-ROM[10] since 2003 is therefore responsible at regional and departmental levels of its public transportation system. One therefore finds the Regional and General Councils, as well as the three built-up areas, CACEM, CAESM and CCNM[11] to organise public transportation. The three last public institutions are designed as urban transport authorities in their concerned areas, but they can delegate the transport organization to another institution. For instance on the CACEM territory, the CFTU company[12] has been designed to take care of public transport. The

[9] Périmètre de Transports Urbains, literally Urban Transport Area
[10] Département d'Outre-Mer and Région d'Outre-Mer
[11] See figure 4.9
[12] Companie Foyalaise de Transport Urbain

CAESM metropolitan area proceeded the same way, choosing the CMT [13] company for its bus network. The CCNM has several delegated companies : CTCN [14] for Trinité public transport, CAD [15] for Gros-Morne public transport. Then, the General Council organizes bus transport in inter-urban cities as well as collective taxis transport. The Regional Council is eventually responsible for train infrastructures or at least guided transport infrastructures [79]. In reality, the Regional Council is responsible for school transport, inter-urban transport and shipping transport. The responsibilities are therefore a lot divided in the territory.

Public buses

Several districts have developed an urban public transport network by buses by setting up PTUs[16]. A PTU corresponds either to a district territory or a public establishment whose task is to organize public transport of persons, or a territory of several districts which have together decided to organize public transport of persons[17]. So far, 15 PTU have been set up among the 29 existing districts of Martinique island. Two PTU have more than 100 000 inhabitants, the CACEM and CAESM ones. The remaining 13 have less than 50 000 inhabitants and they are set up at the district scale. Yet, it is important to notice that only 6 PTU out of 15 are actually providing a public transportation system of people, the 9 left being only organizing so far school transport. These 6 public transport networks are the followings : *Trasla* in Gros-Morne district, *Touché Viré* in Trinité district, *Mozaïk* in CACEM territory, and eventually the ones of Lorrain, Robert and CAESM districts and territory[79]. These public transport networks are summarized on figure 4.21.

[13]Compagnie Martiniquaise de Transports
[14]Compagnie de Transport de la Caravelle et du Nord
[15]Compagnie Antillaise de Déplacement
[16]Plan de Transport Urbain, literally Urban Transport Perimeter
[17]Article 27 of LOTI's french law

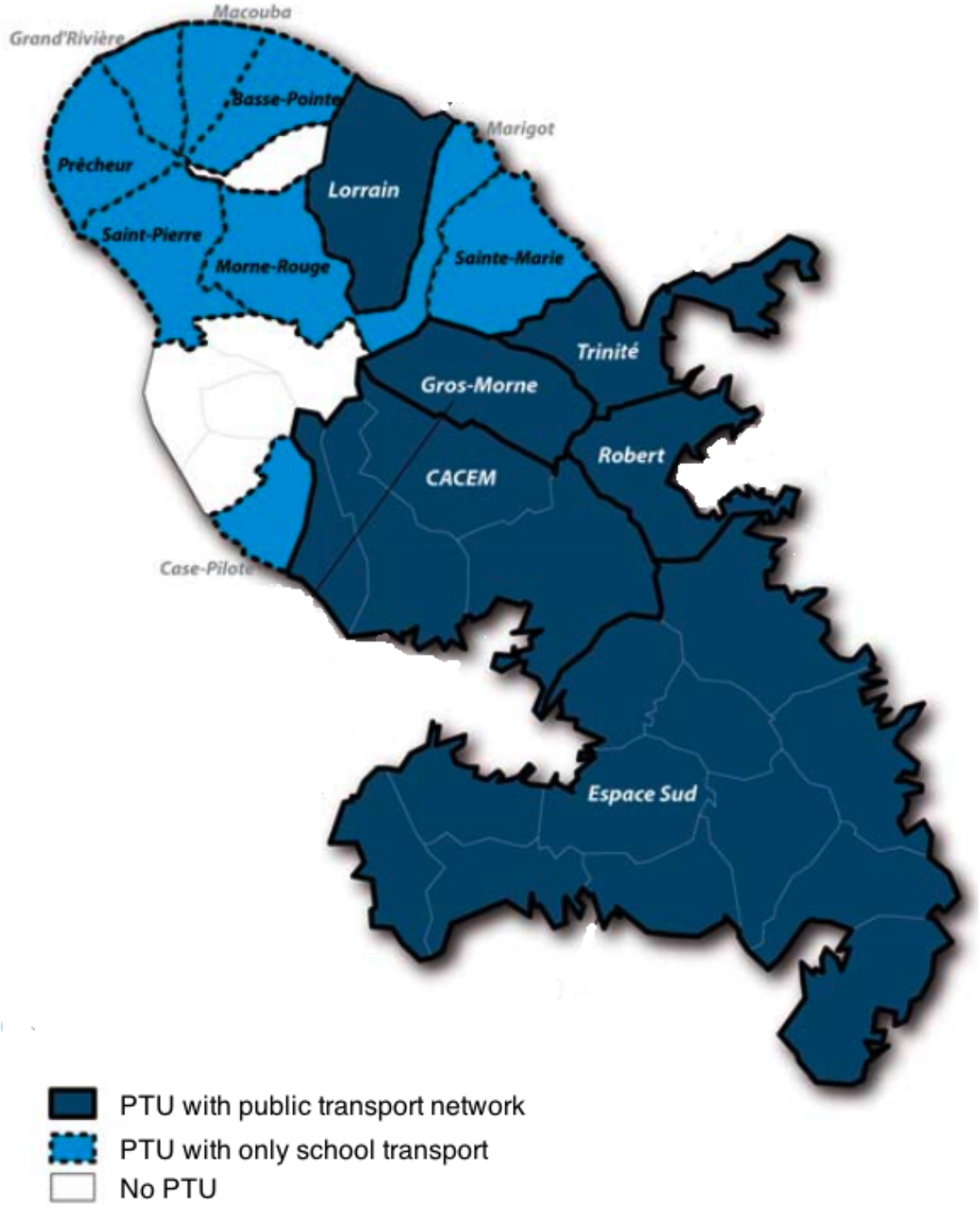

Figure 4.21: Urban transport existence according to Martinique island districts *Source [27] :* ADUAM

Even if it is not the oldest, Mozaïk network is the most structured and the largest public transport network of buses. It has been implemented in January 2006 in Fort-de-France and its suburbs by the CFTU organisation. This company, chosen by the CACEM metropolitan area is the result of the PDU set up in 2003 in order to define a public transport network on that area. Today 320 people are working at the CFTU company. The oldest public transport network is Trasla, set up in 1999. Then one finds *Touché Viré* (4th September 2006) and the Robert district one. Eventually, the last two most recent public bus networks are the Lorrain network (1st of February 2010), and the *Douvan-Douvan* network on CAESM area (1st of December 2010).

Each public bus network has a specific bus fleet and organisation. As presented on the next figure 4.22, the CACEM territory, with 166 000 inhabitants is currently served by 66 interurban lines, with 163 buses [67]. The Mozaïk network accounts in itself for 58 bus lines, the majority of them being working in the capital city Fort-de-France [77].

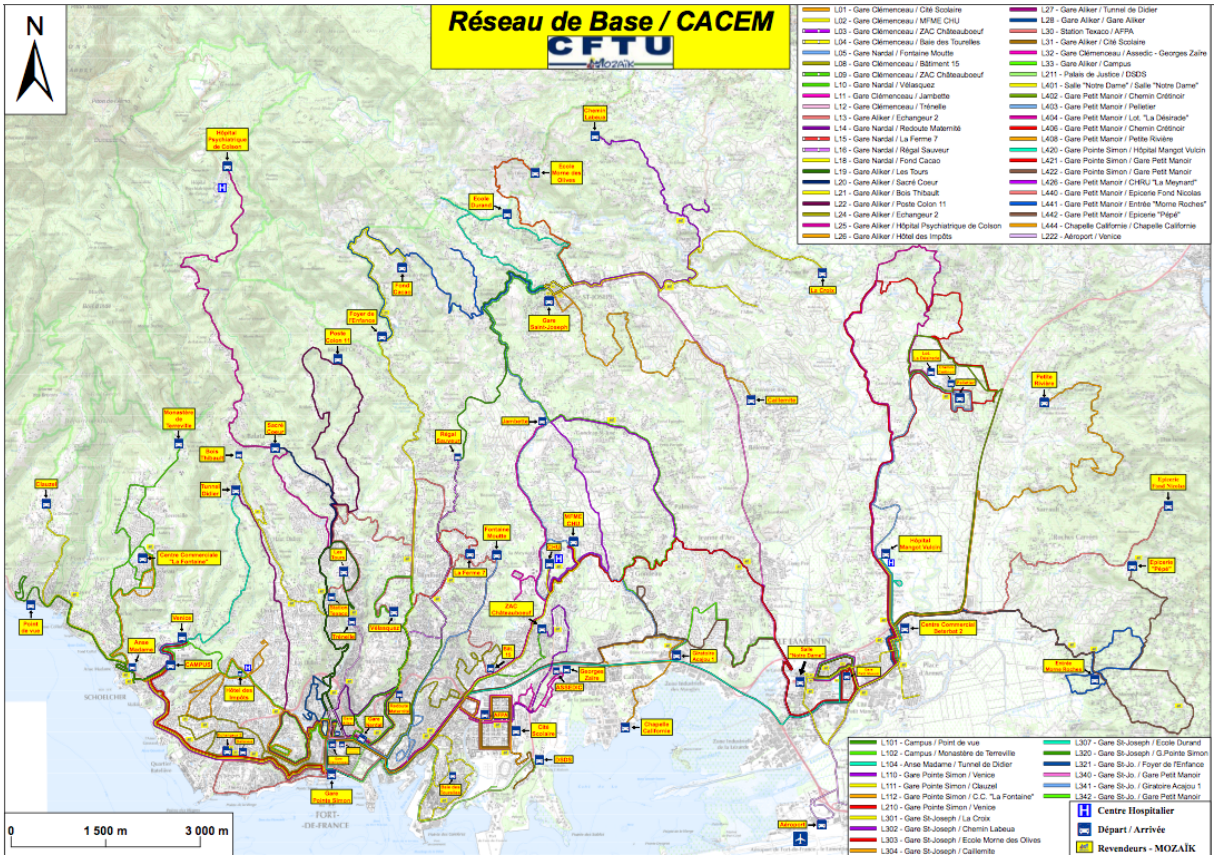

Figure 4.22: The different bus lines found on the CACEM territory, *Source [9] :* IGN *Scan 25*

The other metropolitan area, the CAESM, with 105 000 inhabitants, accounts for 68 bus lines widespread between 5 independent groups : Le François city, with 14 bus

lines, the West district with 11 lines, the East district with 14 lines, the Center district with 16 lines and finally the "North" one with 13 lines. Each of these small networks are organized by different private companies. Bus fleet in CAESM territory reaches 53 buses in 2011[18]. No network map is available. The remaining metropolitan area, CCNM, is much less equipped despite the fact that it accounts for nearly half of Martinique island territory. It is also the oldest one and it counts 109 000 inhabitants. First not all districts on that territory get a global public transport supply (contrary to CACEM and CAESM) and the existing independant public transport networks are smaller than the ones in CACEM and CAESM : 22 bus lines exist (unknown for Robert district), 7 in Gros-Morne (7 buses), 6 in Lorrain (6 buses), and 9 in Trinité (10 buses).

Different buses are used on the different public transport networks, but 3 main types of buses are found : the autobus, rigid and with a capacity of approximately 80 people and showing their direction/terminus with an electronic sign at the bus front as shown in figure 4.23. This bus mainly runs in the city center of Fort-de-France, on Mozaïk transport network. Then, buses met in suburban areas are smaller (midibus category) and can therefore accommodate fewer passengers, around 50 passengers. A picture of a typical one is given in figure 4.24. Eventually, a last category of buses presented in figure 4.25 and belonging to the minibus category is used. They are reserved to the less frequented bus services. The two last categories of bus do not have electronic signs showing their direction/terminus. They are only provided with a paper sign placed at the front and sometimes rear windscreens bottom. These buses are more flexible regarding road characteristics in environmental constraints.

[18]Figures given by the person in charge of public transport on CAESM territory during an interview

Figure 4.23: 27 bus line with a standard bus, [29] *Source : Aceboard forum*

Figure 4.24: A smaller bus : OTOCAR, [29] *Source : Aceboard forum and personal data*

Figure 4.25: Bus used for less busy lines, *Source : personal data*

The number of kilometers made by buses on the different public transport networks is also different among the three metropolitan areas : the CACEM territory, with the Mozaïk network, accounts for roughly 8 730 000 trips in 2010, while it only reaches roughly 500 000 trips on CCNM and more than one million on CAESM in 2011[19]. In terms of kilometers driven, it represents more than 6 310 741 km on CACEM territory, while respectively 750 000 km and 3 754 500 km on CCNM and CAESM territories.

Concerning public buses facilities, two types of shelters are found in Martinique island. The first one, the traditional bus shelter, as presented in figure 4.26 is typically in wood, painted in green and placed on the side of the road with a specific lane where the bus can park. Shelters are provided with a small seat. Due to climatic conditions and the highly deterioration rate, new bus shelters, shown in figure 4.27 are nowadays fabricated with composite materials. The second type of bus stop, much more developed, is however simpler : a single post, provided with bus time schedule sheet but no network map, is placed alongside of the road.The bus stops on the road to take passen-

[19]Uncompleted data for the last two areas

gers, where usually a sign on the floor is to be put to indicate that a public bus can stop there.

Figure 4.26: Traditional bus shelter, *Source : personal data*

Figure 4.27: New bus shelter, *Source : personal data*

A last statement about public bus administration is that this public transport supply is directly influenced by its capacity to be financed. A special tax, called "Versement Transport" has been indeed instituted by the state in 1973 on companies to finance public transport networks [21]. The corresponding revenue are then distributed among the different urban transport authorities within the defined PTU. In Martinique island for instance, Mozaïk network is the most indirectly subsidized network, with a 1,80 % of "Versement Transport" help on the CACEM area. On the contrary, some districts gets no indirect subsidy at all, as it is the case for the Lorrain district.

Local collective transport : "Taxicos"

Public transport achieved by bus is not the only existing collective mean of transport in Martinique island. The "Taxicos" mean of transport has first emerged before any public transport network to be organised. It is specific to Martinique island and it is not an official mean of transport but rather a public transport system in parallel. As presented in figure 5.21 it consists in a small bus, which can transport roughly 10

people. The Insee[20] has registered 390 Taxicos in 2002, but the ADEME[21] has counted 694 Taxicos. Their number is even more difficult to estimate because many of these Taxico companies are not registered and do not officially exist. That partly explains why their number is more estimated than known. These Taxicos self companies are most of time independent. The Regional Council is however the organized transport authority in charge of federating and supervising these communities of Taxicos.

Figure 4.28: Taxicos parked alongside the road *Source : personal data*

[20]National Institute of Statistics and Economical Studies
[21]Agence De l'Environnement et de la Maîtrise de l'Energie

Boat shuttle

Another mean of public transport passengers is sea transport. The Regional Council has developed port facilities along the coast, and it helps financially the private sea passenger shuttle companies. Several projects are today under study to adapt and further develop sea public transport. One of them deals with the construction of a station in Port Coché Harbor in Lamentin. Other studies are considering the development of the south coast, the cities of Schoelcher, Fort-de-France, Lamentin and Trois-Ilets being concerned. An experience of sea public transport between the capital city Fort-de-France and Saint-Pierre city, up in the North Caribbean has also been done but the customer target more concerns tourists rather than daily workers as this bond is only available during week-ends and on Wednesdays. From an infrastructure point of view, many docks have already been built along by the coast which just need to be adapted to their new function. These coast facilities -landing stages- financed by the Regional Council are shown in the next figure 4.29.

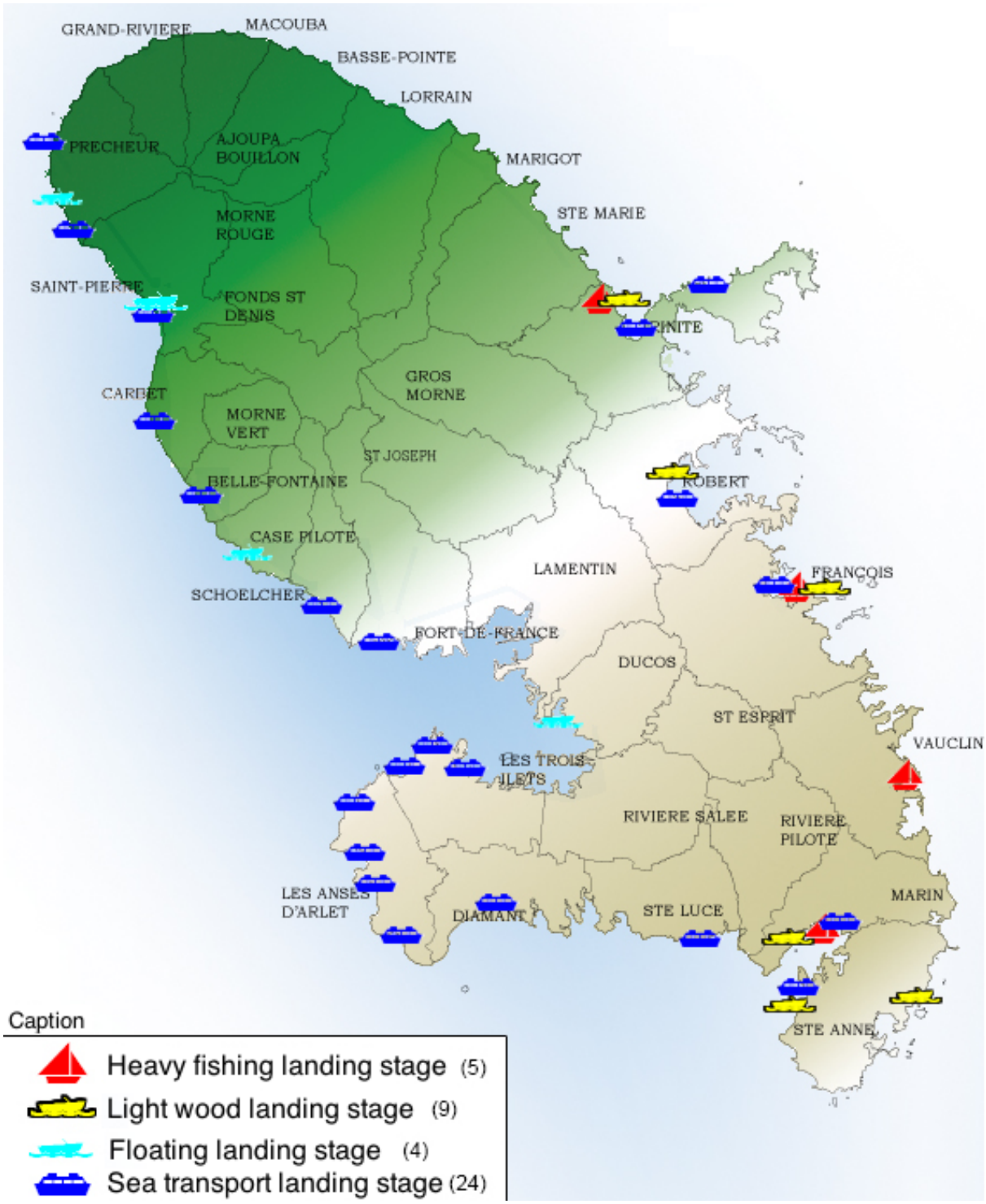

Figure 4.29: Port facilities built up by the Regional Council, [53] *Source : Regional Council*

However, there is currently only one sea passenger shuttle company, called ”Vedette Madinina”, which is crossing the bay of Fort-de-France, transporting people from La Pointe du Bout area to the capital city in 20 min. Four landing stages exist, the village of Trois-Ilets, Anse Mitan, Anse à l’Ane, and Pointe du Bout as shown in figure 4.30.

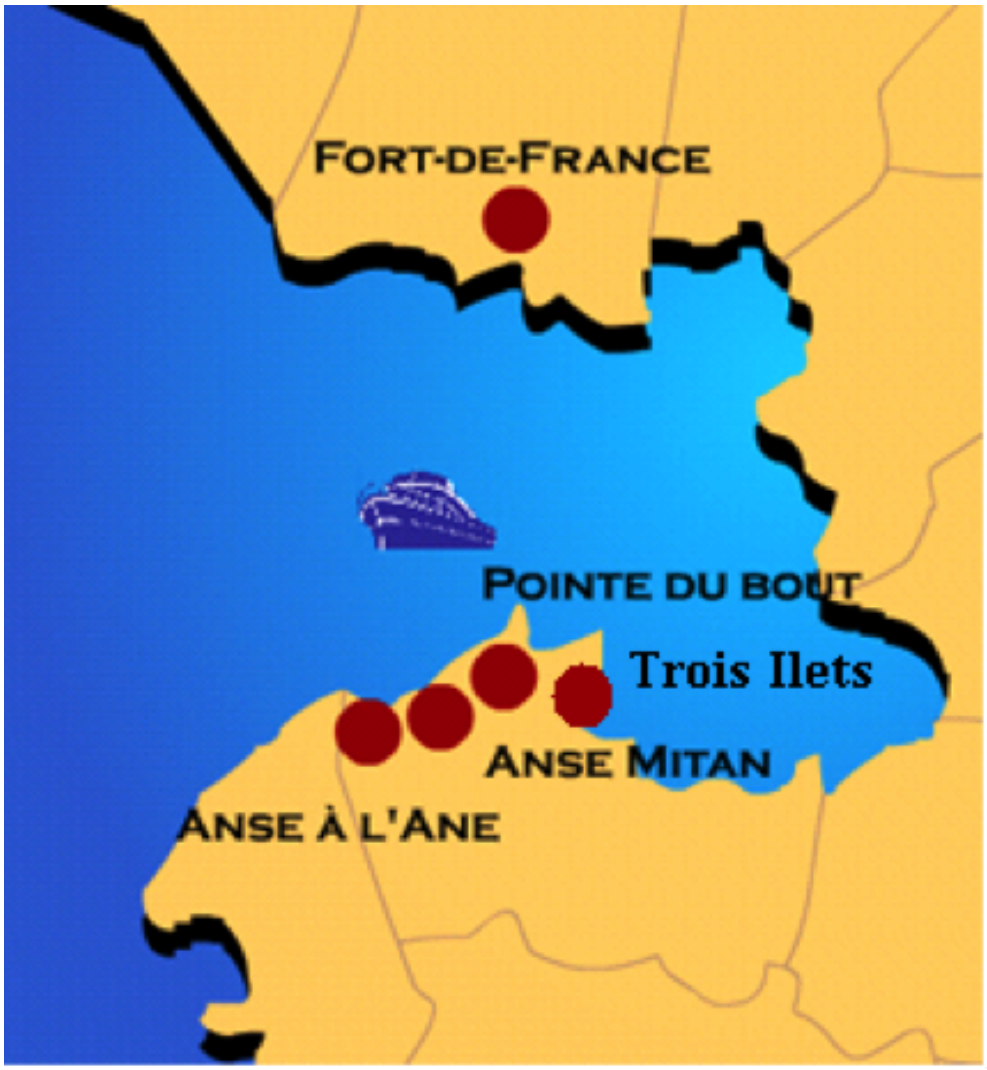

Figure 4.30: The different landing stages of Vedette Madinina shuttle [44] *Source : Vedette Madinina*

Seven boats are doing the rotations : La Foyalaise, Madinina, Gustavia, Ile aux Fleurs, Mona, Victoria, and Kalennda. As it is seen in figure 4.31, they are not all the same, not the same size, the same shape, and they can carry a different number of passengers, from 60 passengers for the smaller Mona, to 143 passengers for La Foyalaise.

Figure 4.31: Six out of seven boat shuttles Vedette Madinina with their passenger's capacity, [44] *Source : Vedette Madinina*

Tramway network project

This paragraph deals with a project of public tramway transport that is not yet over. Compared with the previous described public transports, this tramway line is still under construction, but it has reached such a high level of importance in policy and in population minds that it would not be correct not to talked about it. The idea of introducing a tramway on tires has emerged in 2000, in parallel with the public bus transport system that was at that time developing on the CACEM metropolitan area. This project, called TCSP [22], was divided into two phases, with specific tasks spread over each period. The first period stood from 2000 to 2006, the second one from 2006 to 2011.

As it can be seen in the next figure 4.32, during the first period 2000-2006, section 1 (yellow loop), section 3, section 4 and the diversion (orange line) were to be constructed. This diversion was made to enable people to come into the city center while the road works on section 1 were done. Then, during the second period, the bigger loop in section 1, sections 2 and 5 were to be built. The whole section represents 13.9 km of roadwork for 245.81 M€ budget calculated in 2006. This project is financed by 36% by the FEDER[23], by 4% by French State, the remaining 60% being financed by Martinique island regional authorities : 85,1% by the Region, 10.5% by the Department, 2.8% by the CACEM and 1.6% by the "TCSP Syndicat Mixte", a mixed-ownership entity in charge of the project realization.

At the end of the project, 2 tram lines should open, with a capacity of 2700 passengers/hour. The first one will go from Pointe Simon in Fort-de-France capital city -future

[22]Transport en Commun en Site Propre, or literally public transport on bus lane
[23]Fond Européen de DEveloppement Régional

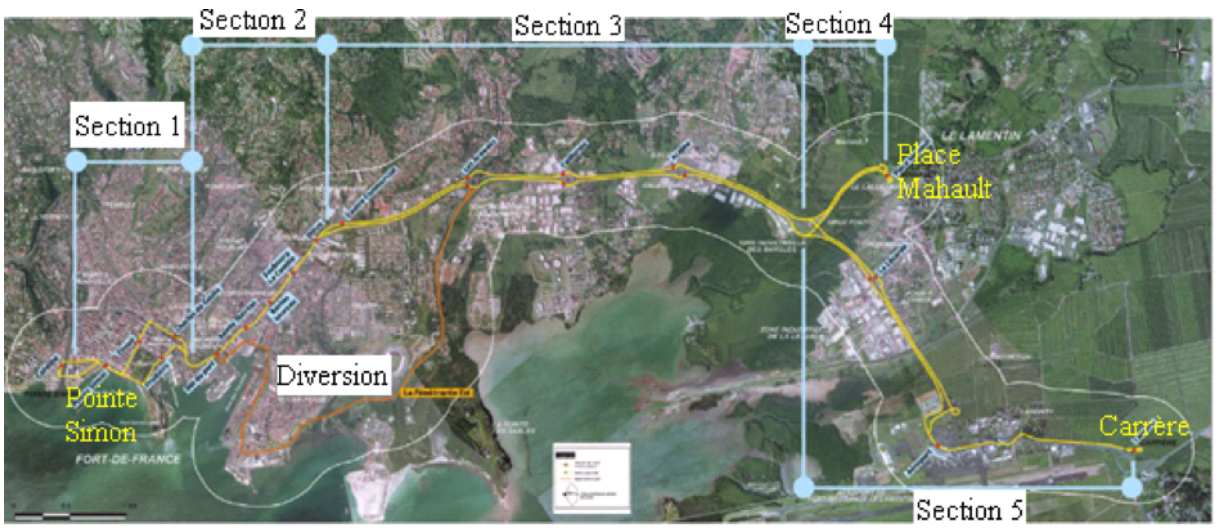

Figure 4.32: TCSP road project, divided into four construction phases [50] *Source [49] : Martinique island Regional Council*

centralized station in the city center for all public transports [24] to Place Mahault (at the end of section 4[25]), a 9.8 km long line with 12 stops for 19 min length. The second TCSP line will go from Pointe Simon to Carrère, running alongside the airport, 12.8km long with 14 stops for 26 min length. To achieve an easy access to both TCSP lines, each terminus will have a car park, 130 places in Mahault (short area available), while 250 at the beginning in Carrère which will have eventually 500 places. These two terminuses should also be the starting point of future tram lines crossing the North Atlantic and South Atlantic urban areas. According to impact studies, the TCSP should enable the transit of 55 000 passengers per day [77], with 22 tramways and a frequency of one tramway every 6 min, from 5 am to 10 pm.

4.6 People's commuting to work habits

As it is described in the methodology part, a specific focus is done in this thesis regarding people commuting to work because this specific displacement leads to major consequences that will be described in the next Chapter 5, section 5.4. This section aims at describing the current situation occurring every working day in Martinique island.

As seen in section 4.2, people live more and more concentrated in the CACEM region.

[24] So far it only centralizes some public bus lines with some Taxicos and with the sea shuttles
[25] See figure 4.32

The latter is also the main economic area of the island[26]. Yet, the number of working people living in a different district than their work place is high. This figure has even significantly increased in the past 20 years. There were indeed 44.8% back in 1990 [62], 48.6% in 1999, and 56.9% in 2008, hence an increase of more than 10%. The different figures are summarized in the following table 4.9.

	1999	%	2008	%
All Together	116062	100.0	134557	100.0
Working :	56351	48.6	57949	43.1
in the district place of residence	59351	51.4	76608	56.9
In an other district than the district place of residence	59527	51.3	75811	56.3
- located in the department place of residence	0	0.0	0	0.0
- located in an other department	0	0.0	547	0.4
- located in an other region in Metropolitan France	184	0.2	251	0.2
- located in an other region outside Metropolitan France (Dom, Com, abroad)				

Table 4.9: Working place of working people older than 15 having a job in the area, [14]
Source [81] : INSEE, RP1999, RP2008

It is interesting to look at how all this working population commutes to work every day. A study from 1999 revealed that almost 70% of the active population was always commuting to work by car, while 14% of it was only using public transport, the remaining 4% stating it was using both types of transport. In 2008, these figures have evolved : 80% of the working population commutes to work by car and 10% with public transports. The 2008 study also reveals that 6% of the working population commutes to work by feet, 1% with a two-wheeler and 3% does not use any mode of transport [27]. These results are presented in table 4.10. The majority of the active population is therefore taking his car to commute to work. Besides, on average and for all types of displacement 1.4 people are counted for one car with an average commuting distance to be less than 20 km.

[26] See figures 4.11 & 4.12

Headed	Year 1999	Year 2008
Number of busy working population	116067	134557
Proportion of working population using only private car	69%	80%
Proportion of working population using only public transportation	14%	10%
Proportion of working population using several means of transport	4%	ng

Table 4.10: Modes of transport preferences for working people, *Source [14] & [27]* :INSEE & ADUAM

This chapter has presented in a comprehensive way the current situation of the different modes of transport existing in Martinique island. They have been introduced in order to give the reader a global picture of available modes of transport. The automobile has an important weight in Martinique everyday life, and public transports are providing a large panel of transport possibilities. People commuting to work use more their automobile than public transports. Yet, this current transport pattern is getting many malfunctionings, and it is besides running at the expense of other factors, especially environmental ones. The results of this transport policy are going to be studied in the next chapter.

Chapter 5

Results of the transport policy organised in Martinique island

In a sustainable city, the set up transport system is expected to respect some criteria that are in accordance with sustainable principles. One can very briefly define sustainable development as "*Meeting the needs of the present without compromising the ability of future generations to meet their own needs*", definition given in 1987, when the United Nations released the Brundtland Report. With that in mind, Holmberg has defined four principles that would help fulfill a sustainable development. The first principle says "*substances extracted from the earth must not systematically accumulated in the ecosphere*", the second "*society-produced substances must not systematically accumulate in the ecosphere*", the third "*the physical conditions for production and diversity within the ecosphere must not become systematically deteriorated*", and the last one "*the use of resources must be efficient and just with respect to meeting human needs*".

These four principles of sustainability are rather vague, that is why they can be slightly rephrased to specifically determine what a transport system should tend to be sustainable. The European arm of the Rand Corporation has therefore defined three principles for a sustainable transport. This definition has been approved by the Ministers of Transport of the 15 European Union countries [76]. First, a sustainable transport system allows, "*the basic access needs of individuals and societies to be met safely and in a manner consistent with human and ecosystem health, and with equity within and between generations*", secondly, it is "*affordable, operates efficiently, offers choice of transport mode, and supports a vibrant economy*", and thirdly, it should "*limits emissions and waste within the planet's ability to absorb them, minimizes consumption of non-renewable resources, limits consumption of renewable resources to the sustainable yield level, reuses and recycles its components, and minimizes the use of land and the production of noise*".

The presented results in this chapter are therefore relevant aspects recommended to

examine if an analysis of the sustainability of Martinique island transport policy is to be done. The analysis of these results will correspond to the next Chapter 6. Results have been classified according to the sustainable transport system principle they were the most corresponding to, so that their analysis in Chapter 6 becomes easier to understand for the reader.

5.1 Private vehicles results as mean of transport within current situation

Fuel consumption

This first result is in relation with the third principle, as it presents results regarding the use of fossil fuels.
The majority of private vehicles is today running with fossil fuels energy. Both fuels, diesel or unleaded gasoline, come from crude oil, a substance extracted from the earth. In Martinique island, the energetic consumption of crude oil has been multiplied by 2.2 between 1980 and 2000. Most of this increase comes from the growing demand of energy from transport sector, the latter being multiplied by 1.9 over the same period, reaching 71% of total energy consumption in the island in 2005, while it was 65% back in 1999 [35] [26]. Besides, 98% of its total primary energy consumption was provided by fossil fuels energies in 2008 [38]. The island not being provided with a soil rich in crude oil resources, all that primary energy is imported. Figure 5.1 summarises the distribution of energy consumed in Martinique island in different sectors back in 2005. As said earlier, if air and road transports part of energy consumption reaches 71% of total energy consumed in 2005 in Martinique island, road transport remains the greediest sector, with 47% of total energy consumption.

To get a more accurate idea of the type of fuel consumed that year in the transportation sector, figure 5.2 is given : it provides each fuel consumption in percentage, considering that three main fuels are consumed in the island : gasoline, diesel and jet fuel. Diesel and gasoline fuels, representing road transport, account therefore for 67% of all the energy consumed in transport in the island, while air transport consumes 33% of that energy. One can notice that more gasoline is consumed than diesel, which is a particularity of the island.

It is interesting to determine which type of transport is the largest fuel consumer in Martinique island. The next figure 5.3 presenting the allocation of energy consumption by types of transport provides the answer. It is the same figure as figure 5.2, but with a detailed allocation for road transport fuel consumption. Obviously, air transport ac-

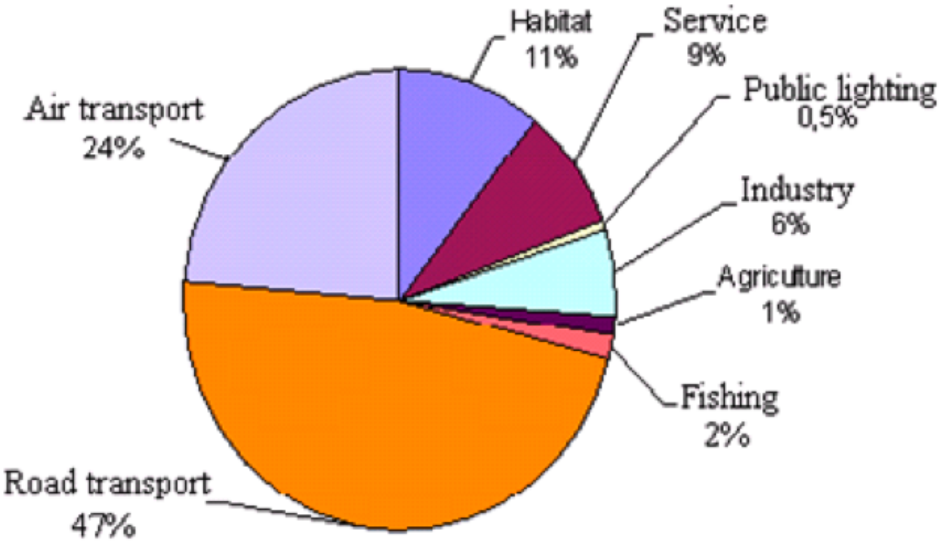

Figure 5.1: Final energy consumption in 2005 according to sectors (excluding transport by sea), *Source [26] :* ADEME M*artinique*

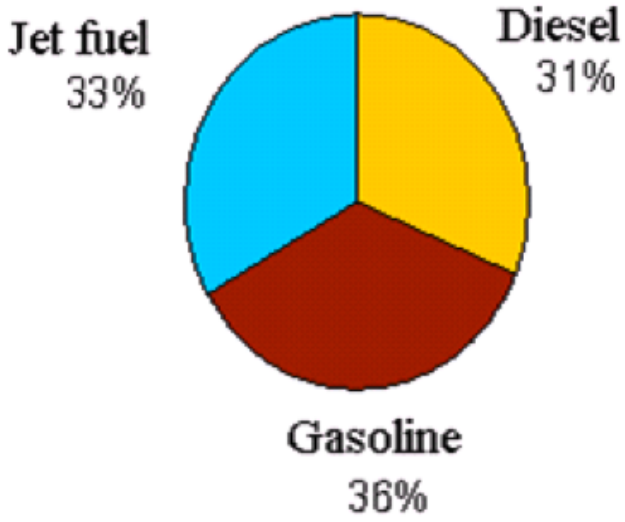

Figure 5.2: Air and road transports : energy consumption allocation by types of fuel in 2005, *Source [26] :* ADEME M*artinique*

counts for all the jet fuel energy consumption, hence 33%. This is partly due to all the importation of goods required on the island. Then, private vehicles consumption comes first with more than half of total energy consumed in road transports (51%). Road transport of goods reaches 14% of energy consumed.

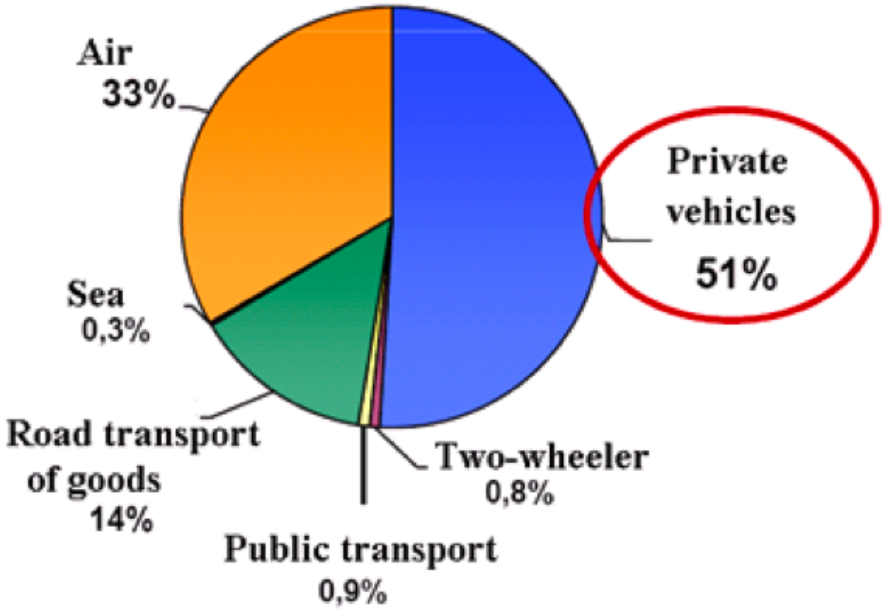

Figure 5.3: Energy consumption by types of transport, *Source [26] :* ADEME M*artinique*

To get a concrete idea of the amount of fuel consumed by cars, the next table 5.1 is given, showing the consumption evolution of both diesel and unleaded gasoline fuels by private vehicles between 2005 and 2008, in tons. The trend shows that diesel engines are increasing among years, confirmed by the increase of diesel oil consumption : 109 188 tons consumed in 2005 against 132 708 tons in 2008, hence an increase of 21.5%. Unleaded gasoline consumption has on the contrary decreased : 125 100 tons were consumed in 2005 while it reached 109 400 tons in 2008, hence a decrease of 12.5%. In 2007, diesel consumption has exceeding unleaded gasoline consumption for the first time. Yet, on average, fuel consumption has increased by 3.3% between 2005 and 2008.

Headed	2005	2006	2007	2008
Leaded gasoline fuel consumption, in tons	0	0	0	0
Unleaded gasoline fuel consumption, in tons	125100	119658	116605	109400
Diesel fuel consumption, in tons	109188	115912	124678	132 708
Total, in tons	234 288	235 570	241 283	242 108

Table 5.1: Vehicles fuel consumption evolution, in tons [14] *Source [26] [7] :* ADEME *Martinique*

Eventually, to go even further in the description of energy consumption, one can analyse figure 5.4 which presents the energy consumption of passengers transport in 2005. Passenger transport with private vehicle is the most important source of energy consumption, with 91% of total energy consumed in passengers transport.

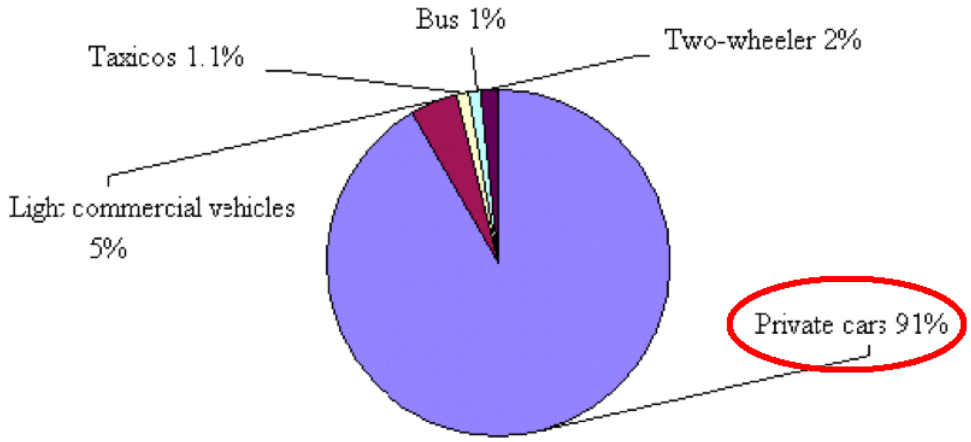

Figure 5.4: Passengers transport : energy consumption in 2005, *Source [26] :* ADEME M*artinique*

Air pollution

As seen in Chapter 4, the automobile is emitting different pollutants, responsible to some extent for air pollution in cities. This paragraph is therefore in relation with the first and the third principles of a sustainable transport system.

In a global context, it may be interesting to look at the transport sector contribution in Martinique island to global emissions. Figure 5.5 enables to see the transport

emissions share for specific polluting gases in Martinique island in 2007. What comes out from this graph is that road transport accounts for emissions share for NOx, CO_2, VOC (Volatile Organic compounds) gases well as for the PM10 and PM2.5 particles. The largest impact belongs to the CO_2 and VOC gases, with 40% of total emission share each time. Then particles emissions come just after, reaching roughly 30% share for both PM 10 and PM2.5, NOx share being 20%. The share for the other gases are low.

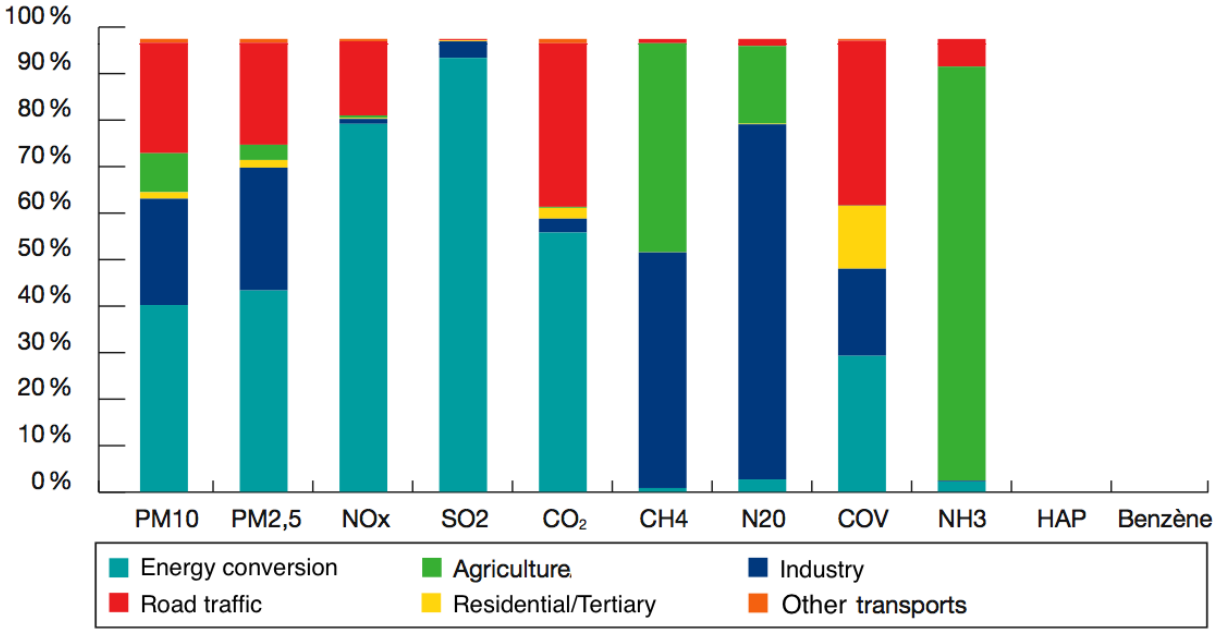

Figure 5.5: Martinique island emissions per sector activity and gas, 2007 *Source [41] : Madininair*, CITEPA and Sustainable Development Ministry

If one then focuses on road transport pollution, figure 5.6 shows the concentration of vehicle pollution in 2010, through the measure of dioxide nitrogen concentration, between the capital city Fort-de-France and the main suburbs Lamentin, Saint-Joseph and Schoelcher. If different gases are measured thanks to these air traffic stations, the one which is taken as reference gas in Madininair association reports is dioxide nitrogen gas, considered as the most representative car pollution gas. Particles PM10 are however also measured for road traffic. Considering the figure, highest concentrations of pollutants are met on the main road axes through all these cities, with black and red concentration dots where pollution rates are the highest. These measures are obtained through the use of passive tubes.

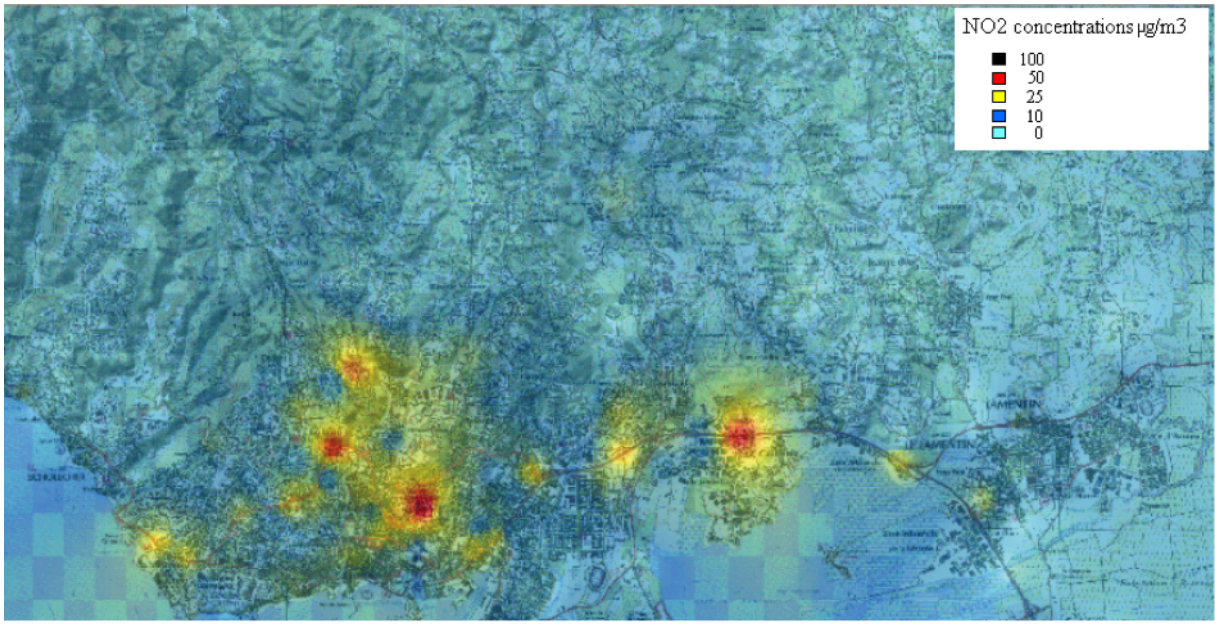

Figure 5.6: Dispersion of car pollution around the districts of Fort-de-France, Schoelcher, and Lamentin, 2010 *Source [47] : Madininair*

However the last two precedent graphics given in figures 5.5 & 5.6 do not allocate the share of private transport in transport sector following the different gases. To get more precise data, figure 5.7 is provided. One can see that private transportation accounts for the major share of transport sector gas emissions, for all gases (75% for CO_2, 53% for NOx, 63% for PM10, 64% for PM2.5 and 76% for SO_2), except the volatile organic compounds which are at a majority emitted by trucks (90%).

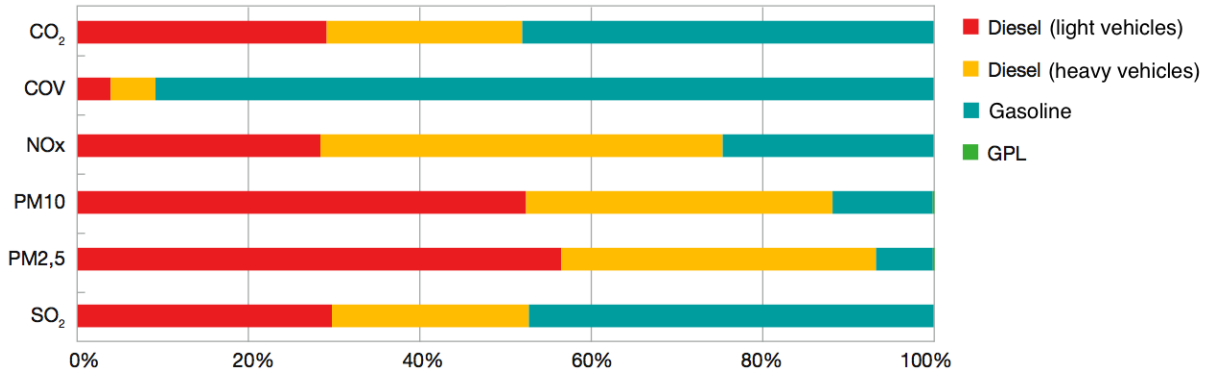

Figure 5.7: Martinique island emissions per mean of transport and gas, 2007 *Source [41] : Madininair*

Another graphic showing the evolution of the nitrogen dioxide annual mean since 2007 is presented in figure 5.8. It provides effective measures of emissions. Renéville air traffic station has been installed in 2010, hence the unique value in the graphic. According to the definition of Ministry of Ecology, Sustainable Development, Transport and Accommodation, the quality objective is "a value to reach on the long term and to keep, to achieve an efficient protection of human health and the environment in its whole". This value is currently fixed to $40\mu g/m^3$, and it regularly is re-evaluated downward. The graphic gives the recorded values compared with the standard.

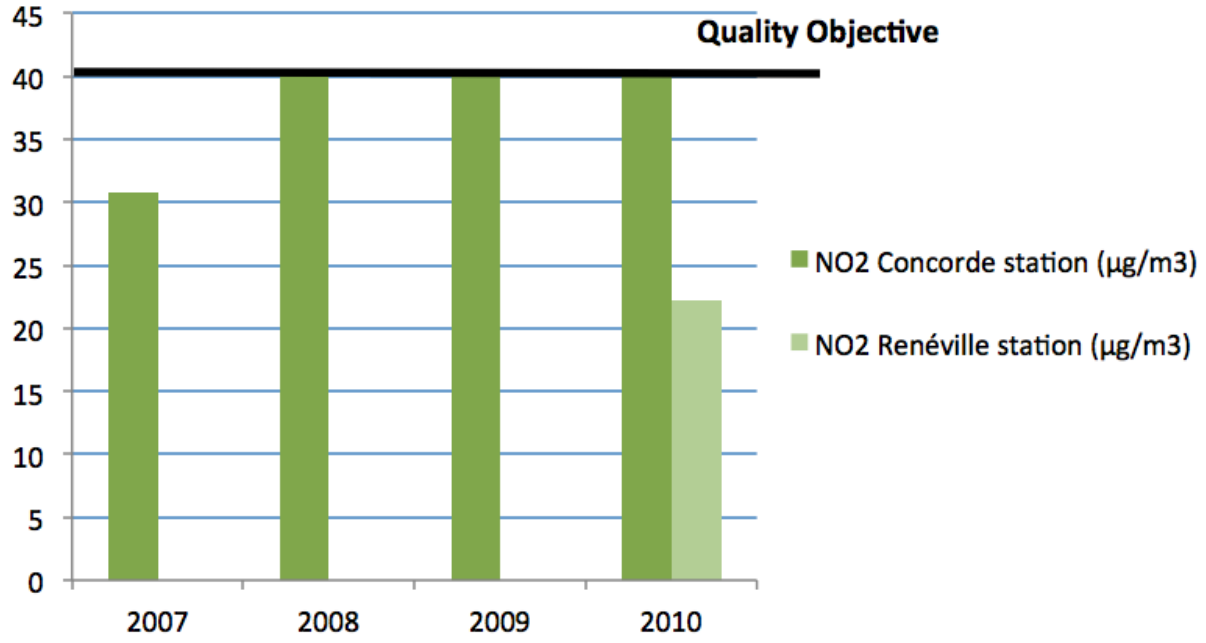

Figure 5.8: Evolution of nitrogen dioxide annual means since 2007 on two air traffic stations, *Source [47] :* M*adininair*

The following table 6.1 shows different results of the measures recorded by Concorde and Renéville air traffic stations the past 3 years for Concorde and 2010 for Renéville. The different air pollution values are compared with the health and environmental thresholds defined by current regulation[1]. This result, being in relation with public health, is more related to principle 4, as having good health conditions is part of meeting human needs.

[1] See Chapter 4 §4.2

	Air traffic station			
	Concorde			Renéville
	2008	2009	2010	2010
Maximum per hour $\mu g/m^3$	191	247	274.4	161.5
Limit value health protection 200 $\mu g/m^3$ (18 authorized overrun) Decree n°2010-1250 (21/10/10)	Not reached	2 overrun	2 overrun	Not reached
Upper health threshold 140 $\mu g/m^3$ (18 authorized overrun)	6 overrun	18 overrun	27 overrun	2 overrun
Lower health threshold 100 $\mu g/m^3$ (18 authorized overrun)	134 overrun	188 overrun	216 overrun	55 overrun
Information and recommendation threshold 200 $\mu g/m^3$	Not reached	2 overrun	2 overrun	Not reached
Warning level 400 $\mu g/m^3$	Not reached	Not reached	Not reached	Not reached
Annual mean ($\mu g/m^3$)	40	40	40.1	22.2
Annual quality objective 40 ($\mu g/m^3$)	Not respected	Not respected	Not respected	Respected
Annual limit value health protection 40 $\mu g/m^3$ Decree n°2010-1250 (21/10/10)	Reached	Reached	Reached	Not reached
Annual limit value vegetation protection 30 $\mu g/m^3$ Decree n°2010-1250 (21/10/10)	Reached	Reached	Reached	Not reached
Annual upper health threshold 32 $\mu g/m^3$	Reached	Reached	Reached	Not reached
Annual lower health threshold 26 $\mu g/m^3$	Reached	Reached	Reached	Not reached

Table 5.2: Comparison of measures at two air traffic stations with regulation in 2010, *Sources [45] [46] [47] : Madininair annual reports*

Climate change

This paragraph is in relation with third principle.
So far results of the automobile influence on its environment has only been locally studied from cities and urbanized regions, but more and more studies highlight the global effect of transport pollution. They among other agree on the fact that car pollution can be a source of impact on climate, because of green house gases emissions, the most known being carbon dioxide gas. To emphasize these comments, it is possible to know which part road transport takes in the emissions of green house gases in Martinique island. Results are given in the following figure 5.14 for Martinique island in 2005. It appears that 35% of green house gas emissions comes from road transport, and that it represents the highest source of emissions, above air transport and habitat.

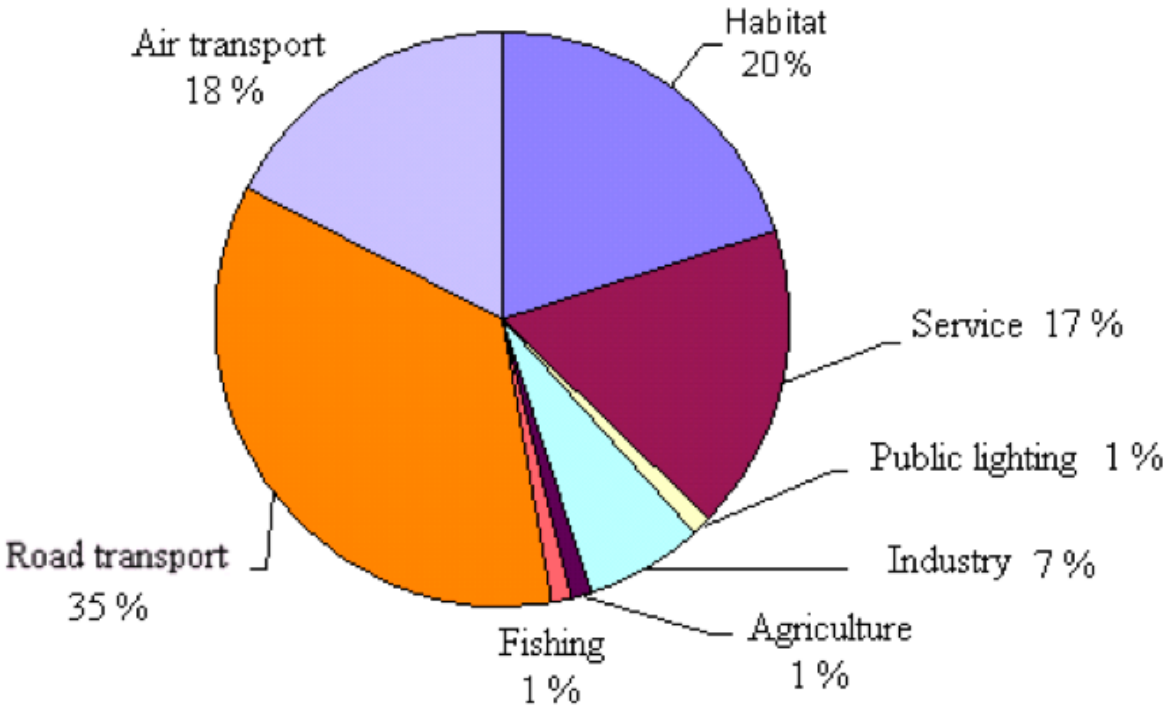

Figure 5.9: Green house gas emissions from energy sources in 2005, *Source [26] :* ADEME

If one focuses on green house gas emissions in relation with passengers transport, then results obtained for Martinique island in 2005 are provided in figure 5.10. Nearly 80% of green house gas emissions coming from road transport belongs to urban and interurban transport of passengers. Moreover, green house gas emissions have in general

increased by 6.5% between 1999 and 2005 in Martinique island [26].

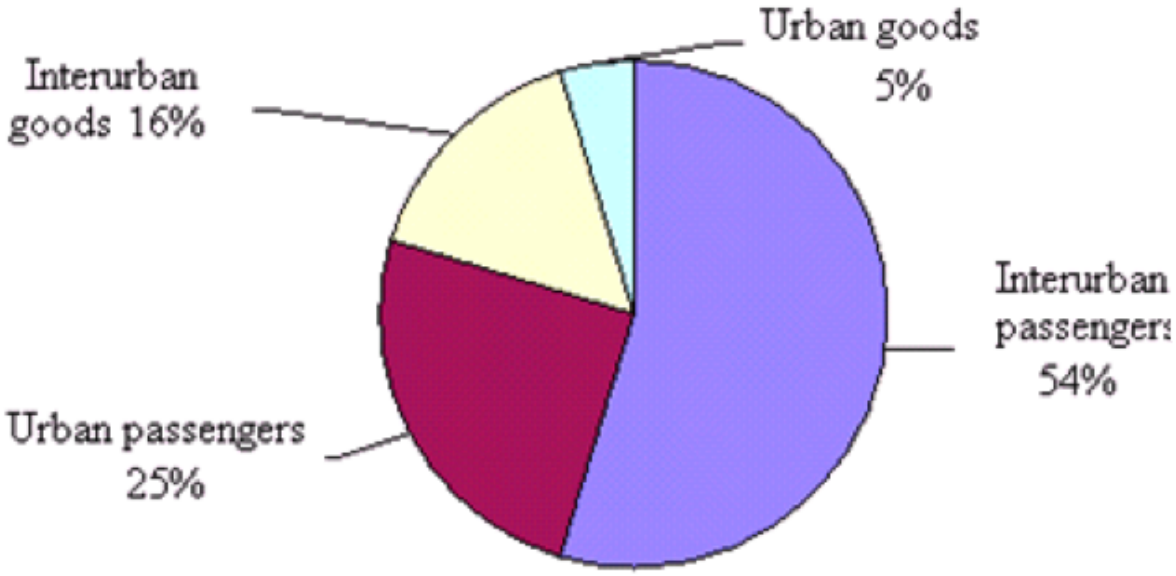

Figure 5.10: Road transport : green house gas emissions allocation in 2005, *Source [26] :* ADEME

Other impacts

This paragraph is more in relation with principle one than the third principle, as it stresses indirectly its human environment but also mainly its natural environment.

An important impact is noise pollution on human health. Transport sector is considered to be the first source of noise pollution by population[2].The production of noise from road transport is influenced by several factors, among them vehicle speed, traffic nature, road surface characteristics, road lenght... There is therefore a higher risk to get high levels of noise pollution nearby highway stretches or ring roads. A street with high traffic produces around 80 dB, which nearly corresponds to the hazardous thresholds for the hearing. Yet, another index is used to measure population exposure to noise pollution from road transport. It is called the Lden index : Level Day Evening Night index. It corresponds to a 24 hours average measure, where both noise pollution

[2]ADEME survey conducted in 2002 in metropolitan France

during day and night are measured. Evenings and nightly noise pollution values are majored by respectively 5 and 10 dB(A) so that measures become relevant with the encountered noise pollution. In Martinique island a 2010 study reveals that on average 2339 people are exposed to road traffic noise pollution with a Lden index level higher than 75 dB(A) level, 1880 people with a Lden index level between 70 and 74 dB(A), 6771 people with the Lden index level between 65 and 69 dB(A), 14096 people with the Lden index level between 60 and 64 dB(A), and eventually 28627 people with a Lden index level between 55 to 59 dB(A). The capital city-Fort-de-France and Lamentin city urban areas account alone for 35% of the roads where noise pollution among the different thresholds previously described has been recorded[3].

Then, a result of automobile pollution is the deterioration of buildings front and all public materials (benches, streetlights...), leading among others to a darkening of all of them : pollution particles indeed stick and accumulate with time on these surfaces and they become a visual effect of air pollution. Besides, the construction of roads and associated facilities (gas station, tolls areas. . .) contribute largely to free land reduction and material reduction. Roads also waterproof soils or quarries and it weakens them, which can increase on the long term the risk of floods in rainy regions, as Martinique island.

Vegetation along side roads is also impacted : on the long term the more fragile trees will indeed suffer from leaves lost. And when it rains, air particles and particles on roads are driven into gutters whose rainwater ends into rivers and finally into the ocean, resulting in a leakage of air polluting particles and a global dispersion. They can threaten aquatic life nearby coasts. However it remains very difficult to measure this pollution leakage.

Another indirect impact can be the visual degradation of the environment where resources from the earth are extracted. Oil rigs and oil refinery are usually large facilities that can be easily spotted as set up in specific areas. Quarries can profoundly change an area. Other products, such as paints or roadsigns also generate indirect pollution, through their fabrication in particular. Yet these just described impacts can only be to some extent imputable to the automobile as the latter is not the only one using road transport facilities and fossil fuels resources.

More generally, a last impact to quote is the animal mortality. First, mortality rate of animals on roads is a reality : in Martinique island, one protected specie is in particular threatened by automobile : the opossum, called locally ”Manicou” is indeed often run over by cars at night because headlights usually blinds it. A study has even been started at Martinique DIREN (Regional Direction for the Environment) to determine the potential impact of road mortality rate on the entire specie. Yet, the opossum is not the only

[3]Regional Council study result

specie concerned by road mortality. Wildlife can also in general be influenced by road light pollution, disturbing biological clock cycles of certain species. Finally, territory splitting up by road modify wildlife territories and diversity.

Dangerousness

This paragraph is more related with principle one : it deals with the ability of private vehicles to achieve displacements without compromising people's safety.
Car road accidents, more or less serious, are more important than any other mean of transport. Road traffic injuries were estimated to account for 1.2 million deaths worldwide in 2000, amounting to 2.3% of all deaths [59]. In Martinique island, drivers category is the one which leads to the most victims, before two-wheelers and pedestrians, as it is shown in figure 5.11. Regarding victims figures, it corresponds to 531 pedestrian victims, 1560 two-wheeler victims and eventually 2420 driver victims between the same period.

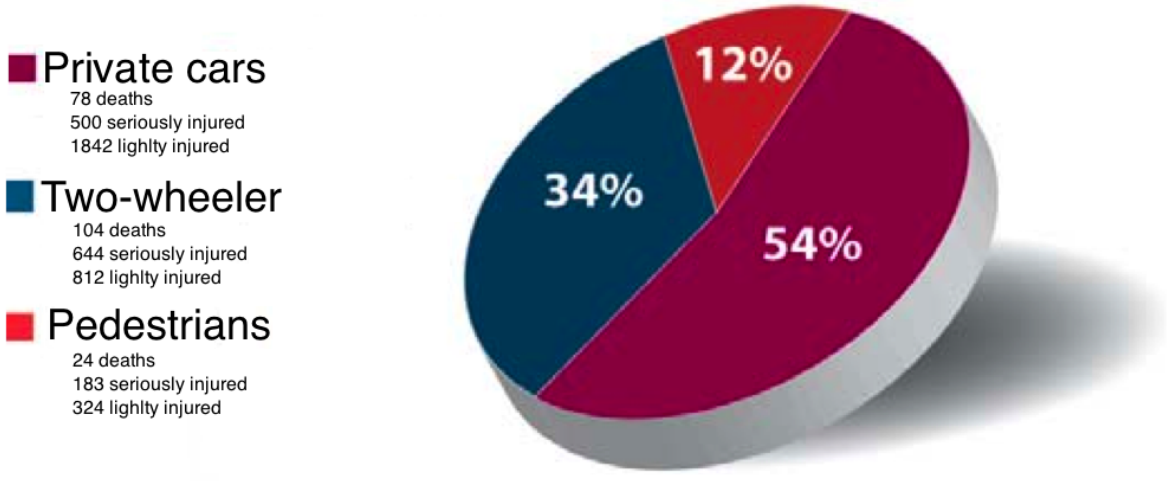

Figure 5.11: Road transport victims per category, 2006-2010 *Source [72] [72] :* DEAL *Observatoire de la sécurité routière*

With prevention and repression campaigns, the amount of accidents presented in the following figure 5.12 went from 848 in 2006 to 456 in 2010, which corresponds to a decrease by 46% in 5 years. This result has required the setting-up of a strict, unwieldy and expensive policy in terms of road safety : between 2006 and 2010, road safety at a national level has cost 24 billion euros [73].

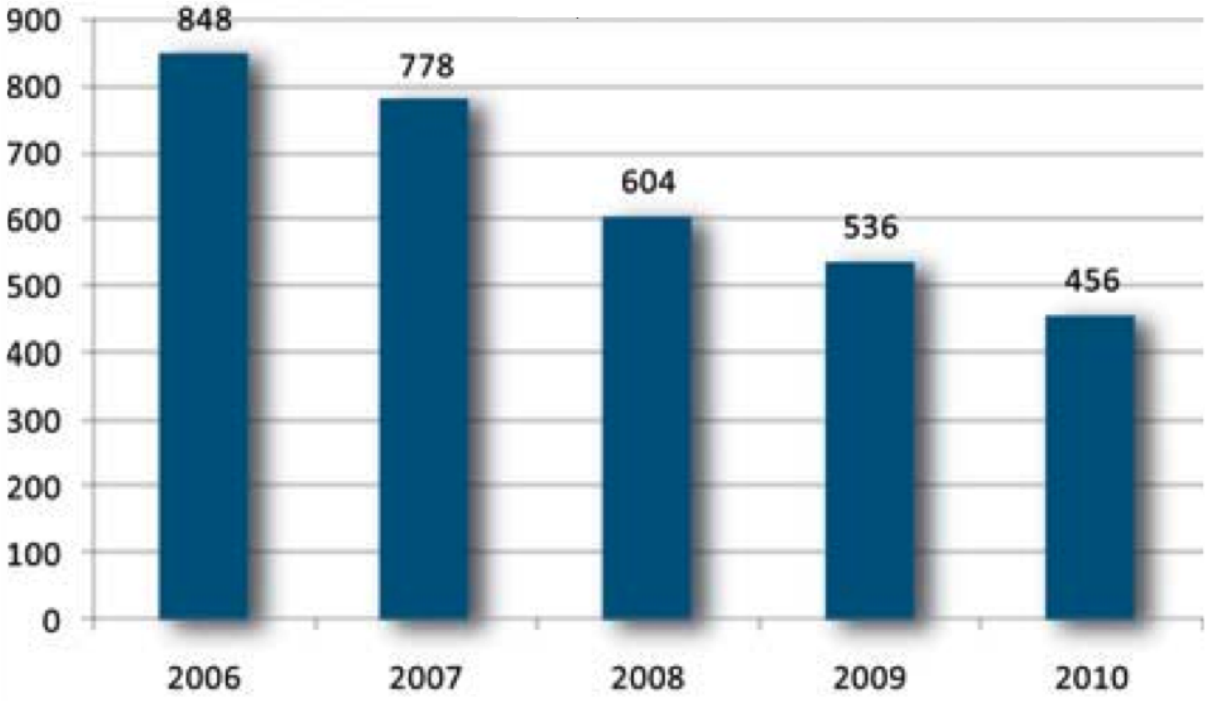

Figure 5.12: Road accident number evolution, *Source [72] [63] :* DEAL O*bservatoire de la sécurité routière*

Private vehicles expenditures

This paragraph deals with the second principle as it shows diverse costs in private vehicles that cannot be necessary afforded by all the population.
The automobile system expansion has generated a world of different charged services. Indeed, it is often wrongfully thought that having a car only costs the fuel one tanks up with and the initial vehicle purchase money. In reality other costs exist, that can be widespread into working costs and ownership costs. Working costs are variable costs that are function of the living place, the way people drive, the driven distance or costs generated by car repairing and maintenance. Ownership costs are fixed costs that include car insurance, driving license, parking charges, or simply the rapid vehicle financial value drop. Indirectly, one also counts taxes share that is used to maintain and develop roads facilities, or to pay human and material facilities correlated with the automobile system. Driver fines in case of traffic law infraction are also strict.

With that in mind, the ADETEC research department in France has conducted a survey in 2008 [4] on French people, asking them how much one kilometer driven by car cost to them. The result shows that 54% of referees widely under estimate their expenditures, taking only into account fuel cost, 20% of sample still under estimate their

expenditures, but to a lesser extent as they consider more costs (for instance fuel cost and insurance). Only 15% of referees include most of car expenditures in their calculation and give an approaching value. On the contrary, 11% of referees over estimate their expenses. To deepen our analysis, the following picture 5.13 sums up the diverse costs that revolve around the automobile sector for households, and their cost share in total costs. Car purchase only represents 29% in the total cost share, while costs that are often forgotten by purchaser reach nearly the half of total cost share.

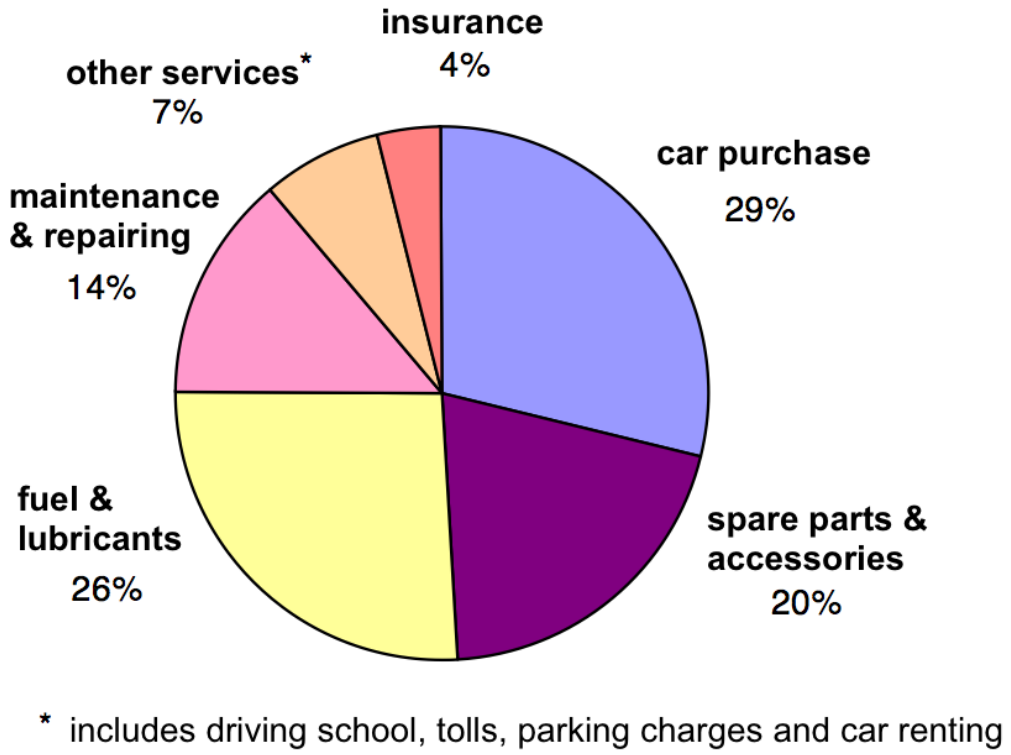

Figure 5.13: Households expenditures in private vehicles, *Source [4] :* ADETEC

In total, households have spent on average in metropolitan France 5130 € per year in private transport, which represents 3700 € per car or 2200 € individually [14][4]. The cost estimation per kilometer driven is therefore approaching 0.28 €/km. In Martinique island, this cost reaches 6500 € for the wealthiest households against 1900 € for the humblest ones [16]. On average, the households expenditures share for automobile reaches nearly 15% in Martinique island in 2008. This share reached respectively 12% in 1985 and 14% in 2006 [17]. This share always comes in third position after food and accommodation in households budget [16].

Different reasons explain why the households expenditures share is increasing with time. Automobile insurance in France has for instance increased by 10 % between 2000

[4]2007 data

and 2010, reaching on average 400 € per year [34]. Car initial purchase price is regularly increasing, even if this can partly be explained by the fact that cars are becoming more and more sophisticated and comprehensive in terms of equipment and services provided. For instance, if one considers the Volkswagen Golf models, from the Golf I to its most recent model Golf IV, its price has increased by 434%. The fuel price evolution is also important. The result of this evolution is given for Martinique island in the figure 5.14. Fuel price has increased by 24% in a little more than 2 years (initial value taken in January 2009 and not November 2008) for diesel and unleaded gasoline fuels. In metropolitan France, diesel fuel has increased by 116% while unleaded gasoline fuel by 85% between 1991 and 2011[3].

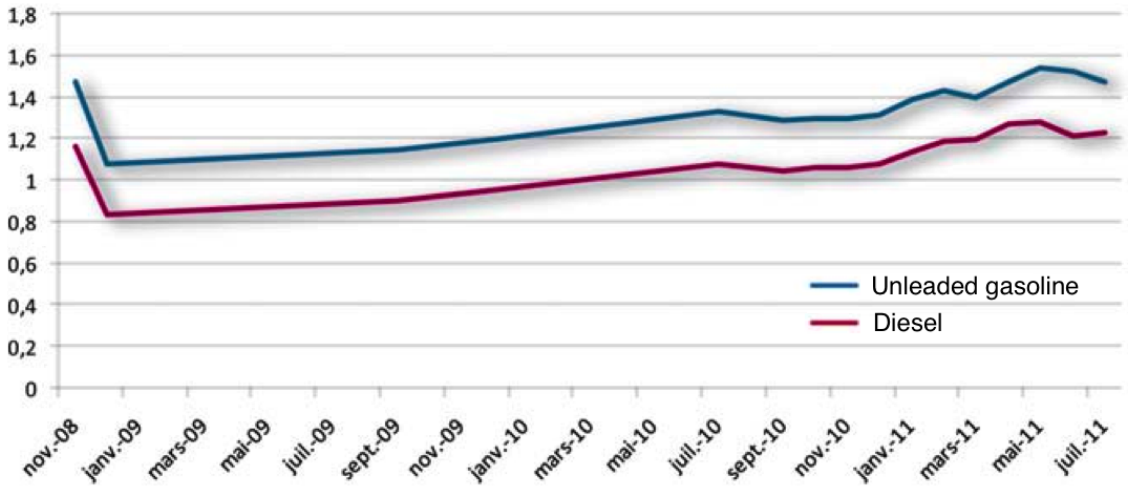

Figure 5.14: Fuel price evolution, Martinque island, *Source :* P*réfecture* M*artinique*

5.2 Other private means of transport results

This section provides results that will help explaining in Chapter 6 why the following means of transport are not favored by the transport policy currently existing in Martinique island. The following results are in relation with the first and second principles of a sustainable transport system.

Walking and Cycling

It has been said in the precedent Chapter 4 that walking was the transport mode used in 17% of displacements. This is an important figure, which supposes the existence of good facilities dedicated to pedestrians. Yet, the study of current situation provides

different results : few pavements in city centers exist, and even in the capital city Fort-de-France where pavement facilities are the most developed, they are usually used as illegal parking space. The same scenario occurs in industrial areas, where pavements are most of time inexistent. In those areas, during lunch time, displacements from work to nearby restaurants are almost all done by car because lack of pavement makes the walk dangerous for pedestrians. The tropical climate may not be the first reason explaining such behaviour as many displacements are still done by feet, even if in higher working classes the notion of comfort is likely to influence the mode of transport choice.

Regarding cycling mode of transport, the precedent chapter has described that it was a popular sport in Martinique island. Yet this sport practice requires safety staff because the cycling activity is not safe on roads. This way of cycling may certainly be enough safe for racing cyclists, but for an isolated or occasional cyclist, achieving the same security conditions remains difficult. That is why the use of bicycle for any displacement external to sport practice (to go to work, for shopping...) is today completely non-existent in the island. The lack of cycle lanes and cycles parks, especially in city centers do not favor the use of bicycle, and in neighbourhoods or suburban areas, the hilly landscape is another break to the bicycle use. Eventually, the island encounters daily and driving rains which make bicycle mode of transport dangerous and uncomfortable. Eventually, little communication is today done to promote this passive mean of transport, especially for very short distance displacements in cities.

Two-wheeler

Two-wheelers sales have been seen to increase the past last years in Martinique island. Yet, the current situation in Martinique island does not describe two-wheelers as a safe mode of transport. Two-wheelers drivers are for most of them young people, who do not adopt a prudent attitude while driving. Motorists are usually not paying attention to them. During rush hours, two-wheelers drive between two cars lanes (same direction or opposite), which does not favor safety. A standard is to sound the horn to prevent motorists as long as two-wheelers make their way to the top of the lineup of vehicles. Security rules as well as a protective clothing are little respected and police controls are even less numerous. The hilly landscape often requires powerful motorized two-wheelers, hence specific driving license and additional costs. Also, as for the bicycle, the island rainy conditions make two-wheeler mode of transport unpopular and dangerous. Eventually, except for highways, all roads are very winding and narrow which increases the driving difficulty and raises the risk of an accident.

The graphic in figure 5.15 presenting the number of death people in Martinique island roads per category since 2006 supports the previous statement. The blue line

represents the evolution of death people for pedestrian, the pink one for two-wheelers and the orange one for other vehicles. Two-wheeler drivers get the highest mortality rate on roads, despite a strong decrease for 2009 data. On average, 52% of two-wheeler accidents occur in the capital city Fort-de-France or in Lamentin city [69], that is to say on most taken and frequented roads and where high speed is encouraged by the long straight line found on the motorway stretch.

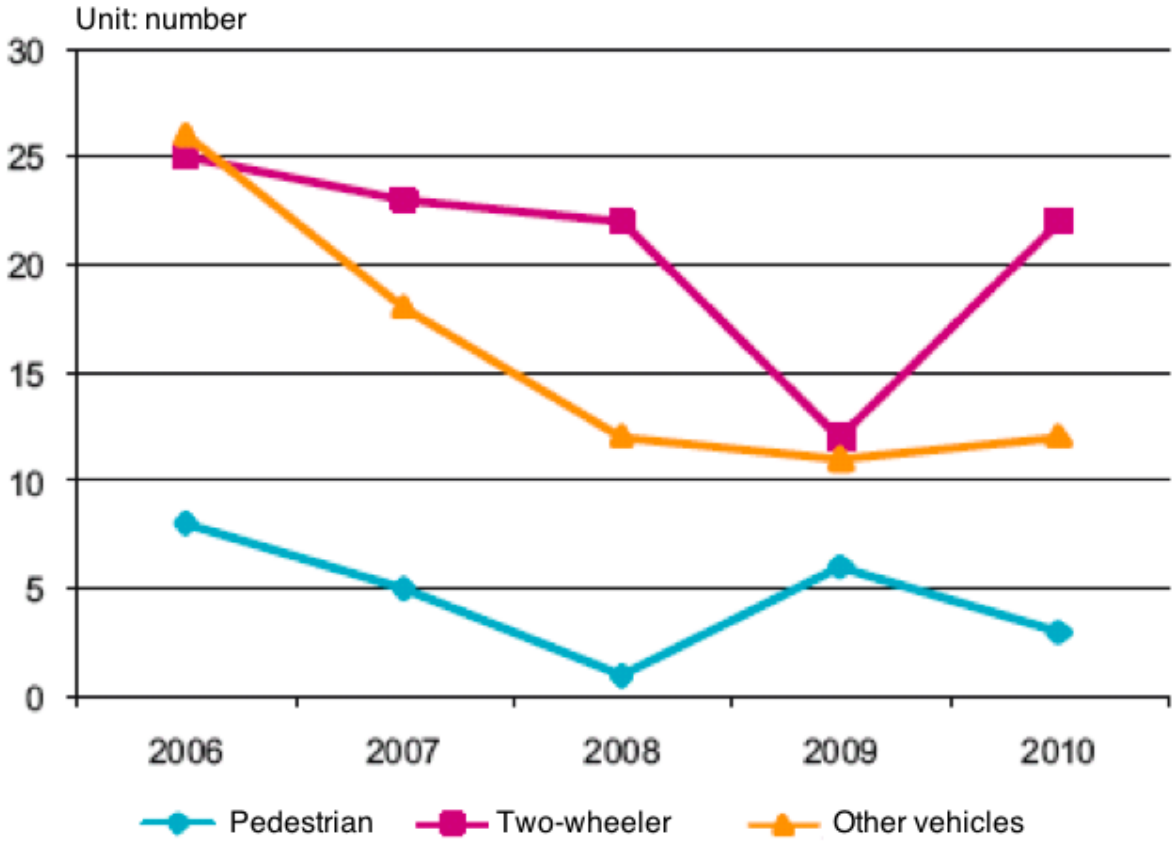

Figure 5.15: Number of death people on roads per category since 2006 in Martinique island, *Source [64] : Observatoire Régional de la Sécurité Routière and [5] :* ANTIANE

5.3 Public means of transport results

If this whole section best belongs to the second principle of a sustainable transport system, it rather aims at providing key results that will help explaining the automobile mode of transport domination detrimental to the other means of transport in the analysis chapter 6.

A study in 2001 has revealed that if 83% of people were thinking that road traffic in general was a source of issues, against 81% for public transport, 77% for road accident risk and car park and 74% for air pollution, when it came to consider the utmost source of issue, then 31% thought that it was public transport, against 28% for road accident risk, 14% for road traffic, 9% for car park, and eventually 8% for air pollution[5] [26]. It means that public transports are supposed to some extent causing current traffic congestion issues.

The description of public transport organisation in Chapter 4 helps describing the difficulty to coordinate at the island global level the different public transport networks. Indeed, the public transport organisation is divided among three metropolitan areas.Each of these metropolitan areas being in themselves shared by several private urban transport companies result in a split of responsibilities which do not favor inter modality between the different administered networks. Besides, financial inequalities, with more or less allocated budget and subsidies through the "Versement Transport" tax, enhance an unequal development of each public transport network, public transport supply being directly function of available financial means. This isolated evolution of every public transport network leads to consequences that can be seen in practical terms as long as one tries to use public transport facilities.

Public buses

Information accessibility

The example of the Mozaïk public transport network existing in CACEM area and considered as the most developed and achieved one is taken as sample to assess the information accessibility of public transport key elements.

There was no website for Mozaïk public transport network until March 2012. People had to go in Mozaïk public transport dedicated stores to get a map of the whole CACEM public transport network, and of the different bus services. It was however difficult to get the address of these different stores as they were nowhere listed. This new website thus launched six years after its creation and whose presentation page is shown in figure 5.16, provides now the main information about the CACEM public transport facilities : it enables to get at a detailed map and the time schedule sheet of most bus lines. So far, this website launch has been advertised through posters on buses.

This website is presented in an elementary way and it is not today totally comprehensive : it is not possible to get automatically a defined trip by giving names of bus stops and some bus line time schedules are missing. Bus stops are neither appearing on

[5]Source : ADEME survey 2001 households trips

the global map. Eventually, the Mozaïk website remains today the only existing website for public transport network in Martinique island, the CAESM transport network website being currently under construction, while the CCNM territory has no website currently under construction. However, the CAESM public transport website will be presented in a different way than the CACEM Mozaïk one. No information centralisation of the different public transport networks is planned.

Figure 5.16: Homepage Mozaïk new website, *Source : www.mozaik.mq*

Yet, Internet is not the only mean of information for public transport networks. Classic means of information can manage to carry all necessary data to achieve successfully a trip. In Martinique island, notice boards in bus stops are rarely found with both the bus time schedule sheet and the global network map. Usually one only finds the time schedule sheet, and even when both information is present, they most of time are jux-

taposed. An example on CACEM public transport network is given below in figure 5.17. In many cases notices have even been teared down and they are not rapidly replaced.

Figure 5.17: The bus map of the Mozaïk network hidden by the bus time schedule sheet at a bus stop, *Source : personal data*

A typical time schedule sheet from Mozaïk network usually placed on many bus stops (but not all of them) is presented bellow in the next picture 5.18. They are pasted up on the two different types of bus shelters : either a single post or a panel placed inside a real bus shelter. These time schedules are not always joined up with the bus network map, and, in that case, the only name of bus stops does not necessarily enable to know where the bus goes if people are not familiar with streets names, districts names or public institutions settlement. It is important to notice that when considering the "global network map", one implies the "global network map of the considered metropolitan area" : on the CACEM territory, one for instance only finds the Mozaïk network map, but not the ones of CAESM or CCNM public transport networks. This can be seen in

figure 5.17 : bus lines are stopped at the CACEM territory boundary, the remaining map being colored in green. In the same way, an information and sales office in the CACEM territory is not likely to get the CCNM or CAESM public transport information, and reciprocally.

The presentation of a Mozaïk bus lane time schedule remains the same for all the CACEM area : bus service name on the right, bus stops names in both directions (buses usually do a loop, they do not take the same return way, that is why bus names and amount of bus stops on the sheet are different according to bus direction). Then, time schedule is given during the week and then on Saturdays, Sundays and on school vacation. Further a note explains where tickets can be bought, either in bus stands, in specific places or directly in the bus, and their purchase cost, the latter not being always updated in case of change.

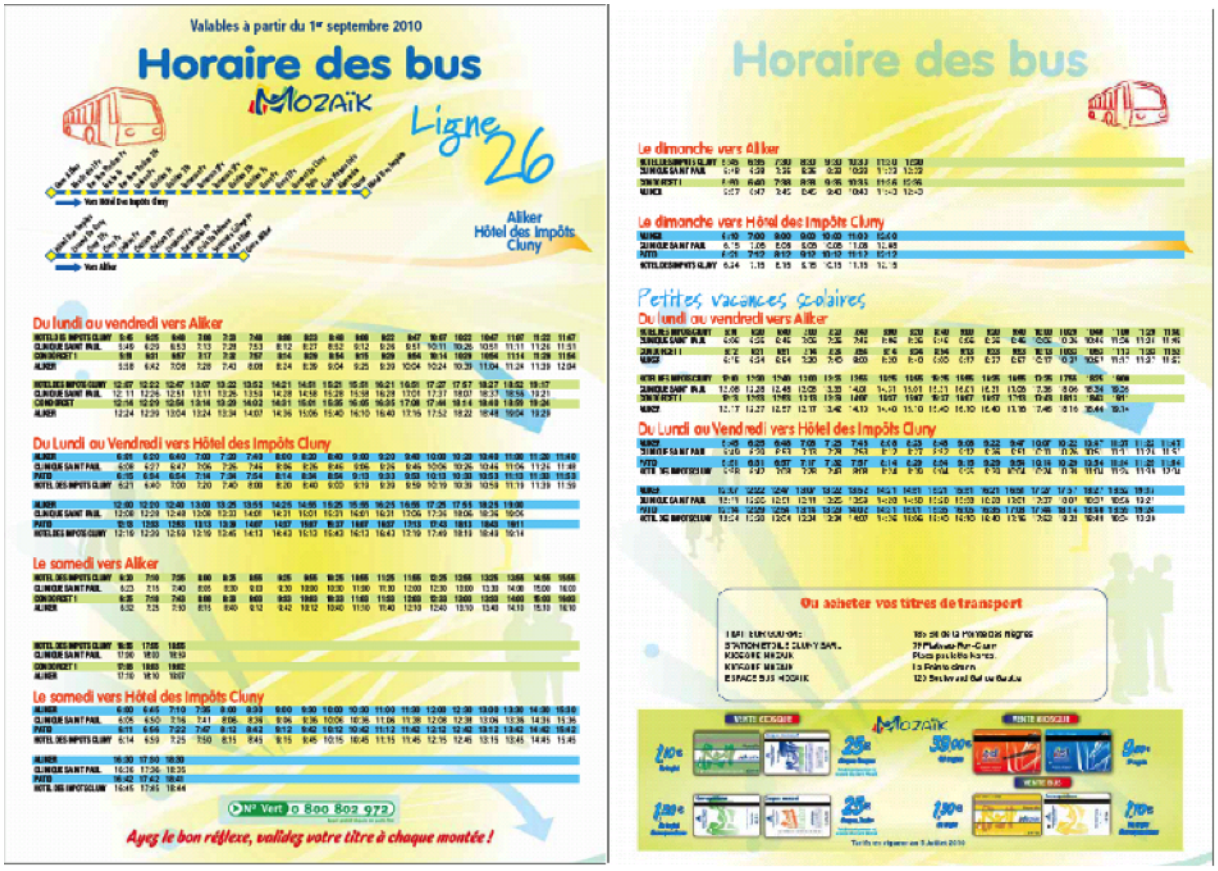

Figure 5.18: A typical time schedule sheet in Mozaïk Network in CACEM community, *Source [10] : www.fortdefrance.fr*

The presentation of a time schedule sheet is however different for each public transport network. Two other time schedule sheets, from the South East (CAESM) and Gros-Morne (CCNM) public transport networks are given in figures 5.19 and 5.20. They both look different with the Mozaïk (CACEM) time schedule sheets.

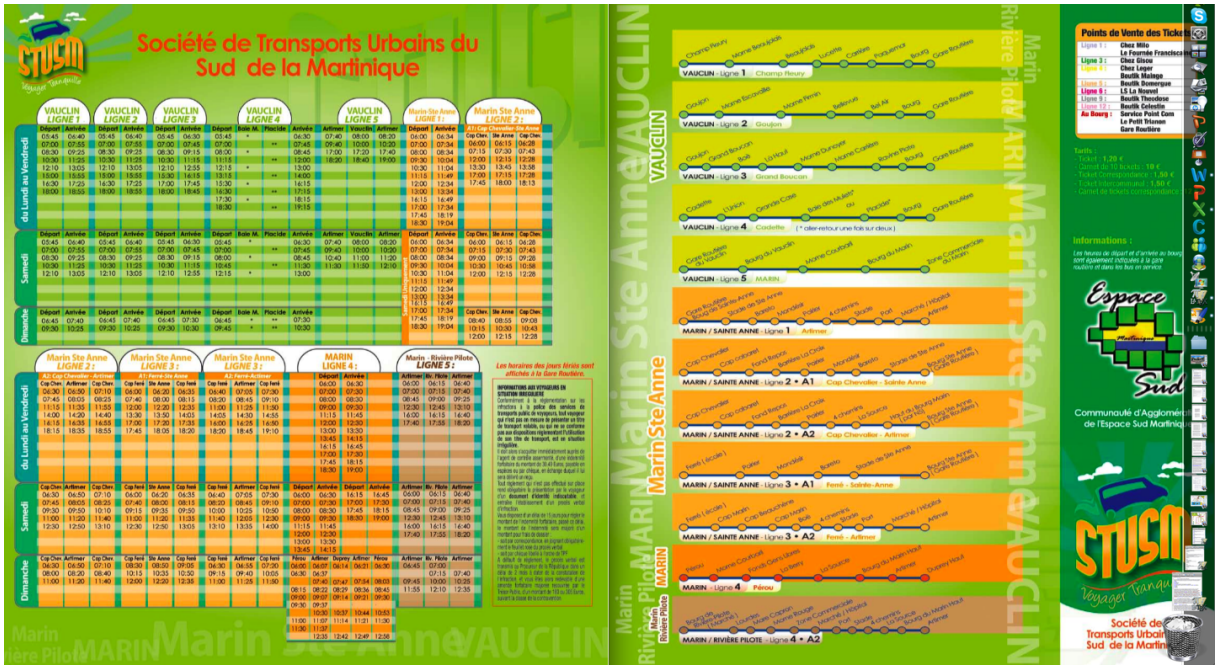

Figure 5.19: Time schedule sheet in CAESM area, South East public transport *Source : CAESM*

Figure 5.20: Time schedule sheet in CCNM area, Trasla public transport in Gros-Morne.

Eventually, a last parameter to consider is the information accessibility provided by buses. Buses in the capital city Fort-de-France, belonging to the Mozaïk public transport network are usually provided with electronic signs both at front and rear windscreens. Front signs give the bus lane and its terminus while rear signs only give the bus lane. Most buses have only a sign at their front. The smallest category of buses is only provided with a paper sign placed at the front and sometimes rear windscreens bottom. Pictures of buses are given in Chapter 4, §4.5.

Time frequency, time schedule range, punctuality and bus shelters

In Martinique island, main bus lanes have 10 to 15 min rotation frequencies -for instance it corresponds for Mozaïk public transport network on the CACEM territory to buses lanes evolving within the capital city Fort-de-France-. The complementary ones evolving in the suburban area and close neighbourhoods have a rotation frequency of 15 to 30 min and eventually the local lanes have a rotation frequency of 30 min to 1h. There are therefore differences among the different lanes.

Time schedule range is also different regarding the bus lane considered and time of the week. During working days, for complementary and local lanes, time schedule on average ranges between 5.45 am and 7 pm, while it reaches 8.30 pm for bus lines in the city center of Fort-de-France. On Saturdays, bus time schedule ranges between 6 am until 1 pm for most buses, 3.30 pm for bus lanes in the capital city Fort-de-France. On Sundays bus supply is usually available until noon, but many bus lanes stop earlier, around 9.30 am.

A parameter that is directly linked with the notion of time is punctuality. In Martinique island, public transport punctuality is not always respected, buses sometimes do not simply come and most of time users are not informed about that and neither explanation is given by the transport company. In the same way, passengers are not informed of buses delays, as no electronic sign forecasts in real time the bus arrival. This embarrassing situation is however happening quite frequently.

Eventually, as described in Chapter 4, two types of shelters are found in the island. Traditional bus shelters are usually located on large road axes and in the capital city Fort-de-France. These shelters provide adequate security and comfort. Starting from nothing, the CFTU company responsible for Mozaïk public transport network in the CACEM territory has for instance today already installed 370 bus shelters in the four cities that belong to the CACEM metropolitan area [70]. Single posts are however not as well comfortable and safe. As seen in the following figure 5.21, the area around some posts can be obstructed, reducing its accessibility. Many signs are besides not placed closed to a streetlight which make users wait into the dark. No dedicated waiting space

is besides either designed or simply possible around these posts.

Figure 5.21: Bus post on a frequented road, almost hidden by parked car *Source : personal data*

Tickets prices and policy

After having providing results regarding the information accessibility, this paragraph deals with the tickets prices and policies existing in Martinique island to take a public bus.

The different existing types of ticket with their corresponding fares are given in figure 5.22 for the Mozaïk (CACEM) public transport network. For instance, one way ticket without transfer costs 1.10 € in stands and 1.30 € in the bus, while a ticket with transfer costs 1.50 € in stands and 1.70 € in the bus. . . Eventually, discount tickets as a 10 ways tickets at 9.90 € or a 40 ways tickets at 39.00 € are available. However, no monthly card or season ticket so far exist as well as no differentiated fares according to social conditions. The only existing monthly cars is specific to school buses which enable to transport students everyday to their high schools and colleges at an affordable price : 25 € per month. Otherwise no preferential price has been for instance set up for them to use the common bus network.

Figure 5.22: The different types of ticket, sold on bus board or in specific stands, CACEM public transport network, *Source [10] : www.fortdefrance.fr*

The precedent given fares are as previously written only valid for the CACEM network. A comparison of the one way ticket fares among the different public transport networks reveals differences, as well as when one looks at the different discount tickets available. Results are given in the next table 5.3. Tickets from one typical public transport system are moreover not valid in another public transport network, because prices are different, and above that because tickets shape is different and cannot suit with the stamping ticket machine.

Networks	One-way ticket	Monthly Card	Preferential tariffs
CACEM	1.10 €	Student	10 ways tickets / 40 ways tickets
CAESM	1.20 €	Student	10 ways tickets (with or without transfers)
Gros-Morne	1.20 €	Student+All ages	6/10/20 ways tickets
Lorrain	1.30 €	Student	10 ways tickets
Trinité	1.10 €	Student	10/20/30/60 ways tickets

Table 5.3: Comparison of one way ticket tariff and available monthly card or preferential offers, *Source [79] :* ADUAM

Local collective transport : taxicos results

Most taxicos drivers are independent companies of one person. The driver health and capability to drive are not regulated, as well as recommended break times. Minibus used do not necessarily respect public transport safety standards, as maintenance controls and vehicle age. As some of these taxico drivers are undeclared companies or independent ones, they do not pay superannuation ticket fare or they do not declare their real revenue to pay less taxes.

Practically, no tickets are given into the minibus, one may pay when one goes in or goes off. The taxico can stop at any place in the street one just needs to wave one hand to show that one wants to take it or tell the driver when one wants to go down. Yet Taxicos are using public bus lanes and therefore some bus stops are both used for public buses and taxicos. It is therefore also possible to wait at some bus shelters designed for public transport near the road. No official time schedule exists and there is no guarantee that the taxico will come. No external signs, platforms, or information panels are provided in the streets. Usually, ticket fares depend on the length of the journey and they are fixed according to the driver will, but this mode of transport is in general a little more expensive than the public transport systems. The driver's salary is therefore function of the amount of carried passengers in the month. Taxicos have usually defined routes, most of time representing the route between their home suburb to the capital city Fort-de-France. The return trip to the home suburb at the end of the worked day can be long because many people are waiting for them and places are rare. On the contrary, during off-hours the driver can decide to wait until its bus to be full before leaving, which can also increase the trip length. Eventually, as for public transport, after 6 pm, it will be difficult to find taxicos on the road.

Taxicos drivers have been said to be independent companies. They have never cho-

sen to cooperate and to define partnerships among them in order to equally share people's mobility market. At least any such project has succeeded. Therefore a tough competition between taxicos drivers is daily occurring in order to drive on the main road axes where customers are the most numerous. This rivalry among taxicos drivers, that can be qualified as "internal" in this transport system is not the only existing one. On a higher level, another competition occurs between official public transport networks and these independent companies. Taxicos drivers are indeed taking the same routes as public buses, in order to transport people who are normally waiting for the public bus. A common behaviour is to see taxicos coming on a public bus official route five minutes before the public bus time schedule to "withdraw" potential public bus customers.

The Regional Council institution has tried to federate the Taxico community explaining that they had everything to gain to join and be supervised by it. Today, few taxicos drivers have accepted to quit their independence. So far, the Regional Council has achieved grouping about fifty taxicos in the entire island territory. On the webpage of the Regional Council it is possible to see a map with the different available taxicos routes, the departure and arrival stops as well as the fare. However, no time schedule is provided. The map is given in figure 5.23.

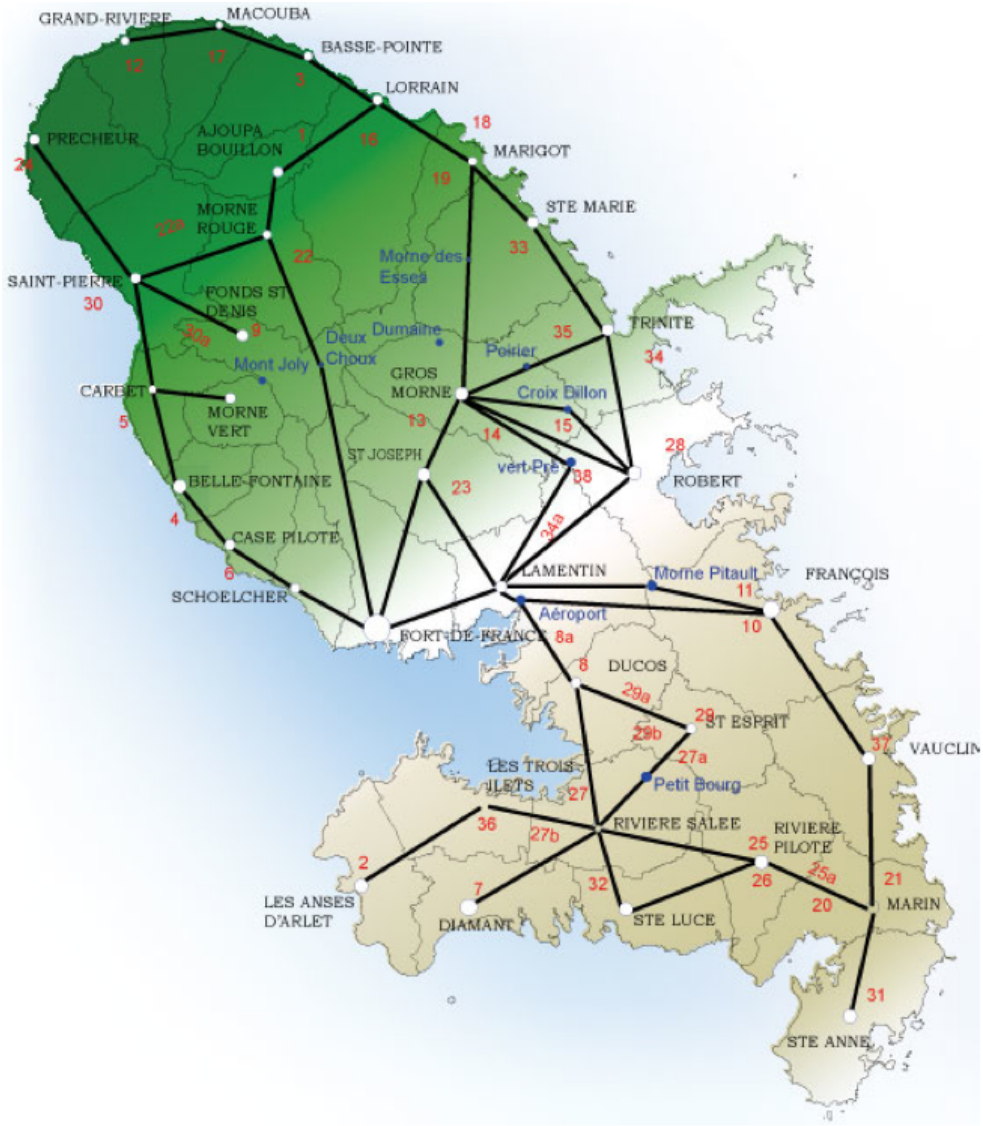

Figure 5.23: Taxicos network, 47 lines *Source [52] : Regional Council*

Still, the number of taxicos in Martinique island in 2000 years was much too high compared to the demand. That is why a reduction policy has been carried out, consisting of setting up a suspension of activities system for drivers older than 65 years old or declared unfit to do this job by medical expertise. This measure has enabled to reduce the number of taxicos drivers from 760 estimated in 2001 to less than 500 in 2007 [79], which may however not be sufficient as the offer, reaching 5700 free seats is still higher than the demand. In parallel to this action, another step is to achieve reducing the number of private companies and the Regional Council has for that purpose fixed the limit to 5 associations. The repression policy especially against illegal taxico drivers will also be reinforced.

Boat shuttle results

This paragraph not only deals with the second principle of a sustainable transport system, but also with principle one as the security notion is briefly tackled. Vedette Madinina boat shuttles company is currently the only one providing a sea public transport. As a private company, it does not get subsidies from the Regional Council. This fact has for result the difficulty for the company to make profits and to achieve the company viability on the long term. The shuttle rotation fluctuates between 30 min during rush hours in the morning and one hour. The earliest shuttle leaves at 5 :50 am from Anse Mitan, the latest leaves La Pointe du Bout at 7 :15 pm. No shuttle navigates on Sundays and holy days due to an increase of insecurity and problems on board between users and staff. A recent article in the France Antilles newspaper, dated from the 26th of June 2012 [54] reveals that these insecurity issues have not been fixed as sea shuttles time schedules have once again been changed on Saturdays this time (they have been reduced) due to an increase of insecurity on that travel times.

The existing shelters provided at the different landing stages are not well adapted : they are either too small regarding the number of passengers waiting for the boat shuttle, or even inexistent, especially in the morning. The next figure 5.24 shows the shelter present in Anse à l'Ane. Its size is rather small compared to the number of passengers estimated on mornings (reaching about an hundred), to protect efficiently against the sun or the rain.

Also, on rush hours, boat shuttles are often too small for the demand, which leads to either a refusal of people, either a non respect of the safety rules on board, with exceeding passengers. And when it comes to consider the inter modality between sea and land public transports, one realizes that nothing is done to promote it.

Concerning information accessibility and reliability, the only ways to consult shuttles time schedule are either to call the dedicated office or to buy the local newspaper "France Antilles" because the official website of Vedette Madinina company has not been updated for several years. A new website is currently under construction, but so far it is not possible to get reliable information from the Internet. On the contrary, the Internet is currently providing in many cases wrong information to potential users of the shuttles. Besides, billboards placed alongside shuttles boarding stages are either unreadable, either they do not give any information on delays and departure times or they are simply inexistent.

Another parameter is the ticket fare : it is more expensive than a bus ticket, going from 4.30 € on average for an adult single way, to 6.50 € for an adult return trip, and no monthly card exist yet. This ticket is neither usable to take another public means of transport.

Figure 5.24: Anse à l'Ane shelter, [82] *Source : Transrade Association*

Tramway network project results

This paragraph presents the results of the TCSP[6] project initiated in 2000. Back in 2012, the work is far from being achieved, many delays being encountered among others at an administrative level, which have postponed the TCSP launching from 2011 to 2013 after a first review, and 2015 after a second review. Then, the chosen mean of transport - tramway on tires- has been abandoned recently the benefit of a BRT -Bus Rapid Transit-[7] system. The precedent chosen transport mode was indeed considered as too expensive in terms of purchase and maintenance and its success was besides not proven in the two other French metropolitan cities where it has been developed. A new organising team is at the origin of such a change. Eventually, all the undertaken roadworks are creating much traffic congestion.

[6]Transport en Commun en Site Propre = Public Transport on Bus Lane
[7]Called "Bus à Haut Niveau de Service" in French

5.4 People's commuting to work results within current situation

Working displacements

This section is mainly in relation with the second and the third principles because it states indirectly the efficiency of fossil fuels resource use during commuting times to work as well as results concerning the ability of current transport policy to fulfill people's basic need of mobility with limited production of emissions.
The fact that people commuting to work as a majority live in a different district than the district place of work results in an increase of energy consumption : the more the distance from homes to work the more the energy consumption, as showed previously in figure 5.31. Indeed, it is seen in that diagram that road transport energy consumption mainly comes from interurban passenger, according to 2005 data : urban passengers energy consumption accounted that year for 25% of road transport energy consumption, but interurban passengers energy consumption reached 54%. These commuting trips to work are presented in the next figure 5.25.

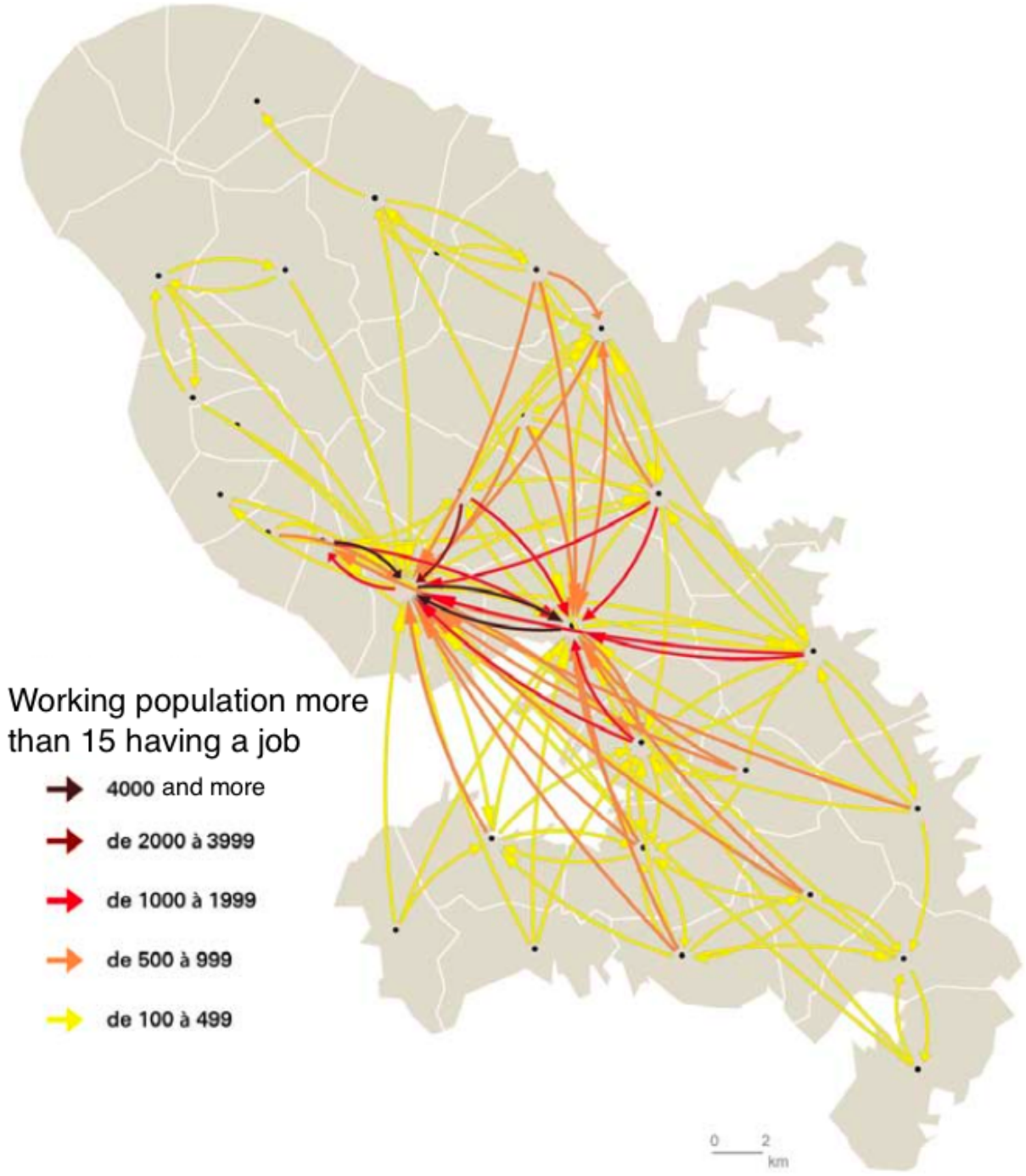

Figure 5.25: Home-to-work migrations, 2008, *Source [27] :* ADUAM

What comes out from this figure is that respectively 42%, 35% and 23% of fluxes originate in the CACEM, CAESM and CCNM regions, while respectively 77%, 13% and 10% of fluxes ended in the same regions. Main trips are therefore located in the CACEM region. In 2008, nearly 60% of all working population is employed in only two regions, Fort-de-France and Lamentin [27]. This area even reaches 72% if the Center Atlantic is

included. This leads to massive daily migrations toward the island center, from all roads axes. Everyday, respectively 46% and 40% of working population leave the CAESM and CCNM areas to go to work [25].

Another figure 5.26, more schematic, clearly summarizes daily migrations only occurring within the CACEM territory. Movements towards the outside suburb are quite low (purple arrows) compared to the one coming inside the suburb (orange arrows). Movements within the suburb (gray arrows) are also very important, with main fluxes concentrated through the capital city Fort-de-France.

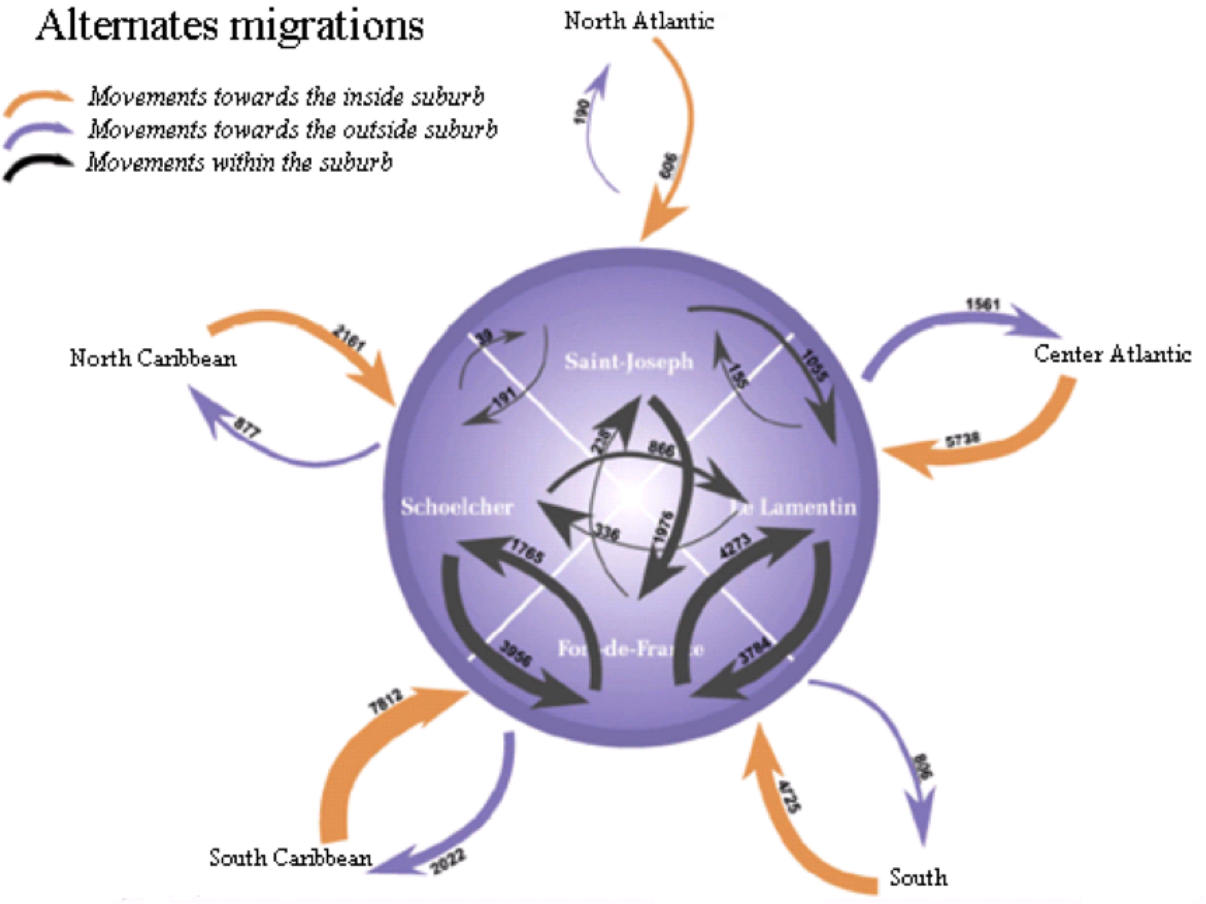

Figure 5.26: Every working day migration of population through Fort-de-France and its suburbs -Schoelcher, Saint-Joseph and Lamentin-, *Source [14] :* INSEE, RP99

Traffic jams

Another parameter that directly influences the efficiency of fossil fuels resource use is traffic congestion. The following paragraph presents the situation in Martinique island. As traffic congestion only occurs during rush hours, corresponding to people's commuting time to work, it appeared judicious to present these results in this section.

With a road traffic increase of 4% annually [77], traffic density has reached nowadays a critical level, especially in the island center, which concentrates as previously said the main economic poles and working places, as well as the only road network capable of binding the island north and south. Inhabitants of Martinique island even consider that traffic congestion issue is the third main concerns that needs to be tackled[8].

One explanation of that traffic congestion is the "H structure" of Martinique island road axes, as illustrated in the following figure 5.27. This situation, added to the fact that the main economic area is located as said previously around the horizontal line of the H letter (Fort-de-France and its suburbs) leads to the fact that the horizontal axe accounts for the only way for people from North Atlantic, South Atlantic, South Caribbean and North Caribbean to go to their work.

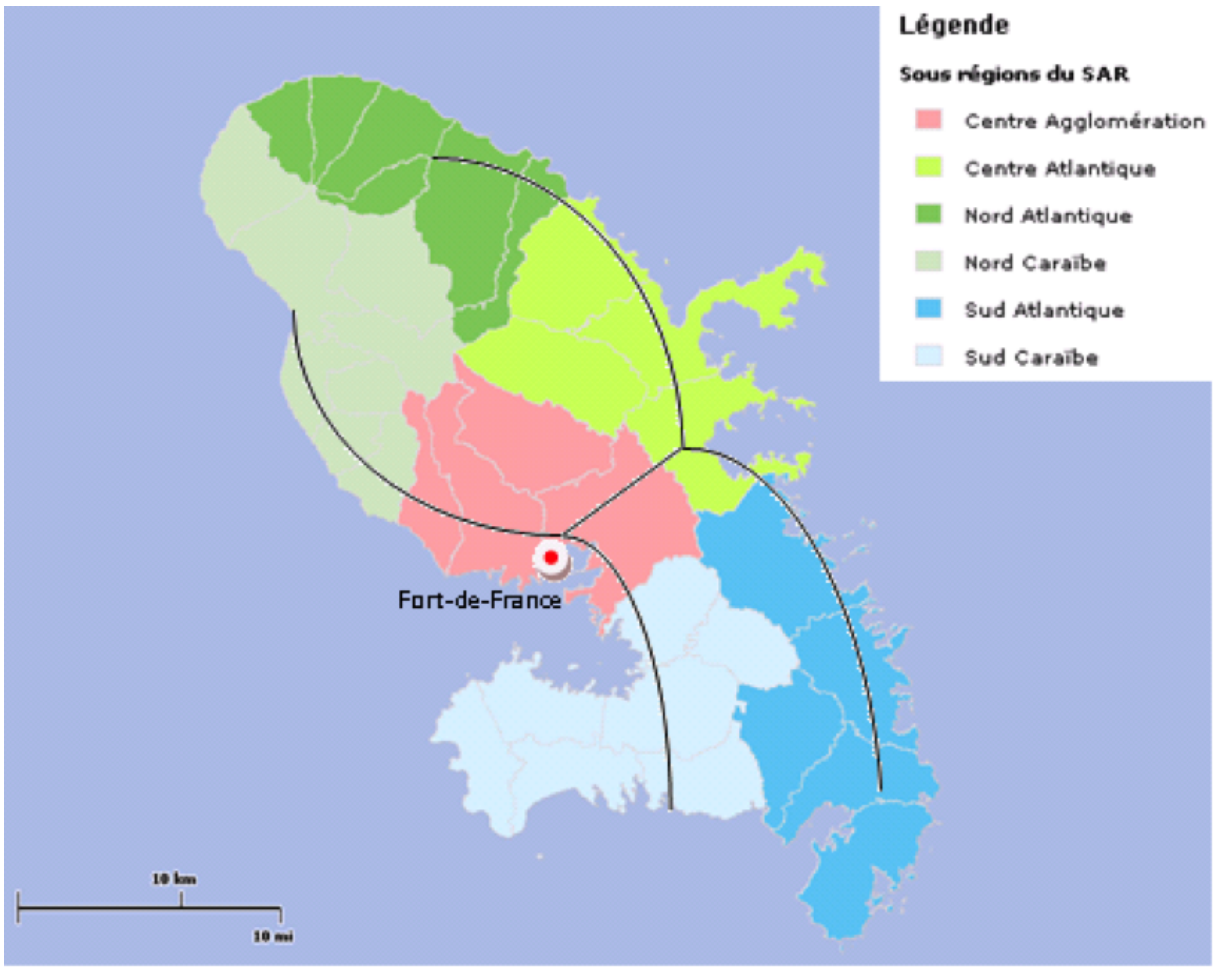

Figure 5.27: The H road axes and the island zoning, *Source [56] : L'Observatoire Territorial de Martinique*

Three linked axes described as following are therefore especially concerned by traf-

[8]Survey from Regional Council in 2005

fic jams : the North and Center Atlantic axes carry everyday 44 000 vehicles on that area, 25 000 other vehicles pass through the North Caribbean axe, and eventually 74 000 vehicles are converging from the South towards Fort-de-France and its suburbs. Therefore, the island center is frequented by more than 118 000 vehicles on average everyday [27]. The ring road around the capital city Fort-de-France is estimated to be taken by more than 90 000 vehicles everyday.

Figure 5.28 sums up the main road sections with the highest traffic density. Not surprisingly, highest densities are encountered on three main roads : the 7 km motorway, the national roads N5 and N1, all serving CACEM region. As it can be seen, national road N4, which could represent a good shortcut compared to the N1, is much less taken (yellow color, less than 10 000 vehicles per day) by drivers, this being likely explained by its winding morphology. As a consequence, between 5 am until 9 :45 am, the island center is completely blocked. In the evening, between 4:30 pm to 6:30 pm new traffic jams occur when people go home.

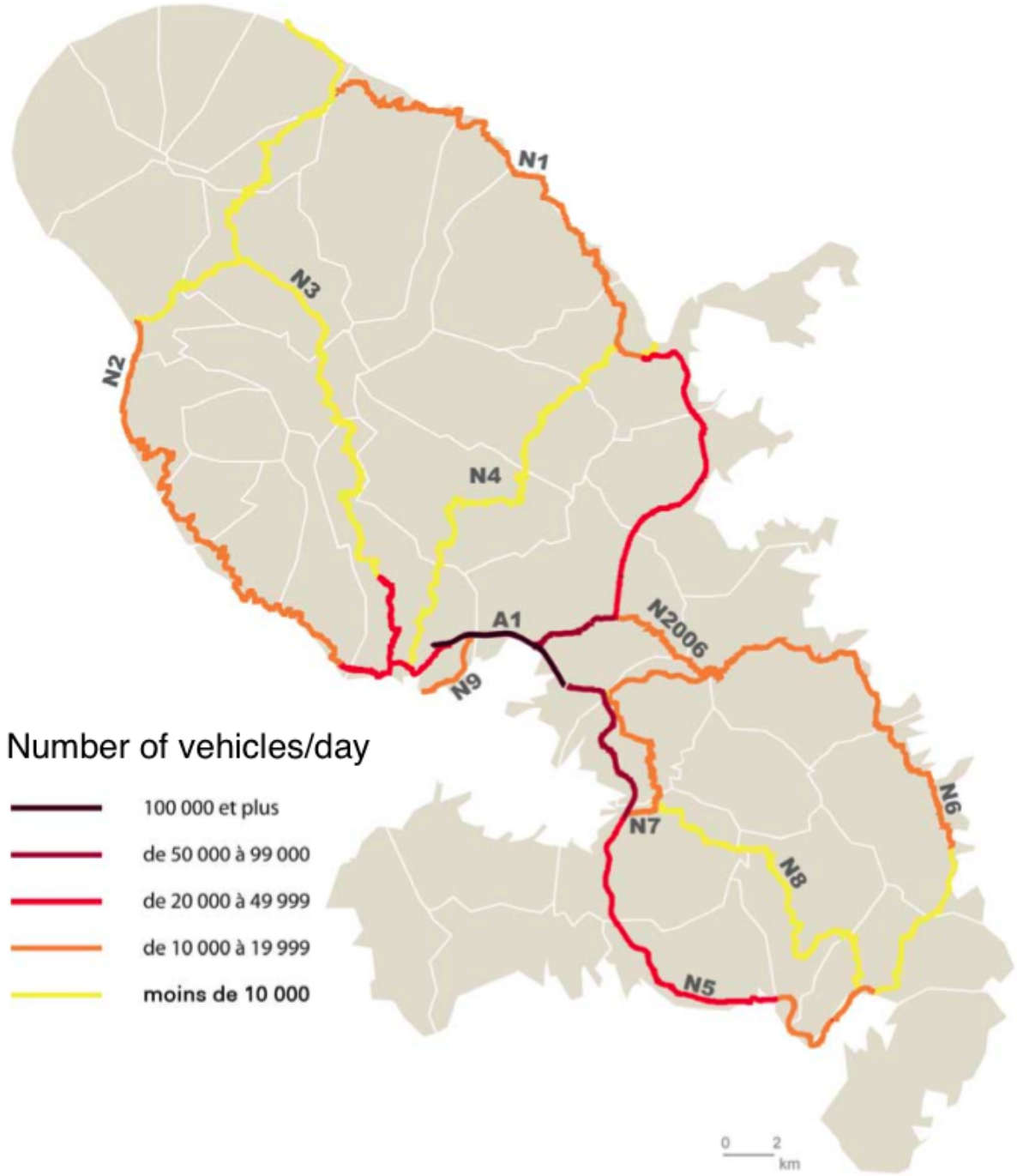

Figure 5.28: Traffic density on regional road network, *Source [27] : L'Observatoire Territorial de Martinique*

What eventually comes out among other things from the conducted survey in the company settled in Les Mangles industrial zone (Lamentin district) is that the traffic congestion phenomenon has reached such a level that people do not think today with the word "distance", but with the combination "distance/time". This commentary comes from the fact that almost 40% of people have not managed to answer to the question

"What is your commuting distance to work?" asked in the questionnaire[9]. The survey also emphasizes the fact that on average, people double or even triple their commuting time to work. For instance, on average, people need 1h30 to drive the 7 km motorway, with a speed between 5 to 10 km/h every working day.

Air pollution result

To better see the direct relationship between air pollution concentration and automobile traffic, the following figure 5.29 is given : it shows the evolution of nitrogen dioxide concentration registered in Concorde and Renéville air traffic stations on Monday 23rd of January 2012, per hour. One can see that the highest concentrations of nitrogen dioxide gas are recorded during rush hours, hence 9 am and 6 pm for Concorde station, and 8 am and 7 pm for Renéville station. A smaller peak appears at noon during lunch time. Yet one can notice a difference in the value of the measure.

The nitrogen dioxide concentration evolution during week ends is different as seen in the next figure 5.30. First, highest concentrations are met at a different time of the day : either at noon or later in the evening, after 8 pm. However, concentration values of this gas are much higher (they nearly double) during working week than during week ends : for instance, the concentration peak recorded by the Concorde station reaches 120μg/m^3 on a working day while it is 68 μg/m^3 on a week end day.

[9] See questionnaire in Appendix B

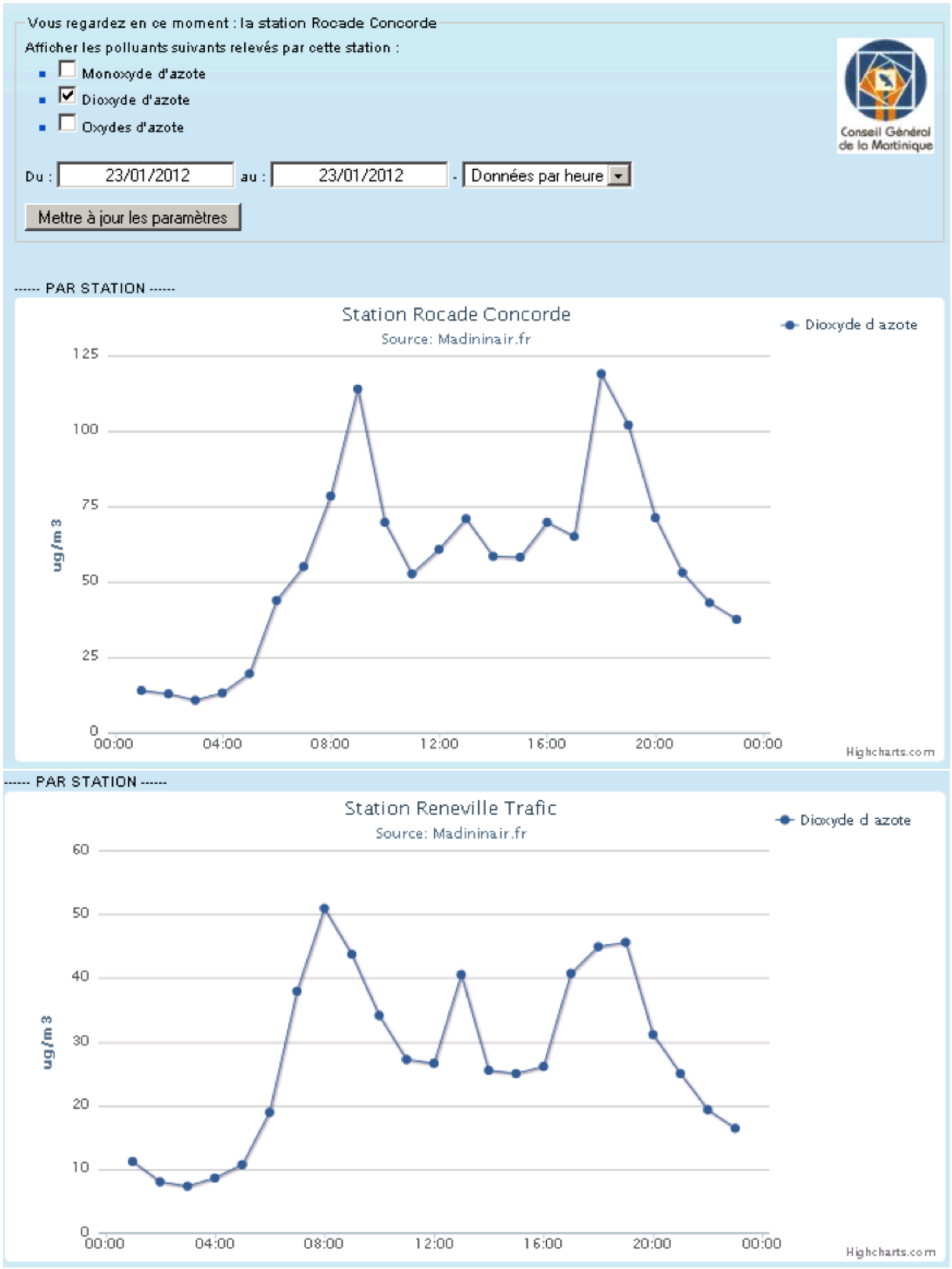

Figure 5.29: Evolution of nitrogen dioxide concentrations during a working day in Concorde and Renéville stations, *Source [47] : Madininair*

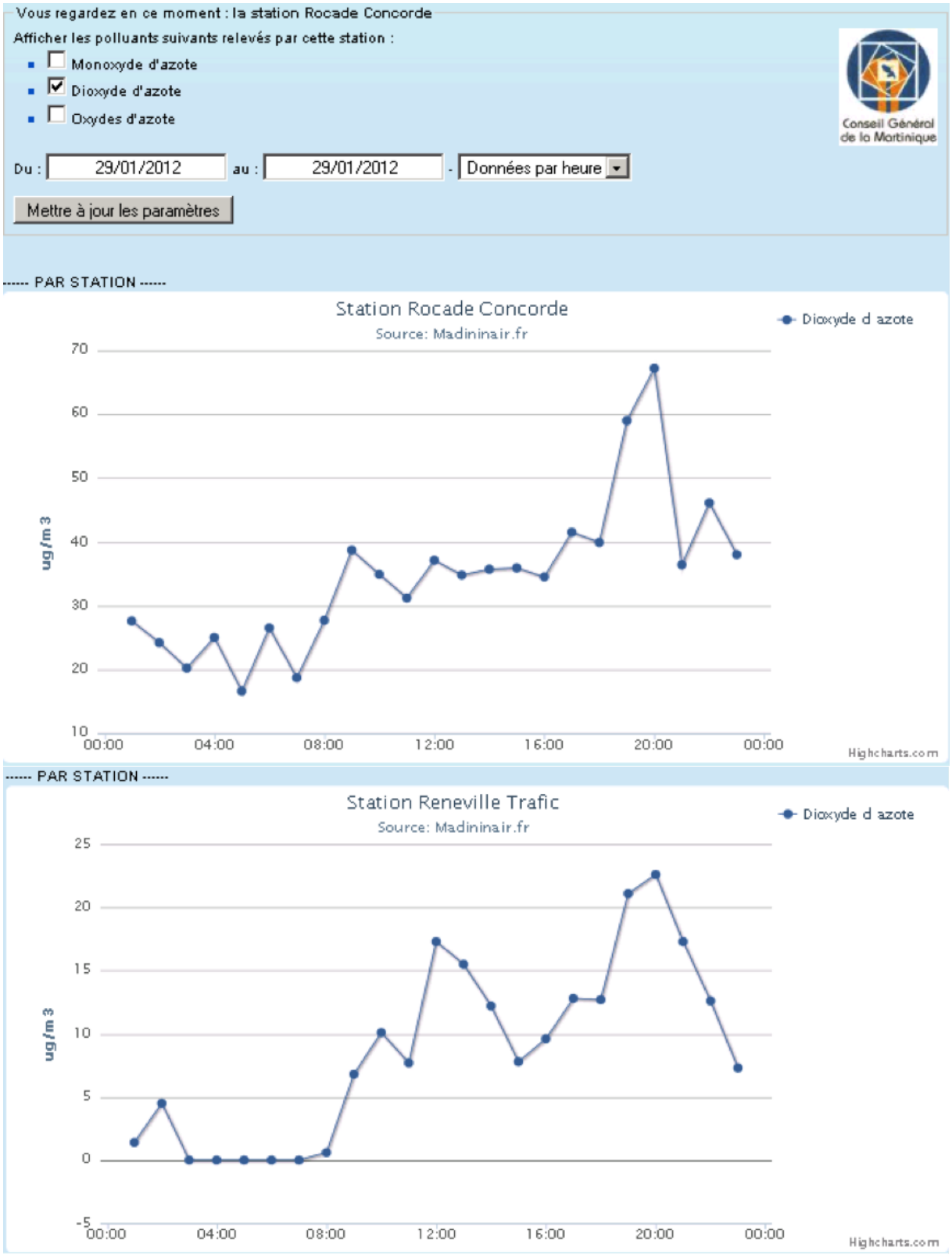

Figure 5.30: Evolution of nitrogen dioxide concentrations on Sunday in Concorde and Renéville stations, *Source [47] : Madininair*

Particles PM10 recorded measures are also given in figure 5.31 for Renéville station only (no measure available for Concorde station), for the same dates. Differences in measures in function of the day are less important than for nitrogen dioxide, and concentrations remain nearly the same with just a little increase during the working day.

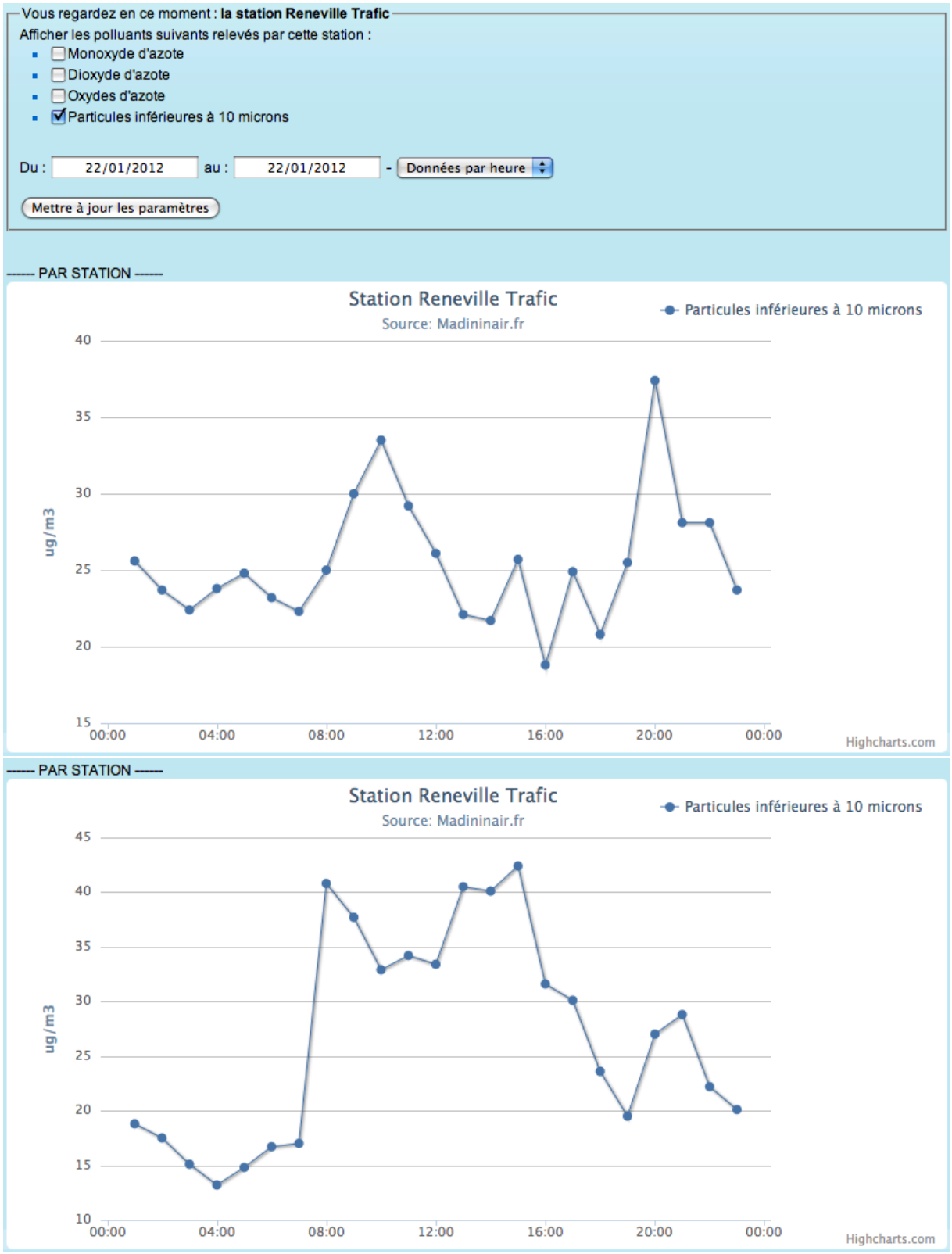

Figure 5.31: Evolution of particles PM10 concentrations on Sunday (Top) and on a working day (Bottom) in Renéville station, *Source [47] :* M*adininair*

Flow model result

Several results can be given from the flow model calculations performed with the parameters given in Chapter 4 describing current situation of people commuting to work in Martinique island.

First, figure 5.32 presents the carbon dioxide emissions as well as the fuel consumption in toe[10] produced in one year by all the working population commuting to work with the current transport model existing in Martinique island. Results are given in both cases, with and without the hypothesis of traffic jams. Diesel cars consumes the most fuel, followed by gasoline cars. Public transport fuel consumption are much lower. The smallest fuel consumption is achieved by two-wheelers. The same pattern exists for carbon dioxide emissions.

[10]toe = tonne of oil equivalent

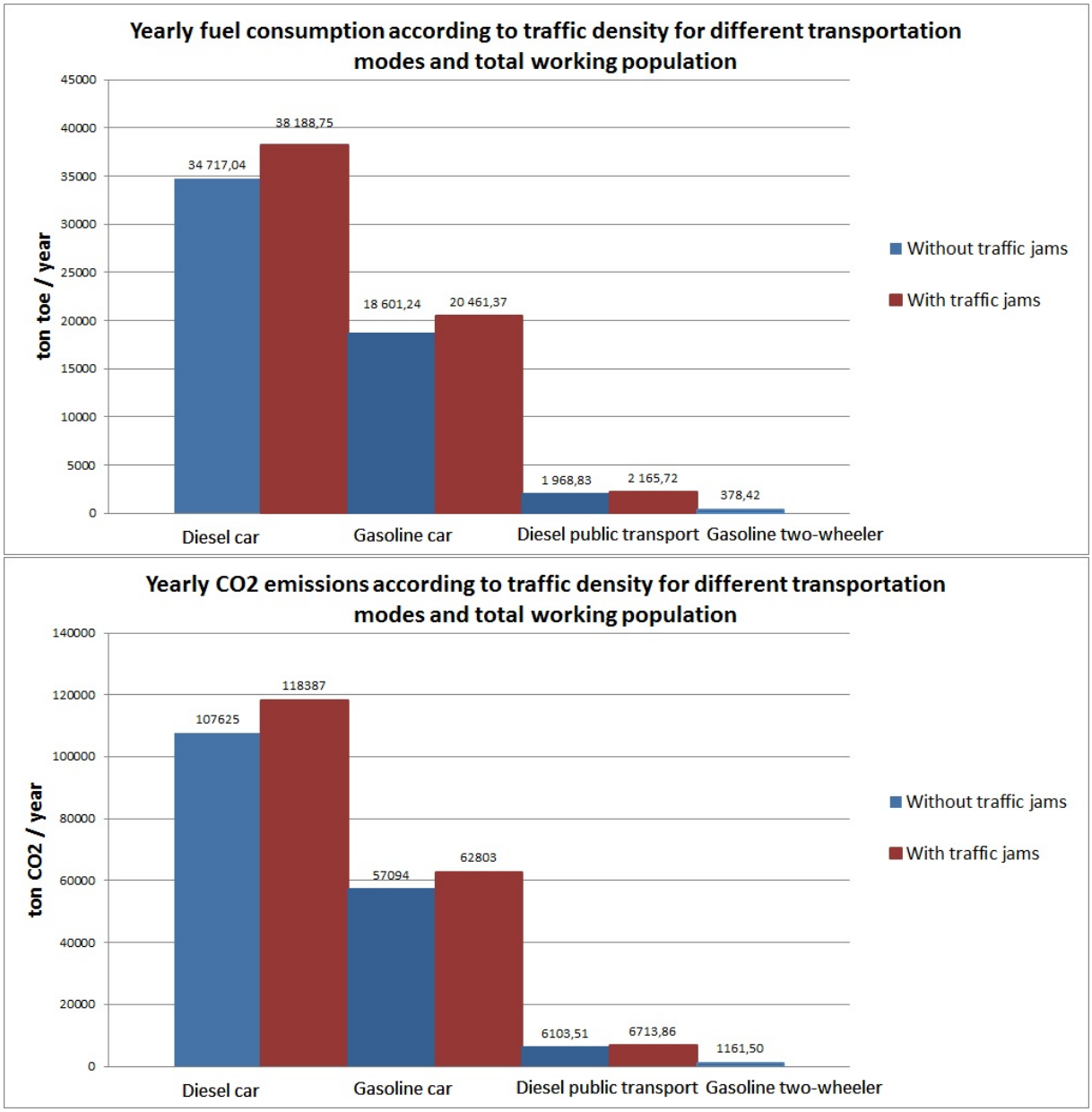

Figure 5.32: Yearly fuel consumption and CO2 emissions according to traffic density for different transportation modes and total working population, Current situation, *Source : Flow model*

The next two figures 5.33 and 5.34 present the allocation of each mode of transport following total fuel consumption and total carbon dioxide emissions.

Each category contribution to total fuel consumption:			
		without traffic jams	with traffic jams
Cars:	diesel	62,37%	62,41%
	gasoline	33,42%	33,44%
	combined	95,78%	95,84%
Public transport		3,537%	3,539%
Two-Wheeler		0,680%	0,618%
Total:		100,00%	100,00%

Figure 5.33: Each category contribution to total fuel consumption, Current situation *Source : Flow model*

Each category contribution to total CO2 emissions:			
		Without traffic jams	With traffic jams
Cars:	diesel	62,58%	62,62%
	gasoline	33,20%	33,22%
	combined	95,78%	95,83%
Public transport		3,549%	3,551%
Two-Wheeler		0,675%	0,614%
Total:		100,00%	100,00%

Figure 5.34: Each category contribution to total CO2 emissions, Current situation, *Source : Flow model*

Eventually, to summarise two major results of this flow model the following figure 5.35 is given : it represents the total yearly fuel consumption and the total emissions produced by one person commuting to work on average with the current transport model, again with and without traffic jams.

Total yearly fuel consumed by people commuting to work, in toe		
without traffic jams	55665,5	toe / year
with traffic jams	91194,3	toe / year
Total yearly CO2 emissions produced by one person commuting to work		
without traffic jams	1,28	ton CO2 / person.year
with traffic jams	1,41	ton CO2 / person.year

Figure 5.35: Total yearly fuel consumption and CO2 emissions produced by one person commuting to work, *Source : Flow model*

5.5 People's commuting to work results with the three developed scenarios

Scenario 1

In this first scenario, the number of people per vehicle is increased, assuming that people are using car pooling solution to commute to work. There are necessarily 2 people in each car, as seen in figure 5.36. The remaining parameters are unchanged. There are therefore less than 54000 cars on the roads from people commuting to work each day.

Parameters that can be changed in the model	Changed parameter(s)	
		Unit
Diesel average fuel consumption	0,067	L/km
Gasoline average fuel consumption	0,079	L/km
Working population only taking their car	0,8	80%
Working population only taking public transport	0,1	10%
Working population only taking a two-wheeler	0,01	1%
Working people only going by feet	0,06	6%
Working people not using any transportation mode	0,03	3%
Percentage of diesel cars in total car fleet	0,65	65%
Percentage of gasoline cars in total car fleet	0,35	35%
Average commuting distance to work (return trip)	36	km
Traffic jams = +10% fuel consumption	1,1	-
Number of persons in one car to commute to work	2	person
Gasoline fuel consumption of a two-wheeler engine	0,045	L/km

Figure 5.36: Changed parameters in Scenario 1, *Source : Flow model*

Figure 5.37 presents the carbon dioxide emissions as well as the fuel consumption in tep produced in one year by all the working population commuting to work with the assumptions of Scenario 1. Diesel cars still consume most of fuel, followed by gasoline cars. Public transport weight is more important, but still lower than private vehicles one. Carbon dioxide emissions provide the same statements.

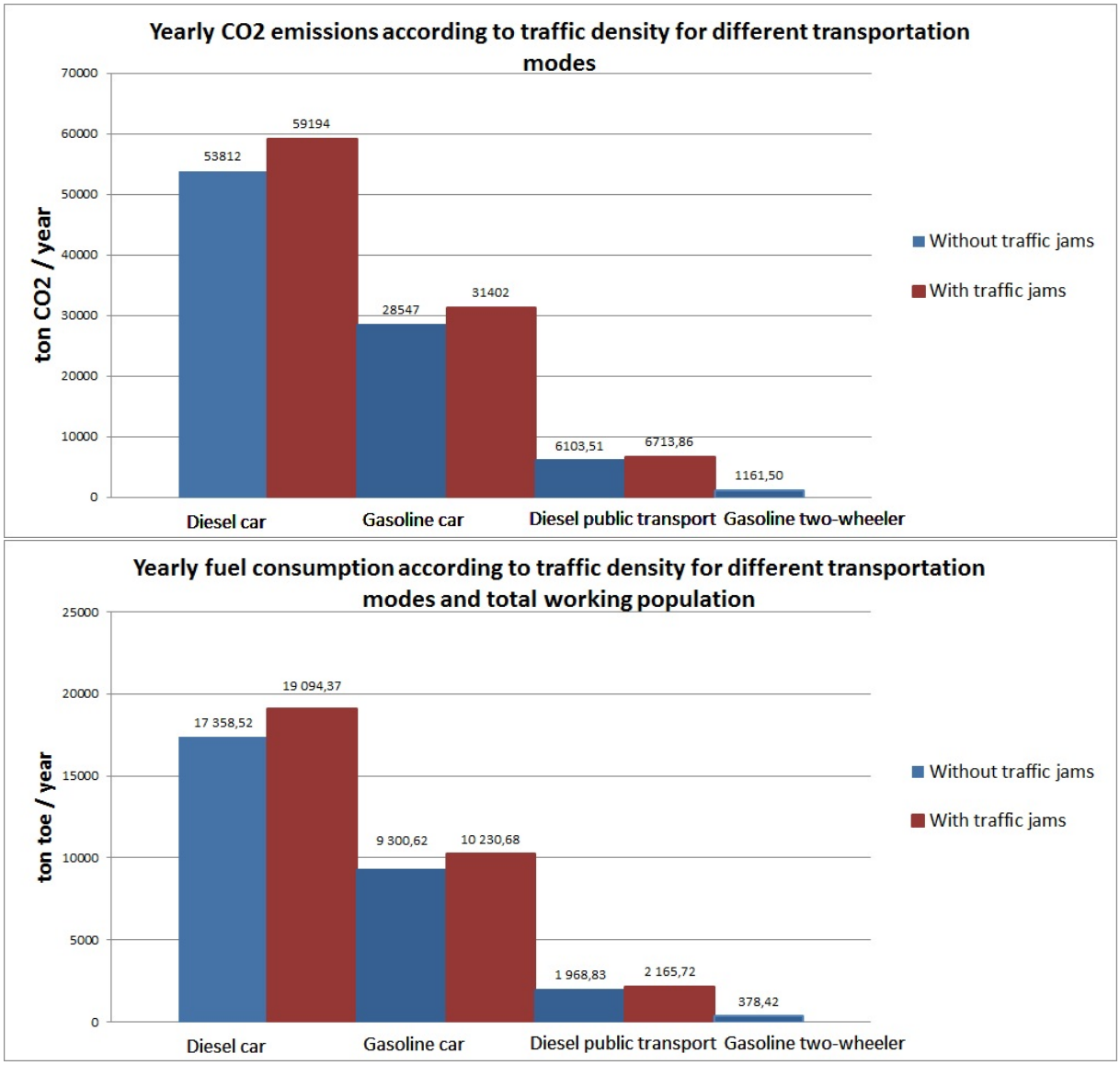

Figure 5.37: Yearly fuel consumption and CO2 emissions according to traffic density for different transportation modes and total working population, Scenario 1, *Source : Flow model*

Scenario 2

In this second scenario, one assumes that public transport development has tremendously increased and that people are massively using them instead of their private car. They are now more than 50 % using public transport, as seen in figure 5.38. The remaining transportation modes distribution are unchanged. One besides assumes that the remaining people taking their private car to commute to work are alone in their vehicle. As for in Scenario 1, less than 54 000 cars are on the roads from people com-

muting to work each day.

Parameters that can be changed in the model	Changed parameter(s) compared with scenario 1	
Diesel average fuel consumption	0,067	L/km
Gasoline average fuel consumption	0,079	L/km
Working population only taking their car	0,4	40%
Working population only taking public transport	0,5	50%
Working population only taking a two-wheeler	0,01	1%
Working people only going by feet	0,06	6%
Working people not using any transportation mode	0,03	3%
Percentage of diesel cars in total car fleet	0,65	65%
Percentage of gasoline cars in total car fleet	0,35	35%
Average commuting distance to work (return trip)	36	km
Traffic jams = +10% fuel consumption	1,1	-
Number of persons in one car to commute to work	1	person
Gasoline fuel consumption of a two-wheeler engine	0,045	L/km

Figure 5.38: Changed parameters in Scenario 2 compared with Scenario 1, *Source : Flow model*

Figure 5.39 presents the carbon dioxide emissions as well as the fuel consumption in tep produced in one year by all the working population commuting to work with the assumptions of Scenario 2. In that scenario, diesel cars are still the largest consumers of fuel but gasoline cars and public transport are almost at the same level of consumption, and for the first time public transport consumption is higher than one type of private vehicle. The same pattern is seen for carbon dioxide emissions.

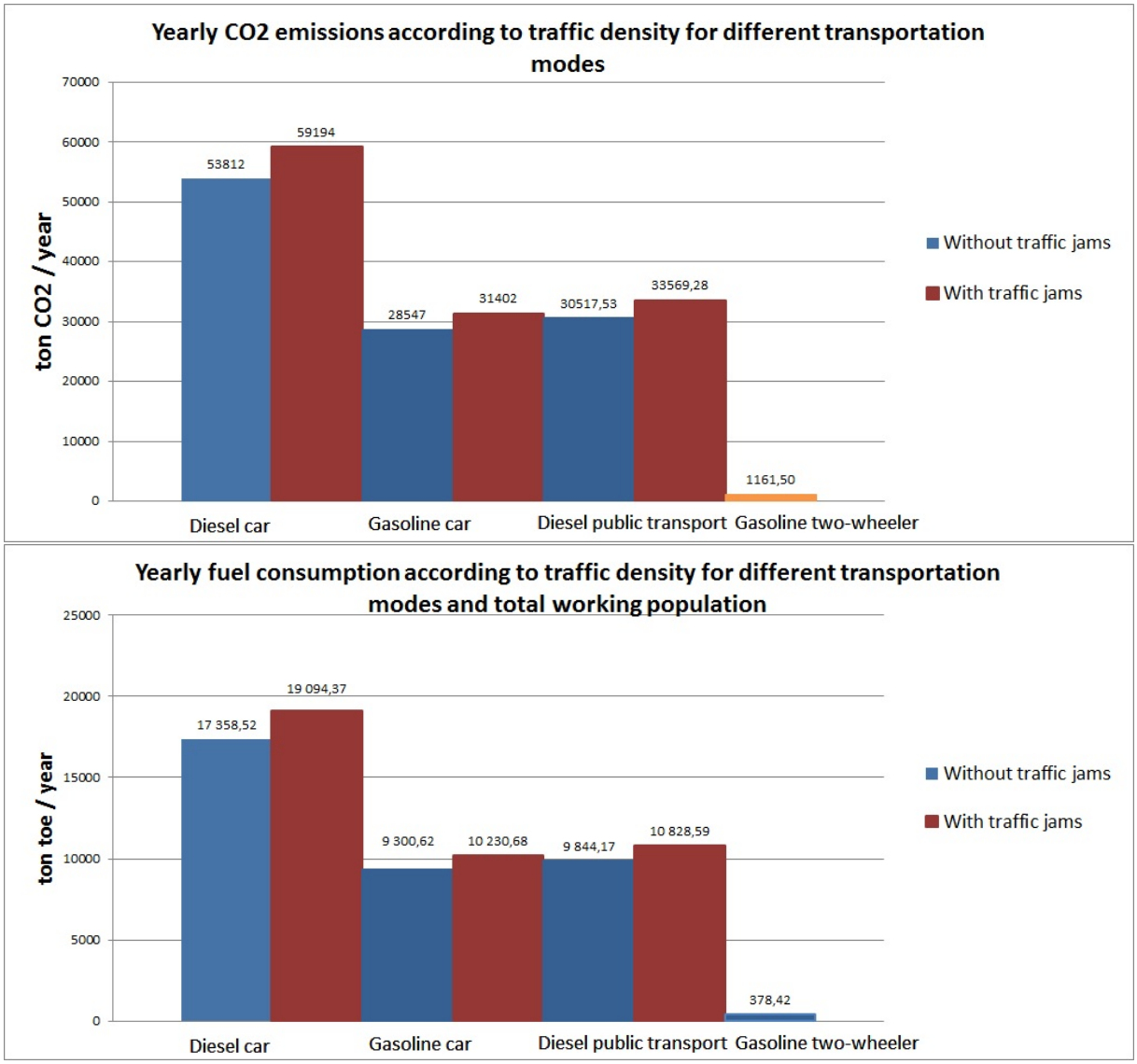

Figure 5.39: Yearly fuel consumption and CO2 emissions according to traffic density for different transportation modes and total working population, Scenario 2, *Source : Flow model*

Scenario 3

In this last scenario, one assumes that the last two previous scenarios are mixed as shown in figure 5.40 to achieve an efficient transportation system. There are therefore less than 27 000 cars on the roads from people commuting to work each day. On the contrary, more busses and infrastructures are being required to fulfill people's demand (assumptions : TCSP is running, carrying 55 000 passengers a day).

Parameters that can be changed in the model	Changed parameter(s)	
		Unit
Diesel average fuel consumption	0,067	L/km
Gasoline average fuel consumption	0,079	L/km
Working population only taking their car	0,4	40%
Working population only taking public transport	0,5	50%
Working population only taking a two-wheeler	0,01	1%
Working people only going by feet	0,06	6%
Working people not using any transportation mode	0,03	3%
Percentage of diesel cars in total car fleet	0,65	65%
Percentage of gasoline cars in total car fleet	0,35	35%
Average commuting distance to work (return trip)	36	km
Traffic jams = +10% fuel consumption	1,1	-
Number of persons in one car to commute to work	2	person
Gasoline fuel consumption of a two-wheeler engine	0,045	L/km

Figure 5.40: Changed parameters in Scenario 2 compared with Scenario 1, *Source : Flow model*

Figure 5.41 presents the carbon dioxide emissions as well as the fuel consumption in tep produced in one year by all the working population commuting to work with the mixed assumptions of Scenario 1 and Scenario 2. In that last scenario, diesel vehicles is no longer the largest consumer of fuel, but public transport is the first one, as it exceeds a little diesel vehicle fuel consumption. Gasoline vehicles fuel consumption are much lower than the two other ones. Carbon dioxide emissions follow the same pattern.

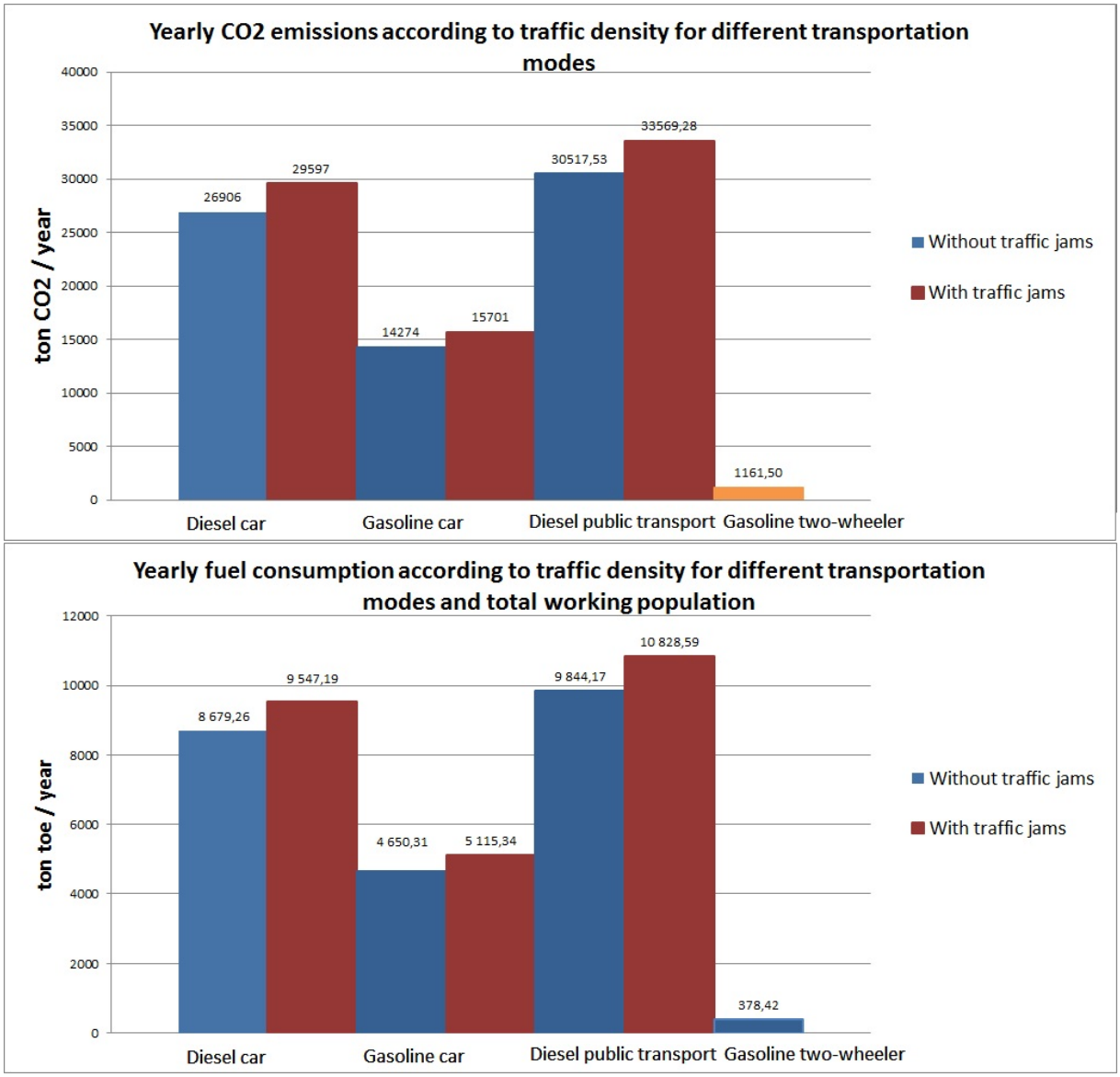

Figure 5.41: Yearly fuel consumption and CO2 emissions according to traffic density for different transportation modes and total working population, Scenario 3, *Source : Flow model*

Synthetic results

In this page, the results of the three different developed scenarios are summarised to enable an easier comparison of them.

Figures 5.42 and 5.43 present the contribution of every mode of transport in percentage to yearly fuel consumption and yearly carbon dioxide emissions for current transport model existing in Martinique island and the three developed scenarios. Scenario 1 achieves the lowest fuel consumption and carbon dioxide emissions by public transport with 6.8% of total share, while this is true in Scenario 3 for diesel and gasoline vehicles which achieve together 56.7% of total share.

Each category contribution to yearly fuel consumption by all working population with traffic jams:					
		Current situation	Scenario 1	Scenario 2	Scenario 3
Cars:	diesel	62,41%	59,91%	47,11%	36,91%
	gasoline	33,44%	32,10%	25,24%	19,77%
	combined	95,84%	92,02%	72,35%	56,68%
Public transport		3,54%	6,796%	26,716%	41,858%
Two-Wheeler		0,62%	1,187%	0,934%	1,463%
Total:		100,00%	100,00%	100,00%	100,00%

Figure 5.42: Each category contribution to yearly fuel consumption by all working population with traffic jams for all scenarios, *Source : Flow model*

Each category contribution to yearly CO2 emissions by all working population with traffic jams:					
		Current situation	Scenario 1	Scenario 2	Scenario 3
Cars:	diesel	62,62%	60,11%	47,23%	36,98%
	gasoline	33,22%	31,89%	25,06%	19,62%
	combined	95,83%	92,00%	72,29%	56,60%
Public transport		3,55%	6,818%	26,786%	41,947%
Two-Wheeler		0,61%	1,180%	0,927%	1,451%
Total:		100,00%	100,00%	100,00%	100,00%

Figure 5.43: Each category contribution to yearly CO2 emissions by all working population with traffic jams for all scenarios, *Source : Flow model*

Figure 5.44 provides real values calculated regarding yearly fuel consumption for all working population, and yearly carbon dioxide emissions produced by one person commuting to work. Scenario 1 achieves less fuel consumption than Scenario 2, but Scenario 3 is the least fuel consumer. Carbon dioxide emissions follow the same pattern and lowest emissions are possible with Scenario 3.

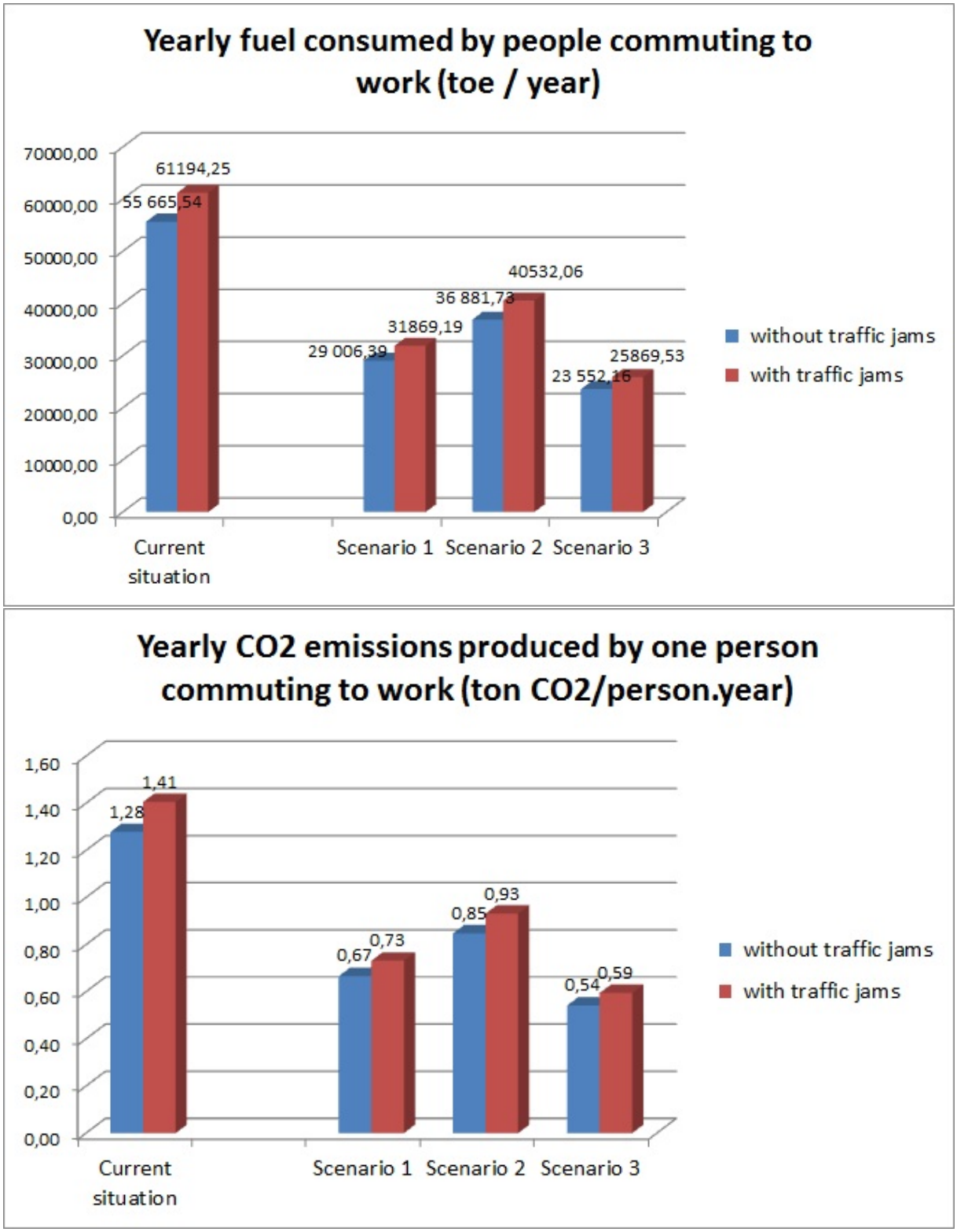

Figure 5.44: Yearly fuel consumption and CO2 emissions according to traffic density for different transportation modes and total working population, synthesis of all scenarios, *Source : Flow model*

Chapter 6

Analysis of the transport policy organised in Martinique island

The precedent Chapter 5 has provided the reader with key elements in relation with the notion of a sustainable transport system. It also presented specific results focusing on people's commuting to work activity. Each result has been widespread among the three principles that define a sustainable transport system. These principles will now in this chapter help assessing the non sustainability of the current transport policy in Martinique island, based on the results study. It will also demonstrate, through the flow model results study, why a transport system with several modes of transport is the best solution to tend to a sustainable transport system.

6.1 Analysis regarding the first principle of sustainable transport system

An unsafe policy transport

The results of the policy transport safety model studied in Martinique island shows that insecurity is an important factor that has not been enough tackled and repressed.
Private vehicles mode of transport are wrongfully thought to be a safe mean of transport by population, mostly because the car interior and its safety equipment provide a secure feeling. However, private vehicles are the mode of transport responsible for the most victims and accident in the island, while in parallel it is the one that received the largest prevention and repression policy campaign as described in Chapter 5, section 5.1. Results of this campaign has enabled to decrease nearly by half the amount of accident due to private cars, but this good figure is achieved through very costly measures: it has represented an investment of 24 billion euros within four years. Besides, it still

represents 456 road victims in 2010, while it is not likely to achieve new dramatic fall in accident figures even if new expensive human and material public expenditures are done. The most used mode of transport in Martinique island is not therefore a safe mode of transport despite tremendous means used to make it safer.

Concerning the second most used mode of transport, walking, result is neither positive. If much less accidents are recorded with pedestrians, it is rather due to the few amount of people carefully walking in Martinique island cities streets than to a safe policy. The lack of isolated lanes for pedestrians, as simple pavements in streets or zebra crossing with electronic traffic lights is a real break to the walking development. Besides, the few existing ones are not respected by motorists who use them as illegal parking space, forcing the pedestrian to walk on the road lane. A more important consequence is that people are not willing to walk even on small distances: this is for instance the case for displacements at lunch times in industrial areas.

Even if public transports are not considered as the safest mode of transport by inhabitants of Martinique island, statistics and results show the contrary. Far away from the private vehicle figures, public transports are responsible for less than 1% of total victims in France[1]. However, several points moderate that statement. First, several public bus shelters on the CACEM area are not always placed in secure street stretches, no dedicated area is given with no separation between the road and the bus stop: people are just waiting alongside the road. Adding to the fact that some bus stops are not located nearby streetlights, users are waiting in the dark which provides a very insecurity feeling. More generally, waiting for the bus in the evening without streetlight nearby does not provides the best security feeling. Secondly, public boat shuttles from Vedette Madinina company are reputed for their insecurity, especially in the evening and during week-ends. Many users are describing scenes of verbal and physical aggressions and the boat shuttle company has encountered a loss of its customers. Eventually, regarding the taxicos companies, the fact that most drivers are not supervised by any medical control and that there is no way to check if drivers are respecting security rules as recommended break times because most of them are not supervised by any public authority is a problem for passengers security. The same questions are raised regarding the taxicos vehicles maintenance: many vehicles are no longer suitable officially to carry passengers simply by looking at their external and internal damaged and old appearances.

Bicycle is the less used conventional mode of transport in the island. While it is an

[1]Road Safety association for 2010 data

appreciated sport, it is not used for any other displacement because of lack of security. Bicycle being considered to be the less safe mode of transport in general[2], with quasi non-existent cycle lanes in Martinique island and both narrow roads and pedestrian pavements, a safe practice is not very favored in cities.

Non human and ecosystem healths good care

The policy transport developed in Martinique island is the source of important threats concerning human and ecosystems healths conditions.
As seen in the results[3], private vehicle mode of transport is the most important source of several pollutants in the air. The analysis of the different air pollution values measured alongside the main road axe, from Lamentin to Schoelcher cities by crossing the capital city Fort-de-France, with the health and environmental thresholds defined by current regulation is worrying. In 2008, only three out of ten measures were not reaching or overrunning the regulation thresholds. In 2010, only two measures remain below thresholds. All the other measures have become worse, revealing that the threats on population health has increased. For instance, if 6 overrun have been encountered in 2008 concerning the upper health threshold, there have been 18 overrun in 2009 and 27 in 2010 for Concorde station, hence an increase of 3.5 points in 3 years. These values being measured close to road traffic axes, they are less high as long as one moves away from the concerned area. It is in fact seen in the figure 5.6 showing the air pollution dispersion cloud with lower emissions concentrations in moving away areas. The transport policy does not respect public health in a consistent way, the situation has only worsened.

The consequences of overrunning air pollution regulation thresholds on public health are serious. Two types of effects can be seen: short term effects, which occur within a couple of days or weeks and correspond to daily atmospheric pollution variations, and long term effects, occurring several months or years after chronic exposition, and leading in some cases to a higher death rate and a shortened life expectancy [68]. According to doctors, many lung diseases are due to a too high exposure of car pollution, especially to particulate air pollution, the risk being even higher for young children and fragile people. Other hearth and respiratory diseases are caused by long term exposure to vehicle pollution. Ambient air pollution causes about 5% of trachea, bronchus and lung cancer, 2% of cardiorespiratory mortality and about 1% of respiratory infections mortality globally [59]. Life expectancy is estimated to decrease by 9.3% because of particulate air pollution PM2.5. In France, a study showed that 6% of total deaths are

[2]See Chapter 6, §6.2
[3]See Chapter 5, §5.1

likely to be caused by urban pollution, while half of them, hence 3%, would be directly linked to transport pollution [58]. If gasoline fuel has been considered since 1989 as "probably carcinogenic" by the IARC [4], and diesel fuel since 1988, a recent publication dated from June 12, 2012 from the same organism has demonstrated that diesel fuel is carcinogenic, leading to lung cancer. Besides, another study has shown that there was a worrying phenomenon of high concentration of pollutants along side of the most used road axes: Bishop Boulevard and Dillon crossroads in Fort-de-France, the motorway section, the city centre of Lamentin as well as neighbourhoods nearby road axes going to the south, especially Ducos and Rivière Salée [65]. These results are in correlation with the air pollution dispersion cloud and the measured values. These sections being densely populated, air pollution impacts could be more important on these populations [80]. Regardless from air pollution emissions, another impact from private vehicle mode of transport especially is noise pollution: the road traffic density is source of stress and tiredness. The current policy transport, supported in majority with polluting technologies is therefore not compatible with human health.

The analysis of the transport model in Martinique island with regards to the ecosystem health is also worrying. All land means of transport used in Martinique island are consuming fossil fuels related fuels, being with 47% of total energy consumption share the greediest sector[5]. Out of this 47% share, road transport of passengers is responsible for 74% of this fossil fuels consumption, therefore the transport model in Martinique island is contributing a lot in worldwide fossil fuels resource depletion. Then, the burning of fossil fuels with combustion engines results in the emissions of this material into the atmosphere, which is contrary to the first principle of sustainability definition. Besides, the high concentration of vehicles on particular road stretches can influence climate change. If one explains in a very short way the reasons which make scientists thinking that way, it can be presented as following. The first consequence in car pollution is the local increase of temperature nearby roads due to the discharge of very hot gas at the exhaust pipe. This increase can locally reach between $+2$ and $+5$ Celsius degree. As a result, lower air layers are gradually warmed-up, and, to a larger extent, this abnormally increase in temperature will influence the global warming of the planet. And, some of these air pollution emissions being green house gases (carbon dioxide gas is the most important one), the phenomenon of climate change can be emphasised, even more threatening the worldwide ecosystem health. The ecosystem health is also locally suffering from current transport policy: nearby vegetation is impacted, rivers and coastal seawater polluted with air pollution infiltration, directly threaten aquatic life.

[4] International Agency for Research on Cancer
[5] See Chapter 5, §5.1

Local animal life can be profoundly modified by road splitting, or damaged as for the opossum specie. However, these impacts on the ecosystem health are difficult to measure, that is was only qualitative analysis is provided and that it is even more important to prevent these impacts. Indirectly, all the facilities required to extract and produce fossil fuels energies can eventually damage local environment and animal ecosystems and they are attributable to some extent to the current transport policy.

A non-egalitarian transport policy

The current policy transport, favoring the automobile mean of transport, leads to inequalities within Martinique island society. First, all the malfunctionnings of the public transports networks described in Chapter 5, added to a transport policy that has developed all the facilities required to favor the automobile mode of transport result today in a domination of the automobile in inhabitants lives, at least for the one who can afford having a car. Having a private vehicle has indeed been described to be very costly for households[6], the transport budget being the third most important in households expenditures. This mean of transport can therefore be source of privations for the poorest ones while it represents the image of social success for the wealthiest: in Martinique island, nearly half of the poorest households do not have any private vehicle. The latter are therefore constraint to move with other means of transport but private vehicles. Not having a private car has even become a criteria that demonstrates households difficult living conditions, according the European SILC[7] system [18]. Private vehicle mean of transport has thus become the reflection of the social inequalities between the population. To emphasise this statement, the following table 6.1 is provided: it shows that the vehicle motorization choice depends on people income, smaller incomes buying smaller vehicles. On a larger scale, it demonstrates that the automobile as mean of transport does not provide the same service quality levels of security, comfort, beauty to everybody. Furthermore, this gap is not likely to decrease if one considers trends that reveal a continuous increase in automobile costs, especially concerning fuel prices.

[6] See, Chapter 5, §5.1
[7] Statistics on Income and Living Conditions

(Unit: %)	1	2	3	4	5	Total
Small engine	51.7	50.2	51.2	46.3	33.9	44.9
Powerful engine	40.1	39.1	40.7	46.7	56,7	46.5
Utilitary vehicles + 4X4	8.2	10.7	8.1	7.1	9.4	8.6
Total	100.0	100.0	100.0	100.0	100.0	100.0

Table 6.1: Vehicle engine size according to quintile standard of living, *Source [16]:* INSEE

If one considers the equity factor between generations, then the transport model in Martinique island is not likely to give future generations the ability to fulfill their own needs if the related environmental impacts and the global energy crisis that is currently met worldwide and whose appearance is partly due to the development of such transport policies are not resolved.

6.2 Analysis regarding the second principle of sustainable transport system

Affordability

The right of mobility has currently an expensive price in Martinique island. As described in the precedent paragraph, private vehicle is the source of important expenditures: it first presents an investment, many households being forced to make a consumer credit to buy a private vehicle: in metropolitan France[8] nearly 60% of all consumer credits are done to purchase a private car. It reaches the third most important source of expenditures in households: in 2008, households in Martinique island were allocating 15% of their expenditures in the transport sector, among which 12% of them were dedicated to the purchase and maintenance costs of a private vehicle [17]. The same study reveals that poorest households will spend around 1900 € per year in transports while it reaches 6500 € for the wealthiest ones.

Private vehicle is the most expensive mean of transport, but public transport networks neither provide an affordable mode of transport. The main reason is that the different existing public transport networks are not coordinated among them at the ticket fares and policies levels, as it has been presented in section Chapter 5, section 5.3. A ticket bought on the CACEM territory is not valid on the CAESM or CCNM territory, sometimes because the ticket fare is different, sometimes because the stamping

[8]No data available for Martinique island

ticket machines are different among buses, most of time both criteria being true. A public transport user who needs to make a displacement within several metropolitan areas (CACEM, CAESM and CCNM) will have to buy one ticket for each areas taken, which can rapidly become expensive. The price of a displacement with a taxico may be cheaper because passenger will pay a global price for the whole journey, regardless of the crossed areas, but it is not necessarily ensured as the price of the journey is decided by the taxico driver will. Besides, this price can fluctuate with time more frequently than for supervised public buses. Yet, road public transports are not the only one concerned: the addition is even higher when different means of public transport are used, such as a boat shuttle from Vedette Madinina company, and a public bus. A last parameter is that for daily users of public transport facilities, few discount tickets are proposed and monthly cards are almost non-existent. Current transport system cannot be considered for all these reasons affordable.

Efficiency of the transport system

The table 6.2 presented below compares different criteria for different means of transport that are useful to assess the efficiency of a mode of transport. Nuisance criteria involves noise, pollution, congestion and security aspects.

	Speed	Door-to-door	Availability	Security	Comfort	Cost	Nuisance
Walking	-	+++	+++	+	+	+++	+++
Bicycle	+	+++	+++	-	+	+++	+++
Two-wheeler	++	+++	+++	-	+	+	+
Public transport	+	-	-	+++	++	+	++
Private car	+++	++	++	++	+++	-	-

Table 6.2: Private transport versus public transport, *Source [30]*

Not surprisingly, private vehicles mode of transport best meets all these criteria, especially the speed one, considered as the most important criteria for people, regarding the questionnaire results presented in Appendix B. This mean of transport is however the worst regarding costs and nuisance parameters, as it will be described in the next section 6.3, but if fundamentally one simply considers transport efficiency as "the ability to carry for any type of displacement one person from point A to point B with the minimum effort", the policy transport defined in Martinique island, massively resting on private vehicles, should thus be very efficient. However the results presented in the precedent table are only theoretical, and in practice slight differences exist, influenced by the time and day of the week considered. Private vehicle remains certainly the most

efficient mode of transport during week ends and off hours, especially in terms of speed and door-to-door aspects. However, during rush hours and commuting times to work during the working week, the main advantage of private car (speed) compared to the other means of transport disappears in Martinique island due to traffic congestions issues occurring in the main CACEM area road axes. The far too important amount of private vehicles on these road axes cancels out their advantages, reducing speed between 5 to 10 km/h [85]. The analysis of the questionnaire results[9] provides the following information: people's journey to commute to work with private cars is between two and three times longer than without traffic jams.

Public transport, with specific bus lanes for road transport or different routes with boat shuttles should therefore becoming competitive with private transport. However, public transport networks in Martinique island are suffering from important malfunctionnings and mismanagements which weaken its whole efficiency and leads to the fact that few people are taking public transports, especially to commute to work (14%). Among several mismanagements, one can enumerate difficulties to find comprehensive information on time schedules, time frequency rotations, buses routes, then, one can quote the non coordination among the different networks on the three different areas (CACEM, CAESM and CCNM) in terms of transfer times, ticket fares and inter-modality platforms. Considering in parallel that nearly 50% of working population leaves the CAESM and CCNM areas to commute to work [25] everyday, these parameters discourage people in taking a public transport service. Another important parameter is the punctuality, not always respected for all public means of transport and reliability: indeed, taxicos mean of transport, which is not supervised by any authority (for most of them) provides any insurance that taxicos will always follow the same route or will pass everyday. A last related example deals with taxicos security: many taxicos drivers are no longer capable of doing their job because they suffer from specific diseases, they do not respect break times or they simply are too old, but also they drive vehicles that do not respect security standards (old damaged vehicles, weak maintenance). This lack of stability and of regulation, crucial to set up an efficient public transport network is therefore a weak point which does not help competing with private vehicle mean of transport but on the contrary reinforces people's mode of displacement choice.

Eventually, one of the most problematic aspects of road public transports that deepen its weakness is the existing rivalry within taxicos drivers and the one between taxicos and official public bus lanes. As explained in Chapter 5, section 5.3, taxicos salary is function of the amount of passengers carried in a month, drivers are thus looking for road axes where potential customers are the most numerous. Taxicos drivers are therefore competing for them. Two bad results appear from such behavior. First, there is

[9] See Appendix B

too much offer for the demand on that road axes while some taxicos would be required in other less frequented roads. Customers demand is thus not fully answered, especially for those leaving far from main road axes. The second point is that taxico drivers at the end do not earn as much money as they could as they do not share in an efficient and equitable way the customer demand, which as a result cannot neither fully satisfy them. The second competition, opposing this time all taxicos drivers against official public bus transport is also leading to inefficiency: taxicos drivers carry public buses customers by passing five minutes before the official public bus time schedule. This is even more problematic that public transport needs a high activity rate in order to be profitable, and that bus capacity and fleet have been calculated according to the estimated demand and available market. The indirect consequence of these rivalries is that many taxicos are not working on roads axes unserved by public transport but where some market exists. Therefore, taxicos drivers and official public bus are fighting a running battle, the former being afraid of losing their job and their customers if the latter grows up. And still, these two public means of transport are required to work together to achieve an efficient transport system because regular buses will never managed to serve narrow and winding roads in hilly districts. At a social level, such competition is however occurring detrimental to customers and people, but also it is inefficient regarding the environment, as this situation leads to waste of diesel and gasoline fuels, hence fossil fuels energies, and at the same time it increases emissions of pollutants. At a financial level, public institutions are investing money in public transports that are not profitable, while households are getting into dept to buy a private vehicle that can neither be used for its speed advantage, and taxicos drivers can not always earn enough money to have a decent life. The current policy transport is therefore not efficient.

Diversity of transport modes

Several modes of transport are existing is Martinique island: private vehicles, public buses, taxicos, boat shuttles, two-wheelers and the two passive means of transport, and they have been largely described in the precedent chapters. A public rapid transit bus network is also under construction in the CACEM territory, and further lanes are planned on the long term. The transport policy is therefore fulfilling this condition for a sustainable transport. However, these multi modes of transport must be smartly coordinated and balanced to make it work efficiently. These conditions, described in the precedent paragraph, are today lacking.

6.3 Analysis regarding the third principle of sustainable transport system

Emissions and waste minimization

The current policy transport in Martinique island is not minimizing its emissions and waste within the planet's ability to absorb them. All the different modes of transport, excepting passive ones, produce and release emissions that are polluting the ecosphere: PM10, PM2.5, NOx, SO2, VOC and CO2. Within current situation, road passengers modes of transport are responsible for the emissions of 63% of PM10, 64% of PM2.5, 53% of NOx, 76% of SO2, 10% of VOC and 75% of CO2. The nitrogen dioxide gas emissions measures, taken as the reference gas for road traffic emissions, have recorded increasing values with time, from 32μg/m^3 in 2007 to more than 40μg/m^3 in 2008, 2009 and 2010[10], reaching the quality objective threshold above which protection of human health and the environment is not guarantee. Most of all public health and environment regulation thresholds have been met for a couple of years, but overrun thresholds are more and more numerous: 6 overrun have been encountered in 2008 concerning the upper health threshold, while there have been 18 overrun recorded in 2009 and 27 in 2010 for Concorde air traffic station. This is even more worrying that the number of authorized overruns by regulation has been reached in 2009 and 2010 while it was not the case for 2007 year. The situation has thus worsened.

Of course, government, by creating laws (bonus malus penalties and taxes), have forced car manufacturers to produce less polluting vehicles. And results are encouraging, car efficiency in terms of fuel consumption and pollution emitted has much decreased especially for the carbon dioxide emissions: between 1995 and 2011, the average CO_2 emissions of new car sales in metropolitan France went from 175 g_{CO2}/km to 127 g_{CO2}/km [37] [8], but this beneficial effect has been decimated by the spectacular automobile expansion encountered in Martinique island with more than 50 000 new private vehicles on the roads in a little more than 10 years [20][85]. Besides, if large decreases of emissions have been encountered so far quite easily by the introduction of new technologies on cars, it may be difficult to achieve such a substantial emission reduction in the coming years. The traffic congestion issue encountered in the island also weakens these improvements, traffic jams reducing speed between 5 to 10 km/h while environmental models recommend a speed between 50 to 70 km/h to reduce polluting gas emissions [85][41][11]. The demand for mobility being eventually increasing, keeping the mobility system in the same way as it exists today, especially in Martinique

[10] See Chapter 5, §5.1
[11] See Appendix A

island will keep emissions from this sector up above recommended standards.

Regarding other waste produced by transport in Martinique island, one can briefly talk about the vehicle end of life waste management. Before, people were not bringing their old vehicles in city dumps, but they were abandoning them in unauthorized dumps. There were a waste of potential recyclable materials, a visual pollution, the use of free land space as well as risks of polluting substances leakages into soils and rivers. In 2000, an association was set up and it now has created 80 centres to collect old batteries among the island. However, dismantling and recycling structures of end-of-life vehicles are not really existing. Here again, the three associations of metropolitan areas (CACEM, CAESM and CCNM) are organising the sector independently. The CCNM had a dismantling structure between 1999 and 2000, and then it stopped because of lack of financial means. In general Martinique island has an industrial backwardness in terms of waste treatment. Until 2007, there was only one demolition contractor and all materials in vehicles were not promoted, as tires for instance. In 2008, four demolition contractors were authorized in the island, but it remains insufficient to treat all the supply. Therefore, if the phenomenon of unauthorized dumps has been reduced within these 10 years, many vehicles are still found in nature, consumers being also to some extent responsible for that than public authorities.

The assessment of this part is mitigated: facilities have been set up, regulation and laws have been created, however there is a risk that these measures become insufficient with time and besides the application of these regulations are not yet fully respected, both because of financial and organizational issues among the different associations of metropolitan areas.

Minimise consumption of non renewable resources

The main problem encountered by Martinique island transport model to fulfill this criteria is its total dependence towards fossil fuels resources. Stress on fossils energy resources as crude oil, natural gas and coal is today a worldwide reality and it is likely to increase. In that context, Martinique island risks all the more becoming dependent to non renewable energy source as nearly all its energy sources are imported, crude oil being the third highest importation rate in 2008 importations [14]. Increasing its importations is not in all cases a reassuring phenomenon: the dependence risk will only increase, even more as the 20% stockage capacity fixed in French overseas departments is not respected in Martinique island [6].

As described in Chapter 5, section 5.1, in Martinique island, the energetic consumption of crude oil has been multiplied by 2.2 between 1980 and 2000. Most of this

increase comes from the growing demand of energy from transport sector, the latter being multiplied by 1.9 over the same period, reaching 71% of total energy consumption in the island in 2005, while it was 65% back in 1999 [35] [26]. More precisely, road transport sector accounts for 67% of all the energy consumed in transport, and 74% of this consumed energy belongs to road passengers transport [26]. The amount of fossil fuels consumed in that sector is therefore already very important, and it increases with time: fuel consumption has indeed increased by 3.3% between 2005 and 2007. The situation is not likely to change in the next years: most of fossil fuels energy imported in Martinique island is used to fulfill the automobile transport demand (private vehicles are responsible for 91% of total energy consumed in road passengers transport). An increase in the amount of cars, as it is forecast (4% road traffic increase annually [77]), coupled with an increase in mobility demands, is currently heightening Martinique island energetic dependence, leading to more non renewable resources importations. The improvement of private vehicles fuel consumption efficiency the past few years have not been sufficient to decouple transport growth with a decrease of fossil fuels resources, with regards to current transport model.

Minimise the use of land and the production of noise

The current road transport model in Martinique island has given a lot of space to roads dedicated to private vehicles. When mobility demand increased, road lanes have been expanded, as for the highway stretch, which was changed from a two lanes road to a three lanes road in the mid 1990 [85]. When Fort-de-France city center has started to become densely taken in the beginning of the 1980s, a ring road was also built. The island has been rapidly organised in function of the different roads that had been built. However, as said in Chapter 4, section 4.2, the most important roads are township roads, reaching 2300 km, while one only finds 7 km stretch of motorway. In the north of the island, some towns are even badly served with roads and their access is difficult. That is why despite the small territory, one can consider that current transport system is not using too much land. Road transport vehicles are recognized to be the first noise pollution producers in urban areas[12]. Main road axes such as highways or city ring roads, where traffic density if high as well as speed represent high places of noise. In Martinique island more than 50 000 people are daily exposed to the different Lden index levels[13] existing for road traffic noise pollution. The capital city-Fort-de-France and Lamentin city account alone for 35% of the roads where noise pollution among the different Lden thresholds previously described has been recorded. It is in accordance

[12]ADEME survey conducted in 2002 in metropolitan France
[13]Level Day Evening Night

with the description of the high traffic densities measured in CACEM metropolitan area. This concentration of noise pollution across a small territory is likely to be one explanation to the population migration towards CAESM and CCNM areas, leading to urban sprawling and Fort-de-France city center recent depopulation. In all cases, the current transport policy developed in the island is noisy and the increase in traffic densities and saturation of main road axes is not far from reducing it.

6.4 People's commuting to work analysis within current situation and the three developed scenarios

Current situation

This section is not analysed through the study of the sustainable transport principles, it rather tends to demonstrate that commuting displacements to work play an important function in road transport impacts in Martinique island. First, the fact that working population in Martinique island does not live nearby their working place leads to daily migrations of workers, withing about a 20 km radius. The problem of this phenomenon is that people are at a majority all living in the same surrounding area, while most of companies are concentrated together in another area, the island center in the CACEM metropolitan area. Between residential and working areas, few road means of access are encountered: it is the "H" road axes phenomenon, people commuting every morning to the same "H" letter horizontal line area. The uniqueness of road axes towards this sector regarding the existing traffic road is likely to create issues on the long term. The reason why the situation has quickly worsened is that these displacements are not dispatched among several means of transport: as already said in Chapter 5, 80% of people commuting to work are using their private car, and in a reasonable risk one can assume that they are alone in their car[14], while10% use public means of transport, the remaining 10% being shared among two-wheeler, walking and people not using any mode of transport. This unbalance in the use share of modes of transport is a key point to assess when developing an efficient policy transport.

Besides, the transport related environmental impacts are to a large extent correlated with the mode of transport chosen by the working population. The evolution of nitrogen dioxide daily emissions are representative of the influence that the working population displacements has in general on air pollution in Martinique island, this influence being strengthened by related traffic congestion issues. The flow model simulation results with current situation parameters reveals that each person commuting to work produces

[14]On average the value reaches 1.4 person per car for all types of displacements

1.28 ton$_{CO2}$ per year without traffic jams, and 1.41 ton$_{CO2}$ per year with traffic jams. As scientists recommend that every person should not produce more than 1 ton$_{CO2}$ in a year regarless of the concerned activities to avoid climate change impact, one realises that commuting displacements to work are already exceeding this value. Transport fossil fuels consumption, reaching without traffic jams 265,07 pet / day, and with traffic jams 289.60 toe/day is also high when one considers the fact that 74% of total road transport energy consumed is used in passenger transport. The current transport mode in Martinique island is therefore to be changed in a less stressing environmental way.

Three scenarios

These scenarios aimed at assessing if a more diversified and balanced policy transport would achieve better environmental results especially regarding carbon dioxide yearly emissions and fossil fuels consumption. The comparison of these three scenarios in provided in the next figures 6.1 6.2.

Yearly CO2 emissions produced by one person commuting to work (ton CO2/person.year)				
	Current situation	Scenario 1	Scenario 2	Scenario 3
without traffic jams	1,28	0,67	0,85	0,54
with traffic jams	1,41	0,73	0,93	0,59
yearly emissions compared with current situation	100%	52,1%	66,3%	42,3%

Best CO2 reduction
Medium CO2 reduction
Lowest CO2 reduction

Figure 6.1: Yearly CO2 emissions produced by one person commuting to work (ton CO2/person.year), *Source: Flow model*

Yearly fuel consumed by people commuting to work (toe / year)				
	Current situation	Scenario 1	Scenario 2	Scenario 3
without traffic jams	55665,54	29006,39	36881,73	23552,16
with traffic jams	61194,25	31869,19	40532,06	25869,53
saved fuel with traffic jam	0	29325,1	20662,2	35324,7
saved fuel without traffic jam	0	26659,1	18783,8	32113,4
saved fuel (%)	0,00%	47,92%	33,76%	57,73%

Best saved fuel
Medium saved fuel
Lowest saved fuel

Figure 6.2: Yearly fuel consumed by people commuting to work (pet / year), *Source: Flow model*

The analysis of the three scenarios provides several results. First, within the simula-

tions conditions defined for each scenario, car pooling adoption (Scenario 1) achieves better environmental results than developing alone public transport (Scenario 2). Indeed, car pooling solution leads to the following figures, 0.67 $ton_{CO2/person.year}$ and 0.85 $ton_{CO2/person.year}$ with and without traffic jams, while public transport produced 0.73 $ton_{CO2/person.year}$ and 0.93 $ton_{CO2/person.year}$ with and without traffic jams. Car pooling option therefore achieves 47.9% carbon dioxide emissions reduction compared with current situation, while public transport "only" reaches 33.7% of reduction. The same pattern exist for fossil fuel consumption, car pooling saving 26659.1 toe/year without traffic jams and 29325.1 toe/year with traffic jams, while public transport figures are 18783.8 pet/year without traffic jams and 20662.2 toe/year with traffic jams. Therefore, if the same amount of people do car pooling or take public transports, the option car pooling gets more CO_2 reduction and more fuel saved than the public transport option. It also shows that the automobile mode of transport must not systematically be removed from transport policies, but rather that a responsible and efficient use of it is required and that if such a behavior is reached, the related environmental impacts of private vehicles can become lower than those of public transports. The fact that public transports in Martinique island are all consuming diesel fuel may explain such a result, but nevertheless it provides interesting results. However, the second important result of these scenarios simulations is that Scenario 3, combining both hypotheses of Scenarios 1 and 2, achieves the best environmental reduction results. Carbon dioxide emissions fall from 57.7% compared with current situation, hence a figure 10% better than the one of Scenario 1 alone. Fossil fuels saved also reaches 57.7% of total fuel consumption with current situation. These results emphasise that a combination of several modes of transport can lead to better environmental results than a unique mode of transport as efficient as it can be in its category. Besides, this diversity enables to reduce substantially the risk of huge traffic congestion as the mobility rush hours are dispatched in several modes of transport independent from each other.

A short conclusion of the main fundings of that analysis chapter is provided in the following paragraph. This analysis aimed at demonstrating two things. The first one was the unsustainability of the current transport policy model occurring in Martinique island, assessed through the comparison of the existing situation with the three principles that define a sustainable transport system. The inefficient policy in reducing the insecurity of several means of transport, the increase threat on both human an natural healths, the strengthened inequalities among the different population social classes which worsen the possibility of poorest households to have an access to mobility and eventually a transport policy that wastes environmental resources and pollutes natural ecosystems without achieving succcessfully a coordinated and diverse transport systems are the reasons that explain the unsustainability of the current policy transport encountered in Martinique island.

The second aim was to show that among all the completed displacements in Martinique island, there was especially one displacement that was leading to major impacts and contributing to a large extent to the failure of the transport policy established in Martinique island: "commuting to work" displacement. Then, the developed scenarios in the flow model enabled to provide the evidence that changing working population habits to commute to work in a smartly way lead to substantial decreases of impacts. This smartly way consists in using diversified modes of transport, both public and private ones. Eventually, a special finding of these scenarios analysis concerns the automobile mean of transport weight regarding environmental impacts: with equal number of people, private vehicles were achieving better environmental impacts reduction than public transport. It demonstrates that a transport policy only based on public means of transport may not achieve better environmental impacts reduction than a policy that optimises private vehicles seat-occupancy rate.

Chapter 7

Conclusion

This Master Thesis of science aimed at learning more about transport systems in cities for people and from a sustainable perspective, especially regarding related environmental impacts, in a worldwide context of mobility increase. The study of people's mobility within urban areas is rich in learnings but it is also a difficult task because many data are required and it is not always easy to find them, some of them being simply missing. The choice of Martinique island case study enabled to discover an interesting urbanised area and its transport policy was an ideal framework for this study. This island, assumed to be a single urbanised area, has followed the same pattern as most of cities in the world: it has massively favored the automobile private mean of transport and it is now getting the results of such a policy. One displacement is particularly highlighting the limits of this transport system: people's commuting to work displacement. Huge and daily traffics jams during rush hours are maybe the most obvious consequence of such a transport policy. This permanent presence of privates vehicles for any displacement reveals another weakness of the transport policy existing in Martinique island: the lack of any other mean of transport that could in an efficient way compete with private vehicles mean of transport. Passive means of transport as walking and bicycle are not encouraged because of the non existence of facilities that would secure them from external threats. Then, if there is a real wish to develop public transports - through the use of public buses networks, taxicos or public boat shuttles, which do already exist on the territory- the situation remains unsustainable for several reasons. First, the traffic congestion issue encountered by private cars and on some stretches by public buses and taxicos leads to an extra consumption of fossil fuels resources that are not renewable. Secondly, public transport networks set up by the three associations of metropolitan areas (CACEM, CAESM and CCNM) are not coordinated at any level, information accessibility, time schedules, ticket fares..., which make them both non affordable and the inter-modality among them very difficult to achieve while the majority of inhabitants in Martinique island are moving on at least two areas. Furthermore, the two many num-

ber of independent taxicos companies without any official supervision does not provide a trust feeling for potential customers which rather prefer using their private vehicles. This independence explains the rivalries that occur between public buses and taxicos, leading to an inefficient global policy transport as well as a waste of financial means, for both official authorities and households. Indeed, households ownership costs and working costs are important and most of them are doing consumer credits to get a private car, which strengthens social inequalities among population classes. Lastly, from an environmental point of view, this policy transport is becoming more and more dependent on non renewable energies, wasting some of it due to its inefficient use. Many other impacts are encountered, the most important being air pollution, worryingly increasing among years and threatening both the ecosystem and public healths. Noise pollution from traffic as well as the space used to extend roads width on free land are other important effect of existing transport policy. To provide some solutions to this transport policy unsustainability, a flow model simulating commuting to work activity for all working population in Martinique island has been created. In parallel with this assessment, the simulation of three different scenarios enabled to provide evidence that coupling several modes of transport in an urban area, for instance car pooling and public transport networks was achieving best environmental impacts reduction in terms of fuel consumptions and carbon dioxide emissions. Besides, much less cars were found on the roads which was deeply reducing traffic congestion. However, an interesting finding of this simulation model is that compared independently, car pooling was achieving better environmental impacts reduction than public transports. It highlights the fact that a private vehicle with a high occupancy rate (at least more than one person) can be a solution as important as developing public transport facilities to come up with a sustainable transport. Of course these results are found in a specific context and within the model assumptions, that is why further work and studies should be conducted to affirm or deny the findings. Further investigation in that field would be to define a flow model that would simulate the environmental impacts of all displacements of inhabitants of Martinique island within current transport policy and with the precedent scenarios assumptions in order to verify its efficiency. Integrating a geographical dimension in that model would beside enable to find out where it is urgent to answer differently to people's needs for mobility in Martinique island.

Appendix A

The optimal vehicle speed to minimize air pollution

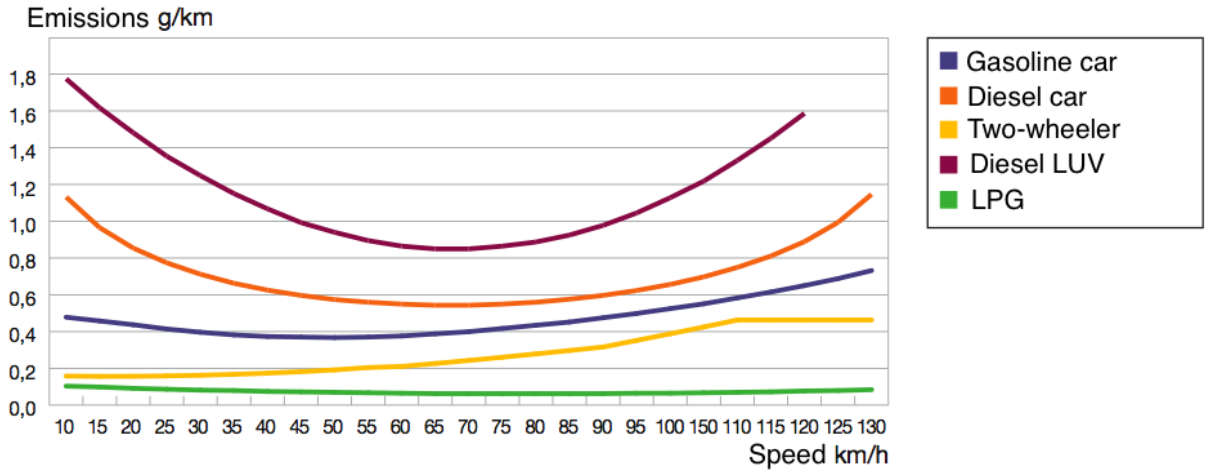

Figure A.1: NOx emissions function of vehicle type, fuel and speed, *Source [41]:* CITEPA

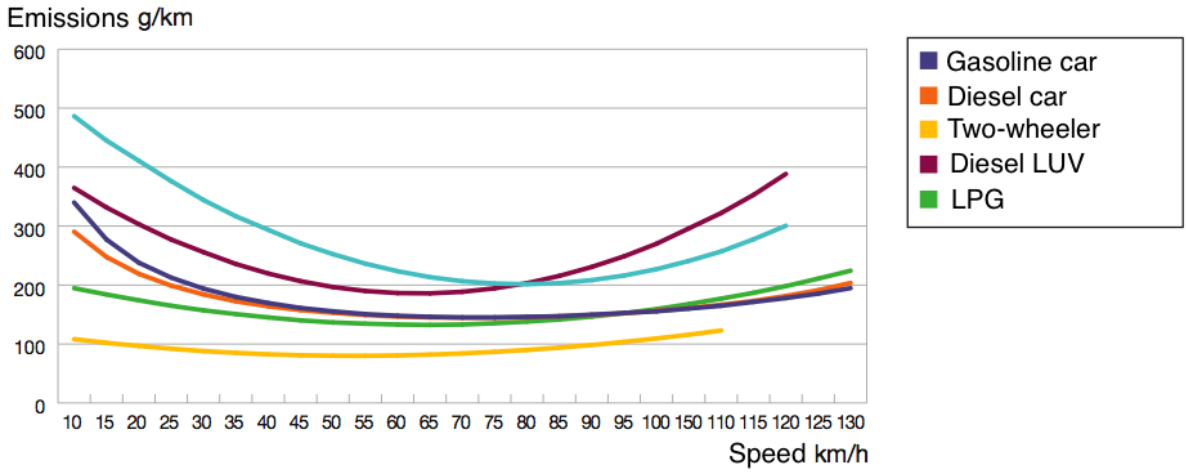

Figure A.2: CO_2 emissions function of vehicle type, fuel and speed, *Source [41]:* CITEPA

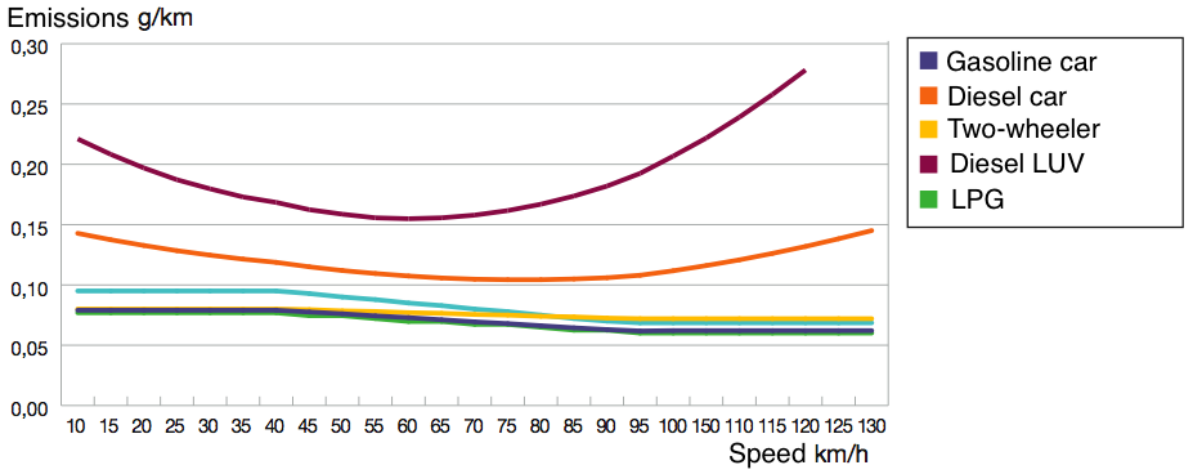

Figure A.3: Particles emissions function of vehicle type, fuel and speed, *Source [41]:* CITEPA

Appendix B

Survey of the employees mobility habits in one company: CCIE car dealer

Results of the survey done at CCIE car dealer company are presented below. This company is settled in Les Mangles Industrial zone, next to the motorway section in Lamentin district. It id therefore placed nearby all main traffic congestion issues. Employees have been asked about their habits concerning the way they were going to work everyday. 25 questionnaires came back among 62, a sample from all represented sectors at the company (white collars, blue collars, administrative employees...).
Results show that people are all using their car to go to work (100% yes answers), with more leaded gasoline cars (60%) than diesel cars (40%). Yet, one notices less leaded gasoline cars under 4 years old (25%) than leaded gasoline cars older than 4 years old (75%). People usually drive city cars (68%) but some also have 4x4 cars (24%). Among people who need to drop off their children to school, 63% drive them by car to school before going to work.
Two main reasons lead people to choose their car rather than public transport: facility and rapidity, even if flexibility and punctuality come just after. Surprisingly, few people mention the "too low bus frequency", "too low bus time range" or "no near public transport from home" as first reasons of this choice. If it seems indeed currently easier to use one car rather than public transport, it becomes more difficult to agree when it comes to the rapidity. Because of traffic jams, people need at least twice or thrice the time they really need to go to work, therefore current public transport offer can almost go as fast as private cars.
Yet, most of people (72%) would still prefer to use their car even if public transport was better developed because they would lake of flexibility. Concerning people who would prefer using public transport (23%), their bigger motivation is the economical factor. Indeed, each person spends on average between 100 € and 200 € each month to tank up their car to go to work, despite the fact that 41% of them live between 10 km and 20 km from work, and 29.4% between 20 km and 30 km, amount of money that is much higher than the monthly cost of using public transport.

Eventually, a last part of the questionnaire dealt with road quality. People almost all agree on the fact that motorway and trunk roads are in a good state, while secondary roads state needs to be improved and township roads are in a bad state. For deeper information, one can consult the following figure which summarizes all the results.

Enquête sur les déplacements du domicile au lieu de travail des employés du CCIE/Citadelle

1 *Dans quelle commune/quartier habitez-vous ?*_____

2 *Avez-vous une voiture ?* ☐ Oui ☐ Non

- Quel type ? ☐ Citadine ☐ Familiale ☐ 4X4 ☐ Autre : _____
- Année du véhicule ? ☐ Moins de 4 ans ☐ Plus de 4 ans
- Motorisation ? ☐ Essence ☐ Diesel

3 *Quel moyen de transport utilisez-vous pour vous rendre au travail ?*

☐ Voiture ☐ Bus ☐ Taxicos ☐ Covoiturage ☐ Deux-roues ☐ Vélo ☐ Autre : _____

4 *Comment vont vos enfants à l'école ?*

☐ Vous n'avez pas d'enfant ☐ Car scolaire ☐ Vous les emmenez en voiture
☐ Quelqu'un les emmène en voiture ☐ Autre : _____

5 *Pour quelle(s) raison(s) prenez-vous votre voiture personnelle plutôt qu'un transport en commun ? Classez vos choix par ordre d'importance, de 1 à 9 :*

___ Facilité ___ Rapidité ___ Flexibilité ___ Confort ___ Ponctualité ___ Economique
___ Pas de transport en commun à proximité du domicile et /ou lieu de travail (rayez)
___ Fréquence de passage des bus trop faible ___ Amplitude horaire des bus trop faible

6 *Quelle distance vous sépare de votre domicile au CCIE ?* _____

7 *Combien de temps mettez-vous pour vous rendre au CCIE ?*

- Avec les bouchons : _____
- Sans les bouchons : _____

8 *A quelle heure quittez-vous généralement votre domicile le matin ?*_____
*A quelle heure quittez-vous généralement le CCIE le soir ?*_____
Choisissez-vous ces heures afin d' éviter les bouchons ? ☐ Oui ☐ Non ☐ Cela dépend

9 *Avez-vous déjà fait du covoiturage ?* ☐ Oui ☐ Non

10 *Si le réseau de transport en commun était mieux développé, les prendriez-vous plutôt que votre voiture pour aller au travail?* ☐ Oui ☐ Non

Si oui pourquoi? ☐ Gain de temps ☐ Moins de fatigue ☐ Economique ☐ Autre : _____
Si non pourquoi? ☐ Manque de flexibilité ☐ Déplacements en cours de journée ☐ Autre : _____

11 *Comment qualifieriez-vous l'état général des routes à La Martinique (revêtement, largeur…) ?*

- Axes principaux (voies rapides) : ☐ Correct ☐ A améliorer ☐ Mauvais
- Routes secondaires : ☐ Correct ☐ A améliorer ☐ Mauvais
- Routes de quartier : ☐ Correct ☐ A améliorer ☐ Mauvais

12 *Combien dépensez-vous en carburant pour vos trajets domicile/CCIE par mois ?*
☐ Moins de 100€ ☐ 100€ à 200€ ☐ 200€ à 300€ ☐ 300€ à 400€ ☐ Plus de 400€

Merci pour votre temps !

Figure B.1: Questionnaire given to the employees regarding their home-to-work mobility habits, November 2011*Source: Personal survey*

Answers / Questions 25 questionnaires	District	Vehicle	Means of transport to go to work	How do children go to school	Why do people choose car rather than public transport	Average distance home/ working place	Time to go to work	Ever done car pooling?	Would you use public transportation if better facilities?	State of motorway and trunk roads	State of secondary roads	State of township roads	Fuel consumption per month?
N	3												
S	4												
E	9												
O	9												
Yes		25											
No													
City car		17											
Family		2											
4x4		6											
less than 4 yrs		10											
more than 4 yrs		15											
leaded gasoline		15											
Diesel		10											
Car			24										
Bus													
Taxico													
Car pooling			1										
Two wheeler													
Bike													
No kids				9									
Scholar bus				1									
You take them by car				10									
Somebody takes them by car				2									
Other				4									
Facility					20								
Rapidity					17								
Flexibility					15								
Comfort					12								
Punctuality					15								
Economical					9								
No near public transport					7								
Bus frequence too low					8								
Bus time range too low					7								
do not know						8							
less than 10 km						5,8,5							
bet 10 and 20						15, 15, 15, 12, 20,15,15							
bet 20 and 30						25, 24, 21,25,25							
more than 30						1,45							
With traffic jam	1h30, 1h30-2h, 45-80min, 45min, 2h, 1h, 25min, 45min, 1h, 2h, more than 1h, 45-60min,10min, 1h15,45, 15,30,1h30,30,20 1h,1h,30,30,45												
Without traffic jam	30, 25, 13, 20, 1h15, 30, 15, 15, 20min, 15, 40, 15, 30,10,8,15,25,20,10,20,20,40,20,10												
Yes								7					
No								18					
Yes									10				
Gain of time									2				
Less tiredness									4				
Economical									9				
Other									ecological				
No									15				
Lake of flexibility									9				
Business trip required during work day									7				
Other									lost of time, comfort, no bus in remote distric				
Good										16	3	2	
To be improved										9	17	8	
Bad											5	15	
Less than 100€													5
Bet 100 and 200€													13
Bet 200 and 300€													3
Bet 300 and 400€													2
More than 400€													2

Figure B.2: Questionnaire detailed results, November 2011*Source: Personal survey*

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