A methodology for measuring the ecological footprint of freight transport in urban areas: a case study of a Moroccan City

Imane MOUFAD
Laboratory of Energy & Sustainable Development (LPE2D)
Sidi Mohamed Ben Abdellah University - EST,
Road of Imouzzer - BP: 2427 - Fez, Morocco
imane.moufad@gmail.com

Fouad JAWAB
LPE2D & Laboratory of International Management Decision techniques and Logistics
Sidi Mohamed Ben Abdellah University - EST,
Road of Imouzzer - BP: 2427 - Fez, Morocco
jawabf@gmail.com

Abstract

The urban freight transport (UFT) plays an important role in the quality of life in urban areas. Previously, strategic decisions were taken with a view of economic and functional optimization; they now take the "green" turn, taking also into account the ecological impacts. Therefore, the purpose of this article is to focus on the ecological weight of UFT. We first delineate the challenges of green urban freight transport. Secondly, we review the approaches to achieving an ecological balance of the urban freight transport. We develop the methodology used to measure the carbon footprint of the urban freight transport and energy consumption. And then, our case study concerns the flow of goods between all the economic establishments of the city of Fez. The analysis of the results obtained makes it possible to draw a number of conclusions which we will present in the form of recommendations.

Keywords

Urban freight transport, Ecological footprint, Case study

1. The issues of the Urban Freight Transport

The stakes of the urban freight transport are numerous and can be classified into five categories:
Functional issues: These issues consider urban mobility in a global vision by integrating UFT into the functional organization of urban infrastructures with regard to the use of roads and parking place (Abdelhai et al, 2014). Two major functional issues then appear. At the scale of the agglomeration, the need for a good integration of freight transport in urban traffic. At the level of the transport operator, the need to improve or at least maintain the performance of the service in a context of strong competition in an increasingly congested urban space.
Economic issues: The performance of the UFT activity is linked to the quality and efficiency of freight services (CODESPAR, 2014). With the spatial spread of cities, the vehicle fleet is increasing, demanding ever-increasing network capacities. The result is an increase in congestion and air pollution. These two phenomena are at the origin of a waste of resources and hinder the economic growth of the cities (Delaître, 2008).
Urban issues: The movement of goods in the city exploits several spaces. As a result, urban planning is a very important lever in the service of the organizational and economic revitalization of the agglomeration. This observation forces public decision-makers to reconsider the configuration of traffic plans and to rethink land policies so that they are in line with the needs of end consumers (Delaître, 2008).
Environmental issues: the major environmental challenge is to be able to limit the negative effects of deliveries in the city center: GHG emissions and energy consumption; local air pollutants (fine particles, NO2 ...); and noise nuisance.
Social and societal issues: It is necessary to rethink the chain of relations between the producer and the consumer by giving the TMV its value through access to training, salary commensurate with the work performed and recognition of the profession. (CODESPAR, 2014).

2. The methodology for measuring the ecological footprint

2.1 Presentation of the methodological approaches

Two approaches can be taken to try to understand the ecological footprint of the UFT (Albergel et al., 2010):

- *Aggregate approach*: this is a simple calculation of the quantities of effluents emitted by the different traffic segments. This aggregate approach addresses the issue of GHG production. In addition, it provides an aggregated pollutant balance of the emissions resulting from the UFT activity according to: the type of vehicle: light-duty vehicles (LDV) and heavy-duty vehicles (HDV); the type of flow and the type of activity.
- *Spatial approach*: It simulates the atmospheric concentrations of pollutants and noise emissions in the study area and presents the results in a mapped form. It then responds to local concerns related to the analysis of the air quality and exposure of people to risks of direct pollution.

2.2 Methodology Followed

The implementation of an environmental assessment of the urban freight transport based on the aggregate approach requires the implementation of numerous steps for the determination of traffic and its urban environment (Albergel et al., 2010). First, we delimit the field of study. Secondly, we collect all technical data in relation with the field of study, for example: Typology of the vehicles, the type of fuel used by each type of vehicle; Unit emission factors for each type of vehicle; the capacities of the roads and the information on the geography of places, topography and climate. Then, we spend the calculation of CO_2 emissions and energy consumption for each category of vehicle.
The figure 1 illustrates all the steps for measuring the ecological footprint of the urban freight transport:

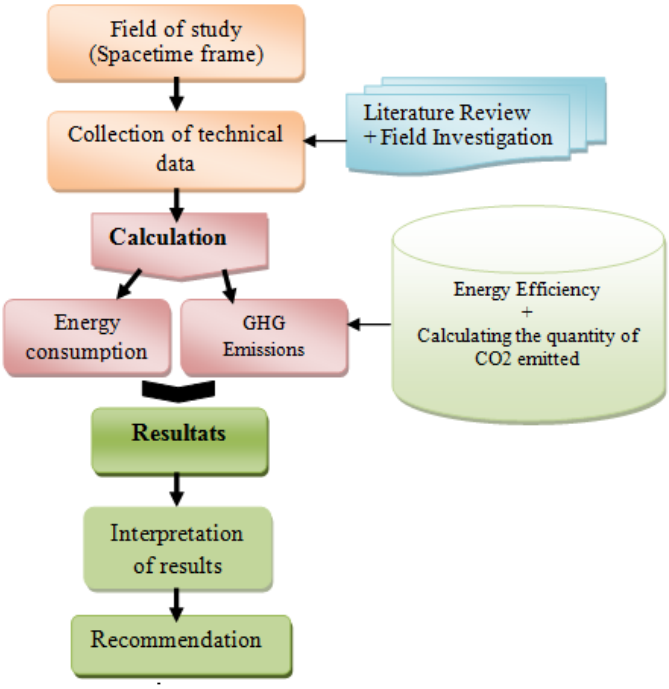

Figure 1. Research Methodology

3. The case study of the city of Fez

3.1 Determination of the field of study

The choice of study area constitutes a constraint of representativeness in order to obtain statistically significant results. As for the temporal modalities, the balance sheet is carried out according to three periods of allocation: average day reported at one hour, morning rush hour (corresponding to the rush hour of freight traffic), evening rush hour at the peak hour of passenger cars).

The reflection on the determination of the field of study concerns the institutional actors of the city of Fez, represented by the urban authorities who decide the planning of delivery areas, urban service and economic development on their territory. These are usually:

- Local authorities
- Urban Agency
- Regional Directorate of the Ministry of Transport, Equipment and Logistics
- Regional Investment Center - Fez
- Chamber of Commerce and Management

3.2 Data collection

- *Data collection Methodology*

The determination of the ecological footprint of the UFT, in particular business establishment flows, in terms of energy consumption and GHG emissions requires the following technical data to be collected:

- Typology of vehicles according to the engine, the type of fuel used by each type of vehicle;
- Unit emission factors for each type of vehicle;
- Speeds according to the capacity of the road network;
- Information on geography, topography and climate;

For reasons of efficiency and neutrality, a mixed survey method was adopted. The technique we used is halfway between the qualitative analysis by semi-directive interview and the support of the quantitative analysis. It goes beyond a questionnaire survey since the goal is to meet the respondent.
The questionnaire submitted to the persons interviewed comprises twenty questions. It consists of two parts, respectively, consisting of ten questions. One is the categories of vehicles, fuel consumption, tonnage, and so on. The second consists of questions concerning companies and their vehicle fleets. The questionnaire was completed directly by interviewees during a half-hour interview.
For information on the CO2 emission factors of each vehicle category, we obtained them from the Regional Observatory for the Environment and Sustainable Development through a report sent by e-mail.

- *Outcome of the survey:*

The survey we carried out among institutional actors in the city of Fez enabled us to collect the following data:

- Category of vehicles: Category N - motor vehicles with at least four wheels and used for freight transport (Source: Regional Directorate of the Ministry of Transport Equipment and Logistics - Fez Region)

Table 1. Category of UFT vehicles in the city of Fez

Category	N1 : Truck or van Total Allowable Weight (PTAC) <3.5 tons	N2 : Truck 3,5 t <PTAC < 8 t	N3: Semi-trailer 8 t <PTAC<14 t	N4: Truck Tractor PTAC>14 t
Fuel consumption in L/100km	16	22	24	30

- Vehicle park:

Table 2. The fleet of companies of UFT in the city of Fez

Own transport	**Number of companies**	**Park**	**Truck or Van**	**Truck**	**Semi-trailer**	**Tractor**
	788	1797	375	800	22	600
For-hire transportation	1822	3004	900	745	716	643

3.3 Calculation results

- *Calculation of the energy Consumption*

The consumption of vehicles dedicated to the goods can be calculated in tep (tons of oil equivalents). It concerns diesel and petrol fuels. Conventionally, one ton of oil equivalent corresponds to an energy value of $42x10^9$ joules.

Table 3. Energy equivalence

Combustible	Equivalence in L	Energetic value	Equivalence in tep
1ton of Diesel oil ($1m^3$)	1000	42 GJ	1 tep
1 ton Gasoline ($1m^3$)	1000	44,016 GJ	1,048 tep

The Energy efficiency makes it possible to specify the variations in consumption according to the parameters chosen, for example, the different periods of traffic (rush hour, night ...), the different types of roads, etc. It is defined as the ratio between the volume of energy consumed by a mode of transport and the traffic assured in t.km by the same mode of transport:

$$\frac{volume\ of\ energy\ consumed\ by\ a\ mode\ of\ transport}{traffic\ in\ t.km\ by\ the\ same\ mode\ of\ transport}$$

Using the previous equation, we calculated the daily energy consumption of the vehicles of the UFT in the case of the city of Fez. The table 4 shows the overall results obtained:

Table 4. The energy consumption of flows related to commercial establishments in the city of Fez.

Vehicle category	Fuel consumption in L/100km	Park of own transport	Total consumption in L	Equivalence in tep	Park of For-hire transportation	Total consumption in L	Equivalence in tep
Truck or Van PTAC < 3,5 t	16	375	(16* 375) = 6000	6	900	14400	14,4
Truck 3,5 t <PTAC < 8 t	22	800	17600	17,6	745	16390	16,39
Semi-trailer 8 t <PTAC<14 t	24	22	528	0,528	716	17184	17,184
Truck tractor PTAC>14 t	30	600	18000	18	643	19290	19,290
Total				**42,128**			**67,264**

In the case of the city of Fez, fuel consumption for the year 2016 is around 26250 tep, for which the for-hire transport accounts for almost 62% of the total.

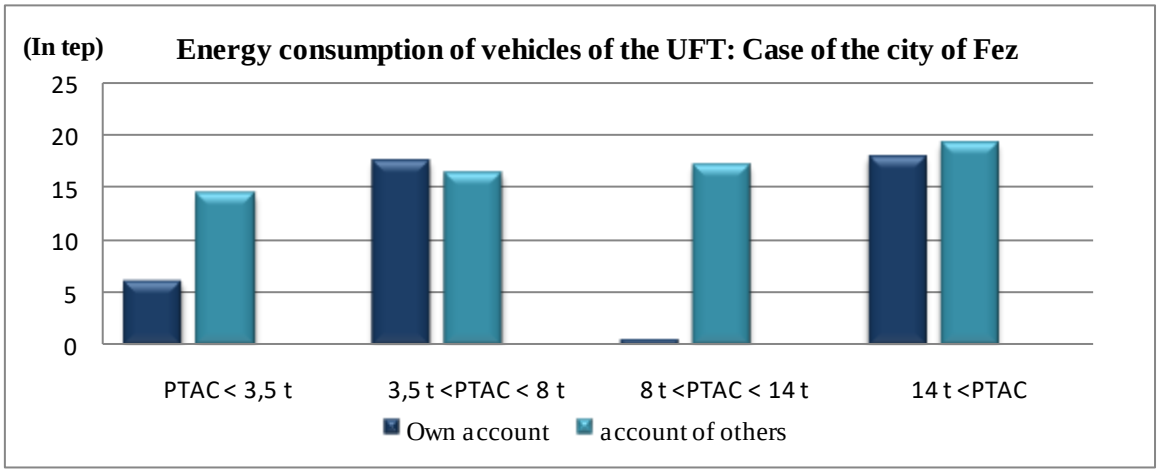

Figure 2. The energy balance of the UFT for the case of the city of Fez

- *Calculation of the CO_2 emissions:*

CO2 emissions are taken as a reference environmental element because of its direct contribution to the greenhouse effect. Previous studies have estimated that urban freight transport emissions account for one quarter of urban mobility-related CO2 emissions (Jami et al., 2013).

To measure air quality, the city of Fez is equipped with a fixed measuring station located in the center of the city of Fez, near the Mechouar and the Regional Investment Center. The station is connected to the central station of the of National Meteorology Direction, where real-time monitoring of cabin measurements is carried out. According to the annual air quality bulletin, the measurement station had a representativeness rate of 46.6% in 2009.

The method of calculating CO2 emissions consists in summing the basic contributions of the circulating vehicles. The emission of an average vehicle in its class is characterized by a unit emission factor that expresses the amount of pollutant emitted per kilometer traveled (Albergel et al., 2010):

Amount of CO2 emitted = Unit consumption per km * Emission factor * Travel distance

The emission factor is expressed in kgCO2 / t.km or Veh.km. It corresponds to the quantities of pollutants emitted during the operation of a vehicle. It depends on the engine, the average driving speed that characterizes the driving cycle, the age of the vehicle, the size of the vehicle, the cycle, and so on.

$$Eu_s\ (Cv, V, Cy, tp)$$

- Eus: Unit emission of the substance;
- s: Polluting substance emitted (s = CO, NOx, etc.);
- Cv: Category of vehicle (Cv = light vehicle (NL) Gasoline, Truck (PL));
- V: Average travel speed;
- tp: Mean distance of vehicle travel (determines the proportion of cold rolling).

Referring to the previous equation, we calculated the amount of CO_2 emissions emitted per 100 km for each vehicle category. The table 5 shows all the results obtained:

Table 5. Quantity of CO_2 emissions of the UFT in the city of Fez in 2016.

Vehicle category	Fuel consumption in ton/100km (10-3)	Emission Factor $KgCO_2$/t.km (Carburant)	CO2 quantity (per 100km) (10^{-3})	Park of own transport	Park of For-hire transportation	CO2 quantity (own transport)	CO2 quantity (For-hire transportation)
Truck or Van PTAC < 3,5 t	16	**0,547**	(16***0,547)** =8,752	375	900	(375*8,752 10^{-3})=3,282	7,87
Truck 3,5 t <PTAC < 8 t	22	**0,762**	16,764	800	745	13,41	12,49
Semi-trailer 8 t <PTAC<14 t	24	**0,83**	19,92	22	716	0,44	14,27
Truck tractor PTAC>14 t	30	**0,946**	28,38	600	643	17,028	18,25
Total							

At the end of the results obtained, it is clear that the UFT is a major emitter of GHGs, in particular CO2. In the city of Fez, which is the subject of our case study, vehicles with a GVW between 3.5 and 8 t emit almost 14 kg of CO2. On the other hand, light-duty vehicles (LDV) issue 8 kg in the case of for-hire vehicles and 3 kg in the case of own-account vehicles. Thus semi-trailers heavy-duty vehicles (HDV) emit almost 18 kg of CO2. The figure 3 summarizes the results obtained in the preceding table:

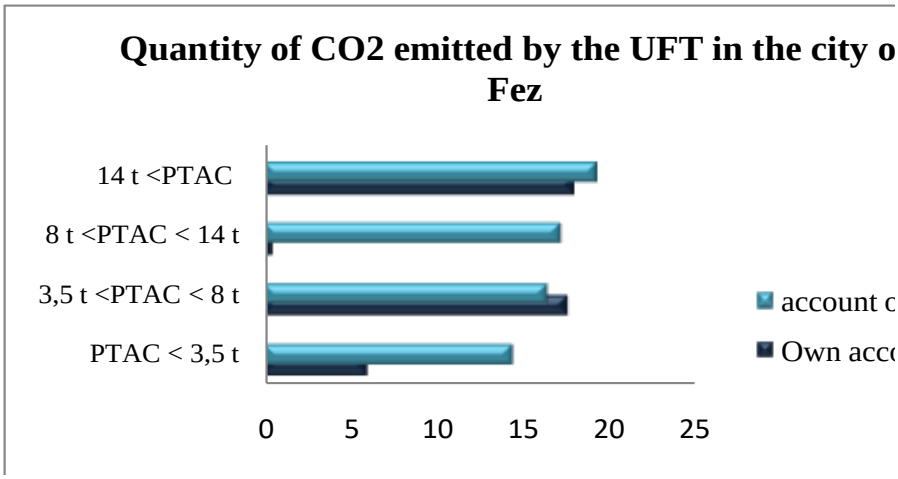

Figure 3. Quantity of the CO2 emissions of the urban freight transport in the city of Fez in 2016.

Now, if we analyze in terms of tonnage: a HDV vehicle can carry one we use four pickup trucks to transport a quantity of 14 ton, we will result in 28 kg of CO2 emitted instead of the 18 kg emitted by a HDV vehicle.
As a result, even though LDVs are more likely to be delivered, they are better suited for urban delivery and emit more GHGs per ton kilometer than heavy goods vehicles.

Conclusion

In this article, we studied the situation of the urban freight transport of the city of Fez. We proposed a methodology for measuring the ecological footprint of the UFT. We tried, first of all, to delineate the challenges of green urban freight transport. Secondly, we presented the approaches using for measuring the ecological footprint of the UFT. Then, we presented our proposed methodology. For reasons of efficiency and neutrality and to collect the technical data related to our methodology, a mixed survey method was adopted. The technique we used is halfway between the qualitative analysis by semi-directive interview and the support of the quantitative analysis. It goes beyond a questionnaire survey since the goal is to meet the respondent. The questionnaire submitted to the persons interviewed comprises twenty questions. It consists of two parts, respectively, consisting of ten questions. One is the categories of vehicles, fuel consumption, tonnage, and so on. The second consists of questions concerning companies and their vehicle fleets. The questionnaire was completed directly by interviewees during a half-hour interview. Using this data we calculated the CO_2 emissions and the energy consumption for different category of vehicle of the urban freight transport of the city of Fez.
As a result, the fuel consumption for the year 2016 is around 26250 tep, for which the for-hire transport accounts for almost 62% of the total. Concerning the CO_2 emissions, we can conclude that the UFT is a major emitter of GHGs, in particular the CO_2 emissions. In the city of Fez, which is the subject of our case study, vehicles with a GVW between 3.5 and 8 t emit almost 14 kg of CO2. On the other hand, light-duty vehicles (LDV) issue 8 kg in the case of for-hire vehicles and 3 kg in the case of own-account vehicles. Thus semi-trailers heavy-duty vehicles (HDV) emit almost 18 kg of CO2.

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