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Annoyance Caused by Air Pollution: A Comparative Study of Two Industrialized Regions

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***Abstract*—**Although there had been a many studies that shows the impact of air pollution on physical health, comparatively less was known of human behavioral responses and annoyance impacts. Annoyance caused by air pollution is a public health problem because it can be an ambient stressor causing stress and disease and can affect quality of life. The objective of this work is to evaluate the annoyance caused by air pollution in two different industrialized urban areas, Dunkirk (France) and Vitoria (Brazil). The populations of these cities often report feeling annoyed by dust. Surveys were conducted, and the collected data were analyzed using statistical analyses. The results show that sociodemographic variables, importance of air quality, perceived industrial risk, perceived air pollution and occurrence of health problems play important roles in the perceived annoyance. These results show the existence of a common problem in geographically distant areas and allow stakeholders to develop prevention strategies.

***Keywords*—**Air pollution, annoyance, industrial risks, perception of pollution, public health, settled dust.

I. Introduction

THERE are some studies correlating annoyance and ambient air pollutant concentration. Reference [1] related mean annoyance score against annual mean of PM_{10} and NO_2 concentrations, and found a significant correlation. Reference [2] found significant association between levels of annoyance caused by air pollution due to traffic and home outdoor concentrations of air pollutants ($PM_{2.5}$ and NO_2). According to [3], the annoyance caused by air pollution is also related to the perception of the amount of dust in urban and residential areas. Reference [4] modelled exposure–response relationships between annoyance from dust/grime and exhaust/smell and indicators of air pollution (NO_2, PM_{10} and $PM_{2.5}$). Air quality perception and assessment of air quality have a positive correlation with the amount of dust [5].

Few studies deal with how and why people perceive different air pollutants react against their effects and what are the variables that can influence the perceived annoyance. According to [6], people can react to air pollution cognitively. The perception of air pollution and perceived health risk can play an important role in understanding and estimating the perceived annoyance [7], [8]. But, in all of these studies was found differences in the correlations that may be explained by the differences in individual characteristics [9]. It is expected that socio-demographic aspects, location, living standards, working conditions, access to means of communication, weather conditions, and others variables can influence individuals' reaction to annoyance caused by air pollution.

The objective of this paper is to analyze the annoyance caused by air pollution in two industrialized regions in order to identify the determinants variable correlated to perceived annoyance and calculate the relative risk as a contribution on this subject. This paper presents a comparison between studies conducted in two distinct regions: a survey realized in metropolitan area in Dunkirk (France) and a survey conducted in metropolitan area in Vitoria (Brazil). These two regions were chosen because the populations of these cities often report feeling annoyed by air pollution (mainly airborne and dust fall particles) emitted by industrial and vehicular sources.

II. Materials and Method

A. About Dunkirk

The metropolitan area of Dunkirk is located on the northern coast of France in the Nord-Pas-de-Calais region. With approximately 210.000 inhabitants, Dunkirk has the third largest port in France and many industrial sites such as oil refinery, steel, food, pharmaceutical and chemical industries and also a nuclear power station for electricity production. In recent years, the metropolitan area of Dunkirk due to the economic crisis in Europe, many industries are reducing productivity or possibly being completely closed due to low market demand [10].

B. About Vitoria

With approximately 1.500.000 inhabitants [11], the metropolitan area of Vitoria is located on the south-eastern coast of Brazil. This region comprises the third largest port system in Latin America and industrial sites including steel plant, iron ore pellet mill, stone quarrying, cement and food industry and asphalt plant [12]. In recent years, the region of Vitoria has experienced a process of economic growth and increased industrial production as well as urban development [13].

C. Air Pollution

Vitoria and Dunkirk are twin cities and have some similar characteristics (despite geographic and socioeconomic differences): both cities are located on coastal areas and comprise large port and industrial sites with potential sources of air pollution. According to a report concerning the

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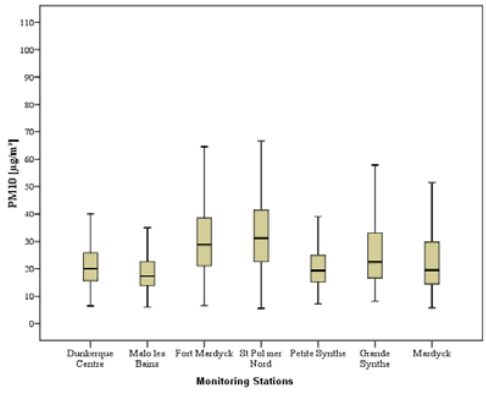
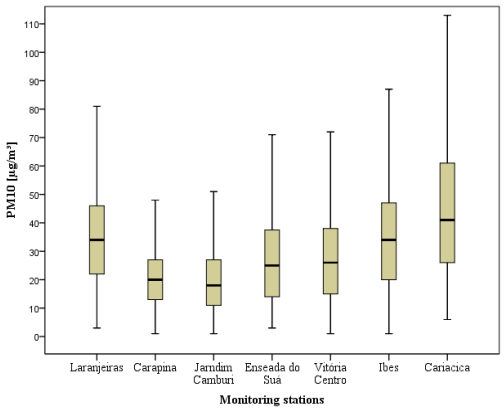
industrial risk perception in Dunkirk [14], air pollution has an outstanding importance among the environmental problems cited by the population in Dunkirk. And according to [15], more than 24% of the complaints to the environmental agency in Vitoria refer to air pollution, especially deposited dust.

The local environmental agencies in both regions provide real-time ambient air quality data for PM_{10} concentration. One-year average concentrations in Dunkirk (2008) and Vitoria (2011) were calculated using the 24-hour mean measurements for PM_{10} concentration and are shown in Figs. 1 (a) and (b), respectively. In both regions there are values above the WHO guideline for PM_{10} equal to 50µg/m³ [16], and, in Vitoria the concentration levels are higher when compared to Dunkirk.



(a) Dunkirk



(b) Vitoria

Fig. 1 Daily mean of PM_{10} concentration in (a) Dunkirk region in 2008 and (b) Vitoria region in 2011

D. The Surveys

In order to investigate more the complaints reported by people, surveys were conducted in both regions. In Dunkirk 518 people (over 18 years) was interviewed through questionnaires face to face in 2008 (late April to early July). From the survey realized in Dunkirk, was developed and adapted the questionnaire to carry out in Vitoria. Totalling 515 individuals (over 16 years) was interviewed in Vitoria in July 2011.

E. The Variables and Statistical Analysis

All selected variables were extracted from questionnaires in both studies (Dunkirk and Vitoria) that are: annoyance by air pollution, air pollution perception, industrial risk perception, importance of air quality, assessment of air quality, health effects, meteorological conditions, source of air pollution, air quality perception and socio-demographics aspects (gender, age, level of education, occupation, number of children).

The statistical analysis was performed by applying the chi-square test to examine the equivalence of the selected variables (except socio-demographic variables) between responses in both studies [17] with a significance level of 0,05. The Logistic regression [18] was also applied in order to identify the variable determinant of perceived annoyance and to calculate the relative risk in both regions.

III. Results and Discussions

A. Respondents Profile

Table I shows the profiles of the respondents in both surveys. With regard to gender, approximately 40% of the respondents are male, and 60% are female. With regard to age, it is important to observe that the percentage of respondents aged 16 to 24 years old is higher in Vitoria and the percentage of respondents aged 35 to 44 years old is higher in Dunkirk. This difference is typical for each country; in Brazil, the majority of the population is young, whereas in France, the young people are the minority.

TABLE I
Respondents Profile in Both Surveys

	Dunkirk	Vitoria
Gender		
Male	211(40.7%)	204 (39.6%)
Female	307 (59.3%)	311 (60.4%)
Age		
16-24	77 (14.8%)	140 (27.1%)
25-34	83 (16%)	71 (13.8%)
35-44	107 (20.7%)	51 (9.9%)
45-54	84 (16.2%)	94 (18.3%)
55-64	75 (14.5%)	73 (14.2%)
>65	92 (17.8%)	86 (16.7%)
Highest level of education		
None to incomplete elementary school	48 (9.2%)	7 (1.4%)
Elementary school	92 (17.8%)	131 (25.4%)
High school	213 (41.1%)	238 (46.2%)
University	165 (31.9%)	139 (27%)
Occupation		
Employed	247 (47.7%)	226 (44%)
Unemployed	107 (20.7%)	113 (21.9%)
Retired	108 (20.8%)	100 (19.4%)
Student	56 (10.8%)	76 (14.7%)
Have children		
No	324 (62.5%)	208 (40.4%)
Yes	194 (37.4%)	307 (59.6%)

There is no significant difference in percentage of respondents according to level of education and occupation in both study areas. But the number of respondents that have children is higher in Vitoria when compared to Dunkirk, as expected, because the birth rate in Brazil is higher than in

France.

B. Annoyance, Exposed and Risk from Industrial Pollution

Data in Table II indicate that in Dunkirk and Vitoria, more than 80% of the respondents reported feeling slightly annoyed or very annoyed, and less than 17% reported not feeling annoyed by air pollution. Table II also shows that over 90% of respondents claim to feel exposed and very exposed to industrial risk pollution. There is little difference in the air pollution perception of respondents in Vitoria; approximately 54% always and 40% often perceive air pollution, but in Dunkirk, only 18.5% of respondents always perceive and 63% often perceive air pollution from dust, odour, and the opacity of the air.

According to [9], perceived air quality is an important measure for evaluating the impact on health and quality of life in environmental studies. Thus, these results show that the annoyance caused by air pollution is a real problem, people feel exposed to industrial risk and also the indicator of the presence of dust, odour and opacity of the air can be an indicator of perceived air quality.

Notes to the three questions in the p-value (0.933; 0.713; 0.647), respectively, are not significant, then do not reject the hypothesis of equivalence for the significance level of 0.05. Thus, the responses of surveys are proportionally equivalent.

C. Importance and Assessment of Air Quality

Regarding Table III, approximately 90% of the respondents in both surveys consider air quality important or very important and more than 70% of respondents considered air quality bad or horrible, in their area/neighbourhood. This result shows that people are aware of the importance of air quality in their daily lives and that they are very sensitive to the effects of air pollution. According to [5] understanding the human assessment of air quality can allow the development of targeted outreach campaigns by local authorities and policy makers to protect the population from such exposure.

The p-value equal to 0.039 indicates that should reject the hypothesis of equivalence for the level of significance of 0.05. But, for the assessment of air quality the p-value of 0.644 is not significant, indicating responses proportionally equivalent.

TABLE II
QUESTIONS AND RESPONSE FREQUENCIES (%) PERTAINING TO ANNOYANCE AND PERCEIVED RISK BY AIR POLLUTION

	Dunkirk	Vitoria	χ^2	p-value
Do you feel annoyed by air pollution?			0.840	0.933
Not annoyed	85(16.5%)	83(16.1%)		
Slightly annoyed	172 (33.4%)	218 (42.3%)		
Very annoyed	258 (50.1%)	214 (41.6%)		
How do you feel regarding industrial risk pollution?			2.124	0.713
Not exposed	38 (7.4%)	44 (8.5%)		
Exposed	97 (18.8%)	208 (40.4%)		
Very exposed	380 (73.8%)	263 (51.1%)		
How often do you perceive air pollution due to dust / odour / visibility?			2.489	0.647
Never	20 (3.9%)	10 (1.9%)		
Often	70 (13.6%)	79 (15.3%)		
Always	425 (82.5%)	426 (82.7%)		

TABLE III
QUESTIONS AND RESPONSE FREQUENCIES (%) PERTAINING TO IMPORTANCE AND ASSESSMENT OF AIR QUALITY

	Dunkirk	Vitoria	χ^2	p-value
Is air quality important to you?			6.472	0.039
Not important	14 (2.7%)	7 (1.3)		
Important	24 (4.7%)	25 (4.9)		
Very important	477 (92.6%)	483 (93.8)		
How do you rate air quality in your neighborhood?			6.932	0.644
Horrible	97 (18.8%)	129 (25%)		
Bad	288 (55.9%)	121 (23.5%)		
Good	110 (21.4%)	192 (37.3%)		
Excellent	20 (3.9%)	73 (14.2%)		

D. Health Effects

In Table IV, the occurrence of health problems caused by settled dust was reported by more than 60% of respondents in Dunkirk and more than 70% in Vitoria. This is interesting because according to Table I, more than 60% of the respondents in Dunkirk and almost 40% of those in Vitoria do not have children. This may indicate that the respondents themselves are experiencing health problems caused by air pollution.

It is worth noting that the reported occurrence of respiratory and pulmonary problems was quite high in Dunkirk and Vitoria compared with other diseases such as cancer, headache, eye irritation, and leukemia. Although the effects of air pollution on mortality due to cancer, cardiovascular disease, and pulmonary disease are well documented [19], according to [7], health-related symptoms vary depending on the category of pollutant, such as gaseous pollutants and particulate matter. Particulate matter typically consists of dust and soot, which cause upper respiratory and pulmonary symptoms [20], so the depositions rates of settled dust may explain these results.

For the two questions in Table IV, the p-value is not significant; then do not reject the hypothesis of equivalence for the level of 0.05.

TABLE IV
QUESTIONS AND RESPONSE FREQUENCIES (%) PERTAINING TO OCCURRENCE OF HEALTH PROBLEMS

	Dunkirk	Vitoria	χ^2	p-value
Do you or someone in your household have (or have had) health problems caused by air pollution?			0.431	0.511
No	193 (37.5%)	133 (25.8%)		
Yes	322 (62.5%)	382 (74.2%)		
What are the main health problems caused by air pollution?			8.179	0.516
Respiratory /pulmonary	323 (62.7%)	131 (25.4%)		
Allergies / irritation	38 (7.4%)	161 (31.3%)		
Bronchitis / Asthma	119 (23.1%)	57 (11.1%)		
Other	35 (6.8%)	166 (32.2%)		

E. Perceived Source of Air Pollution and Meteorological Conditions

According to the respondents, the origin of settled dust is attributed mainly to industrial sources located in the urban area, either in Dunkirk and Vitoria (Table V). However, vehicular are also important source of air pollution identified by respondents in Vitoria (24%), whereas in Dunkirk, they are not so represented, only 10%. This result is consistent with the reality of both regions. In fact, in Dunkirk, industries have the

greatest impact on air quality [21]. In Vitoria, in addition to industrial source, as pointed by the study conducted by [22], vehicle traffic is source of particulate matter, as is the suspension of soils that occurs because of the direction and intensity of the wind (northeast).

More than 60% of respondents in Dunkirk and Vitoria perceive differences in air pollution/settled dust according to seasons. However, over 30% of respondents in both studies did not know in which season air pollution is better or worse. In Dunkirk, 44% of respondents reported that emissions of settled dust is worse during the summer, whereas in Vitoria, 29% and 31% of the respondents reported that air pollution is worse, respectively, during the winter and summer. This difference can be explained by the differences in climate, which directly affects people's perceptions. In Dunkirk, freezing temperatures are reached, and thus people stay indoors longer, keep windows closed, and do not spend time in open spaces such as gardens, parks, and beaches, whereas during the summer, the conditions are more favourable for outdoor activities, keeping windows open, drying clothes outside the houses, and visiting public spaces, which in turn favours the perception of settled dust and sky visibility. In Vitoria, there is no significant difference between the average temperature in winter (18°C) and in summer (23°C) [23] that would affect life habits, and as a consequence, the perception of air pollution/settled dust seems to be indifferent to seasons, even considering the fact that summer in Vitoria is characterised as the rainy season and winter as the dry season.

Meteorological conditions have a major influence on the suspended particles concentrations, with significant differences in the particle mass concentrations between different periods of the year, under different meteorological conditions [24]. So, although located in different geographic regions with completely different climates, in both surveys, most of the population reported that air pollution/settled dust changes according to the season.

In Table V p-value results (0.534, 0.084 and 0.713) are not significant, that indicate the opinion of respondents are proportionally equivalents in both regions.

TABLE V
QUESTIONS AND RESPONSE FREQUENCIES (%) PERTAINING TO PERCEIVED SOURCES AND METEOROLOGICAL CONDITIONS

	Dunkirk	Vitoria	χ^2	p-value
What is the main source of air pollution in your neighborhood?			3.145	0.534
Industry	449 (87.2%)	236 (45.8%)		
Vehicle	51(9.9%)	139 (27%)		
Others	15 (2.9%)	140 (27.2%)		
Do you think that air pollution/ dust changes according to seasons?			8.225	0.084
Yes	345(67%)	363(70.5%)		
No	129(25%)	122(23.7%)		
NA/NK	41 (8%)	30 (5.8%)		
If yes, in which season air pollution/ dust is worse?			12.445	0.713
Summer	229 (44.5%)	160 (31.1%)		
Autumn	23 (4.5%)	24 (4.7%)		
Winter	39 (7.6%)	150 (29.1%)		
Spring	31 (6.0%)	18 (3.5%)		
NA/NK	193 (37.4%)	163 (31.7%)		

F. Determinants of Perceived Air Pollution

The logistic regression was applied in order to identify the determinant variables of perceived annoyance considering as a result for the model the levels of "slightly annoyed" and "very annoyed" with the reference the level "not annoyed". For each study area all variables selected were added into to the model at the same time and the odds ratio for each variable related to the levels of annoyance was used to compare the relative odds of the occurrence of the outcome of interest (e.g. multinomial levels of annoyance), given influence to the variable of interest (as item II- C). In this case the odds ratio is going to be used to determine whether a particular variable is a factor determinant for perceive levels of annoyance, and to compare the magnitude of these variables of interest for that outcome variable (annoyance). E.g., i) OR=1 the variable does not affect odds of annoyance; ii) OR>1 the variable is associated with higher odds of annoyance; iii) OR<1 the variable associated with lower odds of outcome [25]. The odds ratio results by the multivariate logistic model are summarized in Table VI (it was selected only the significant results).

There are more variable associate to the level "very annoyed" compared to the level "slightly annoyed". Thus in both study areas to be "very annoyed" is determined by the variables: "importance of air quality", "perceived industrial risk", "perceived air pollution by dust" and "gender feminine".

For the variable "importance of air quality" the odds ratio approximately equal to 4 means that respondents who considered air quality important have 4 times the odds to be very annoyed by air pollution than the others who not considered air quality important. For the variable "perceived industrial risk", in Dunkirk the odds equal to 1.8 means that who perceived industrial risk have 1.8 times the odds to be very/extremely annoyed, and in Vitoria they have 3.5 times the odds do be very/extremely annoyed than respondents who not perceived exposed to industrial risk.

TABLE VI
DETERMINANTS OF PERCEIVED ANNOYANCE

Determinant variables	Odds Ratio			
	Dunkirk		Vitoria	
	Slightly/ annoyed	Very annoyed	Slightly/ annoyed	Very annoyed
Importance of air quality	1.868**	3.909**	1.837**	4.339**
Perceived industrial risk	1.199	1.836**	2.330*	3.513**
Perceived air pollution by dust	1.778**	2.636*	1.074**	2.819*
Frequency of health problems	0.836	1.140	1.555	3.620**
Gender (feminine)	0.987	1.119***	0.994	1.722**
Age >55 years	0.834	0.864	1.122	1.393**

*P<0.001; **P<0.05; ***P<0.1;

G.Relative Risk

The relative risk (RR) is frequently used in epidemiological studies to measure the impact of atmospheric pollutants concentrations on health. The RR can be defined as the probability that an event will occur following a certain exposure to a risk factor. Soon their application is relevant in the context of this work to assess the risk of annoyance when exposed to the PM_{10} concentrations. In this context, to

estimated RR for the logistic regression model [26] is in (1).

$$RR \cong e^{\beta x} \quad (1)$$

where x is the variation in the pollutant concentration given by the interquartile variation, and β is the estimate parameter in the logit model.

Finally, the RR estimated for the PM_{10}modeling were calculated to compare the results between Dunkirk and Vitoria, as showed in Table VII. As a comparative analysis of the RR values, while in Dunkirk the RR estimated for the pollutant PM_{10} increase approximately 5%, and in Vitoria the RR increase 14%.

TABLE VII
ESTIMATED MODEL, RELATIVE RISK (RR) AND 95% CONFIDENCE INTERVAL FOR ANNOYANCE

Regions		*β*	*Sig.*	*RR*	*95% C.I.for RR*	
					Lower	Upper
Dunkirk	PM_{10}	,050	,000	1,05	1,037	1,079
	Intercept	-,757	,325			
Vitoria	PM_{10}	,135	,000	1,14	1,102	1,189
	Intercept	-1,34	,000			

IV. Conclusions

Face-to-face surveys were conducted in two different cities to assess the opinions about annoyance caused by air pollution. For this study, we selected distinct regions (Dunkirk and Vitoria) located in different countries (France and Brazil). Even though there are geographical and cultural differences between them it was found that majority of the population reported annoyance caused by air pollution,

A group of variables was selected including: annoyance caused by air pollution, air pollution perception, industrial risk perception, air quality perception, importance of air quality, assessment of air quality, source of air pollution, health effects, meteorological conditions, and sociodemographic aspects (gender, age, level of education, occupation, number of children). And the most of answers related to selected variables are proportionally equivalents, as showed by chi-square test.

About the form of air pollution perception, was cited settled dust, odour, and opacity of the air. In addition, people reported to perceive themselves exposed or very exposed to industrial risk. The population in both cities considered air quality to be bad or horrible in their area/neighborhood. And, most of the respondents think that air quality is an important issue to their lives, although the main emission sources are different.

The origin of settled dust was attributed mainly to industrial sources located in the urban area in both cities, and in Vitoria there are also vehicular source considered important sources of dust identified by people. It is important to note that air quality perceptions mark differences in the two study areas which indicates that perceptions in general depend on an area's overall setting and availability of industries, others pollutions sources or daily activities.

Observing peoples opinion about occurrence of health problems, and the concentrations levels of PM_{10} above the WHO guidelines, it is possible to conclude that perceived annoyance are related to many symptoms reported by respondents.

People reported that air pollution can change according to the season. Considering the climatic differences between these two regions we can conclude that annoyance caused by air pollution can be influence by the weather. This trend was more pronounced in Dunkirk.

The multivariate logistic model carry out the determinants variables to perceived annoyance: perceived air quality important, fell exposed to industrial risk pollution, and perceived air pollution by dust and gender feminine. The difference in the occurrence of health problems and older age range explain the differences can be explained by difference between these two localities. Therefore, it can be concluded that different culture and economic contexts, can affect the relationship between these aspects and levels of perceived annoyance.

An important result from this paper is although the difference in the values to the relative risk, 5% in Dunkirk and 14% in Vitoria, in general the pollutant PM_{10} contribute significantly to the increase in the numbers of people the reported annoyed by air pollution.

In summary, the results may help the environmental management authorities understand the need to direct effort on strategies in local communities aware of sources of air pollutions and related to risk, especially in Vitoria region. This approach enhance to individual's understand the importance of environmental policy, effective to minimize the annoyance caused by air pollution.

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