Atmospheric Pollution Research 9 (2018) 439–445

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Atmospheric Pollution Research

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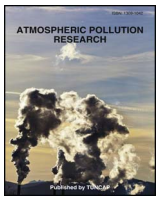

How economic crisis influence air quality over Portugal (Lisbon and Porto)?

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ARTICLE INFO

Keywords:
Pollutants
Air quality
Economic crisis
Indicators
Portugal

ABSTRACT

The aim of this specific study is to discuss the impact of the economic crisis on air quality in Portugal, with focus on particulate matter and nitrogen dioxide. For this purpose, a long-term period of economic and air quality monitoring data was analysed, including both periods before and after the crisis (2004–2015). The analysis was focused on the main urban areas of Portugal – Lisbon and Porto municipalities.

All the economic indicators highlight a decreasing trend since 2007, which is also evident for energy consumption, while for Gross Domestic Product (GDP) and disposal income there are signs of recovery after 2010. In terms of pollutants concentration, there is a negative trend since 2007 with reductions in the annual values higher in Porto (about 40% for NO_2 and PM10) than in Lisbon (25–30% of NO_2 and PM10). Correlations were found between pollutant concentrations and energy consumption, with a correlation factor superior to 0.7, for both Lisbon and Porto municipalities. No evidence of a linear relationship was found for the disposable income per capita. The results presented in the study support the notion that a significant alteration is undergoing to the air quality in Portugal, directly related to the reduction of energy consumption, consequence of the economic crisis, that starts to be registered after 2007 and after 2012 stops decreasing. While the economic indicators like GDP and disposable income reveal an increase after 2010–2102, no positive trend was found on the annual average of pollutants concentration.

1. Introduction

Improvement of air quality related to economic crisis has been defined recently in several works, mainly relating both emission and ambient air pollution levels (Sánchez de la Campa and de la Rosa, 2014; Cusack et al., 2013; Lyamani et al., 2011). Recent studies have reported several, both positive and negative, impacts of economic crisis on air quality. Several methodologies have been used to identify the relationships between economic crisis and air quality, such as satellite imaging (Castellanos and Boersma, 2012; Vrekoussis et al., 2013), contaminant gas levels (Santacatalina et al., 2011), and chemical composition of PM (Arruti et al., 2011; Cusack et al., 2013). Castellanos and Boersma (2012) analysed satellite observations and reported a reduction of at least 20% in NO_2 emissions throughout Europe for the period 2004–2010, attributed to both the global economic recession and environmental emission controls. Similarly, large reductions in NO_2 concentrations have been detected across the US during the respective US economic recession period [2007–2009] and over urban areas and power plants (Russell et al., 2012).

Castellanos and Boersma (2012) showed that in many large European cities, the reduction in NOx emissions during 2009 (recession year) outweighed approximately 4 years of policy improvements. Possibly due to the economic recovery in Europe, the NO_2 reductions slowed down in 2010. Vrekoussis et al. (2013) also used satellite observations of tropospheric NO_2 columns and reported significant reductions in large parts of Greece between 2008 and 2011 (the country is still facing the crisis that started in 2008). In the capital, the overall NO_2 decrease was in the range of 30–40%. The authors also analysed the temporal variability of surface concentrations of CO, NOx, SOx, and O_3 from 2004 to 2011 and identified two distinct periods (from 2004 to 2007 and from 2007 to 2011) where a sharp decrease in all primary pollutant levels occurred during the second period (economic crisis period). The significant differences reported by Vrekoussis et al. (2013) since 2008 are well correlated to various economic indicators of the anthropogenic activity and are attributed to the economic crisis. Karagiannidis et al. (2015) analyzed air quality data in a Greek city, Patras, between 2008 and 2011. They also argued that the economic crisis contributed to a significant reduction in particulate matter and several trace gases, namely CO, NO, and NO_2, due to a decrease in the anthropogenic activities. According to Russell et al. (2012), in the USA, large reductions in the observations of tropospheric NO_2 vertical column densities were detected, due to regulatory efforts and to the

Peer review under responsibility of Turkish National Committee for Air Pollution Research and Control.
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https://doi.org/10.1016/j.apr.2017.11.009
Received 3 July 2017; Received in revised form 10 November 2017; Accepted 11 November 2017
Available online 01 December 2017

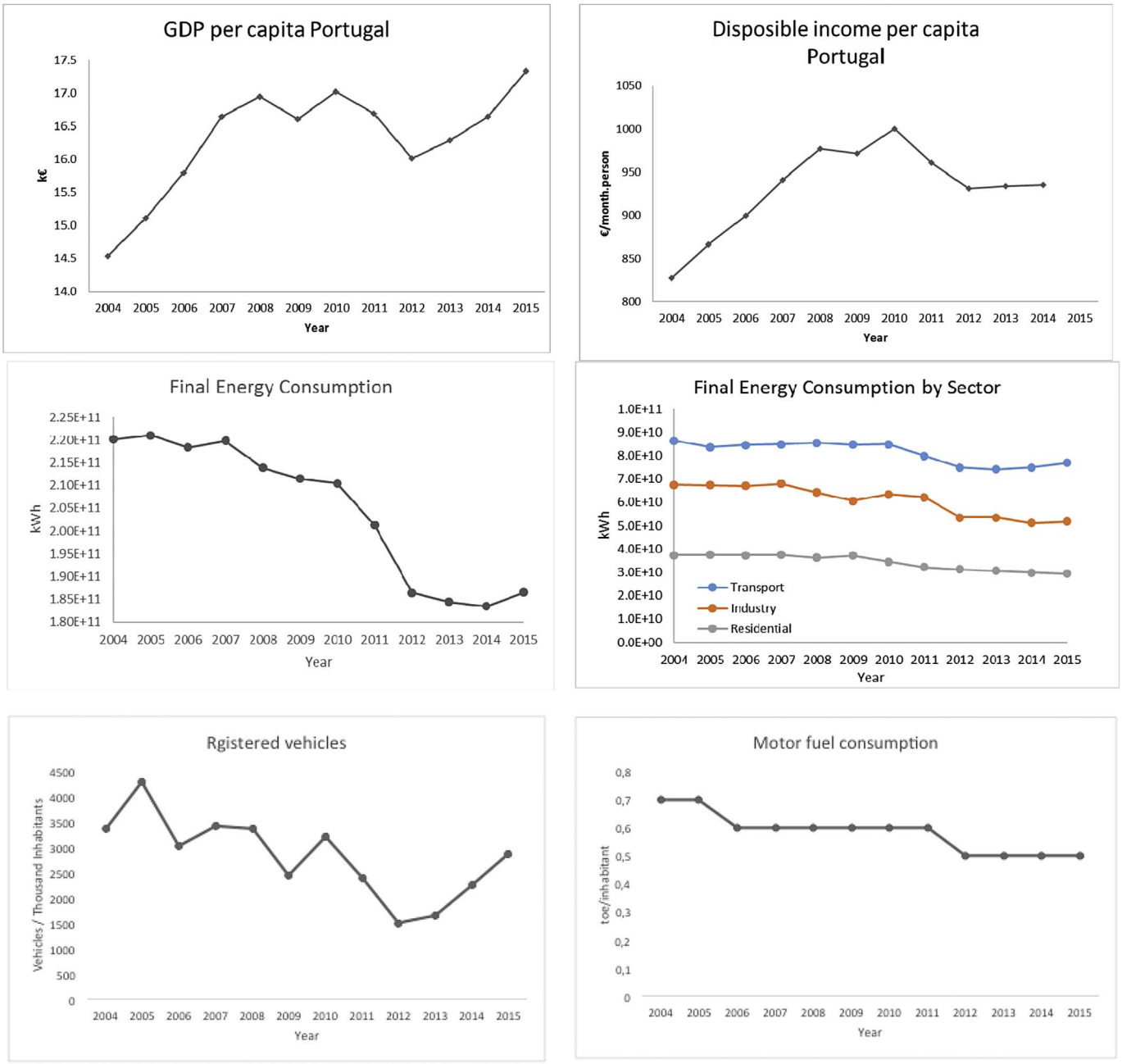

Fig. 1. Economic indicators (GDP per capita; Disposable income per capita; final energy consumption and per sector; Registered vehicles and Motor fuel consumption) at national level, for the period 2004–2015.

economic recession of 2008–2009. These authors showed that emission reductions from light-duty vehicles dominated the NO_2 decreases prior to the recession and a reduction in diesel truck activity has had a larger impact on emissions reduction since the start of the recession. Saffari et al. (2013) also conducted a wintertime sampling campaign for fine particles (PM2.5) in Thessaloniki during the winters of 2012 and 2013. These results indicate that the increase in airborne fine particles was mostly due to the replacement of fuel oil by the cheaper wood for domestic heating, as the price of fuel oil has nearly tripled.

The abovementioned articles mainly report a positive impact of economic recession on air quality. However, other studies have shown that the economic crises can also result in serious air pollution episodes. The impact of economic crisis in terms of air pollutants concentrations is twofold. On the one hand, the emissions are reduced due to the significantly lower consumption of diesel and the reduction of vehicle utilization for personal needs. On the other hand, people try to find cheaper ways in order to satisfy their heating needs such as timber and biomass heating systems, which are characterized by notably higher PM emission levels per kWh_{th} (Gaidajis et al., 2014). Despite its potential use as renewable and sustainable energy source, wood-fired winter heating is considered as one of the major emission sources of local air pollution (Bari et al., 2011; McNamara et al., 2013). For example, in previous studies over the city of Athens (Malico et al., 2017), where a decrease of NOx was registered, an increase in the ozone concentrations was reported.

Portugal is also among the European countries facing a serious financial/economic crisis in the aftermath of the 2008–2009 global recession, which affected its energy consumption profile due to the increased price of domestic heating oil and gasoline. According to Eurostat, the country's real gross domestic product (GDP) growth rate was negative from 2011 to 2013 and no real growth was verified in the last 12 years (Eurostat, 2016). The country seems to be recovering, with

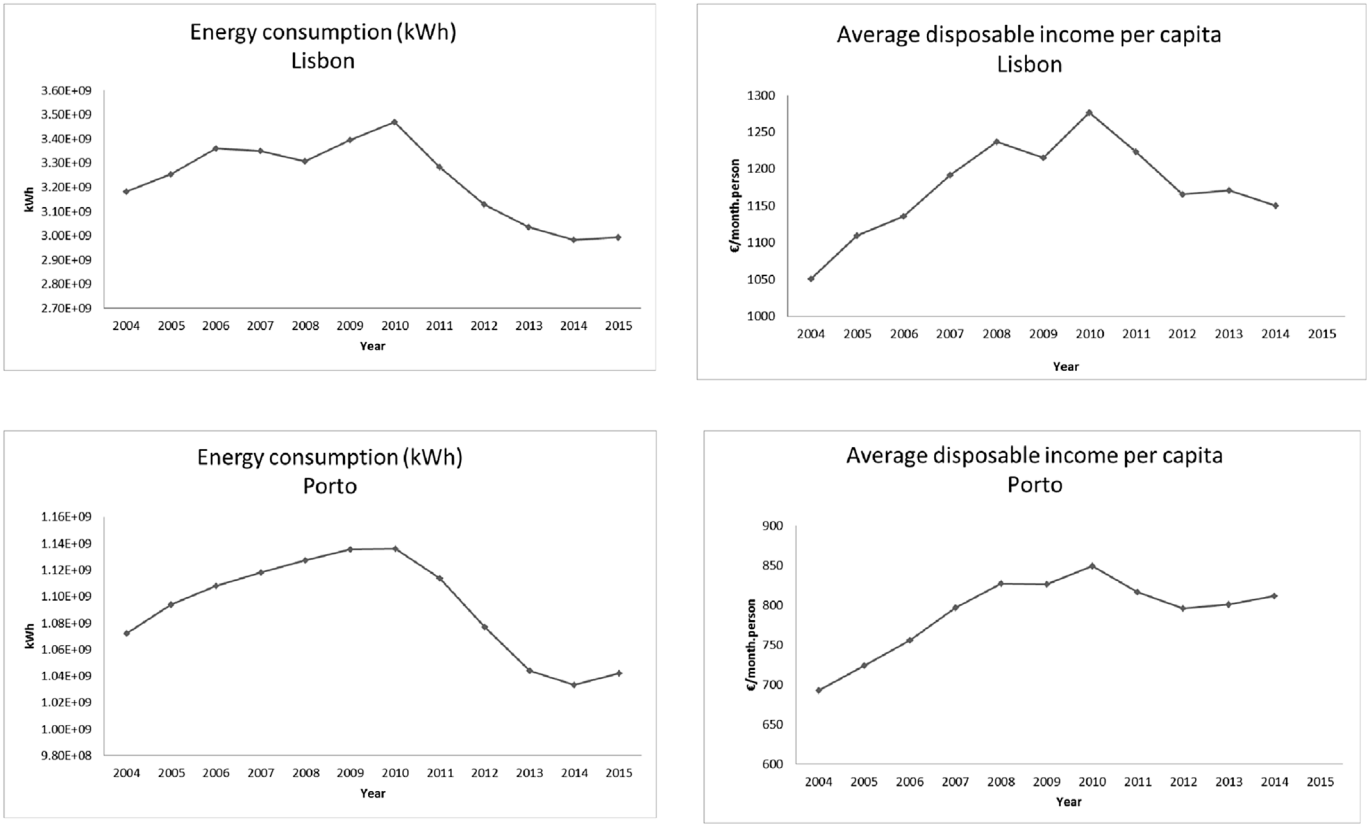

Fig. 2. Economic indicators (energy consumption and disposable income per capita) for Lisbon and Porto municipalities, for the period 2007–2015.

growth rates of 0.9 in 2014 and 1.5 in 2015, as estimated by the Eurostat. The prices of conventional fuels have increased between 2010 and 2015 (DGEG, 2016), and families have lost income (Eurostat, 2016). This might have led either to a reduction of anthropogenic activities and therefore of emissions or, on the contrary, to an increase in uncontrolled biomass burning and consequent air quality deterioration.

The main objective of this paper is to investigate the resulting impact of the economic crisis (from 2008 onward) on air quality in relation to the most critical pollutants, like PM and NOx, in Portugal (in particular over the main cities of Porto and Lisbon). A long term data series of 12 years (2004–2015) of air quality monitored at different locations was used covering two distinct periods: pre-financial crisis (2004–2007) and the crisis period (after 2008). A comprehensive analysis of this long-term dataset was performed in order to assess to which extent the ambient air was impacted by the economic crisis.

The present work is organized as follows: Section 2 describes and characterizes the financial/economic crisis over Portugal using different indicators, while section 3 analyse the air quality data recorded along the study period in different air quality sites over Portugal. A statistical analysis performed to correlate both economic and environmental variables is performed in Section 4, and finally conclusions are drawn in Section 5.

2. The portuguese economic crisis

2.1. Economic indicators

Relevant economic and energy consumption data was gathered to assess the impact of the economic recession on pollutant concentrations (data gathered from: Eurostat, 2016; PORDATA, 2017; and INE, 2017). The energy consumption per sector for the study period was collected at national scale but only total energy consumption was available per municipality. Regarding the economic indicators, two different types of indexes were selected: the average disposable income per capita (at municipal level) and the gross domestic product (GDP, only available at national level, base year 2011). The average disposable income values can reveal information regarding citizen behaviour, with higher prices the amount income available for everyday purchases is decreased. The GDP is a means of measuring the output of an economic system, which provides insight into the economic evolution and stability of a country or municipality (Malico et al., 2017). Besides these ones, also road traffic indicators were investigated: the number of registered vehicles and the motor fuel consumption at national scale were the only available data for the study period (2004–2015).

Fig. 1 shows all these indicators collected at national scale for the time period 2004–2015.

The pre-crisis period (2004–2007) is characterized by an increase of GDP and disposable income, which is not verified for energy consumption. The GDP per capita starts to decrease significantly after 2010 and decreases until 2012, from 17 k€ to 16 k€, which reflects the economic/financial crisis (2007–2009 should be identified as pre-crisis period), but after this period it exhibits an increase (reaching 17.5 k€ in 2015) which can be translated to a recovery of the economic sector. The same is not observed for disposable income per capita, which shows a decrease only after 2010. This can be explained since this indicator is not directly linked to the economic and financial conditions of the country, and the consequences of the crisis can be delayed in terms of disposable income available for families. In terms of energy consumption, there is a clear trend of reduction since 2007, which only stops in 2012. This reduction is registered in all the three sectors (Transports; Industry and Residential). Regarding the transport sector, the data collected for motor fuel consumption and number of registered vehicles confirms the regression during the crisis period (after 2007), besides an increase of the vehicles after 2012. These indicators confirm a shift in citizen behaviour during and, in some cases, after the economic crisis, namely regarding energy consumption (amount of vehicles on the roads

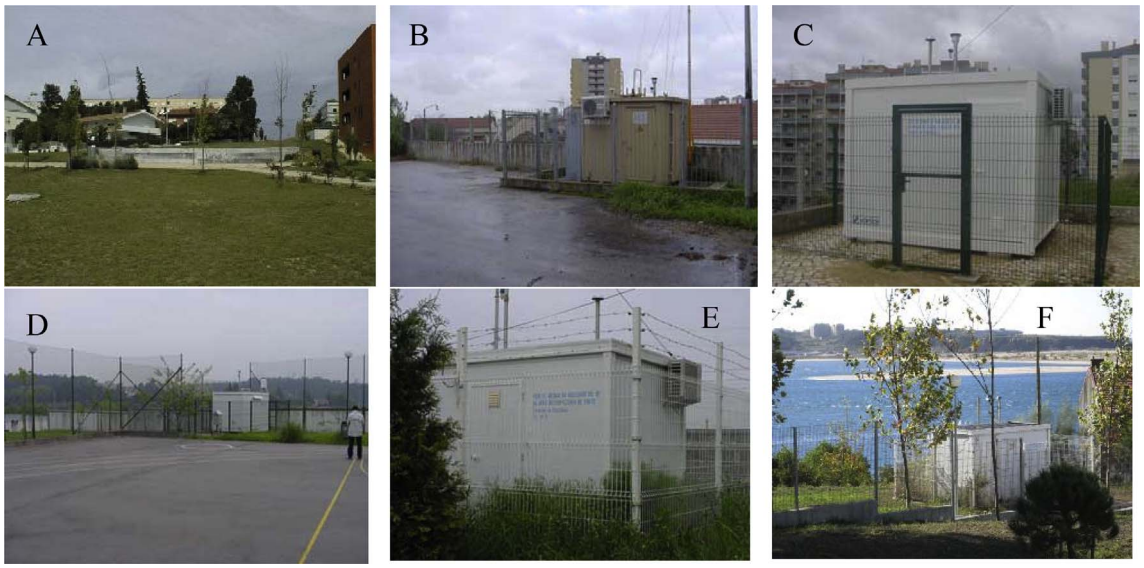

Fig. 3. The monitoring stations selected for this study – Lisbon (A – Restelo, B – Olivais, C-Laranjeiro) and Porto (D- Leça, E - Custóias, F - Sobreiras) urban areas.

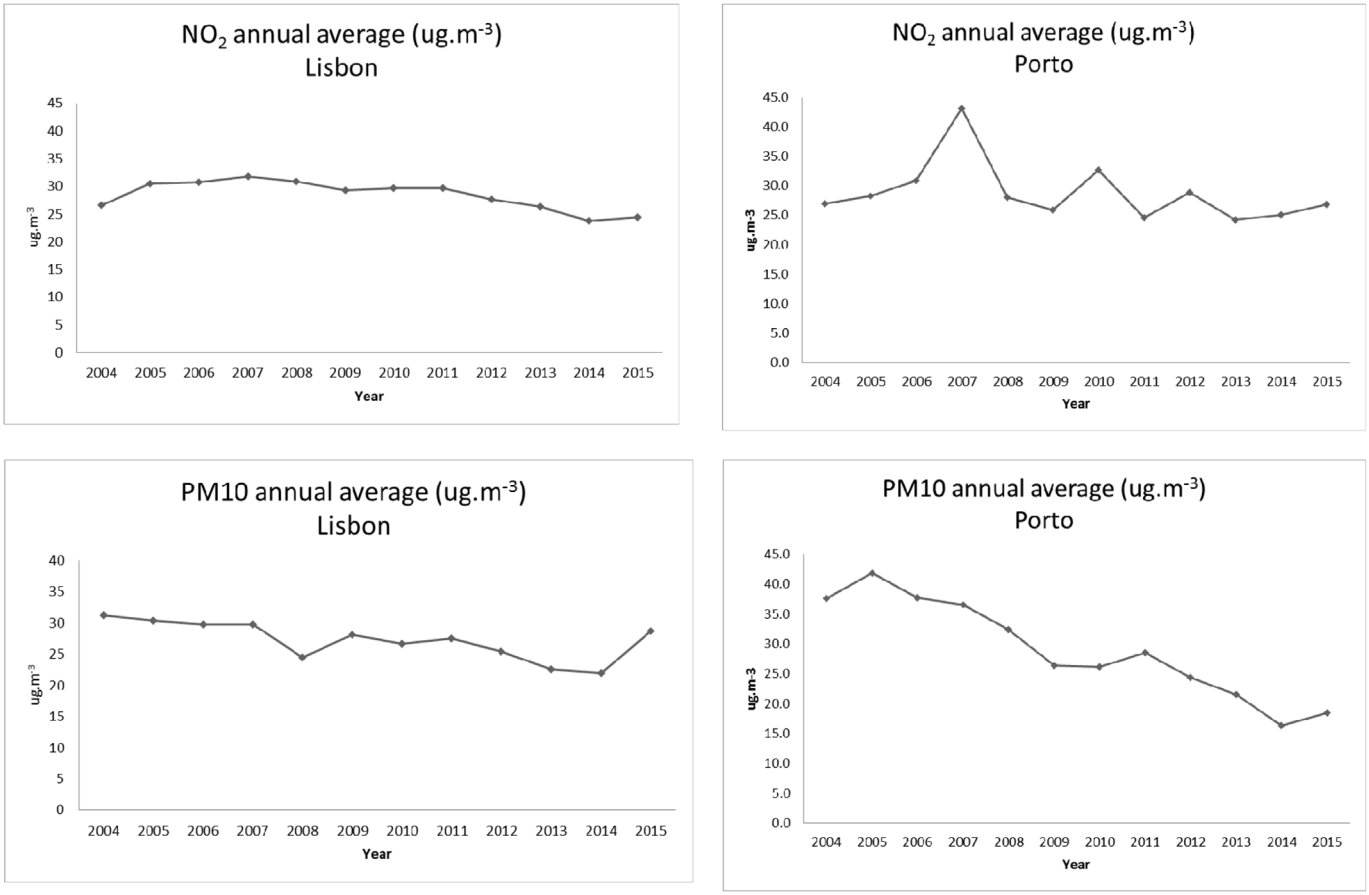

Fig. 4. NO_2 and PM10 annual averages registered at the monitoring stations located in Porto and Lisbon urban areas, during the period 2007–2015.

and energy consumption in homes).

Since this study intends to investigate the link between economic and air quality indicators, a larger spatial detail is needed to correlate these two variables. For that, the energy consumption and disposable income indicators for the two main urban municipalities of Portugal - Porto and Lisbon – are presented in Fig. 2.

Contrarly of what is observed for the total national energy consumption, in Lisbon and Porto municipalities there is an increase of both energy consumption and disposable income. After that, the overall reduction observed at national level (Fig. 1) was found also for both municipalities, regarding the energy consumption and disposable income per capita. Nevertheless, there is a noticeable exception regarding the energy consumption in Lisbon (and in Porto with less magnitude) where an increase was observed during 2008–2010.

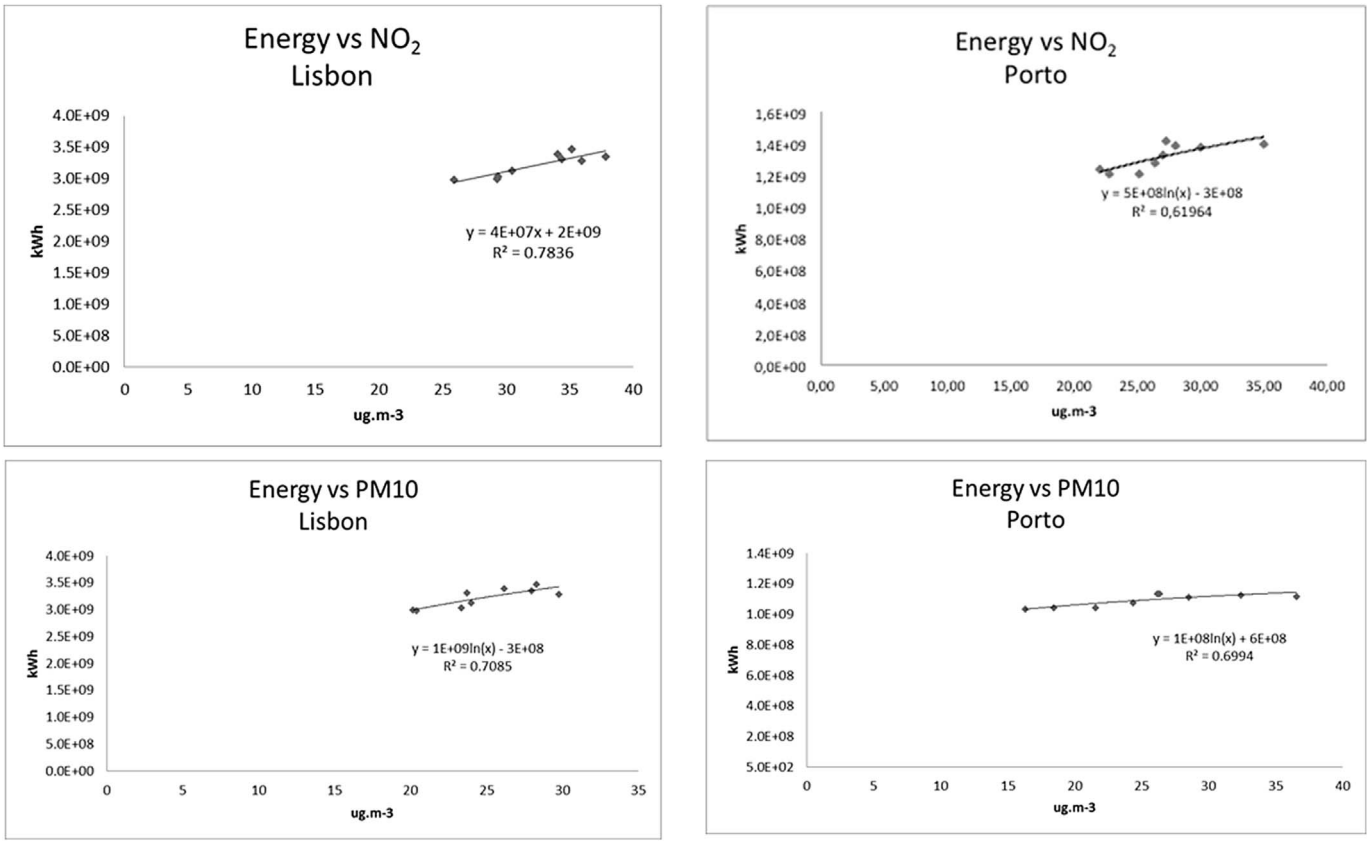

Fig. 5. Energy consumption vs pollutants concentration (NO_2 and PM10 annual averages) for Lisbon and Porto municipalities (2007–2015).

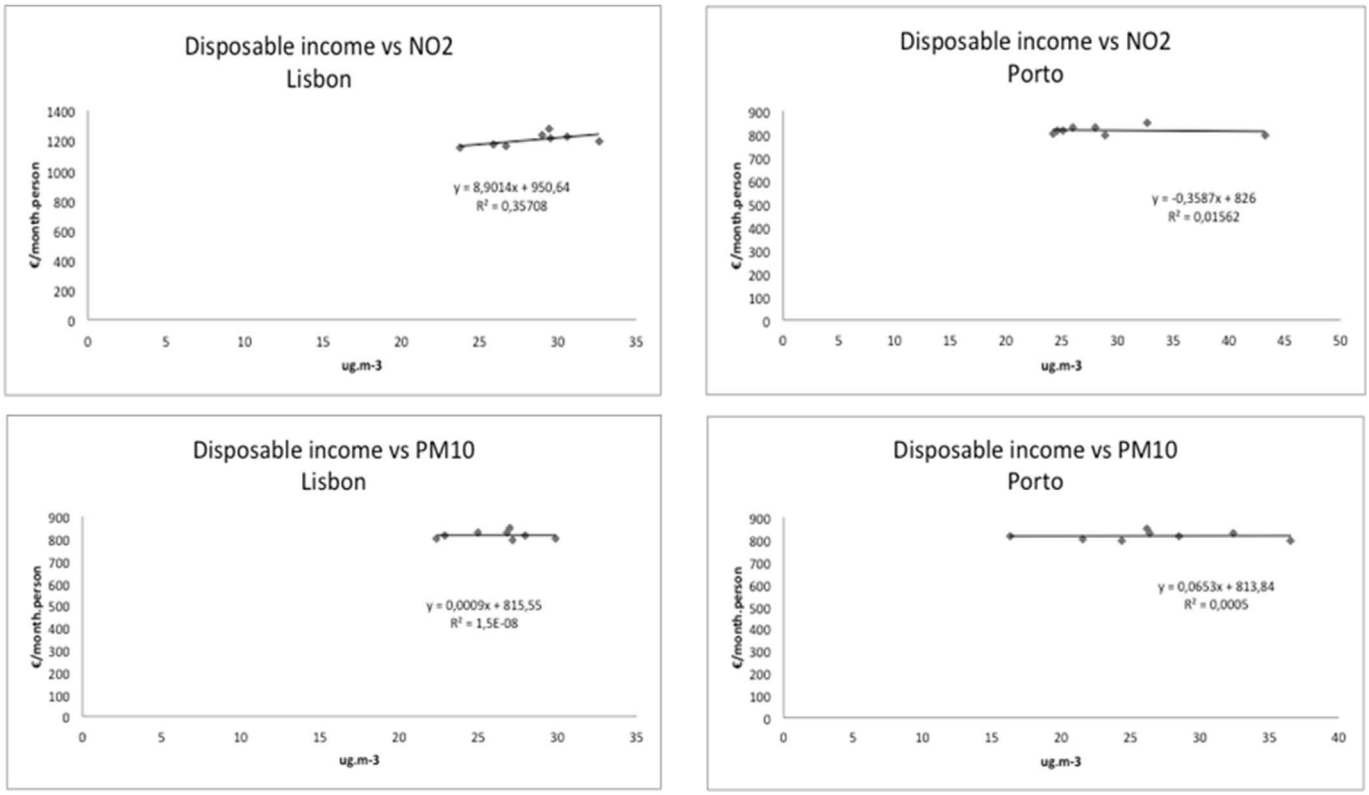

Fig. 6. Disposable income per capita vs pollutants concentration (PM10 and NO_2 annual averages) for Lisbon and Porto municipalities (2007–2015).

3. Air quality data

Hourly air quality data was obtained from the national air quality monitoring network/QualAr database (http://qualar.apambiente.pt/), for the study period 2007–2015. 5 background air quality stations located in Porto and Lisbon municipalities were selected, namely: 3 in Lisbon - Restelo (urban), Olivais (urban) and Laranjeiro (urban) - and 3 in Porto - Leça (suburban), Custóias (suburban) and Sobreiras (urban). These monitoring sites were selected according to their spatial representativeness (no traffic stations could be chosen since they only represent a very restricted area surrounding the street) and data collection efficiency for the study period (a minimum of 90% of hourly data collection was defined).

Fig. 3 shows the place and environment where each monitoring station is located. None of which have direct influence of traffic sources and are characterized by urban/suburban influence.

Although several pollutants are being monitored in the selected stations, this work will focus on NO_2 and PM10, which are the main critical pollutants in urban areas (Monteiro et al., 2007).

Fig. 4 presents the annual average of NO_2, and PM10 (averaged of the different stations), per municipality. An annual limit value of 40 μg m^{-3}, for the protection of human health, is established by legislation (EU, 2008) for the annual means of both NO_2 and PM10. The analysis of annual averages regarding air pollutants concentration allows reducing the meteorological influence and its variation along the years (Thunis et al., 2015).

An overall decrease was registered in all cases, for both pollutants and municipalities, with exceptions during 2011 year (where an increase was registered in both pollutants and cities). The annual limit value for the protection of human health was only surpassed for NO_2 and in the Porto municipality during 2007, with compliance after this period. In terms of trend, the reductions registered in the annual values are significantly higher in Porto (~15 μg m^{-3} for NO_2 and PM10) than in Lisbon (~10 μg m^{-3} of NO_2 and 5 μg m^{-3} for PM10).

A Mann-Kendall test (Libiseller and Grimvall, 2002) was applied for the daily values of PM10 and NO_2 in order to support this trend analysis. Negative Z values were found for all the stations, in the range of [-16; -3] for NO_2 and [-24;-6] for PM10, which confirms the negative trend verified for both pollutants along the study period. By other side, the p-values obtained were inferior to 10^{-15}, supporting that this trend is statistically significant.

4. Air quality VS economic data

The annual averages of NO_2 and PM10 were intersected with the economic indicators presented before and their correlations are analysed in Fig. 5 (air quality vs energy consumption) and Fig. 6 (air quality vs disposable income).

The analysis of these indicators and their correlation with pollutant concentrations (considering the crisis period 2007–2015) can reveal a shift in citizen behaviour during and after the economic crisis, which can affect the amount of vehicles on the roads and energy consumption in homes. The correlation coefficients between energy consumption and the annual averages of both pollutants are higher than 0.6, with values around 0.8 in the case of Lisbon.

The correlations between air quality values and disposable income available for Porto and Lisbon municipalities are shown in Fig. 6.

As expected from previous analysis, there is no direct association between this economic indicator (that characterize the economic situation of families) and air pollutants concentration. This type of economic indicator does not depict the habits and behaviours of the citizens, and so, no direct link exists between this index and air quality conditions.

5. Summary and conclusions

This study intends to discuss the impact of the economic crisis on air quality in Portugal with a focus on PM10 and NO_2 pollutants. A long-term period of economic and air quality monitoring data was analysed, including periods before and after crisis (2004–2015), for the main urban areas of Portugal – Lisbon and Porto municipalities. The temporal variations of the main economic indicators available per municipality areas, namely individual disposal income and energy consumption, were analysed and correlated with the annual average of pollutants concentration measured in both municipalities.

All the economic indicators highlight a decreasing trend since 2007, also evident for energy consumption, while for the GDP and disposal income there are signs of improvement after 2010. In terms of pollutants concentration, there is a negative trend since 2007 with reductions in the annual values higher in Porto (about 40% for NO_2 and PM10) than in Lisbon (25–30% of NO_2 and PM10), which was supported with a Mann-Kendall test (with negative Z values found with very low p-values). The only correlations found were between pollutant concentrations and energy consumption, with a correlation factor superior to 0.7, for both Lisbon and Porto municipalities. No sign of linear relationship was found for the disposable income per capita. The results presented in the study support the notion that a significant alteration is undergoing to the air quality in Portugal, directly related to the reduction of energy consumption, consequence of the economic crisis, that starts to be registered after 2007 and after 2012 stops decreasing. While the economic indicators like GDP and disposable income reveal an increase after 2010–2102, no positive trend was found on the annual average of pollutants concentration. A sociological study would be interesting to investigate in which way new habits or behaviour changes could form and contribute to air quality improvement.

Acknowledgements

The authors wish to thank the financial support of the FUTURAR project (PTDC/AAG-MAA/2569/2014 - POCI-01-0145-FEDER-016752) through the Project 3599 – Promoting the scientific production and the technological development, and thematic networks (3599-PPCDT) and through FEDER. The authors are also grateful to the Ph.D. grant of C. Gama (SFRH/BD/87468/2012).

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