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# A SPATIAL ECONOMETRIC ANALYSIS OF ENVIRONMENTAL KUZNETS CURVE IN EUROPE

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**Abstract**

Energy consumption has been found to be important in understanding national and global emissions. This paper investigates the relationships between $SO_2$, $NO_x$, CO, VOC, $NH_3$, $CO_2$ emissions, income, and energy consumption in Europe from 1990 to 2012. Environmental Kuznets Curve literature has excluded spatial interdependence and this could bias the estimates. By employing the spatial Durbin model and using panel data sets from 36 European countries, this study finds that there is an inverted-U shaped Environmental Kuznets Curve for $SO_2$, $NO_x$, CO and $CO_2$ while $NH_3$ emissions follow a U-shaped relationship. Results indicate that the per capita emissions from surrounding countries strongly influenced national per capita emissions for $SO_2$, $NO_x$, and VOC. Our findings also show that population density has a negative direct and indirect impact on the $SO_2$, CO, and VOC emissions of European countries.

**Keywords:** Environmental Kuznets Curve, Emissions, Spatial Econometrics, Europe

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## 1 Introduction

Subsequent to Grossman and Krueger's (1991) study, the relationship between economic growth and environmental quality has been widely investigated by numerous researchers and institutions. These studies have determined that economic growth and environmental degradation stepwise rises with national income at low income levels; but as income increases, pollution diminishes and environmental quality increases. Kuznets (1955) suggested that there is an inverted U-shaped relationship between economic development and income inequality. According to Stern (2004, p. 1419), if this phenomenon prevails, it is an Environmental Kuznets Curve (EKC). Fossil fuel combustion and cement manufacturing directly affecting carbon dioxide ($CO_2$) emissions and the amount of $CO_2$ emissions is determined by the type of fossil fuels used. A major local emitter of $SO_2$ can be released mostly during metal smelting and other industrial processes. $NO_x$ comes principally from road transport, motor vehicle exhaust, electric utilities and industrial boilers; however, diesel vehicles emit more $NO_x$ than do petrol vehicles, and their market share accounts for 53% of all new registrations in Europe (ICCT, 2014, p.6). CO is a byproduct of motor vehicle exhaust and is mostly seen in cities where automobile exhaust can account for as much as 95% of all emissions. Widely residential combustion of European beech, Pyrenean oak and black poplar in a domestic woodstove and fireplace produces VOC in Southern and mid-European countries. As a major greenhouse gas emission, $CO_2$ emissions and other local emissions, such as $SO_2$, $NO_x$, CO, VOC, and $NH_3$, appear to decrease labor force productivity by negatively affecting human health; for example, causing breathing and respiratory illness and lung cancer. It also raises sea levels; affects climatic changes on rainfall; reduces agricultural productivity; and so on. However, these emissions are transported through the atmosphere over long distances, causing researchers and policymakers to examine the relationship between economic growth and environmental degradation.

Current debate on sustainable development and environmental degradation studies have focused on two main reasons. The first reason is that the effects of local and global emissions would probably result in a widespread international externality, such as global warming. Secondly, these emissions are promptly linked to the use of energy, which is a vital principle factor of production economies. Consequently, it is crucial to study the relationship between economic growth and local and global emissions and to evaluate the environmental results of economic development in order to propose political advice for long-term pollution control.

$CO_2$ emissions have dramatically increased within the last 50 years and are still increasing worldwide by almost 3% each year. The European Union (EU) was the third largest emitter in 2012 with 11% share following China and the United States at 29% and 16% respectively. Despite the effort to reduce these gases in Europe, exposure to fine particles (as in Eastern Europe, Benelux, and Italy), excess ozone (as in the Mediterranean) and acidification (as in Benelux, Central Europe, and the Scandinavian lakes) have become a more regional problem while excess nitrogen deposition will remain a widespread European problem in 2020 (ECOFYS, 2010). Spatial distribution of average local and global emissions densities in Europe can be seen in Figure 1. During the period of analysis, Eastern Europe has higher densities in $SO_2$; Nordic countries have higher value in $NO_X$; and both Eastern European and Nordic countries have volatile organic compound values. Moreover, almost 90% of $NH_3$ emissions come from agricultural activities and 60% of $SO_2$ come from energy production and distribution, while more than 40% of emissions of $NO_x$ come from road transport in Europe (EEA, 2013, p.4). The main sources of current volatile organic compounds emissions are 'Solvent and product use' and road transport.

Although EU certified an integrated approach between climate and energy policy to mitigate greenhouse gas emissions at least 20% below 1990 levels in 2007 (Pardo and Moya, 2013), reduction policies would probably come on behalf of economic growth among countries in Europe. EEA-32 countries decreased total greenhouse gas emissions by 10.9% between 1990 and 2010.

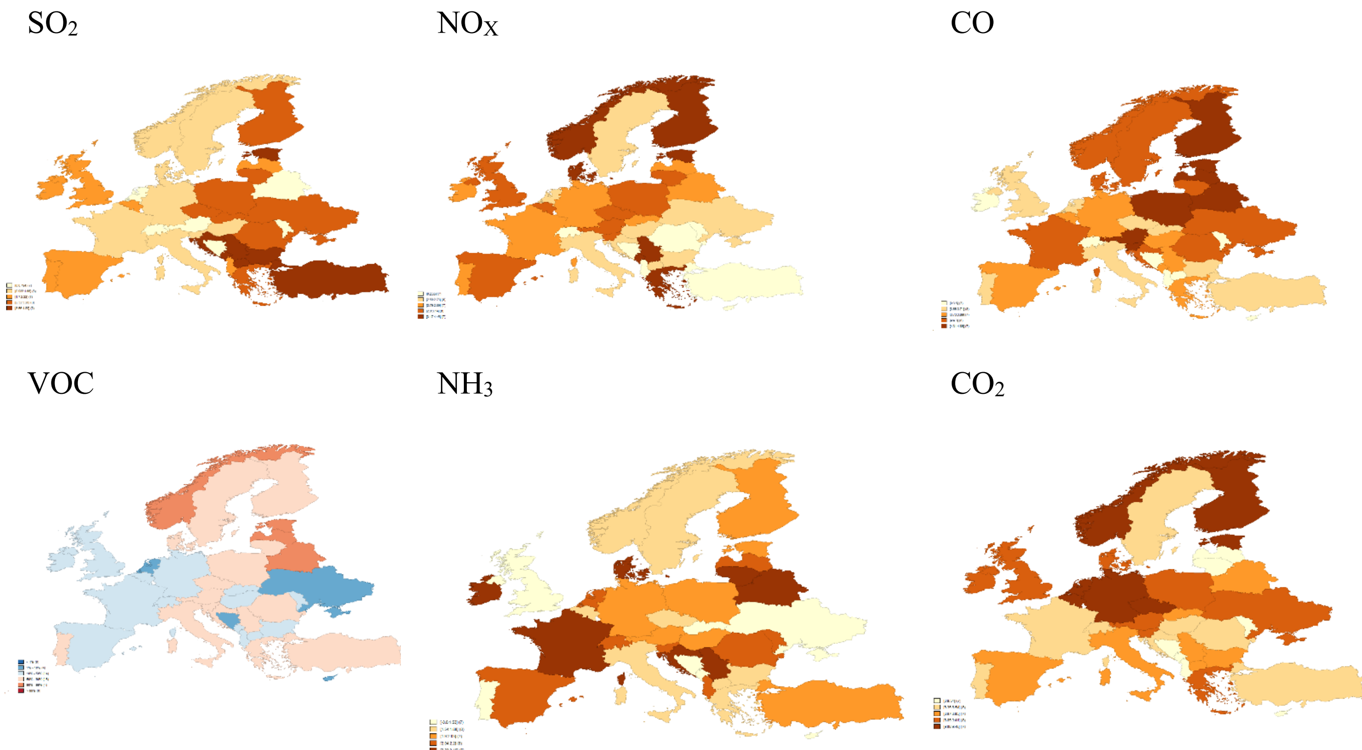


*Figure 1. Spatial distribution of per capita local and global emissions in Europe in 2010.*

Even though most of the European countries have been reducing $SO_2$ emissions by 76% between 1990 and 2009, Luxembourg, Hungary and Iceland have increased their $SO_2$ emission value. $NO_x$ emissions have increased by 34% in Turkey, 14% in Greece and 2% in Portugal in this term. Ammonia emissions have declined by 26% during this time because of a reduction in livestock numbers. Emissions from 'Solvent and product use' and road and non-road transport combined contribute approximately 55% of total VOC and has reduced half of VOC reduction since 1990.

A vast number of theoretical and practical studies have been done on the relationship between economic growth and environmental degradation. Despite the wealth of literature that has analyzed this relationship, most previous papers have not included a control for spatial effects into the EKC regression models for Europe. In other words, these papers presume that a countries' emissions are unaffected by the rise in emissions of their neighbors. Ignoring spatial interdependence in the relationship between economic growth and environmental degradation could lead to bias estimates in the EKC studies. Because of transboundary movement of pollutants across countries, spatial relationships could appear in Environmental Kuznets Curve where countries' emissions are affected by the emissions of neighboring countries. There could be some strategic response between governance; for example, one country's policymakers could be reluctant to reduce their own $SO_2$ emission levels yet, at the same time, follow the developments with deep concern of $SO_2$ emission levels of their neighboring countries. To reduce the costs of decision making, governments frequently use environmental policies that are similar to other government's policies. In an inverted-U shaped EKC, $\beta_1 > 0$ and $\beta_2 < 0$ and also $\frac{-\beta_1}{2\beta_2}$ shows the threshold level or the income turning point (Stern, 2004). Plotting the inverted-U shaped relationship between per capita GDP and environmental quality can be seen in Figure 1. Level 1 accounts for the early steps of a country`s economic growth in which a country tends to increase production and ignore environmental control. While Level 2 shows stabilization stage, country`s aware of environmental quality is a luxury good and in level 3 that shows gradually decrease of environmental deterioration.

Although very few studies take into account spatial interdependence in the EKC for Europe, this assumption has recently been questioned by Rupasingha et al. (2004), Maddison (2006), Auffhammer and Carson (2009), Wang et al. (2013), Li et al. (2014), Georgiev and Mihaylov (2014), and Keene and Deller (2013) for different countries using spatial econometric methods.

This study is important to the field of EKC because it will shed some light on economic growth and environmental degradation for Europe taking spatial interdependence into account. Spatial EKC takes into consideration spatial autocorrelation of environmental pollutants as an independent variable. The aim of this study is to examine the relationships among both local ($SO_2$, $NO_x$, CO, VOC, $NH_3$) and global ($CO_2$) emissions and income, energy consumption, population density, and urbanization in Europe from 1990 to 2012.

The findings of this study shows an inverted-U shaped relationship between global emissions measures and economic growth. Moreover, this study reports \$857, \$10.823, and \$21.195 as the turning points for $SO_2$, $NO_x$ and $CO_2$ of EKC, as well as direct and indirect effects of income to emissions.

The rest of this paper is organized as follows. Section 2 describes spatial econometric estimation, and Section 3 describes data used in the empirical part of the study. Section 4 discusses the findings. Section 5 concludes the paper for further researches.

## 2 Data and Methodology

This study uses the annual data of $SO_2$, $NO_x$, CO, VOC, $NH_3$ and $CO_2$, per capita GDP, energy use, population density and urbanization for 36 European countries over the period 1990-2012. Dependent variables of this study are per capita $SO_2$, $NO_x$, CO, VOC, $NH_3$ and $CO_2$ emissions (metric tons), respectively. Sulfur dioxide generally comes from the combustion of coal and oil, which are enclosed in fuel and also produced during metal smelting. Nitrogen oxides cause smog, which is emitted by burning fossil fuels at electric power plants and in automobiles, mix with other chemicals in the air. $CO_2$ emissions are the major component for the rise of greenhouse gases and global warming. Sulfur dioxide, nitrogen oxides, non-methane VOCs and carbon monoxide emissions data for each country come from the European Monitoring and

Evaluation Programme (EMEP) and carbon monoxide and $CO_2$ data comes from World Development Indicators. These indicators of emissions are measured in per capita kilogram. $CO_2$ emissions measured in thousands of metric tons. $inc$ is a proxy of the income and measured by GDP per capita in constant 2005 prices. Per capita energy use ($energy$) refers to the use of primary energy before transformation to other end-use-fuels and is measured in kg of oil equivalent. The data for population density ($pop$) is computed by land area in square kilometers over midyear population. Urbanization data ($urban$) refers to people living in urban areas. The source of these data is World Development Indicators of Worldbank. Table 1 presents the summary statistics of the data. The database contains observations for 36 European countries; Bosnia and Herzegovina and Cyprus are excluded from the sample because they have missing data.

The SDM model uses spatially lagged values of independent variables to predict dependent variables. The SDM model is specified as:

$$SO_{2it} = \rho \sum_{j=1}^{n} W_{ij} SO_{2jt} + X_{it}\beta \sum_{j=1}^{n} W_{ij} X_{jt\gamma} + \mu_i + \varphi_t + \varepsilon_{it}$$
(1)

where ρ is the spatial auto-regression coefficient and $\gamma$ is a spatial autocorrelation coefficient of independent variables, and where $W_{ij}SO_{2jt}$ $W_{ij}X_{jt\gamma}$ stands for the spatial lag of dependent and independent variables, respectively. In other words, local emissions at a particular European country is partially determined by a spatially weighted average of neighboring countries' emissions. LeSage and Pace (2009) stated that SDM should be used when spatially correlated omitted variables exist in a model and even these variables are correlated with an independent variable in the model. SDM is the most appropriate model if these two conditions hold. In this study, a potential omitted variable may be a measure of the trade/GDP ratio of European countries. This ratio could be correlated with both per capita GDP and energy use variables. We used longitude and latitude coordinates for each country to create a spatial 3-nearest neighbors matrix with Map Window and used LeSage's (1999) Spatial Econometrics Toolbox for MATLAB to estimate the spatial models.

## 3 Empirical Findings

This study will continue to test which spatial model offers the best fit for the data. Table 3 shows the estimated results of SDM, which includes both country and year fixed effects for $SO_2$, $NO_x$, and CO. The table presents only the results of the spatial fixed effects model as a result of the Hausman test. LeSage and Pace (2009) pointed out that the SDM is the only model that produces unbiased coefficient estimates under all of the possible data generating processes implied by equation (5) even when the true model is a spatial lag or spatial error model. As noted in Elhorst (2012), the hypothesis $H_0: \gamma = 0$ can be tested to determine if the SDM can be simplified to the spatial lag model or the hypothesis $H_0: \gamma + \rho\beta = 0$ can be tested to determine if the SDM can be simplified to spatial error model. The results of our Wald tests and LR tests for all models indicate that both of the hypotheses are rejected at a 1% level, which means the SDM model could not be simplified to either the SAR or the SEM models. SDM produces direct, indirect and total effects. Direct effects represent how a change in the explanatory variable at country $i$ affects its own gas emissions. Lesage and Pace (2008) point out that the indirect or spillover effects show how a change in the explanatory variable at neighboring countries affects the gas emissions at country *i* or the impact country *i* has on all other countries. The total effect is the sum of the previous two. Romero and Burkey (2011) explain that the coefficients of SDM cannot be interpreted as the marginal effects of non-spatial models. Hence, following LeSage and Pace (2009), this study estimates the direct, indirect and total effects to interpret the spatial spillover effects. Table 3 represents the estimated marginal effects of $SO_2$, $NO_x$, CO.

All of the spatial models demonstrate the inverted-U shaped EKC relationship. To determine this, we look at the total effect first, which is the summation of the direct and indirect effects. The results in Table 1 reveal that the total effects of all the explanatory variables are statistically significant at 1% level. Regarding the per capita GDP and squared per capita GDP, we find a positive and statistically significant at 1% level of *inc*, while a negative and statistically significant at 1% level of *inc2*. According to the results in Table 3, the total effect of per capita $SO_2$ emissions is 6.548 and it is significant at the 1% level, which means that as a country increases its own per capita GDP by 1%, $SO_2$ emissions in that same country increases by 6.5%. On the contrary, the coefficient of inc2 is negative, as expected, and also statistically significant. The coefficient value 0.444 of the square term of the per capita GDP shows that, after a turning point, a 1% increase in income will reduce the per capita $SO_2$ emissions by 0.44%. The turning point of per capita GDP is $1,594 for $SO_2$ emissions. The turning points of $NO_x$ and CO are $2.334 and $4.385 respectively. The point estimate for the total effect of a change in the energy use is 1.478 and is statistically significant at the 1% level. This estimate shows that, as the energy use increases by 1%, per capita $SO_2$ emissions increases by 1.5% and both per capita $NO_x$ and CO emissions increase by 0.84% and 0.60%. This results implies that the greater the amount of energy production and consumption from fossil fuel, the larger amount of $SO_2$, $NO_x$ and CO emissions may be caused in Europe. Coal combustion for electricity and heat production clarifies more than 70% of all $SO_2$ emissions in Poland. However, in Germany and Poland combusted lignite at some lignite-burning power plants caused the highest emissions of $SO_2$. We also find that population density is associated with low per capita $SO_2$ emissions, indicating that higher rates of population density decrease the per capita $SO_2$ emissions. One possible explanation of this result is when people live closer to each other, per capita road transportation emissions are likely to be lower and denser housing also causes a reduction in energy consumption by low heating requirements. Finally, the coefficient of the urban variable is positive and statistically highly significant in all three models. This shows that the levels of emissions are likely to be higher in urban areas due to higher population density, using intensively buses, taxicabs, passenger vans, flights and industrialization. Turning to the direct effect, the direct effect of a change in a countries' per capita GDP measures how a change in a particular countries' per capita GDP affects emissions in that same country.

In Table 3, interestingly, the direct effect is -1.614 and it is significant at a 5% level. This means that as a country increases its own per capita GDP by 1%, per capita $SO_2$ emissions in that same country decreases by 1.6%. On the other hand, squared value of per capita GDP is positive and statistically significant at a 10% level. This also shows that as a country increases its own income by a 1% level, per capita $SO_2$ emissions in that same country increases by 0.072%. This result shows a U shaped relationship. Conversely, the direct effect is 0.777 for $NO_x$ and 1.446 for CO and both of them are statistically significant at 1% level. This means that as a country increases its own income by 1% level, per capita $NO_x$ and CO emissions in that same country increases by 0.8% and 1.5% respectively and it will also decrease after a turning point. The direct effect of energy consumption is significant and positive for all three models, with a coefficient equal to 1.905, 0.710 and 0.922; this means that the energy consumption of a country has a positive impact on its own per capita $SO_2$, $NO_x$, CO emissions. This result is consistent with a large body of literature that considers energy usage as being a major contributor of local and global emitters.

| | **$SO_2$** | | **$NO_X$** | | **CO** | |
|---|---|---|---|---|---|---|
| | **FE** | | **FE** | | **FE** | |
| **direct** | | | | | | |
| inc | -1.614** | (-2.164) | 0.777*** | (2.878) | 1.446*** | (3.886) |
| inc2 | 0.072* | (1.635) | -0.033*** | (-2.122) | -0.093*** | (-4.287) |
| energy | 1.905*** | (11.586) | 0.710*** | (11.722) | 0.922*** | (11.438) |
| pop | -1.383*** | (-3.653) | -0.062 | (-0.442) | -1.330*** | (-6.762) |
| urban | 0.574 | (0.728) | 0.770*** | (2.651) | 0.302 | (0.754) |
| **indirect** | | | | | | |
| inc | 8.162*** | (7.267) | 0.867** | (1.914) | 0.684 | (1.037) |

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| inc2 | -0.516*** | (-7.795) | -0.072*** | (-2.723) | -0.034 | (-0.883) | cannot be controlled by catalytic reduction. |
| energy | -0.427* | (-1.938) | 0.133 | (1.332) | -0.320*** | (-2.565) | |
| pop | -0.490 | (-0.795) | -1.463*** | (-5.220) | -1.303*** | (-3.403) | |
| urban | 4.493*** | (3.085) | 3.251*** | (4.848) | 2.717*** | (2.996) | |
| **total** | | | | | | | |
| inc | 6.548*** | (6.008) | 1.644*** | (3.241) | 2.130*** | (3.011) | |
| inc2 | -0.444*** | (-6.974) | -0.106*** | (-3.628) | -0.127*** | (-3.119) | |
| energy | 1.478*** | (6.626) | 0.843*** | (7.894) | 0.602*** | (4.562) | |
| pop | -1.873*** | (-2.653) | -1.525*** | (-4.678) | -2.632*** | (-5.803) | |
| urban | 5.067*** | (2.879) | 4.021*** | (5.018) | 3.019*** | (2.724) | |
| spatial rho | 0.078*** | (6.016) | 0.182*** | (4.410) | 0.179*** | (4.282) | |
| Hausman test | 48.958 | [0.000] | 29.404 | [0.002] | 47.710 | [0.000] | |
| Wald Spatial lag | 141.637 | [0.000] | 104.538 | [0.000] | 48.277 | [0.000] | |
| Wald Spatial error | 133.972 | [0.000] | 99.163 | [0.000] | 55.795 | [0.000] | |
| Observations | 828 | | 828 | | 828 | | |

***Table 1.*** *Estimation results of Spatial Durbin models with spatial fixed and random effects (marginal effects)*

As outlined in detail above in population density, the estimated coefficients indicate a negative effect for $SO_2$ and CO in Table 3 which implies that higher population densities contribute to shorter trip lengths, and make transportation and nonmotorized proceedings more feasible, which reduces transport energy consumption. Therefore, the more densities there are in a country, the less per capita $SO_2$ and CO emissions there are. This finding is in line with Kennedy et al. (2009) and Georgiev and Mihaylov (2014). The direct effect of the urbanization variable is significant and positive in Column 2 of Table 3; the urbanization of country i has a positive impact on its per capita $NO_x$ emissions. One possible explanation for this result is that urbanization increases road transportation by encouraging car ownership and greater travel distances. Moreover, houses are increasingly far away from workplaces and commercial centers, and people are living further away from leisure activities, shopping centers and schools in the urban sprawl of European countries such as UK, Denmark and Belgium. According to the Eurostat, there was a big increase in the use of passenger cars, especially in Bulgaria, Estonia, Slovakia, Lithuania, and Turkey. The vast majority of the European new car market is dominated by modern diesel vehicles in which $NO_x$ emissions

Regarding indirect effects, the indirect effect of income is positive and significant for all three emitters except for CO. The positive sign indicates that as a country increases its per capita GDP, $SO_2$ and $NO_x$ in adjacent countries increases as well. On the other hand, squared value of income are negative and statistically significant at %1 level. This shows that as a country increases its income 1% continuously, per capita $SO_2$ and $NO_x$ emissions in neighboring countries decreases 0.5% and 0.07%. The indirect effect of energy is significant and negative, with a coefficient equal to 0.427 for $SO_2$ and 0.320 for CO. This result indicates that neighbors' energy use negatively affects the per capita $SO_2$ and CO emissions of country i. Hence, a 1% increase in energy consumption in all surrounding countries will generate on average a 0.427% and 0.320% decrease in per capita $SO_2$ and CO emissions of country i, which implies that improved energy efficiency and fuel switching in all surrounding countries are leading to reduce emission intensity and an improve air quality. Similarly, a 1% increase in population density in all neighboring countries produce a 1.463% and 1.303% decrease in per capita $NO_x$ and CO emissions for country i. One possible explanation for this result is populous countries have less demand for personal transport and traffic congestion. Finally, the indirect effect of urbanization is positive and significant for all three local emitters (with a coefficient of 4.493, 3.251 and 2.717) and the implication is that an increase in own-country urbanization leads to an increase in surrounding countries $SO_2$, $NO_x$ and CO emissions due to increasing energy demand, road traffic, traffic congestion, and overcrowding in urban areas.

According to the indirect effect results in Table 4, the estimates of *inc* and *inc*-squared are totally different from the results in Table 2. For the total effect of per capita $CO_2$ emissions, all explanatory variables are statistically significant at a 1% level except for urban. Our results proved the existence of an inverted-U shaped EKC for per capita $CO_2$ emissions, which means that $CO_2$ emissions increased with per capita income at the early stages of economic growth, and then declined with per capita income after arriving at a turning point. We find that energy consumption increases per capita $CO_2$ emissions. One possible explanation for this is that all Central and Eastern European countries' energy use was fairly higher than the European Union (EU) average before twenties and the energy intensity was still on average at least double that of the EU. Also the dominance of coal in the power generation sources in Poland, Hungary, Czech Republic, and Slovakia increased $CO_2$ emissions. The positive coefficient on the direct effect and negative coefficient on the indirect effect of energy use threaten that own-country energy use will increase its own per capita $CO_2$ emissions but decrease the emissions of surrounding countries. Europe has had increasingly more anxious energy efficiency policies since 2000, and approved the Emissions Trading System which should be seeking the most cost-effective ways to reduce carbon emissions. In order to produce more thermal power energy, related $CO_2$ emissions increased by 4.2% between 1999 and 2003, while they decreased by 0.8% between 2003 and 2005 in the 27 EU member countries. The main reasons for this reduction is that Northern European countries generated more electricity from hydropower then thermal power, and German and Netherlands households and services emitted low $CO_2$ due to warmer winters. (European Environment Agency, 2008). Reducing energy use due to energy efficiency in industry and transportation can lead to significant reductions in $CO_2$ emissions of neighboring countries.

The direct effect and total effect coefficients of *pop* variable is positive and significant, which implies that countries with higher population density have higher per capita $CO_2$ emissions than countries with a lower population density. This phenomenon can be explained by food consumers who are spatially separated from producers, thus requiring more transportation of products. Additionally, industrial clustering uses more energy per capita than traditional manufacturing in densely populated countries. This result is in line with Hosseini and Kaneko (2013), Auffhammer and Carson (2008). We also find negative coefficients on both direct and indirect effects of urban as expected but this is statistically insignificant. The negative coefficients of urban can be explained by governments and markets that may create improved public transportation and roads that could reduce the total emissions for increasing the urban demand for goods, services, employment and schools. However, the EU has agreed to an 8% reduction of GHG emission below 1990 levels between 2008 and 2012 on the 1998 Kyoto protocols specific targets, and the target of Europe 2020 development strategy was to reduce the $CO_2$ emissions from its 28 member states by 20% by 2020, compared to the 1990 level.

In the VOC equation the statistically significant positive direct effect and negative indirect effect coefficients of the per capita GDP implies that own-country per capita income increases will increase own-country VOC emissions intensity but decrease the surrounding countries VOC emissions. The indirect effect coefficient of squared value per capita GDP is positive and statistically significant and shows that as income increases continuously in own-country, neighboring countries VOC emissions intensity will also increase. The statistically significant positive coefficient of direct effect of energy variable imply that an increase in own-country energy consumption leads to a significant increase in own country VOC emission intensity.

| | VOC | | $NH_3$ | | $CO_2$ | |
|---|---|---|---|---|---|---|
| | **FE** | | **FE** | | **RE** | |
| **direct** | | | | | | |
| inc | 0.906*** | (2.566) | 0.342 | (0.897) | 0.287* | (1.644) |
| inc2 | -0.033 | (-1.563) | -0.011 | (-0.502) | -0.015 | (-1.514) |
| energy | 0.531*** | (6.708) | 0.404*** | (4.706) | 1.337*** | (32.947) |
| pop | -0.317* | (-1.718) | 0.332* | (1.686) | 0.185*** | (3.221) |
| urban | 0.409 | (1.075) | -1.083*** | (-2.585) | -0.123 | (-0.675) |
| **indirect** | | | | | | |
| inc | -1.063* | (-1.818) | -1.681*** | (-2.691) | 0.280 | (1.169) |
| inc2 | 0.063* | (1.822) | 0.091*** | (2.485) | -0.023* | (-1.617) |
| energy | 0.109 | (0.906) | 0.353*** | (2.938) | -0.103** | (-2.100) |
| pop | -2.367*** | (-6.865) | -0.929*** | (-2.549) | 0.086 | (0.843) |
| urban | 4.716*** | (5.286) | 1.519** | (1.796) | -0.100 | (-0.335) |
| **total** | | | | | | |
| inc | -0.157 | (-0.243) | -1.339*** | (-2.096) | 0.567*** | (2.664) |
| inc2 | 0.030 | (0.810) | 0.080*** | (2.167) | -0.038*** | (-3.049) |
| energy | 0.640*** | (5.031) | 0.757*** | (6.398) | 1.233*** | (27.411) |
| pop | - | (- | 0.757 | (- | 0.271** | (3.090 |

| | | | | | | |
|---|---|---|---|---|---|---|
| | 2.683*** | 6.579) | | 1.424) | * | ) |
| urban | 5.124*** | (4.850) | -0.596 | (0.431) | -0.223 | (-0.696) |
| spatial rho | 0.153*** | (3.607) | 0.436 | (1.007) | 0.078*** | (6.017) |
| Hausman test | 31.534 | [0.001] | 25.821 | [0.007] | 8.566 | [0.662] |
| Wald Spatial lag | 64.204 | [0.000] | 14.868 | [0.011] | 16.013 | [0.007] |
| Wald Spatial error | 73.560 | [0.000] | 16.246 | [0.006] | 26.642 | [0.000] |
| Observations | 828 | | 828 | | 828 | |

*Table 2. Estimation results of Spatial Durbin models with spatial fixed and random effects (marginal effects)*

According to the direct effect results in Table 4, income increase VOC and $CO_2$ emissions and also energy use increase all of them as well. The coefficients of both the direct and indirect effect of population density of VOC are negative and significant, and the implication is that an increase in own-country population density leads to a decrease of both own-country and surrounding countries' VOC emission intensities because dense populations demand less personal transportation. This result is in line with Newman and Kenworthy's (1989) study which identified an inverse relationship between population density and transportation energy consumption for 32 global cities and Ewing and Cervero's (2010) denser housing, which relates to less energy consumption by heating. Moreover, under the National Emission Ceilings Directive the majority of EU-28 member countries have reduced VOC emissions by 57% between 1990-2010 time span.

The direct effect of urbanization, interestingly, is no longer significant at 10% level but indirect effect is positive and statistically significant at the 1% level and the implication is that an increase in own-country urbanization rate leads to an increase of neighboring countries VOC emissions. Using solvent is the main source of VOC emissions throughout Europe, and important sources of solvent emissions include paint application, printing processes, application of glues, road transportation, and dry-cleaning. On the other hand, changing behavior of the car market from gasoline vehicles to diesel vehicles would not lead to strong reductions in the emissions intensity (Schipper and Fulton, 2013). One possible explanation for this result is because urban sprawl in highly urbanized countries have higher demands for personal car transportation.

Finally the coefficient of rho shows significant positive spatial autocorrelation. This means that the more country i is surrounded by highly polluted countries, the higher its level of pollutions is expected to be. This finding is in line with the results of Georgiyev and Mihaylov (2014). The rho coefficient is not significant for $NH_3$ model. This means that the spatial Durbin model can be further simplified to SLX for $NH_3$.

## 4 Conclusion

On the basis of the results of spatial dependence and spillover effects of this study, transboundary pollution associated with local and global emissions exists in European countries. This implies that the more a country $i$ is surrounded by high (low) emissions countries, the higher (lower) its level of emissions is expected to be. Our further analysis using spatial Durbin model verifies that economic growth, energy consumption, population density and urbanization level are vigorous strengths of $SO_2$, $NO_x$, CO, VOC, and $CO_2$ emissions in European countries. Empirical findings of spatial Durbin models supports an inverted U-shaped relationship between income and $SO_2$, $NO_x$, CO, and $CO_2$ emissions for given term. The estimation results of the SDM model implies that economic growth could play a crucial role in the reduction of $SO_2$, $NO_x$, CO, and $CO_2$ emissions, and energy consumption, population density and urbanization have significant impact on pollution as well.

This study also finds a strong spatial relationship between $SO_2$, $NO_x$, CO, and $CO_2$ emissions and a country's own GDP per capita. In addition, our results indicate that greater economic growth of neighboring countries boosts a European country's $SO_2$, $NO_x$, and $CO_2$ emissions, and these emissions also decrease after a turning point. Since greater energy consumption in a country is found to have a positive impact on its local and global emissions.

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