# Economic development and multiple air pollutant emissions from the industrial sector

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Abstract

This study analyzed the relationship between economic growth and emissions of eight environmental air pollutants ($CO_2$, $CH_4$, $N_2O$, NOx, SOx, CO, NMVOC, and $NH_3$) in 39 countries from 1995 to 2009. We tested an environmental Kuznets curve (EKC) hypothesis for 16 individual industry sectors and for the total industrial sector. The results clarified that at least ten individual industries do not have an EKC relationship in eight air pollutants even though this relationship was observed in the country and total industrial sector level data. We found that the key industries that dictated the EKC relationship in the country and the total industrial sector are existed in $CO_2$, $N_2O$, CO, and NMVOC emissions. Finally, the EKC turning point and the relationship between economic development and trends of air pollutant emissions differ among industries according to the pollution substances. These results suggest inducing new environmental policy design such as the sectoral crediting mechanism, which focuses on the industrial characteristics of emissions.

Keywords: environmental Kuznets curve, air pollution, industrial sector, key industry, sectoral crediting mechanism, industrial characteristics

## 1. Introduction

Industrial sectors discharge large amounts of pollutants into the air. These emissions cause severe damage to human respiratory and cardiovascular systems, increasing incidences of premature mortality as well as hospital admissions and outpatient visits (Kan and Chen, 2004; Levy and Greco, 2007; Fujii et al. 2013). To efficiently reduce air pollutant emissions, emissions forecasting can be useful for selecting appropriate environmental policies to balance social cost and economic losses. Additionally, the identification of a relationship between economic activities and emissions levels is important to forecast the future.

There are many earlier studies focusing on the relationship between environmental pollutant emissions and economic development; this relationship is called the environmental Kuznets curve (EKC) hypothesis.[1] From this research, findings addressing those pollutants that cause local environmental problems (e.g., acid rain or river pollution) often support the EKC. Typical local pollutants are sulfur dioxide ($SO_2$) and nitrogen oxide (NOx). However, it is often noted that emissions related to global environmental problems (e.g., $CO_2$ for climate change) do not support an inverted U-shaped curve relationship with economic growth.

In most previous studies addressing the relationship between environmental pollutant emissions and economic growth, the applied data are cross-country (regional) or are from all industries within one country but do not include individual industrial characteristics. Cross-country EKC analysis tends to show the close relationship between environmental emissions and gross domestic product (GDP) or related policy variables (Farzin and Bond, 2006; Wagner, 2008; Galeotti et al., 2009; Tsurumi and Managi, 2010).

[1] The EKC hypothesis has been tested in many countries using various pollutant data. EKC studies addressing $SO_2$ emission and NOx emission are mainly from the 1990s and early 2000s (see Dinda, 2004; Stern, 2004). In recent EKC studies, most focus on $CO_2$ emissions, such as in Scotland (Turner and Hanley, 2011), in Spain (Esteve and Tamarit, 2012), 27 EU countries (Lopez-Menendez et al., 2014), 7 Arctic countries (Baek, in print), 19 OECD countries (Wang, 2013), Turkey (de Vita et al., 2015), Vietnam (Al-Mulali et al., 2015), 14 Asian countries (Apergis and Ozturk, 2015) and Tunisia (Jebli and Youssef, 2015).

Here, we consider the mechanism of the EKC. Grossman and Krueger (1995) suggested three factors as keys to understanding the shape of the EKC. These factors are (1) economic scale, (2) technology level, and (3) industrial composition effects. The industrial composition effect is especially difficult to interpret with respect to the EKC (Tsurumi and Managi, 2010). Additionally, Steinbuks (2012) suggests using industry level data to avoid the measurement error associated with aggregation over industries. It is clear that the required investment and combustion technologies of fossil energy vary by industry based on the usage of energy inputs (e.g., intermediate materials or combustion). That is, pollution intensity and abatement costs differ across industries. Therefore, we establish the following research hypothesis:

**Research hypothesis 1**

*There are some industrial sectors that do not have an inverted U-shape relationship between sectoral pollutant emissions per capita and economic development even though an inverted U-shape curve is observed in country or industrial sector level data.*

This hypothesis represents the observation that the EKC relationship at the country or industrial sector level observed in previous literature is mainly caused by industrial structure change instead of technical change or economic scale change. Therefore, we assume that there are some industrial sectors that will not have the observed EKC relationship if we directly control for effects from industrial structure change.

Fujii and Managi (2013) propose estimating the EKC relationship by separately controlling for economic scale and technology according to the type of industry. Following Fujii and Managi (2013), this study applies the estimation model separately to each type of industry. Thus, we discuss the EKC relationship in the context of detailed compositional differences in industrial characteristics and types of air pollution substances. Therefore, the objective of this study is to clarify the relationship between economic development and sector-level air pollution emissions.

**Research hypothesis 2**

*There are key industrial sectors that dictate the EKC relationship at the total industrial sector or country level.*

The second hypothesis states that the observed EKC relationship at the total industrial sector or entire country level strongly depends on the performance of several key industries. It is clear that industries that contribute a high ratio of air pollutant emissions in relation to the entire industry play an important role in reducing air pollutants. However, the difficulty of emission reductions is that industries do not always show the same trend with their share of emissions. We assume that some industries decrease their air pollutant emissions with economic growth, while the other industries share a low ratio of emissions across the entire industrial sector.

We can observe various scenarios in an EKC relationship. The first case is when an industry with a high ratio of emissions decreases those emissions through economic development. In this case, the key industries are identified as those industries that share a high ratio of emissions. The second case is when an industry with a high ratio of emissions does not reduce emissions through economic development. Meanwhile, other industries with low emission ratios reduce those emissions rapidly with economic development. In this case, the key industries in the observed EKC relationship are the latter industries with low emission ratios. Thus, our second research hypothesis tries to clarify how the EKC relationship of each air pollutant is constructed, focusing on key industries.

The main objective of this study is to examine the possibility of an EKC relationship between multiple air pollutant emissions and economic development when controlling for the industrial structure composition effect. Another objective is to identify the key industries that dictate the EKC relationship for the emission of each air pollutant (i.e., the identification of key industries in the EKC). These objectives are not clarified in previous research, and we believe that they are novel.

## 2. Methodology

We apply a panel regression analysis to the environmental Kuznets curve (EKC) relationship. To examine the relationship between environmental pollutants and economic development, we consider the specifications shown in equations (1) and (2). The relationships are assumed to be quadratic or cubic.

$$Pollutionper_{ijk}^{t} = \beta_1 \cdot GDPper_k^t + \beta_2 \cdot (GDPper_k^t)^2 + \mathbf{X\beta} + \eta_k + \mu^t + \varepsilon_k^t \tag{1}$$

$$Pollutionper_{ijk}^{t} = \beta_1 \cdot GDPper_k^t + \beta_2 \cdot (GDPper_k^t)^2 + \beta_3 \cdot (GDPper_k^t)^3 + \mathbf{X\beta} + \eta_k + \mu^t + \varepsilon_k^t \tag{2}$$

To capture those country characteristics influencing GDP per capita *(GDPper)*, control variable vector $\mathbf{X}$ is incorporated into the models. $\eta$ and $\mu$ are unobserved country- and time-specific fixed effects, respectively. $\varepsilon$ is an idiosyncratic error term. $\beta$ are the estimated coefficients. We estimate the quadratic and cubic models by applying a random effect generalized least squares regression and a fixed effect generalized least squares regression.

The vector $\mathbf{X}$ represents country characteristics. Based on the above equations, we use five control variables (defined below), which include (1) high pollution intensity fossil fuel dependency (DEPEND), (2) energy efficiency (EE), and (3) skilled labor (SKILLED). These three variables are applied to control for the technology level. Additionally, we use (4) industrial value share (SHARE), which is applied to control for the scale and (5) the country's political situation (POLITY). By applying these control variables, we try to control for each country's characteristics in the estimation. To analyze the EKC relationship by type of pollutant, we calculate the quadratic and cubic models using environmental pollution emissions per capita separately as a dependent variable.

We define the DEPEND variable as the share of coal and oil energy use in total energy use, as calculated by the amount of coal and oil energy consumed in relation to total energy use. According to Barros et al. (2012) and Barros et al. (2013), choice of clean and dirty energy is important to understand the trend of environmental pollution due to fuel combustion. Therefore, we focus on the pollution intensive fossil fuels such as coal and oil in this study. DEPEND can be reduced by decreasing the coal and oil energy use share in total energy consumption. DEPEND controls the level of use of dirty energy, which generates air pollution in the combustion process. A detailed definition of coal and oil energy is included in appendix A1.

Second, the energy efficiency (EE) indicator, which indicates efficient energy use, is calculated as industrial value added in relation to total energy use. This indicator can be increased by increasing the amount of unused or "saved" energy due to technological improvements in energy use. Third, the SHARE indicator is calculated by dividing each industry sector's value added by GDP, yielding each industrial sector's share of value added in total GDP. This indicator (e.g., SHARE, k) decreases if the value added of industry k decreases more quickly than GDP or if the value added of industry k increases more slowly than GDP. This indicator captures the scale effect of industrial production activities relative to the country's economic activities.

Fourth, the high-skilled labor ratio (SKILLED) is calculated by recording the number of high-skilled persons employed in relation to the total number of employees (share in total employees). Highly skilled labor contributes to the design of an efficient production process that can promote energy savings and pollution prevention. Finally, we use the polity variable (POLITY) to control for the country's political situation. Corrupted or unstable governments disturb industrial development and disrupt the enforcement of environmental policy in pollution abatement activities. As Leitão (2010) noted, "Higher corruption delays governments' concerns and control for environmental quality, postponing stricter environmental laws and stricter enforcement of those laws". Additionally, decision makers at companies hesitate to invest in expensive efficient modern production equipment if they have concerns about the economic environment of the country. Thus, we use the POLITY variable to control for the effect of the political environment on emissions.

## 3. Data

Our dataset is from 39 countries and 14 industries and covers 1995 to 2009 (see Table 1). We took the industrial value added (or efficient energy use), the amount of energy consumed, the skilled labor ratio, and the air pollution data from the World Input Output Database (WIOD) (Timmer, 2012). The industrial value added data are deflated to 2005 prices (U.S.$). The price deflator is also found in the WIOD data. We apply the International Energy Agency's energy type clarification for the DEPEND variables (see appendix Table A1).

Air pollution data include Carbon Dioxide ($CO_2$), Methane ($CH_4$), Nitrous oxide ($N_2O$), Nitrogen oxide (NOx), Sulfur oxide (SOx), Carbon monoxide (CO), (Non-Methane Volatile Organic Compounds) NMVOC, and Ammonia ($NH_3$) from the WIOD. $CO_2$ emissions are critical air pollutants that have been found to drive climatic change. The other seven air pollutants also critically impact human health, biodiversity, crop success, urban ozone, and global warming problems (de Leeuw, F., 2002; Tollefsen et al., 2009).

<Table 1 about here>

GDP and population data are observed from the World Development Indicator database. GDP data are deflated to 2005 prices. The polity variable is from the Worldwide Governance Indicators (WGI) published by WorldBank. The WGI evaluates each country's policy using six criteria: [1] Voice and Accountability, [2] Political Stability and Absence of Violence/Terrorism, [3] Government Effectiveness, [4] Regulatory Quality, [5] Rule of Law, and [6] Control of Corruption. The WGI score ranges from one to five, and a higher score indicates greater freedom. In this study, we use the numerical average of the six WGI scores to represent the degree of political freedom for industrial activities. We created 18 panel datasets with 585 samples (39 countries x 15 years) by industry type. The average data score of each industrial dataset is shown in Table 2.

<Table 2 about here>

## 4. Results

### 4-1. Definition of the EKC relationship

We conducted a model specification F-test to assess the quadratic and cubic effects of GDP per capita. Then, to estimate the sectoral air pollutant emissions per person, we applied the most preferable functional form following the results of the F-test. Additionally, we select the preferable specification—fixed effects or random effects—using the Hausman test results. We also estimated the correlation score and variance inflation factor (VIF) of the independent variable to check for multicollinearity problems. If the VIF scores of all control variables are below 6.0, we conclude that there are no multicollinearity problems in our estimation.

Here, we define the pattern of the relationship between economic development and air pollutant emissions using the coefficient parameter combination from the panel regression analysis. Following Lopez-Menendez et al. (2014) and Balsalobre et al.(2015), we categorize the patterns of the relationships using coefficient parameters $\beta_1$ , $\beta_2$ ,and $\beta_3$ estimated by equations (1) and (2). We summarize the patterns of the relationships in Table 3. Seven patterns for the relationships are described in Table 3. Each relationship pattern is defined by a parameter sign and the GDP per capita of the turning point's (TP's) coordinates. This study defines the inverted U-shape as an EKC relationship.

<Table 3 about here>

Table 4 shows the GDPper score of the TPs' coordinates for the observed EKC relationships. Three patterns for the relationship between air pollutants and economic development have the potential to yield an EKC relationship. We consider the N-shape and the inverted N-shape curve with two TPs to describe the same trend as the inverted U-shape curve if the TPs have the condition described in Table 4.

<Table 4 about here>

First, the inverted U-shape relationship can be identified as an EKC if the TP is not close to zero and the absolute value of GDPper at the TP's coordinates are below three standard deviations (σ) of the mean value of GDPper. This describes an EKC because the inverted U-shape curve has almost the same trend as a monotonically decreasing curve if the TP is close to zero (see Appendix Figure A1). Similarly, the inverted U-shape curve has almost same trend as a monotonically increasing curve if the TP is beyond three σ of the mean GDPper score in the data sample.[2] In the latter case, it is not expected that air pollution will decrease with economic growth in the short term because only a few of the countries are located beyond the GDP per capita level of the TP's coordinates. Therefore, we do not identify the inverted U-shape curve without the conditions for the TP from Table 4.

Second, we can identify the N-shape curve condition in Table 4 as an EKC relationship because it has almost the same trend as the inverted U-shape curve if the GDPper at the TP's coordinates satisfies the condition in Table 4. In other words, the N-shape curve can be understood as an inverted U-shape curve if there is a monotonically decreasing relationship in the area beyond first TP's coordinate. As we explain above, it is more realistic to understand the U-shape or inverted U-shape curve as a monotonic relationship if the GDPper values at the TP's coordinates are extremely high or low. The N-shape curve in the area beyond the first TP's coordinates has a U-shape curve (see Appendix Figure A2). Therefore, the N-shape curve can be understood as an

[2] Under a nominal distribution, 99.7% of data are located between mean value ± three times of standard deviation. Therefore, the score located out of this data range can be understood as an extreme value.

inverted U-shape curve in the short term if the second TPs' coordinates can satisfy the condition in Table 4. Similarly, the inverted N-shape curve is also identified as an EKC relationship if both the lower and higher TPs' coordinates satisfy the condition in Table 4.

## 4-2. Results of country and industry level data

The coefficient scores for GDP per capita are summarized in Table 5. Additionally, we estimate the predicted value of air pollutant emissions per capita using the panel regression results (see Appendixes Table A3 to Table A10 for specification results). In Table 5, each alphabet symbol represents the type of relationship between pollutant emissions per capita and GDP per capita: "L" represents linear, "Q" is quadratic, "C" means cubic, and "N.S." indicates a non-significant relationship. Each coefficient has a positive or a negative sign, which we put in parentheses. Additionally, we describe the coordinate data for GDP per capita (1,000 US$) if the functional form has a TP. If the cubic functional form does not have a TP, we put the word "monotonic" in parentheses. The bold letter represents the EKC relationship observed in the estimation results.

<Table 5 about here>

From Table 5, we observe the following relationships using country level data. (1) An inverted U-shape curve is observed in the $CO_2$ case. (2) The N-shape relationship is observed in the $CH_4$, $N_2O$, NMVOC, and $NH_3$ cases. (3) The inverted N-shape relationship is observed in the NOx and SOx cases. Next, we identify the EKC relationship using the TPs' coordinates from Table 4. Because the mean value plus three σ of GDPper in our data sample is $69,688[3], we apply this score to represent the upper limit of the TPs' coordinates to identify the EKC relationship.

From Table 4 and Table 5, we can observe that $CO_2$, $CH_4$, $N_2O$, NMVOC, and $NH_3$ emissions have an EKC relationship on the country level, and $CO_2$, $N_2O$, CO, NMVOC emissions have an EKC relationship on the total industry level. Therefore, $CO_2$, $N_2O$ and NMVOC emissions are observed to have EKC relationships on both the country level and the total industry level. However, $CH_4$ and $NH_3$ emissions do not have an EKC relationship on the total industry level even though one is observed on the country level. Additionally, the predicted values of air pollutant emissions described as a line chart in the appendix (Figure A3 to Figure A10) trend differently between country and industry for $CH_4$, $N_2O$, NOx, CO, NMVOC, and $NH_3$ emissions.

The interpretation of these results is that these emissions' share of the industrial sector on the country level is low (see Table 2). Therefore, the emissions change in the industrial sector does not strongly affect the emissions trend at a country level. In addition, the pollution generation mechanisms and the abatement activities differ among emitters.[4] The main emitters of $CH_4$ and $NH_3$ are cattle and animals; these emissions are difficult to abate with the types of equipment introduced in industrial plants. These types of issues drive differences in emissions with economic development trends between the country and industry levels.

In table 5, we do not observe an EKC relationship for NOx and SOx emissions. These results differ from several previous studies that indicated an EKC relationship for sulfur

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[3] Only Luxembourg has a GDPper beyond the mean value plus three σ. The mean value minus three σ is -$27,607.

[4] The U.S. EPA (2015) notes that "Ruminant animals (e.g., cattle, buffalo, sheep, goats, and camels) are the major emitters of CH4 because of their unique digestive system. Ruminants possess a rumen, or large "fore-stomach," in which microbial fermentation breaks down the feed they consume into products that can be absorbed and metabolized." Behera et al. (2013) explain that most of the $NH_3$ emissions are from the agricultural sector.

emissions (Cole et al., 1997; Selden and Song, 1994; Stern and Commons, 2001). The primary reason for the different result is that the research periods covered differ. Previous research that supported an EKC relationship for sulfur emission were analyzed using mainly 1970s and 1980s data. Meanwhile, this study uses a dataset from 1995 to 2009. Because fossil fuel combustion equipment and pollution abatement technologies were developed in the 1990s, developing countries can now introduce highly efficient machines at a relatively low cost compared with previous decades. The modernization of pollution abatement technologies allows developing countries to leapfrog the traditional pattern of increasing air pollution emissions with economic development (Bhupendra and Sangle, 2015).

### 4-3. Verification of research hypotheses

Next, we discuss the results by focusing on the two research hypotheses introduced in chapter 1. The first research hypothesis assumes that there are some industrial sectors that do not have an EKC relationship even though this relationship is observed at a country level or a total industrial sector level. From the previous section, we clarify that the $CO_2$, $CH_4$, $N_2O$, NMVOC, and $NH_3$ emissions have an EKC relationship on the entire country level, and $CO_2$, $N_2O$, CO, NMVOC emissions have the EKC relationship in total industrial sectors.

Table 5 indicates that there are many industrial sectors that do not have an EKC relationship (hereafter, non-EKC industries). We observe fourteen, thirteen, and eleven non-EKC industries from the model using $CO_2$, $N_2O$, and NMVOC emissions, respectively. Additionally, results from the model using $CH_4$, CO, and $NH_3$ emissions are also included in the non-EKC industries, even though the EKC relationship is observed on the country level or the total industry level. Therefore, we consider the first research hypothesis to be supported in the cases of $CO_2$, $CH_4$, $N_2O$, CO, NMVOC, and $NH_3$ emissions. However, the first research hypothesis is not confirmed with regard to SOx and NOx emissions because the EKC relationship is not observed on the country or the total industry level.

Next, we discuss the second research hypothesis by focusing on the key industry dictating the EKC relationship. We particularly consider $CO_2$, $N_2O$, and NMVOC emissions, which have an EKC relationship on both the country and the industry level. To clarify the key industry, we apply a panel regression analysis using country and industry data and deduct each industry's data. In other words, we confirm the EKC relationship by using country and industry data and then exclude each industry's data. Here, we explain the estimation process using the food industry as an example. In this case, the emissions data are set as "emissions data of country – emission data of food industry" and each control variable is set as "control variable of country data – control variable of food industry".[5] We identify the food industry as the key industry if the EKC relationship is not observed in the estimation results after deducting the food industry data.

Table 6 represents the results of the key industry identification. In table 6, we focus only on the emissions data, which detect the EKC relationship at the country and total industry level. The bold letters indicate that the EKC relationship is not observed in the deducted data. From Table 6, we identify the oil industry as the key industry dictating the EKC relationship for NMVOC emissions at the country and total industry levels. Additionally, the metal industry is identified as the key industry dictating the EKC relationship for $CO_2$ and CO emissions at the total industry level. Third, the construction industry is identified as the key industry for $N_2O$ emission in the total industry level data. Therefore, we consider the second research hypothesis to be supported by NMVOC emissions at the country level and $CO_2$, $N_2O$, CO,

[5] Several control variables are defined as the ratio scale. In these example cases, we deduct both the numerator and denominator country data by the same for food industry data.

NMVOC emissions at the total industry level.

<Table 6 about here>

In our estimation, we observed five key industries that had an EKC relationship on both the country and industry levels. The results in table 6 imply that NMVOC emissions and CO emissions would decrease monotonically with economic development if air pollution management was successfully introduced into the key industries. Therefore, the oil and metal industries have important roles in decreasing NMVOC emissions and CO emissions, respectively.

Surprisingly, the electricity sector is not identified as a key industry, even though its share of emissions is high (see table 2). One interpretation of this result is that air pollution emissions from the electricity sector strongly depend on the method of power generation. Air pollution is emitted from thermal power generation, but little air pollution is emitted from hydro and nuclear power generation. Electricity generation portfolios are diverse among the countries in our sample and are more strongly affected by the characteristics of the geography, resources, and disaster conditions than by the economic development stage. Therefore, the electricity sector does not exhibit an EKC relationship and is not a key industry in air pollution emissions.

## 5. Conclusion and policy implication

This study investigated how differences in industry and type of air pollutants affect the relationship between economic growth and air pollutant emissions. We tested the EKC for 16 industrial sectors. From the results, we found that the EKC turning point and the relationship between GDP per capita and sectoral environmental pollutant emissions differed across industries and type of air pollutant.

We also clarified that several industries did not have an EKC relationship even though an EKC relationship is observed in country and total industrial sector data. Another finding is that key industries that dictate the EKC relationship at the country and total industrial sector levels differed by air pollutants. In addition, we found that the EKC turning points and the relationship between GDP per capita and sectoral environmental pollutant emissions differed across industries and types of air pollutant.

Two policy implications from this study are available. Firstly, the results of this study can suggest the priority for air pollutant reduction considering industrial characteristics and pollutant emission trend with economic development. According to UNEP (2013) and IPCC (2014), effects of air pollution for human health and climate change issue is different among substances. Additionally, the abatement cost of each air pollutant substances differ among industries. Under budget constraint for air pollution control, each country can set the reduction strategy referring relationship between economic development and air pollution emissions by industries.

Second policy implication is about new pollution control mechanism considering industrial characteristics. Differences of turning points and relationship between economic development and pollution emission trends tell us the importance of establishing the emission targets of air pollutants and creating a system to achieve sustainable development. Additionally, the ability to forecast emissions based on economic development could be helpful in estimating the potential magnitude of environmental problems. If we could detect conditions in which economic development leads to increased air pollution, we might be able to treat the source of emissions earlier and at a lower cost. We believe that this research results suggest inducing new environmental policy design such as the Sectoral Crediting Mechanism (SCM), which focuses on the industrial characteristics of emissions (Cai et al., 2012).

Further research should investigate the relationship between economic growth and air pollution from the services and household sectors, including the transportation system in addition to industrial sectors. Such an analysis could clarify this causal relationship in relation to industrial characteristics. Based on individual EKC relationships, we can foster the effective environmental policies needed by each country to achieve sustainable development.

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Table 1. Description of sample

| | |
|---|---|
| Country Name(38) | Australia, Austria, Belgium, Bulgaria, Brazil, Canada, China, Cyprus, Czech Republic, Germany, Denmark, Spain, Estonia, Finland, France, United Kingdom, Greece, Hungary, Indonesia, India, Ireland, Italy, Japan, Korea, Lithuania, Luxembourg, Latvia, Mexico, Malta, Netherlands, Poland, Portugal, Romania, Russia, Slovak Republic, Slovenia, Sweden, Turkey, United States |
| Industry name and code (16) | [1] Whole Country (ALL)<br>[2] Industrial sector total (INDUSTRY)<br>[3] Mining and Quarrying (MINING) [secC]<br>[3] Food, Beverages and Tobacco (FOOD) [sec15, sec16]<br>[4] Textiles and Textile Products (TEXTILE) [sec17, sec18]<br>[5] Leather, Leather and Footwear (LEATHER) [sec19]<br>[6] Wood and Products of Wood and Cork (WOOD) [sec20]<br>[7] Pulp, Paper, Paper , Printing and Publishing (PULP) [sec21, sec22]<br>[8] Coke, Refined Petroleum and Nuclear Fuel (OIL) [sec23]<br>[9] Chemicals and Chemical Products (CHEMICAL) [sec24]<br>[10] Rubber and Plastics (RUBBER) [sec25]<br>[11] Other Non-Metallic Mineral (MINERAL) [sec26]<br>[12] Basic Metals and Fabricated Metal (METAL) [sec27, sec28]<br>[13] Machinery, Nec (MACHINE) [sec29]<br>[14] Electrical and Optical Equipment (ELECTRIC PRODUCT) [sec30-sec33]<br>[15] Transport Equipment [sec34, sec35]<br>[16] Electricity, Gas and Water Supply (ELECTRICITY) [secE]<br>[17] Construction [secF] |
| Year (15) | 1995-2009 |

Note 1: Industry type is categorized by International Standard Industrial Classification of All Economic Activities Revision.3.1 (ISIC Rev.3.1) defined by United Nations.

Note 2: Name in parentheses shows abbreviated form of industry name. Code in square bracket represent industry code in ISIC Rev.3.1.

## Table 2. Data description by industry

| | $CO_2$ | $CH_4$ | $N_2O$ | NOx | SOx | CO | NMVOC | $NH_3$ | GDPper | DEPEND | EE | SHARE | SKILLED | POLITY |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | 1,000 ton-$CO_2$ | ton | ton | ton | ton | ton | ton | ton | Million US$ per person | % | Million US$ Tera joule | % | % | WGI score |
| All | 450,465 | 4,683,536 | 171,580 | 1,689,124 | 1,849,935 | 6,039,252 | 1,614,492 | 508,160 | 0.021 | 49.7% | 0.086 | 74.17% | 20% | 3.356 |
| Indstry | 349,284 | 1,430,687 | 19,779 | 820,879 | 1,417,196 | 2,890,574 | 881,927 | 10,019 | 0.021 | 44.0% | 0.037 | 16.92% | 18% | 3.357 |
| Mining | 16,257 | 1,139,848 | 254 | 49,758 | 29,563 | 187,317 | 69,274 | 5,348 | 0.021 | 47.5% | 0.068 | 0.68% | 13% | 3.356 |
| Food | 7,781 | 3,747 | 326 | 35,517 | 28,577 | 63,373 | 82,864 | 268 | 0.021 | 32.0% | 0.110 | 1.51% | 12% | 3.356 |
| Textile | 3,267 | 665 | 84 | 12,669 | 11,181 | 50,059 | 17,360 | 20 | 0.021 | 35.2% | 0.144 | 0.68% | 12% | 3.356 |
| Leather | 236 | 146 | 7 | 981 | 873 | 3,979 | 2,873 | 2 | 0.020 | 39.9% | 0.208 | 0.10% | 12% | 3.334 |
| Wood | 1,310 | 1,083 | 85 | 9,000 | 4,555 | 33,718 | 13,105 | 27 | 0.021 | 24.8% | 0.101 | 0.40% | 12% | 3.356 |
| Pulp | 5,291 | 2,007 | 271 | 28,408 | 24,787 | 43,842 | 19,954 | 141 | 0.021 | 25.9% | 0.135 | 1.01% | 14% | 3.356 |
| Oil | 17,055 | 22,065 | 374 | 28,206 | 102,104 | 887,508 | 231,609 | 48 | 0.020 | 70.8% | 0.062 | 0.25% | 15% | 3.334 |
| Chemical | 19,287 | 14,234 | 13,265 | 41,791 | 67,631 | 136,269 | 131,877 | 3,004 | 0.021 | 32.6% | 0.088 | 1.23% | 15% | 3.356 |
| Rubber | 1,538 | 290 | 95 | 5,558 | 4,649 | 17,752 | 11,780 | 22 | 0.021 | 28.3% | 0.202 | 0.50% | 13% | 3.356 |
| Mineral | 30,771 | 4,499 | 439 | 86,205 | 62,204 | 123,295 | 53,416 | 611 | 0.021 | 51.1% | 0.041 | 0.59% | 12% | 3.356 |
| Metal | 35,701 | 16,306 | 448 | 58,597 | 86,191 | 814,759 | 53,069 | 166 | 0.021 | 35.4% | 0.073 | 1.46% | 13% | 3.356 |
| Machine | 2,192 | 452 | 74 | 7,542 | 5,021 | 24,311 | 9,509 | 36 | 0.021 | 40.8% | 0.332 | 0.96% | 13% | 3.356 |
| Electric | 1,748 | 327 | 90 | 7,191 | 5,915 | 23,311 | 8,767 | 31 | 0.021 | 38.3% | 0.623 | 1.99% | 15% | 3.356 |
| Transport equ | 2,392 | 439 | 103 | 8,280 | 4,890 | 26,037 | 21,215 | 27 | 0.021 | 32.2% | 0.275 | 1.00% | 14% | 3.356 |
| Electricity | 197,877 | 223,496 | 3,480 | 377,795 | 960,610 | 326,894 | 32,723 | 122 | 0.021 | 43.4% | 0.006 | 1.42% | 21% | 3.356 |
| Construction | 6,582 | 1,082 | 384 | 63,381 | 18,445 | 128,149 | 122,532 | 146 | 0.021 | 74.5% | 0.434 | 3.15% | 10% | 3.356 |

*Note*: Because we drop the Luxemburg which has missing value, GDPper and polity variable of leather industry and oil industry is different with others.

Table 3. Pattern of relationship in first quadrant

| | [1] N-shape | [2] Inverted N-shape | [3]U-shape | | [4]Inverted U-shape | | [5]Monotonically Increasing | | | | [6]Monotonically decreasing | | | | [7] Level |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | (1) | (2) | (1) | (2) | (1) | (2) | (3) | (4) | (1) | (2) | (3) | (4) | |
| $\beta_1$ | Any | Any | <0 | Any | >0 | Any | >0 | >0 | Any | Any | <0 | <0 | Any | Any | N.S. |
| $\beta_2$ | Any | Any | >0 | Any | <0 | Any | N.S. | >0 | >0 | Any | N.S. | <0 | >0 | Any | N.S. |
| $\beta_3$ | >0 | <0 | N.S. | >0 | N.S. | <0 | N.S. | N.S. | >0 | >0 | N.S. | N.S. | <0 | <0 | N.S. |
| GDPper of TP's coordinate | >0 | >0 | >0 | >0 and <0 | >0 | >0 and <0 | N.O. | <0 | <0 | N.O. | N.O. | <0 | <0 | N.O. | N.O. |

Note1. N.S. indicates parameter is not significantly reject the null hypothesis assuming parameter equal to zero

Note2. N.O. shows that not observed.

Table 4. The GDP per capital condition of TP's coordinate for EKC relationship

| | Lower GDPper of TP's coordinate | Higher GDPper of TP's coordinate |
|---|---|---|
| Inverted U-shape | (1) $\lvert GDPper^{TP} \rvert < Mean\ value\ of\ GDPper\ \pm 3\sigma$ and (2) $GDPper^{TP}$ is not close to zero | Not available for second TP |
| N-shape | (1) $\lvert GDPper^{TP} \rvert < Mean\ value\ of\ GDPper\ \pm 3\sigma$ and (2) $GDPper^{TP}$ is not close to zero | (1) $GDPper^{TP} > Mean\ value\ of\ GDPper + 3\sigma$ |
| Inverted N-shape | (1) $GDPper^{TP} < Mean\ value\ of\ GDPper - 3\sigma$ and (2) $GDPper^{TP}$ is negative value | (1) $\lvert GDPper \rvert < Mean\ value\ of\ GDPper\ \pm 3\sigma$ and (2) $GDPper^{TP}$ is not close to zero |

Note. $\lvert GDPper^{TP} \rvert$ represents absolute value of GDPper at TP's coordinate. $\sigma$ represent standard deviation of GDPper data in whole sample.

Table 5. Summary of estimation results

| | $CO_2$ | $CH_4$ | $N_2O$ | NOx | SOx | CO | NMVOC | $NH_3$ |
|---|---|---|---|---|---|---|---|---|
| All | **Q[-] (39.8)** | **C[+] (18.1, 90.0)** | **C[+] (23.5, 94.2)** | C[-] (18.2, 56.0) | C[-] (40.0, 70.7) | N.S. | **C[+] (10.6, 91.2)** | **C[+] (14.6, 98.4)** |
| Industry | **C[+] (37.0, 148.5)** | C[+] (14.5, 64.5) | **C[+] (22.5, 70.8)** | C[-] (monotonic) | C[-] (44.4, 70.5) | **Q[-] (28.7)** | **C[+] (18.8, 79.3)** | C[-] (26.8, 71.1) |
| Mining | Q[-] (78.2) | Q[+] (73.4) | L[+] | C[-] (10.1, 61.0) | C[-] (37.6, 73.1) | N.S. | L[-] | **C[+] (32.8, 78.4)** |
| Food | L[+] | C[+] (10.1, 52.8) | N.S. | Q[-] (-0.2) | Q[+] (85.5) | Q[+] (30.2) | C[-] (18.4, 61.4) | C[-] (42.1, 81.5) |
| Textile | C[+] (-5.0, 43.4) | N.S. | **Q[-] (13.4)** | C[-] (monotonic) | C[-] (36.1, 73.7) | C[+] (6.1, 49.8) | L[-] | N.S. |
| Leather | C[+] (-15.8, 37.7) | Q[+] (37.8) | Q[+] (60.3) | Q[+] (35.3) | Q[+] (38.7) | L[-] | Q[+] (38.0) | Q[+] (25.9) |
| Wood | **Q[-] (31.5)** | Q[+] (49.4) | C[+] (2.9, 62.9) | **Q[-] (5.8)** | C[-] (37.8, 74.1) | C[+] (6.9, 61.1) | C[+] (-6.2, 75.3) | N.S. |
| Pulp | C[+] (9.1, 52.3) | N.S. | N.S. | Q[-] (-7.6) | Q[+] (72.2) | C[+] (9.1, 44.9) | **C[+] (15.0, 72.4)** | C[-] (8.1, 73.5) |
| Oil | C[+] (27.2, 42.6) | N.S. | C[+] (15.8, 42.9) | Q[+] (46.8) | Q[+] (38.7) | N.S. | **Q[-] (35.0)** | Q[+] (39.8) |
| Chemical | N.S. | **C[+] (33.4, 70.2)** | **C[+] (18.5, 72.8)** | C[-] (monotonic) | C[-] (50.9, 69.0) | C[-] (12.5, 42.7) | C[+] (-1.9, 85.0) | N.S. |
| Rubber | N.S. | C[-] (24.5, 81.7) | Q[+] (59.9) | C[-] (monotonic) | C[-] (40.2, 72.8) | L[-] | **C[+] (25.5, 71.7)** | C[-] (26.3, 78.1) |
| Mineral | **C[-] (-101.0, 52.5)** | **C[+] (37.0, 81.5)** | **C[-] (-18.2, 69.0)** | **Q[-] (25.2)** | C[-] (31.7, 80.1) | L[+] | **C[+] (27.9, 77.3)** | N.S. |
| Metal | C[-] (10.0, 37.0) | N.S. | N.S. | C[-] (monotonic) | C[-] (monotonic) | **C[-] (-9.7, 53.0)** | **C[+] (14.6, 88.2)** | N.S. |
| Machine | C[-] (18.2, 58.5) | C[-] (54.8, 65.8) | Q[+] (82.3) | C[-] (18.7, 33.9) | C[-] (42.7, 63.3) | L[-] | N.S. | L[+] |
| Electric | N.S. | Q[+] (50.8) | N.S. | C[-] (17.8, 34.3) | C[-] (50.7, 60.6) | C[+] (13.4, 49.4) | C[+] (16.6, 62.9) | C[-] (17.5, 67.7) |
| Transport equ | C[+] (16.2, 44.5) | C[+] (11.0, 49.2) | Q[+] (72.9) | C[-] (monotonic) | C[-] (43.4, 65.7) | C[+] (8.9, 44.9) | Q[+] (88.7) | N.S. |
| Electricity | C[+] (monotonic) | C[+] (26.7, 58.0) | Q[-] (70.9) | C[+] (-4.0, 69.1) | C[-] (42.6, 77.7) | Q[+] (36.4) | N.S. | C[-] (14.5, 74.0) |
| Construction | C[+] (monotonic) | Q[+] (46.1) | C[+] (20.6, 45.5) | **C[-] (-4.1, 32.7)** | C[-] (monotonic) | C[+] (7.5, 48.1) | **C[+] (17.2, 82.7)** | N.S. |

*Note1*: Each alphabet symbol represents the type of relationship between pollutant emissions per capita and GDP per capita.

L represents linear, Q shows the quadratic, C means cubic, and N.S. indicates not significant relationship, separately. Because coefficient has either positive or negative sign, we put the sign in parentheses. Additionally, we describe coordinate data of GDP per capita (1,000 US$) if functional form has the turning point. If cubic functional form does not have turning point, we put the word “monotonic” in parentheses.

*Note2:* The bold letters represents EKC relationship is observed.

Table 6. Results of key industry identifying

| | | *Country level data* | | | | | *Total industrial sector data* | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | | $CO_2$ | $CH_4$ | $N_2O$ | NMVOC | $NH_3$ | $CO_2$ | $N_2O$ | CO | NMVOC |
| | Country / Industry | Q[-] (39.8) | C[+] (18.1, 90.0) | C[+] (23.5, 94.2) | C[+] (10.6, 91.2) | C[+] (14.6, 98.4) | C[+] (37.0, 148.5) | C[+] (22.5, 70.8) | Q[-] (28.7) | C[+] (18.8, 79.3) |
| Deducted industry data | Mining | Q[-] (39.4) | C[+] (18.6, 91.3) | C[+] (23.3, 94.3) | C[+] (12.3, 90.4) | C[+] (19.2, 99.1) | C[+] (36.2, 144.9) | C[+] (22.1, 70.8) | Q[-] (34.1) | C[+] (20.0, 78.4) |
| | Food | Q[-] (39.9) | C[+] (18.0, 90.0) | C[+] (23.4, 94.1) | C[+] (11.7, 89.2) | C[+] (19.5, 98.4) | C[+] (37.0, 140.6) | C[+] (22.1, 70.7) | Q[-] (27.8) | C[+] (19.4, 78.5) |
| | Textile | Q[-] (39.9) | C[+] (18.0, 90.0) | C[+] (23.4, 94.2) | C[+] (11.1, 91.2) | C[+] (19.1, 98.8) | C[+] (36.3, 140.4) | C[+] (22.4, 70.7) | Q[-] (28.8) | C[+] (19.4, 79.3) |
| | Leather | Q[-] (39.7) | C[+] (18.0, 90.0) | C[+] (23.4, 94.2) | C[+] (10.7, 91.2) | C[+] (19.4, 98.7) | C[+] (37.0, 148.3) | C[+] (22.5, 70.8) | Q[-] (28.8) | C[+] (18.9, 79.3) |
| | Wood | Q[-] (39.7) | C[+] (18.0, 90.0) | C[+] (23.4, 94.5) | C[+] (10.5, 91.8) | C[+] (19.5, 98.6) | C[+] (36.8, 148.8) | C[+] (22.3, 70.8) | Q[-] (30.1) | C[+] (19.0, 79.4) |
| | Pulp | Q[-] (40.0) | C[+] (18.1, 90.0) | C[+] (23.4, 94.2) | C[+] (9.7, 93.9) | C[+] (14.5, 98.3) | C[+] (37.6, 151.9) | C[+] (22.2, 70.7) | Q[-] (29.0) | C[+] (18.9, 79.8) |
| | Oil | Q[-] (40.6) | C[+] (18.3, 89.6) | C[+] (23.0, 94.0) | **L[-]** | C[+] (20.0, 97.6) | C[+] (39.1, 131.8) | C[+] (19.7, 72.1) | Q[-] (33.5) | **C[+] (0.3, 83.6)** |
| | Chemical | C[-] (-140.6, 41.5) | C[+] (18.0, 90.3) | C[+] (23.9, 131.9) | C[+] (12.6, 92.6) | C[+] (19.6, 99.4) | C[+] (37.7, 162.2) | Q[-] (19.5) | Q[-] (29.7) | C[+] (20.2, 79.3) |
| | Rubber | Q[-] (39.8) | C[+] (18.1, 89.9) | C[+] (23.5, 94.0) | C[+] (10.4, 91.6) | C[+] (19.5, 98.6) | C[+] (37.0, 145.6) | C[+] (22.4, 70.6) | Q[-] (29.1) | C[+] (18.5, 79.3) |
| | Mineral | Q[-] (38.7) | C[+] (18.0, 90.1) | C[+] (23.4, 94.4) | C[+] (10.6, 91.6) | C[+] (19.7, 99.2) | C[+] (35.0, 128.4) | C[+] (22.6, 71.3) | Q[-] (27.1) | C[+] (18.8, 79.0) |
| | Metal | Q[-] (48.5) | C[+] (18.1, 89.4) | C[+] (23.5, 92.5) | C[+] (11.5, 89.8) | C[+] (19.2, 99.0) | **C[+] (monotonic)** | C[+] (22.0, 70.3) | **L[-]** | C[+] (19.1, 79.0) |
| | Machine | Q[-] (39.7) | C[+] (18.1, 89.9) | C[+] (23.5, 94.1) | C[+] (10.8, 91.0) | C[+] (19.4, 98.7) | C[+] (36.9, 144.9) | C[+] (22.4, 70.7) | Q[-] (28.8) | C[+] (18.8, 79.2) |
| | Electric | Q[-] (39.8) | C[+] (18.1, 89.9) | C[+] (23.5, 94.0) | C[+] (10.9, 91.4) | C[+] (19.5, 98.2) | C[+] (37.1, 147.5) | C[+] (22.3, 70.8) | Q[-] (28.4) | C[+] (19.1, 79.3) |
| | Transport equ | Q[-] (39.7) | C[+] (18.1, 90.0) | C[+] (23.5, 94.2) | C[+] (11.0, 91.6) | C[+] (19.5, 98.5) | C[+] (36.9, 149.8) | C[+] (22.4, 70.8) | Q[-] (28.8) | C[+] (18.8, 79.5) |
| | Electricity | C[-] (-51.5, 38.8) | C[+] (17.1, 91.8) | C[+] (21.5, 93.2) | C[+] (8.9, 89.0) | C[+] (11.7, 95.0) | C[-] (-155.6, 30.2) | C[+] (18.4, 72.1) | Q[-] (27.5) | C[+] (20.3, 77.4) |
| | Construction | Q[-] (38.7) | C[+] (18.6, 89.4) | C[+] (23.7, 93.6) | C[+] (12.6, 92.4) | C[+] (21.1, 95.7) | C[+] (37.3, 159.0) | **C[+] (24.4, 68.9)** | Q[-] (44.4) | C[+] (20.4, 79.7) |

*Note1*: Each alphabet symbol represents the type of relationship between pollutant emissions per capita and GDP per capita.
L represents linear, Q shows the quadratic, C means cubic, and N.S. indicates not significant relationship, separately. Because coefficient has either positive or negative sign, we put the sign in parentheses. Additionally, we describe coordinate data of GDP per capita (1,000 US$) if functional form has the turning point. If cubic functional form does not have turning point, we put the word "monotonic" in parentheses.
*Note2:* The bold letters represents EKC relationship is not observed.

## Appendix

Table A1. Definition of fuel type

| | |
|---|---|
| Coal (coal, coal product and peat) | *Anthracite, BKB/peat briquettes, Brown coal, Coal tar, Coke oven coke, Coking coal, Gas coke, Hard coal, Lignite, Other bituminous coal, Patent fuel, Peat, Sub-bituminous coal* |
| Oil (petroleum product and crude oil) | *Additives/blending components, Aviation gasoline, Bitumen, Crude oil, Crude/NGL/feedstocks, Ethane, Fuel oil, Gas/diesel oil, Gasoline type jet fuel, Kerosene type jet fuel, Liquefied petroleum gases (LPG), Lubricants, Motor gasoline, Naphtha, Natural gas liquids, Non-specified oil products, Other hydrocarbons, Other Kerosene, Paraffin waxes, Petroleum coke, Refinery feedstocks, Refinery gas, White spirit & SBP* |
| Natural gas | *Blast furnace gas, Coke oven gas, Gas works gas, Natural gas, Other recovered gases* |
| Electricity | *Elec/heat output from non-specified manufactured gases, Electricity, Electric boilers* |
| Renewable Energy | *Biodiesels, Biogases, Biogasoline, Charcoal, Other recovered gases, Municipal waste (renewable), Non-specified primary biofuels and waste, Other liquid biofuels, Primary solid biofuels, Geothermal, Other sources, Solar photovoltaics, Solar thermal, Tide, wave and ocean, Wind, Hydro* |

Table A2. Result of specification (dependent variable is $CO_2$ emission per capita)

| | All | Industry | Mining | Food | Textile | Leather | Wood | Pulp | Oil | Chemical | Rubber | Mineral | Metal | Machine | Electric product | Transport equipment | Electricity | Construction |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | coef. | coef. | coef. | coef. | coef. | coef. | coef. | coef. | coef. | coef. | coef. | coef. | coef. | coef. | coef. | coef. | coef. | coef. |
| GDPper | 0.31 ** | 0.21 ** | 0.01 ** | 0.00 ** | -0.00 | -0.00 ** | 0.00 ** | 0.01 ** | 0.04 ** | 0.00 | 0.00 | 0.03 ** | -0.06 ** | -0.00 | 0.00 | 0.00 | 0.23 ** | 0.01 ** |
| GDPper2 | -3.88 ** | -3.62 ** | -0.04 ** | -0.03 | -0.04 | -0.01 | -0.01 ** | -0.33 ** | -1.16 ** | -0.01 | -0.00 | -0.12 | 3.63 ** | 0.04 ** | -0.00 | -0.06 ** | -3.79 ** | -0.17 ** |
| GDPper3 | | 12.99 ** | | | 0.66 ** | 0.18 ** | | 3.54 ** | 11.04 ** | | | -1.59 ** | -51.48 ** | -0.33 ** | | 0.65 ** | 22.82 ** | 1.94 ** |
| DEPEND | 0.00 ** | 0.00 ** | 0.00 ** | 0.00 ** | 0.00 ** | -0.00 ** | 0.00 ** | 0.00 ** | 0.00 ** | 0.00 | 0.00 ** | 0.00 ** | 0.00 ** | 0.00 ** | 0.00 ** | 0.00 ** | 0.00 ** | -0.00 |
| EE | -0.00 ** | -0.00 ** | 0.00 | -0.00 ** | -0.00 ** | -0.00 ** | -0.00 ** | 0.00 | -0.00 | -0.00 ** | -0.00 ** | -0.00 ** | -0.00 ** | -0.00 ** | -0.00 ** | -0.00 ** | -0.01 ** | -0.00 ** |
| SHARE | 0.00 ** | 0.00 ** | -0.00 | -0.00 | 0.00 ** | 0.00 ** | 0.00 ** | 0.00 | -0.00 | 0.00 ** | 0.00 ** | 0.00 ** | 0.00 ** | 0.00 ** | 0.00 ** | 0.00 ** | 0.00 ** | 0.00 ** |
| SKILLED | -0.00 | 0.00 | 0.00 | -0.00 ** | -0.00 ** | -0.00 | 0.00 | -0.00 | -0.00 | -0.00 ** | -0.00 | -0.00 ** | -0.00 | -0.00 | -0.00 ** | -0.00 | -0.00 | -0.00 |
| POLITY | 0.00 | -0.00 | 0.00 ** | -0.00 | 0.00 ** | 0.00 ** | 0.00 ** | -0.00 ** | -0.00 | -0.00 | 0.00 ** | 0.00 | 0.00 ** | 0.00 | -0.00 | -0.00 | -0.00 ** | -0.00 |
| Constant | 0.00 | 0.00 | -0.00 | 0.00 ** | -0.00 | 0.00 | -0.00 ** | 0.00 ** | -0.00 | 0.00 ** | -0.00 | 0.00 | -0.00 | 0.00 | 0.00 ** | 0.00 ** | 0.00 | 0.00 ** |
| # of obj | 585 | 585 | 585 | 575 | 575 | 548 | 574 | 575 | 559 | 585 | 585 | 585 | 575 | 585 | 575 | 575 | 585 | 585 |
| R-squares | | | | | | | | | | | | | | | | | | |
| within | 0.33 | 0.19 | 0.06 | 0.32 | 0.28 | 0.26 | 0.27 | 0.19 | 0.12 | 0.10 | 0.10 | 0.39 | 0.39 | 0.26 | 0.27 | 0.14 | 0.29 | 0.29 |
| between | 0.36 | 0.25 | 0.02 | 0.02 | 0.00 | 0.02 | 0.18 | 0.23 | 0.20 | 0.01 | 0.22 | 0.15 | 0.03 | 0.05 | 0.01 | 0.00 | 0.32 | 0.40 |
| overall | 0.35 | 0.25 | 0.02 | 0.02 | 0.00 | 0.01 | 0.19 | 0.22 | 0.21 | 0.01 | 0.20 | 0.16 | 0.03 | 0.08 | 0.03 | 0.01 | 0.32 | 0.38 |
| | RE | RE | RE | RE | FE | FE | RE | FE | RE | RE | RE | RE | RE | RE | RE | FE | RE | RE |

*Note:* * and ** indicate statistical significance at the 10% and 5% levels, respectively.

Blank in $GDPper^3$ coefficient space represent we assume quadratic formula model. We select either cubic or quadratic formula model referring the result of F-test which check the probability that coefficient of $GDPper^3$ equal to zero.

FE represent fixed effect model, RE shows random effect model.

## Table A3. Result of specification (dependent variable is $CH_4$ emission per capita)

| | Country | Industry | Mining | Food | Textile | Leather | Wood | Pulp | Oil | Chemical | Rubber | Mineral | Metal | Machine | Electric product | Transport equipment | Electricity | Construction |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | coef. | coef. | coef. | coef. | coef. | coef. | coef. | coef. | coef. | coef. | coef. | coef. | coef. | coef. | coef. | coef. | coef. | coef. |
| GDPper | 2.72 ** | 0.18 | -0.18 ** | 0.01 | -0.00 | -0.00 ** | -0.01 ** | 0.00 | 0.01 | 0.03 ** | -0.01 ** | 0.02 ** | -0.00 | -0.00 ** | -0.00 ** | 0.00 | 0.19 ** | -0.00 ** |
| GDPper2 | -90.50 ** | -7.65 ** | 1.22 ** | -0.53 ** | 0.00 | 0.01 ** | 0.09 ** | 0.01 | -0.03 | -0.65 ** | 0.24 ** | -0.30 ** | 0.04 | 0.03 ** | 0.01 ** | -0.04 ** | -5.30 ** | 0.03 ** |
| GDPper3 | 558.57 ** | 64.52 ** | | 5.63 ** | | | | | | 4.21 ** | -1.52 ** | 1.68 ** | | -0.16 ** | | 0.41 ** | 41.68 ** | |
| DEPEND | 0.02 ** | 0.00 | 0.00 | -0.00 ** | 0.00 ** | 0.00 ** | 0.00 | 0.00 ** | -0.00 | 0.00 | -0.00 ** | 0.00 | 0.00 ** | 0.00 | 0.00 ** | -0.00 ** | 0.00 | 0.00 ** |
| EE | -0.01 ** | -0.00 | 0.00 | 0.00 | -0.00 ** | -0.00 | -0.00 | -0.00 | -0.00 | -0.00 | -0.00 | 0.00 | -0.00 | -0.00 ** | -0.00 ** | 0.00 ** | 0.00 | -0.00 |
| SHARE | 0.00 ** | 0.00 ** | -0.00 ** | 0.00 | 0.00 ** | 0.00 ** | 0.00 | 0.00 | 0.00 | 0.00 ** | 0.00 | -0.00 ** | 0.00 ** | 0.00 ** | 0.00 ** | -0.00 ** | -0.00 ** | 0.00 ** |
| SKILLED | -0.00 ** | -0.00 | 0.00 | 0.00 ** | 0.00 ** | -0.00 | 0.00 | -0.00 | -0.00 | -0.00 | -0.00 ** | -0.00 | 0.00 | 0.00 ** | 0.00 | 0.00 | -0.00 | -0.00 |
| POLITY | -0.00 | 0.00 ** | 0.00 ** | 0.00 ** | 0.00 ** | 0.00 ** | 0.00 ** | 0.00 ** | -0.00 | -0.00 | -0.00 | -0.00 ** | 0.00 | 0.00 ** | 0.00 ** | -0.00 | -0.00 | 0.00 ** |
| Constant | 0.05 ** | 0.01 | 0.00 | -0.00 | -0.00 ** | -0.00 ** | -0.00 ** | -0.00 | 0.00 | 0.00 | 0.00 ** | 0.00 | 0.00 | 0.00 | -0.00 | 0.00 ** | 0.00 | -0.00 |
| # of obj | 585 | 585 | 585 | 575 | 573 | 546 | 573 | 575 | 556 | 585 | 583 | 583 | 575 | 583 | 573 | 573 | 585 | 585 |
| R-squares | | | | | | | | | | | | | | | | | | |
| within | 0.59 | 0.06 | 0.06 | 0.08 | 0.18 | 0.12 | 0.05 | 0.03 | 0.01 | 0.02 | 0.07 | 0.09 | 0.12 | 0.07 | 0.09 | 0.04 | 0.11 | 0.08 |
| between | 0.00 | 0.00 | 0.04 | 0.00 | 0.00 | 0.02 | 0.01 | 0.01 | 0.03 | 0.00 | 0.01 | 0.01 | 0.02 | 0.02 | 0.06 | 0.01 | 0.01 | 0.04 |
| overall | 0.00 | 0.00 | 0.04 | 0.00 | 0.00 | 0.01 | 0.01 | 0.01 | 0.02 | 0.00 | 0.01 | 0.00 | 0.02 | 0.02 | 0.06 | 0.01 | 0.01 | 0.05 |
| | RE | RE | RE | RE | RE | RE | RE | RE | RE | RE | FE | FE | RE | FE | RE | RE | RE | RE |

*Note:* * and ** indicate statistical significance at the 10% and 5% levels, respectively.

Blank in $GDPper^3$ coefficient space represent we assume quadratic formula model. We select either cubic or quadratic formula model referring the result of F-test which check the probability that coefficient of $GDPper^3$ equal to zero.

FE represent fixed effect model, RE shows random effect model.

Table A4. Result of specification (dependent variable is $N_2O$ emission per capita)

| | All | Industry | Mining | Food | Textile | Leather | Wood | Pulp | Oil | Chemical | Rubber | Mineral | Metal | Machine | Electric product | Transport equipment | Electricity | Construction |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | coef. | coef. | coef. | coef. | coef. | coef. | coef. | coef. | coef. | coef. | coef. | coef. | coef. | coef. | coef. | coef. | coef. | coef. |
| GDPper | 0.24 ** | 0.10 ** | 0.00 ** | -0.00 | 0.00 | -0.00 ** | 0.00 0.71 | 0.00 | 0.00 ** | 0.07 ** | -0.00 ** | 0.00 | -0.00 | -0.00 ** | 0.00 | -0.00 ** | 0.00 ** | 0.00 ** |
| GDPper2 | -6.42 ** | -2.87 ** | -0.00 | 0.00 | -0.00 ** | 0.00 ** | -0.01 ** | -0.00 | -0.03 ** | -2.43 ** | 0.00 ** | 0.00 | -0.00 | 0.00 ** | -0.00 | 0.00 ** | -0.02 ** | -0.01 ** |
| GDPper3 | 36.39 ** | 20.53 ** | | | | | 0.06 ** | | 0.35 ** | 17.72 ** | | -0.03 ** | | | | | | 0.15 ** |
| DEPEND | 0.00 ** | 0.00 ** | -0.00 | 0.00 ** | 0.00 ** | 0.00 | -0.00 ** | 0.00 | 0.00 ** | -0.00 ** | -0.00 ** | 0.00 | 0.00 ** | 0.00 ** | -0.00 | 0.00 ** | 0.00 ** | -0.00 |
| EE | -0.00 ** | -0.00 ** | -0.00 | -0.00 | -0.00 ** | -0.00 ** | -0.00 ** | 0.00 | -0.00 | -0.00 | -0.00 ** | -0.00 | -0.00 ** | -0.00 ** | -0.00 ** | -0.00 ** | -0.00 | -0.00 ** |
| SHARE | 0.00 ** | 0.00 ** | 0.00 | 0.00 | 0.00 ** | 0.00 ** | 0.00 ** | -0.00 | 0.00 | 0.00 ** | 0.00 ** | 0.00 | 0.00 | 0.00 ** | 0.00 ** | 0.00 ** | 0.00 | 0.00 ** |
| SKILLED | -0.00 ** | -0.00 ** | 0.00 | 0.00 ** | -0.00 | -0.00 | 0.00 ** | -0.00 | -0.00 | -0.00 ** | 0.00 | -0.00 ** | 0.00 | -0.00 | -0.00 ** | -0.00 | -0.00 | -0.00 ** |
| POLITY | 0.00 | 0.00 | 0.00 ** | 0.00 ** | 0.00 ** | 0.00 ** | 0.00 ** | -0.00 | 0.00 | 0.00 | 0.00 ** | 0.00 | 0.00 ** | 0.00 ** | 0.00 ** | 0.00 ** | 0.00 | 0.00 |
| Constant | -0.00 | -0.00 ** | -0.00 | 0.00 | -0.00 ** | -0.00 ** | 0.00 | 0.00 ** | -0.00 | -0.00 | -0.00 | 0.00 | 0.00 | -0.00 | 0.00 | 0.00 | -0.00 ** | 0.00 |
| # of obj | 585 | 585 | 585 | 567 | 567 | 526 | 567 | 567 | 534 | 585 | 577 | 577 | 567 | 577 | 560 | 565 | 585 | 585 |
| R-squares | | | | | | | | | | | | | | | | | | |
| within | 0.63 | 0.33 | 0.02 | 0.04 | 0.18 | 0.18 | 0.10 | 0.02 | 0.06 | 0.29 | 0.13 | 0.04 | 0.05 | 0.16 | 0.18 | 0.14 | 0.15 | 0.20 |
| between | 0.00 | 0.02 | 0.12 | 0.04 | 0.03 | 0.04 | 0.00 | 0.05 | 0.01 | 0.03 | 0.03 | 0.15 | 0.02 | 0.04 | 0.06 | 0.01 | 0.09 | 0.16 |
| overall | 0.01 | 0.04 | 0.12 | 0.05 | 0.04 | 0.01 | 0.00 | 0.06 | 0.02 | 0.05 | 0.03 | 0.15 | 0.04 | 0.01 | 0.02 | 0.01 | 0.09 | 0.15 |
| | FE | FE | FE | FE | FE | FE | FE | FE | FE | FE | RE | RE | FE | FE | FE | FE | FE | FE |

*Note:* * and ** indicate statistical significance at the 10% and 5% levels, respectively.

Blank in $GDPper^3$ coefficient space represent we assume quadratic formula model. We select either cubic or quadratic formula model referring the result of F-test which check the probability that coefficient of $GDPper^3$ equal to zero.

FE represent fixed effect model, RE shows random effect model.

## Table A5. Result of specification (dependent variable is NOx emission per capita)

| | All | Industry | Mining | Food | Textile | Leather | Wood | Pulp | Oil | Chemical | Rubber | Mineral | Metal | Machine | Electric product | Transport equipment | Electricity | Construction |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | coef. | coef. | coef. | coef. | coef. | coef. | coef. | coef. | coef. | coef. | coef. | coef. | coef. | coef. | coef. | coef. | coef. | coef. |
| GDPper | -1.40 ** | -0.46 ** | -0.01 | -0.00 | -0.01 ** | -0.00 ** | 0.00 | -0.00 | -0.03 ** | -0.03 ** | -0.00 | 0.01 | -0.05 | -0.02 ** | -0.02 ** | -0.01 ** | -0.03 | 0.01 |
| GDPper2 | 50.90 ** | 7.34 ** | 0.69 | -0.09 ** | 0.18 ** | 0.03 ** | -0.11 ** | -0.19 ** | 0.36 ** | 0.45 | 0.21 ** | -0.17 ** | 2.02 ** | 0.89 ** | 0.75 ** | 0.51 ** | -3.75 ** | 1.18 ** |
| GDPper3 | -457.22 ** | -95.96 ** | -6.47 ** | | -2.34 ** | | | | | -4.26 ** | -3.25 ** | | -40.85 ** | -11.27 ** | -9.57 ** | -7.58 ** | 38.49 ** | -27.66 ** |
| DEPEND | 0.06 ** | 0.01 ** | -0.00 | 0.00 ** | 0.00 ** | -0.00 | -0.00 | -0.00 | 0.00 | 0.00 | -0.00 | 0.00 ** | 0.00 ** | -0.00 | -0.00 ** | -0.00 ** | 0.01 ** | -0.00 ** |
| EE | -0.02 ** | -0.01 ** | -0.00 | -0.00 ** | -0.00 ** | -0.00 ** | -0.00 ** | 0.00 ** | 0.00 | -0.00 | -0.00 ** | -0.00 ** | -0.00 | -0.00 ** | -0.00 | -0.00 | -0.02 ** | -0.00 ** |
| SHARE | 0.00 ** | 0.00 ** | -0.00 | 0.00 ** | 0.00 ** | 0.00 ** | 0.00 ** | -0.00 | 0.00 ** | 0.00 ** | -0.00 | 0.00 ** | 0.00 | 0.00 ** | 0.00 ** | 0.00 | 0.00 | 0.00 ** |
| SKILLED | 0.00 | -0.00 ** | -0.00 ** | -0.00 ** | -0.00 | -0.00 ** | 0.00 | -0.00 ** | -0.00 ** | -0.00 | 0.00 | -0.00 ** | 0.00 ** | -0.00 | -0.00 ** | 0.00 | -0.00 | 0.00 |
| POLITY | 0.02 ** | 0.00 | 0.00 ** | -0.00 | -0.00 | 0.00 ** | 0.00 ** | -0.00 | -0.00 | -0.00 | 0.00 ** | 0.00 ** | -0.00 | 0.00 | 0.00 | -0.00 | -0.00 | -0.00 |
| Constant | -0.06 ** | 0.01 ** | -0.00 | 0.00 ** | 0.00 ** | 0.00 | -0.00 | 0.00 ** | 0.00 ** | 0.00 ** | -0.00 | 0.00 | 0.00 | 0.00 ** | 0.00 ** | 0.00 ** | 0.00 ** | 0.00 ** |
| # of obj | 585 | 585 | 585 | 570 | 570 | 533 | 570 | 585 | 559 | 585 | 570 | 585 | 585 | 570 | 585 | 570 | 585 | 585 |
| R-squares | | | | | | | | | | | | | | | | | | |
| within | 0.07 | 0.47 | 0.04 | 0.27 | 0.34 | 0.20 | 0.21 | 0.23 | 0.10 | 0.12 | 0.45 | 0.20 | 0.55 | 0.59 | 0.58 | 0.56 | 0.38 | 0.52 |
| between | 0.27 | 0.08 | 0.07 | 0.04 | 0.04 | 0.05 | 0.00 | 0.11 | 0.20 | 0.00 | 0.61 | 0.04 | 0.34 | 0.88 | 0.55 | 0.81 | 0.07 | 0.33 |
| overall | 0.24 | 0.05 | 0.07 | 0.02 | 0.01 | 0.02 | 0.01 | 0.08 | 0.15 | 0.00 | 0.15 | 0.05 | 0.09 | 0.26 | 0.16 | 0.28 | 0.08 | 0.11 |
| | RE | FE | RE | FE | FE | FE | FE | FE | FE | FE | FE | FE | FE | FE | FE | FE | FE | FE |

*Note:* * and ** indicate statistical significance at the 10% and 5% levels, respectively.

Blank in $GDPper^3$ coefficient space represent we assume quadratic formula model. We select either cubic or quadratic formula model referring the result of F-test which check the probability that coefficient of $GDPper^3$ equal to zero.

FE represent fixed effect model, RE shows random effect model.

## Table A6. Result of specification (dependent variable is SOx emission per capita)

| | All | Industry | Mining | Food | Textile | Leather | Wood | Pulp | Oil | Chemical | Rubber | Mineral | Metal | Machine | Electric product | Transport equipment | Electricity | Construction |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | coef. | coef. | coef. | coef. | coef. | coef. | coef. | coef. | coef. | coef. | coef. | coef. | coef. | coef. | coef. | coef. | coef. | coef. |
| GDPper | -5.46 ** | -6.19 ** | -0.11 ** | -0.06 ** | -0.05 ** | -0.01 ** | -0.04 ** | -0.11 ** | -0.18 ** | -0.22 ** | -0.04 ** | -0.11 ** | -0.16 ** | -0.05 ** | -0.04 ** | -0.04 ** | -3.79 ** | -0.13 ** |
| GDPper2 | 107.02 ** | 113.72 ** | 2.24 ** | 0.36 ** | 1.05 ** | 0.09 ** | 0.70 ** | 0.75 ** | 2.38 ** | 3.82 ** | 0.85 ** | 2.42 ** | 2.75 ** | 0.96 ** | 0.78 ** | 0.84 ** | 69.07 ** | 1.91 ** |
| GDPper3 | -644.91 ** | -660.15 ** | -13.52 ** | | -6.36 ** | | -4.18 ** | | | -21.23 ** | -5.02 ** | -14.42 ** | -37.86 ** | -6.07 ** | -4.67 ** | -5.14 ** | -384.63 ** | -10.54 ** |
| DEPEND | 0.05 ** | 0.05 ** | 0.00 | 0.00 ** | 0.00 ** | -0.00 | 0.00 ** | 0.00 ** | 0.00 ** | 0.00 ** | -0.00 | 0.00 ** | 0.00 ** | 0.00 ** | -0.00 | 0.00 | 0.03 ** | 0.00 ** |
| EE | -0.02 ** | -0.04 ** | -0.00 | -0.00 ** | -0.00 ** | -0.00 ** | -0.00 ** | 0.00 ** | 0.00 | -0.00 | -0.00 | -0.00 | -0.00 | -0.00 ** | -0.00 | -0.00 ** | -0.02 | -0.00 |
| SHARE | 0.00 ** | 0.00 ** | -0.00 | 0.00 ** | 0.00 ** | 0.00 ** | 0.01 ** | -0.00 ** | 0.00 ** | 0.00 | -0.00 | 0.00 | 0.00 | 0.00 ** | 0.00 ** | 0.00 ** | 0.01 | 0.00 ** |
| SKILLED | -0.00 ** | -0.00 ** | -0.00 | -0.00 ** | -0.00 | -0.00 | -0.00 | -0.00 | -0.00 ** | -0.00 | -0.00 | -0.00 ** | -0.00 | 0.00 | 0.00 | -0.00 | -0.00 ** | 0.00 ** |
| POLITY | 0.01 ** | 0.01 ** | 0.00 ** | -0.00 | 0.00 ** | 0.00 ** | -0.00 ** | 0.00 ** | 0.00 ** | 0.00 | 0.00 ** | 0.00 ** | -0.00 | -0.00 | -0.00 | -0.00 ** | 0.01 ** | -0.00 ** |
| Constant | 0.03 ** | 0.04 ** | 0.00 | 0.00 ** | 0.00 | 0.00 ** | 0.00 ** | 0.00 ** | 0.00 ** | 0.00 ** | 0.00 | 0.00 | 0.00 ** | 0.00 ** | 0.00 ** | 0.00 ** | 0.04 ** | 0.00 ** |
| # of obj | 585 | 585 | 585 | 582 | 582 | 545 | 581 | 585 | 554 | 582 | 582 | 585 | 585 | 581 | 585 | 582 | 585 | 585 |
| R-squares | | | | | | | | | | | | | | | | | | |
| within | 0.39 | 0.42 | 0.09 | 0.42 | 0.31 | 0.34 | 0.47 | 0.34 | 0.14 | 0.16 | 0.09 | 0.23 | 0.41 | 0.27 | 0.09 | 0.19 | 0.36 | 0.26 |
| between | 0.00 | 0.02 | 0.01 | 0.01 | 0.06 | 0.04 | 0.09 | 0.03 | 0.10 | 0.04 | 0.10 | 0.03 | 0.04 | 0.01 | 0.05 | 0.01 | 0.09 | 0.00 |
| overall | 0.01 | 0.03 | 0.00 | 0.00 | 0.09 | 0.05 | 0.12 | 0.01 | 0.06 | 0.02 | 0.06 | 0.01 | 0.01 | 0.01 | 0.05 | 0.01 | 0.10 | 0.00 |
| | FE | FE | FE | FE | FE | FE | FE | FE | FE | FE | FE | FE | FE | FE | FE | FE | FE | FE |

*Note:* * and ** indicate statistical significance at the 10% and 5% levels, respectively.

Blank in $GDPper^3$ coefficient space represent we assume quadratic formula model. We select either cubic or quadratic formula model referring the result of F-test which check the probability that coefficient of $GDPper^3$ equal to zero.

FE represent fixed effect model, RE shows random effect model.

## Table A7. Result of specification (dependent variable is CO emission per capita)

| | All | Industry | Mining | Food | Textile | Leather | Wood | Pulp | Oil | Chemical | Rubber | Mineral | Metal | Machine | Electric product | Transport equipment | Electricity | Construction |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | coef. | coef. | coef. | coef. | coef. | coef. | coef. | coef. | coef. | coef. | coef. | coef. | coef. | coef. | coef. | coef. | coef. | coef. |
| GDPper | -0.14 | 0.72 | -0.00 | -0.05 ** | 0.03 | -0.00 ** | 0.04 | 0.07 ** | -0.01 | -0.21 ** | -0.02 ** | 0.07 ** | 0.39 | -0.02 ** | 0.04 ** | 0.07 ** | -0.46 ** | 0.23 ** |
| GDPper2 | -6.47 | -12.45 ** | -1.40 | 0.85 ** | -2.47 ** | 0.02 | -3.01 ** | -4.98 ** | -0.82 | 10.99 ** | 0.09 | -0.65 | 16.37 | 0.04 | -1.73 ** | -4.42 ** | 6.28 ** | -17.35 ** |
| GDPper3 | | | | | 29.41 ** | | 29.55 ** | 61.50 ** | | -132.53 ** | | | -251.65 ** | | 18.34 ** | 54.79 ** | | 208.05 ** |
| DEPEND | 0.12 ** | 0.02 | 0.00 | 0.00 | 0.00 | -0.00 | -0.00 ** | -0.00 | -0.00 | -0.00 ** | -0.00 ** | 0.00 | 0.00 | 0.00 ** | 0.00 | -0.00 ** | 0.00 | -0.00 |
| EE | -0.01 | 0.01 | 0.00 | -0.00 | -0.00 | -0.00 | -0.00 | 0.00 | 0.03 | 0.00 | -0.00 ** | -0.00 | -0.01 | -0.00 ** | -0.00 | -0.00 ** | -0.00 | -0.00 ** |
| SHARE | 0.00 | -0.00 | -0.00 | 0.00 | 0.00 | 0.00 | 0.00 | -0.00 | -0.01 | -0.00 | 0.00 ** | -0.00 | 0.01 | 0.00 ** | -0.00 ** | 0.00 ** | -0.00 | 0.01 ** |
| SKILLED | -0.00 | -0.00 | -0.00 | -0.00 | 0.00 | -0.00 | 0.00 ** | -0.00 ** | 0.00 | -0.00 | 0.00 | -0.00 ** | -0.00 | 0.00 | -0.00 ** | 0.00 | -0.00 | 0.00 |
| POLITY | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 ** | 0.00 ** | -0.00 | -0.01 ** | 0.00 ** | 0.00 ** | 0.00 | 0.00 | 0.00 ** | 0.00 | 0.00 | -0.00 | -0.00 |
| Constant | -0.00 | 0.02 | 0.00 | 0.00 | 0.00 | -0.00 | -0.00 ** | 0.00 ** | 0.02 ** | 0.00 | -0.00 | 0.00 | -0.00 | -0.00 | 0.00 | 0.00 ** | 0.02 ** | 0.01 ** |
| # of obj | 585 | 585 | 570 | 555 | 570 | 548 | 570 | 570 | 545 | 555 | 570 | 570 | 585 | 570 | 570 | 570 | 570 | 570 |
| R-squares | | | | | | | | | | | | | | | | | | |
| within | 0.05 | 0.02 | 0.03 | 0.02 | 0.09 | 0.06 | 0.18 | 0.15 | 0.01 | 0.05 | 0.19 | 0.03 | 0.04 | 0.23 | 0.15 | 0.23 | 0.04 | 0.21 |
| between | 0.00 | 0.00 | 0.03 | 0.01 | 0.00 | 0.00 | 0.00 | 0.17 | 0.27 | 0.05 | 0.04 | 0.04 | 0.06 | 0.06 | 0.00 | 0.07 | 0.00 | 0.05 |
| overall | 0.00 | 0.00 | 0.02 | 0.00 | 0.00 | 0.00 | 0.00 | 0.14 | 0.22 | 0.05 | 0.01 | 0.04 | 0.06 | 0.02 | 0.00 | 0.03 | 0.00 | 0.03 |
| | RE | RE | FE | RE | FE | RE | FE | FE | RE | RE | FE | RE | RE | FE | RE | FE | FE | FE |

*Note:* * and ** indicate statistical significance at the 10% and 5% levels, respectively.

Blank in $GDPper^3$ coefficient space represent we assume quadratic formula model. We select either cubic or quadratic formula model referring the result of F-test which check the probability that coefficient of $GDPper^3$ equal to zero.

FE represent fixed effect model, RE shows random effect model.

Table A8. Result of specification (dependent variable is NMVOC emission per capita)

| | All | Industry | Mining | Food | Textile | Leather | Wood | Pulp | Oil | Chemical | Rubber | Mineral | Metal | Machine | Electric product | Transport equipment | Electricity | Construction |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | coef. | coef. | coef. | coef. | coef. | coef. | coef. | coef. | coef. | coef. | coef. | coef. | coef. | coef. | coef. | coef. | coef. | coef. |
| GDPper | 0.32 | 0.71 ** | -0.03 ** | -0.03 | -0.01 ** | -0.01 ** | -0.00 | 0.05 ** | 0.69 ** | -0.01 | 0.02 ** | 0.02 ** | 0.05 ** | -0.00 | 0.00 | -0.02 ** | -0.01 | 0.10 ** |
| GDPper2 | -16.84 ** | -23.42 ** | 0.19 | 0.98 ** | 0.04 | 0.07 ** | -0.23 ** | -1.94 ** | -9.89 ** | -1.48 | -0.48 ** | -0.59 ** | -2.14 ** | -0.00 | -0.17 ** | 0.13 ** | -0.00 | -3.39 ** |
| GDPper3 | 110.16 ** | 159.22 ** | | -8.22 ** | | | 2.25 ** | 14.83 ** | | 11.85 ** | 3.28 ** | 3.72 ** | 13.88 ** | | 1.41 ** | | | 22.60 ** |
| DEPEND | 0.01 | -0.01 | 0.00 | 0.00 | 0.00 | -0.00 | 0.00 | -0.00 | 0.00 | -0.00 ** | -0.00 ** | 0.00 ** | 0.00 | 0.00 | -0.00 ** | -0.00 | 0.00 ** | -0.00 |
| EE | -0.00 | -0.00 | 0.00 | -0.00 ** | -0.00 | -0.00 ** | -0.00 ** | -0.00 | -0.00 | 0.00 | -0.00 ** | -0.00 ** | -0.00 | -0.00 ** | -0.00 ** | -0.00 | -0.00 ** | -0.00 ** |
| SHARE | 0.00 | 0.00 | -0.00 | 0.00 | 0.00 | 0.00 ** | 0.00 ** | 0.00 | -0.00 | -0.00 | 0.00 ** | 0.00 ** | 0.00 | 0.00 ** | 0.00 ** | 0.00 | 0.00 | 0.00 ** |
| SKILLED | 0.00 | 0.00 ** | 0.00 | 0.00 | 0.00 | -0.00 | -0.00 | -0.00 ** | 0.00 | 0.00 ** | -0.00 | 0.00 | 0.00 ** | -0.00 | -0.00 ** | 0.00 | 0.00 | -0.00 |
| POLITY | 0.00 ** | 0.00 | 0.00 ** | 0.00 | 0.00 | 0.00 ** | 0.00 ** | -0.00 | -0.00 | 0.00 ** | -0.00 | -0.00 | 0.00 ** | 0.00 ** | 0.00 | 0.00 ** | 0.00 | 0.00 |
| Constant | 0.00 | 0.00 | 0.00 | 0.00 ** | 0.00 | -0.00 ** | -0.00 | 0.00 ** | -0.01 ** | 0.00 | 0.00 ** | 0.00 | -0.00 | -0.00 | 0.00 | -0.00 | 0.00 | 0.00 |
| # of obj | 585 | 585 | 583 | 585 | 573 | 536 | 585 | 583 | 559 | 585 | 585 | 585 | 585 | 571 | 585 | 585 | 583 | 585 |
| R-squares | | | | | | | | | | | | | | | | | | |
| within | 0.12 | 0.09 | 0.01 | 0.03 | 0.05 | 0.12 | 0.21 | 0.32 | 0.09 | 0.05 | 0.10 | 0.03 | 0.09 | 0.09 | 0.08 | 0.09 | 0.03 | 0.13 |
| between | 0.01 | 0.03 | 0.01 | 0.06 | 0.01 | 0.04 | 0.05 | 0.04 | 0.01 | 0.00 | 0.06 | 0.00 | 0.08 | 0.02 | 0.01 | 0.03 | 0.05 | 0.02 |
| overall | 0.01 | 0.03 | 0.00 | 0.03 | 0.01 | 0.02 | 0.01 | 0.03 | 0.00 | 0.00 | 0.05 | 0.00 | 0.05 | 0.00 | 0.00 | 0.02 | 0.06 | 0.03 |
| | RE | RE | FE | RE | FE | RE | FE | FE | FE | FE | RE | RE | FE | FE | RE | RE | RE | RE |

*Note:* * and ** indicate statistical significance at the 10% and 5% levels, respectively.

Blank in $GDPper^3$ coefficient space represent we assume quadratic formula model. We select either cubic or quadratic formula model referring the result of F-test which check the probability that coefficient of $GDPper^3$ equal to zero.

FE represent fixed effect model, RE shows random effect model.

Table A9. Result of specification (dependent variable is $NH_3$ emission per capita)

| | All | Industry | Mining | Food | Textile | Leather | Wood | Pulp | Oil | Chemical | Rubber | Mineral | Metal | Machine | Electric product | Transport equipment | Electricity | Construction |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | coef. | coef. | coef. | coef. | coef. | coef. | coef. | coef. | coef. | coef. | coef. | coef. | coef. | coef. | coef. | coef. | coef. | coef. |
| GDPper | 0.18 ** | -0.02 ** | 0.00 ** | -0.01 ** | 0.00 | -0.00 | 0.00 | -0.00 | -0.00 ** | -0.00 | -0.00 ** | 0.00 | -0.00 | 0.00 ** | -0.00 | -0.00 | -0.00 ** | 0.00 |
| GDPper2 | -7.19 ** | 0.50 ** | -0.06 ** | 0.25 ** | 0.00 | 0.00 ** | -0.00 | 0.02 ** | 0.00 ** | 0.04 | 0.00 ** | -0.00 | 0.00 | -0.00 | 0.00 ** | 0.00 | 0.01 ** | -0.00 |
| GDPper3 | 42.41 ** | -3.42 ** | 0.37 ** | -1.35 ** | | | | -0.19 ** | | | -0.02 ** | | | | -0.03 ** | | -0.11 ** | |
| DEPEND | 0.00 | -0.00 ** | -0.00 ** | -0.00 ** | 0.00 | -0.00 | 0.00 | 0.00 | -0.00 | 0.00 | 0.00 | -0.00 ** | 0.00 | 0.00 | 0.00 ** | 0.00 | 0.00 | -0.00 |
| EE | -0.00 ** | -0.00 ** | -0.00 | 0.00 | -0.00 ** | -0.00 ** | -0.00 | -0.00 ** | 0.00 | -0.00 | -0.00 ** | -0.00 | -0.00 ** | -0.00 ** | -0.00 ** | -0.00 ** | 0.00 | -0.00 |
| SHARE | 0.00 ** | 0.00 ** | 0.00 | -0.00 | 0.00 ** | 0.00 ** | 0.00 | 0.00 ** | 0.00 | 0.00 ** | 0.00 ** | 0.00 | 0.00 ** | 0.00 ** | 0.00 ** | 0.00 ** | -0.00 | 0.00 |
| SKILLED | -0.00 ** | -0.00 ** | -0.00 | 0.00 | -0.00 ** | -0.00 ** | -0.00 | -0.00 ** | 0.00 | -0.00 | -0.00 ** | -0.00 | -0.00 | -0.00 ** | -0.00 ** | -0.00 | 0.00 | -0.00 ** |
| POLITY | -0.00 | -0.00 ** | -0.00 | -0.00 | -0.00 ** | 0.00 | -0.00 | 0.00 | -0.00 | -0.00 ** | -0.00 | -0.00 ** | 0.00 | -0.00 ** | 0.00 | -0.00 ** | 0.00 | 0.00 |
| Constant | 0.01 ** | 0.00 ** | 0.00 | 0.00 ** | 0.00 ** | 0.00 | 0.00 | -0.00 | 0.00 ** | 0.00 ** | 0.00 ** | 0.00 ** | -0.00 | 0.00 ** | 0.00 | 0.00 ** | 0.00 | 0.00 |
| # of obj | 585 | 585 | 529 | 536 | 532 | 475 | 536 | 536 | 478 | 554 | 532 | 554 | 551 | 546 | 536 | 533 | 536 | 543 |
| R-squares | | | | | | | | | | | | | | | | | | |
| within | 0.38 | 0.29 | 0.03 | 0.10 | 0.20 | 0.12 | 0.01 | 0.10 | 0.04 | 0.16 | 0.15 | 0.04 | 0.01 | 0.13 | 0.17 | 0.10 | 0.10 | 0.01 |
| between | 0.19 | 0.05 | 0.03 | 0.00 | 0.00 | 0.15 | 0.03 | 0.06 | 0.07 | 0.02 | 0.01 | 0.13 | 0.08 | 0.13 | 0.14 | 0.00 | 0.04 | 0.04 |
| overall | 0.13 | 0.06 | 0.02 | 0.00 | 0.02 | 0.11 | 0.02 | 0.06 | 0.07 | 0.03 | 0.01 | 0.11 | 0.05 | 0.12 | 0.14 | 0.00 | 0.05 | 0.03 |
| | FE | FE | RE | FE | FE | FE | FE | RE | FE | FE | FE | FE | RE | RE | RE | FE | RE | RE |

*Note:* * and ** indicate statistical significance at the 10% and 5% levels, respectively.

Blank in $GDPper^3$ coefficient space represent we assume quadratic formula model. We select either cubic or quadratic formula model referring the result of F-test which check the probability that coefficient of $GDPper^3$ equal to zero.

FE represent fixed effect model, RE shows random effect model.

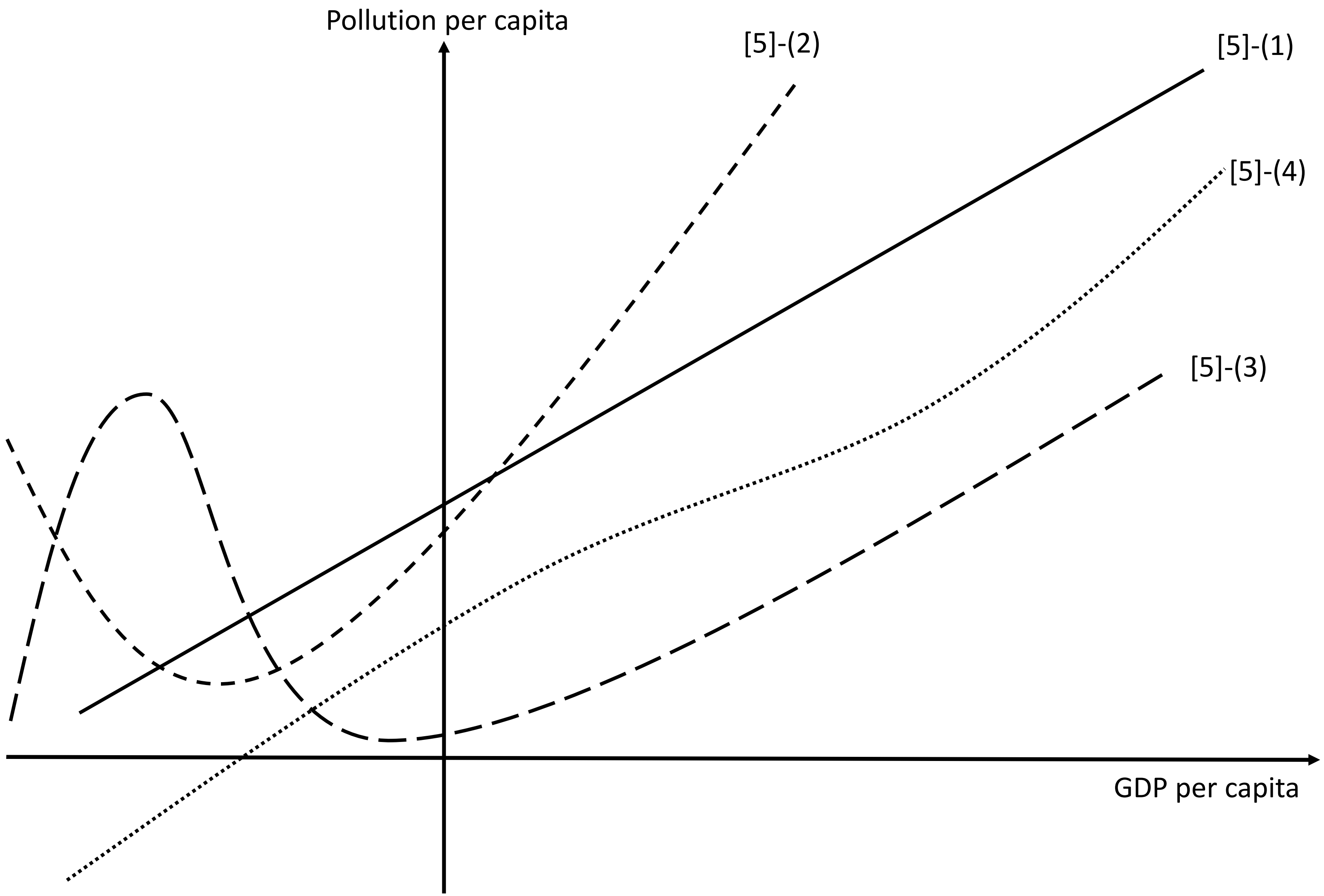


Figure A1. Relationship pattern of Monotonically increasing

Note: The figures in parentheses represent the specific pattern of relationship explained in Table 3.

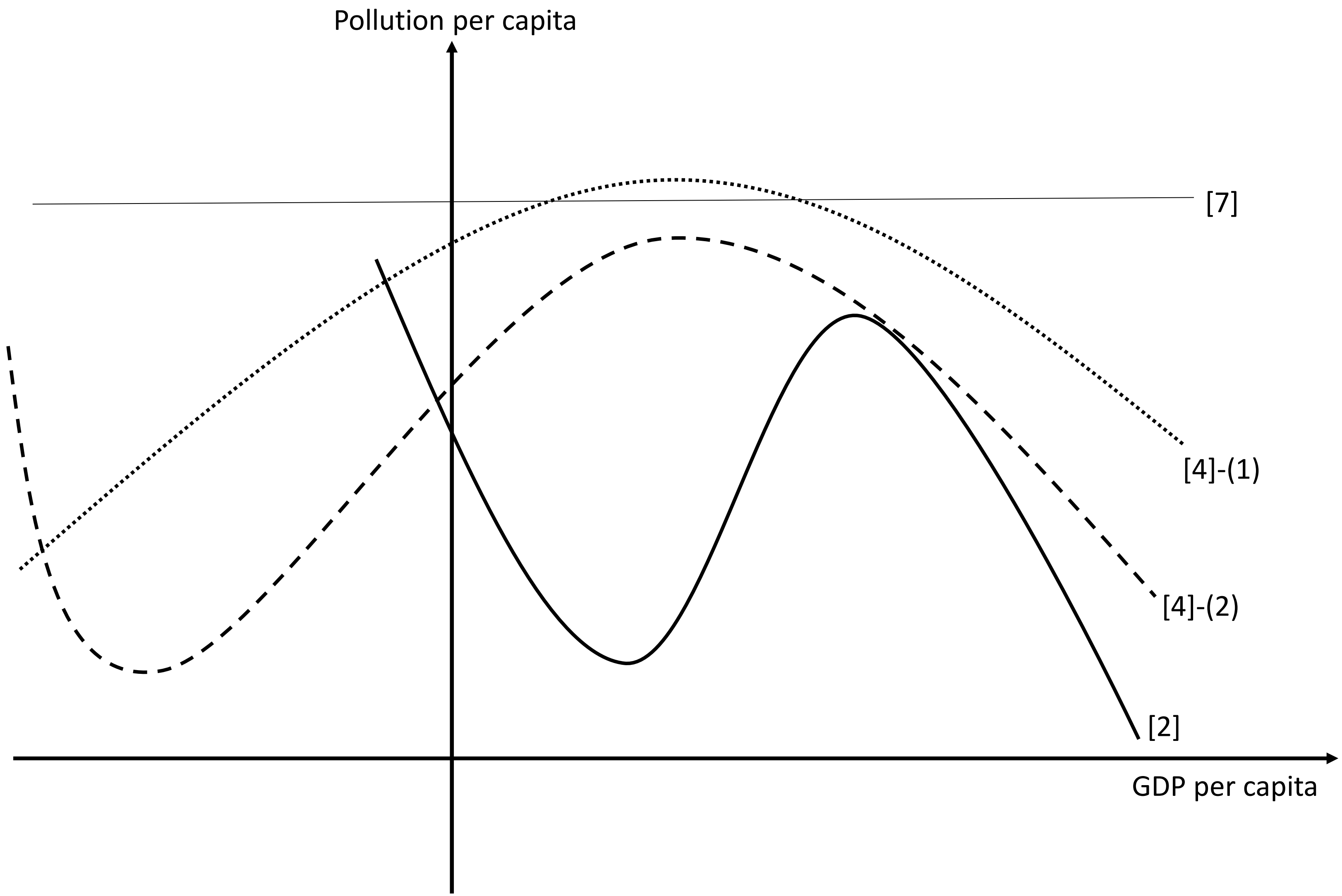


Figure A2. Relationship pattern of Inverted N-shape[2], Inverted U-shape[4] and level[7]

Note: The figures in parentheses represent the specific pattern of relationship explained in Table 3.

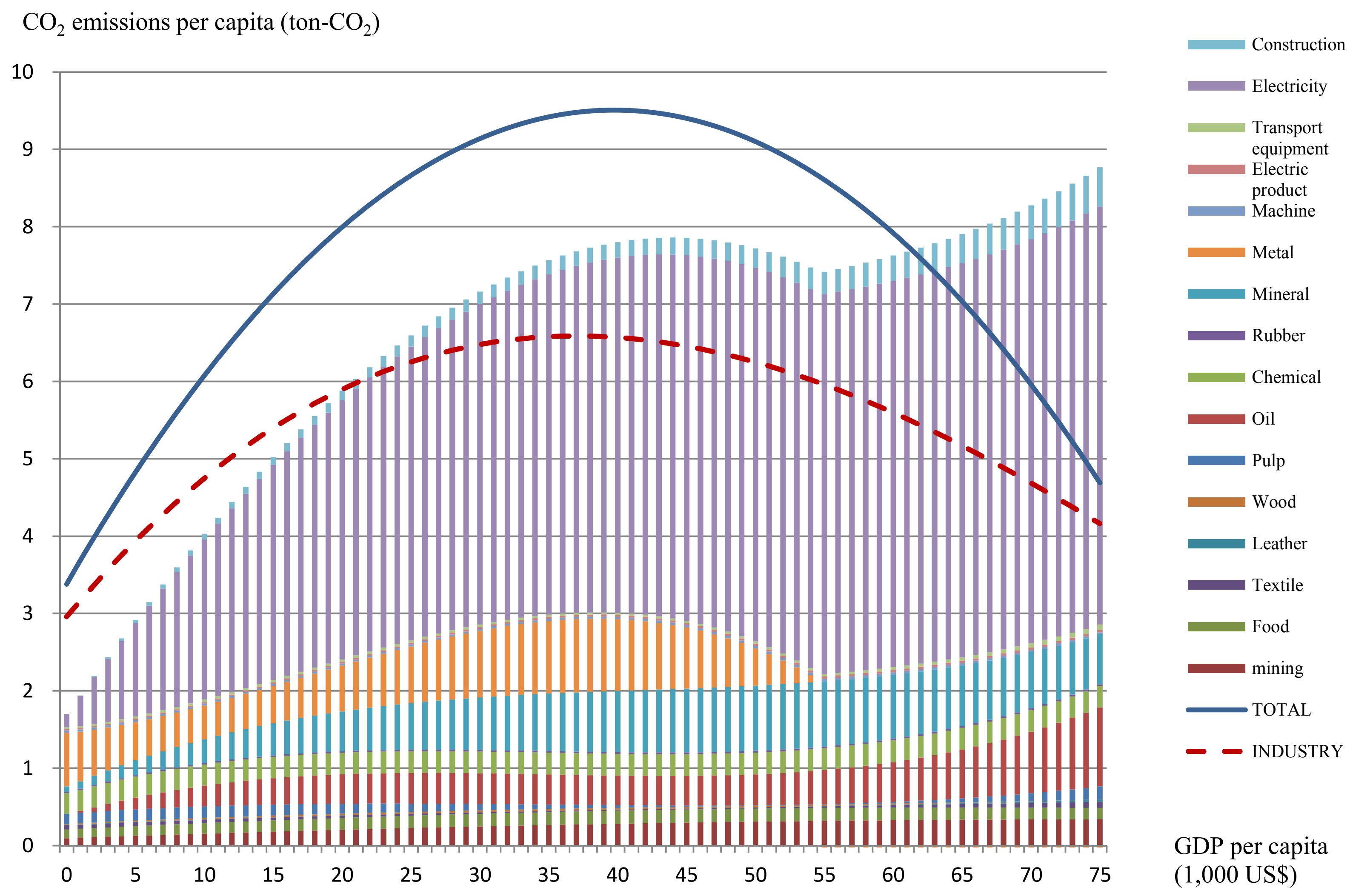


Figure A3. Predicted $CO_2$ emissions

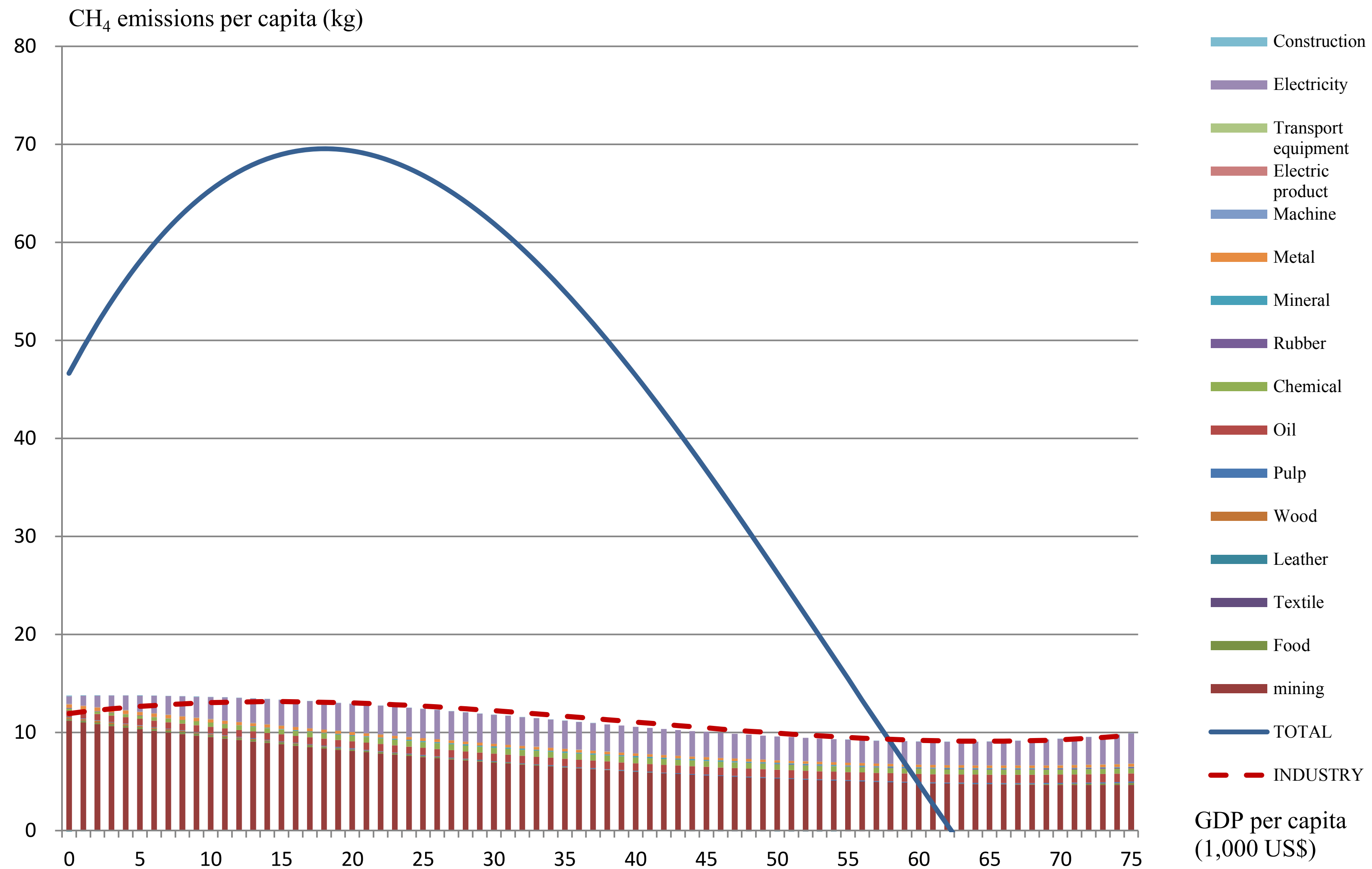


Figure A4. Predicted $CH_4$ emissions

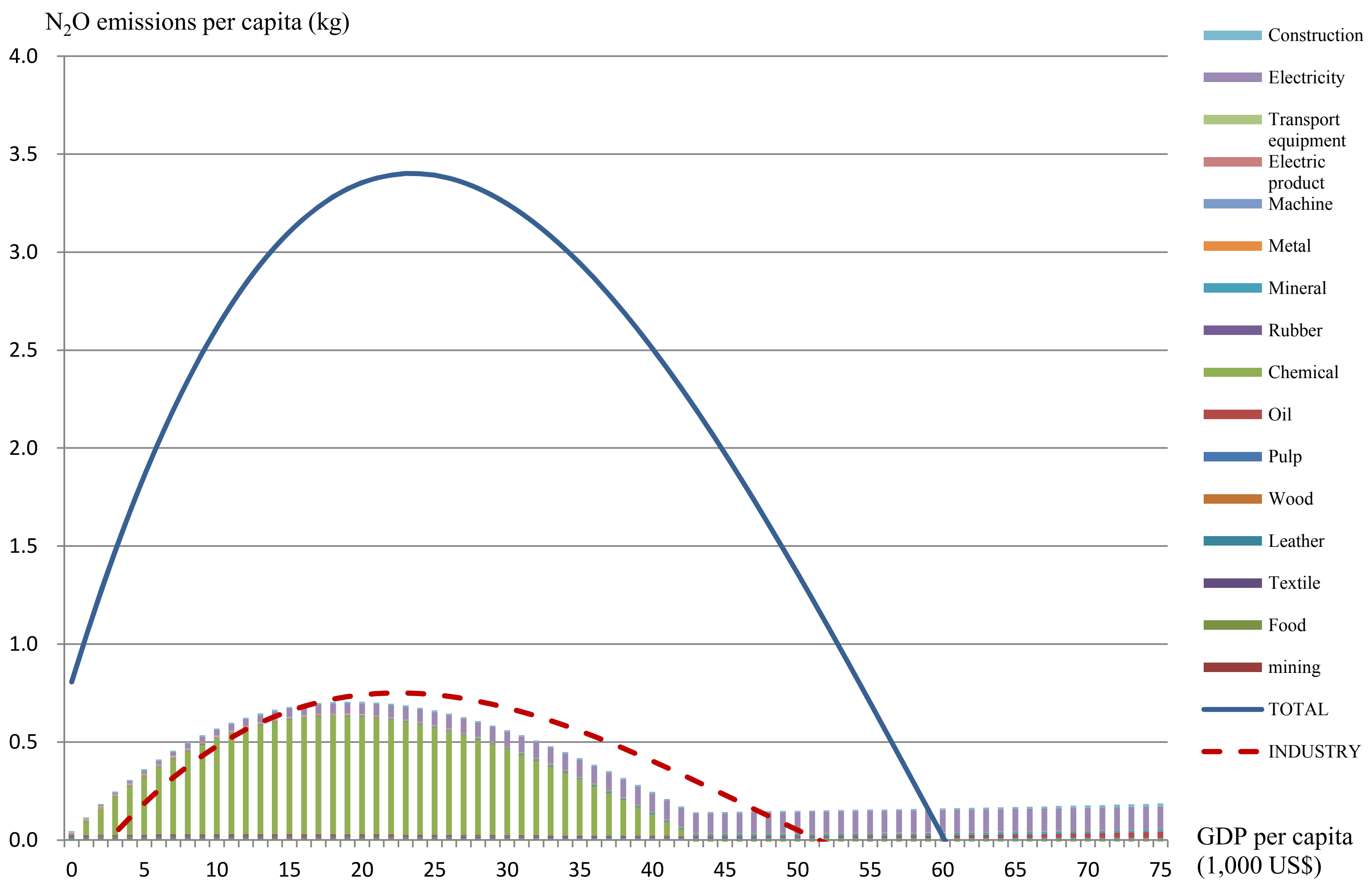


Figure A5. Predicted $N_2O$ emissions

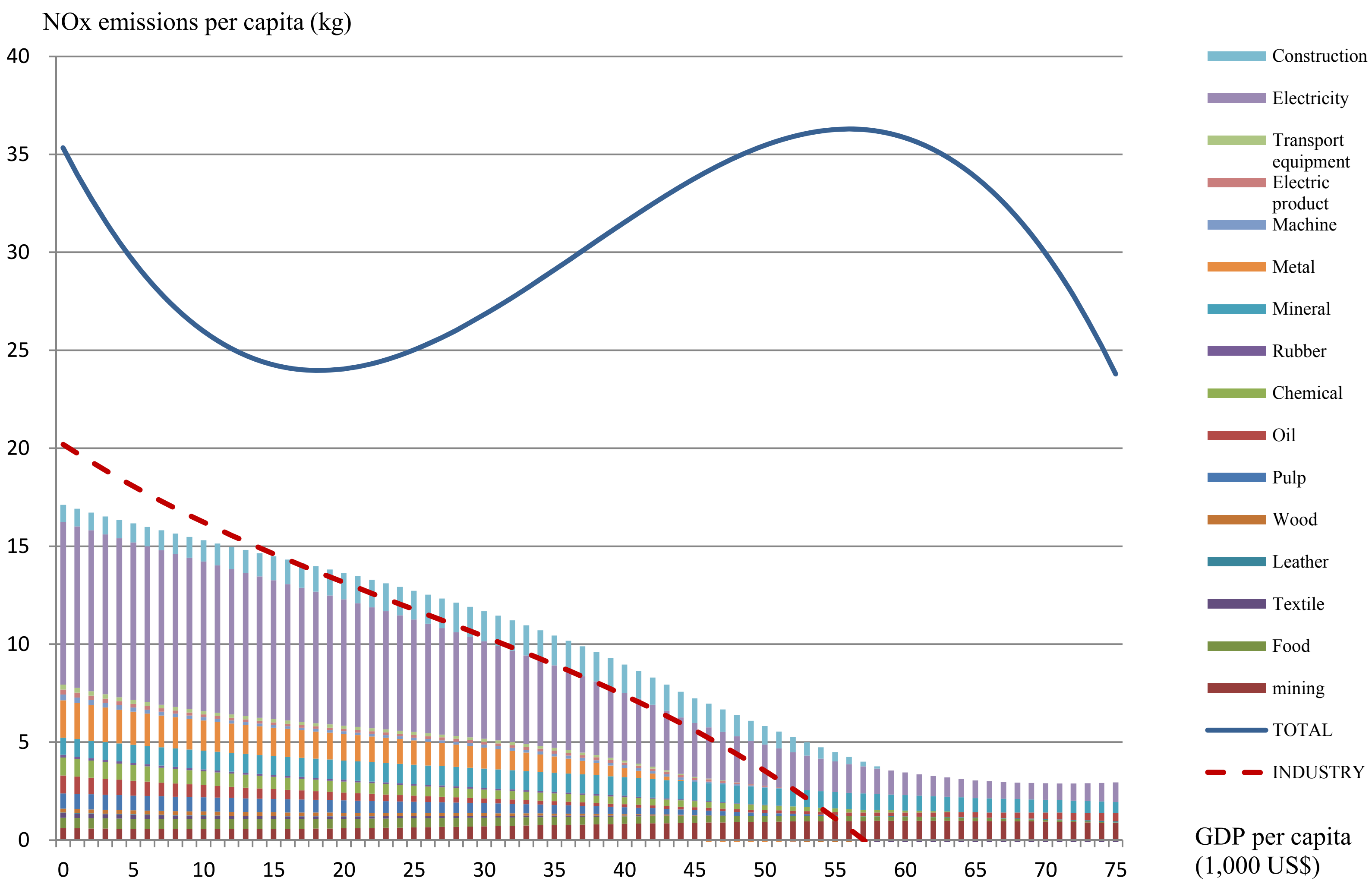


Figure A6. Predicted NOx emissions

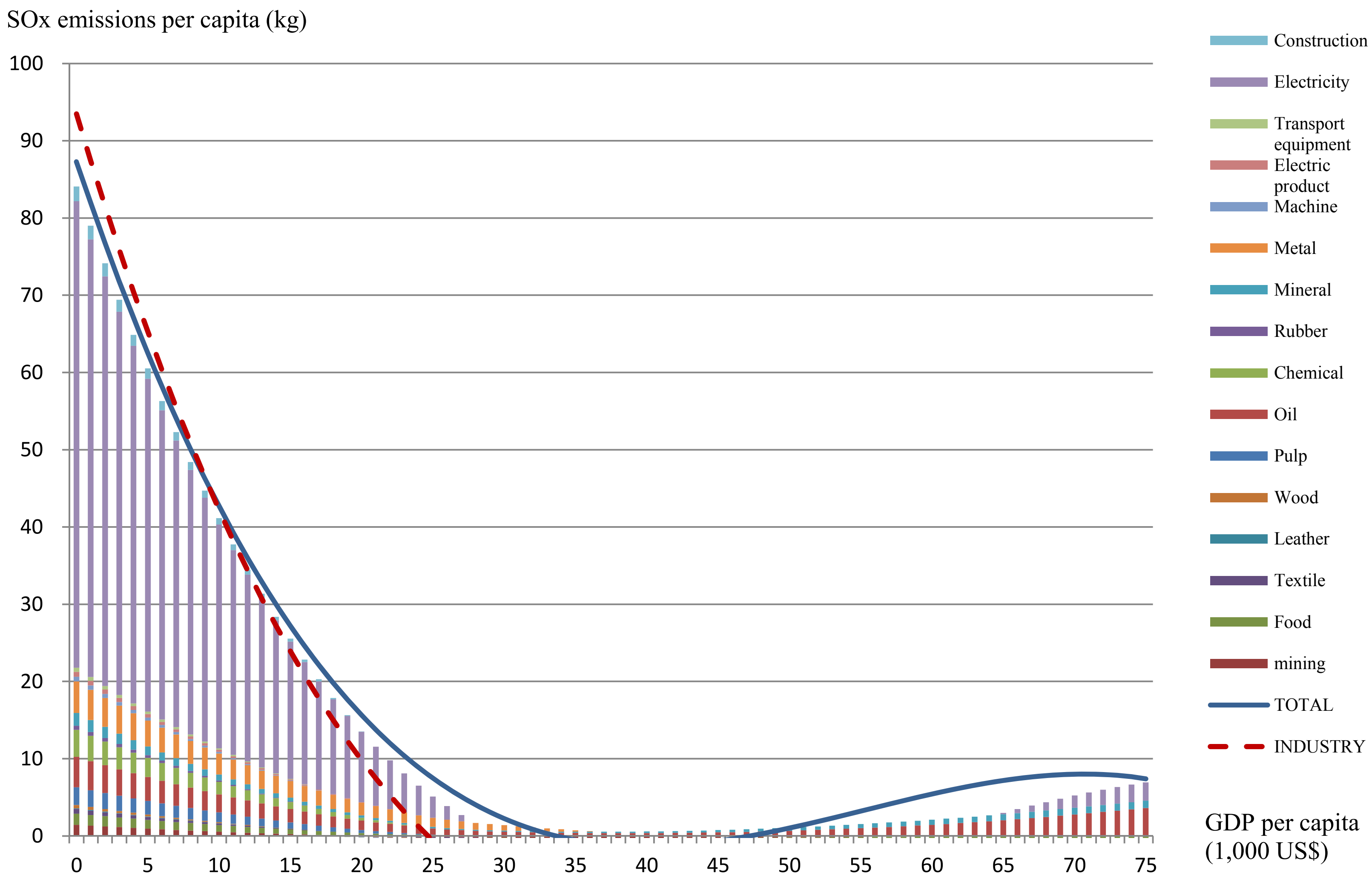


Figure A7. Predicted SOx emissions

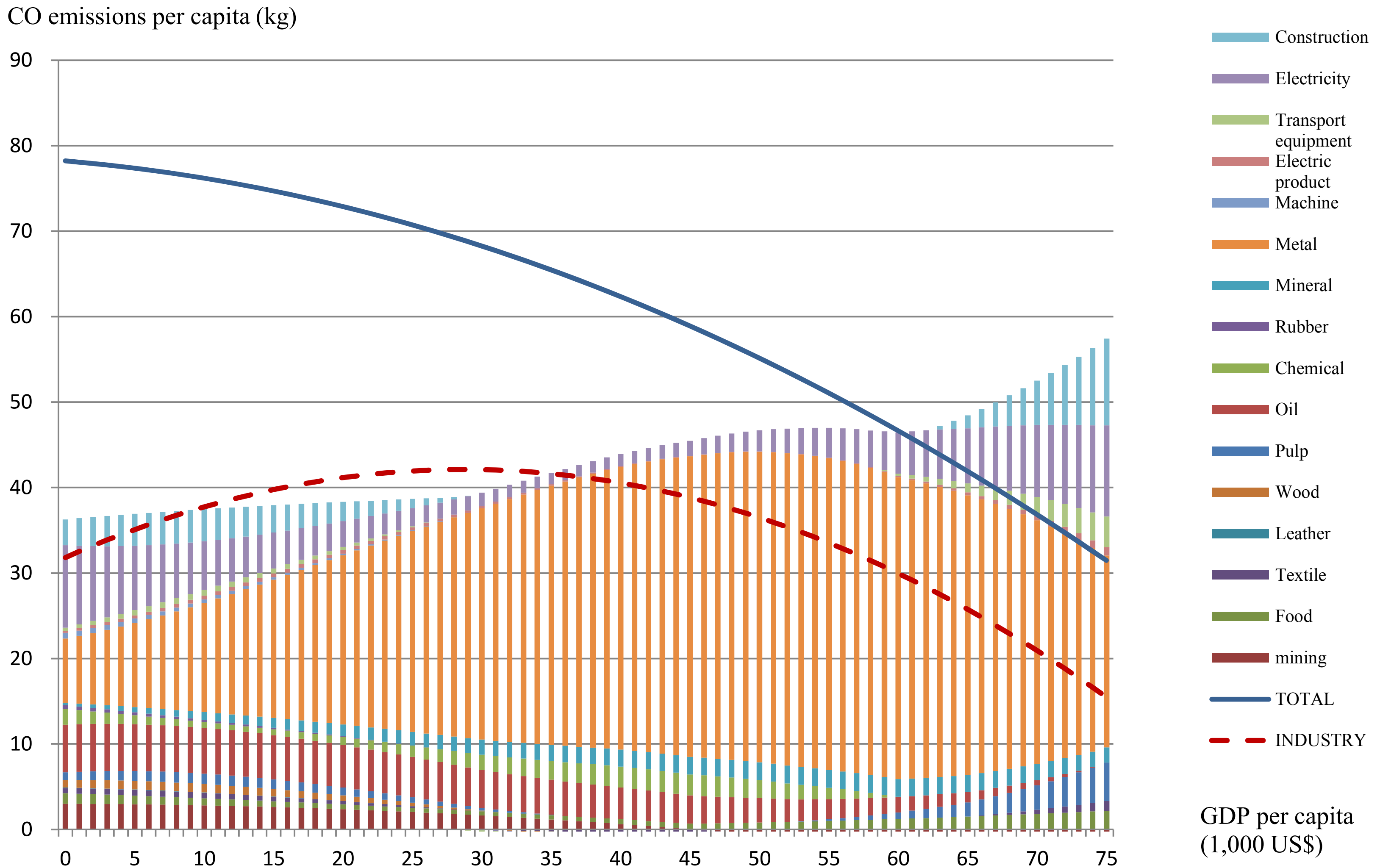


Figure A8. Predicted CO emissions

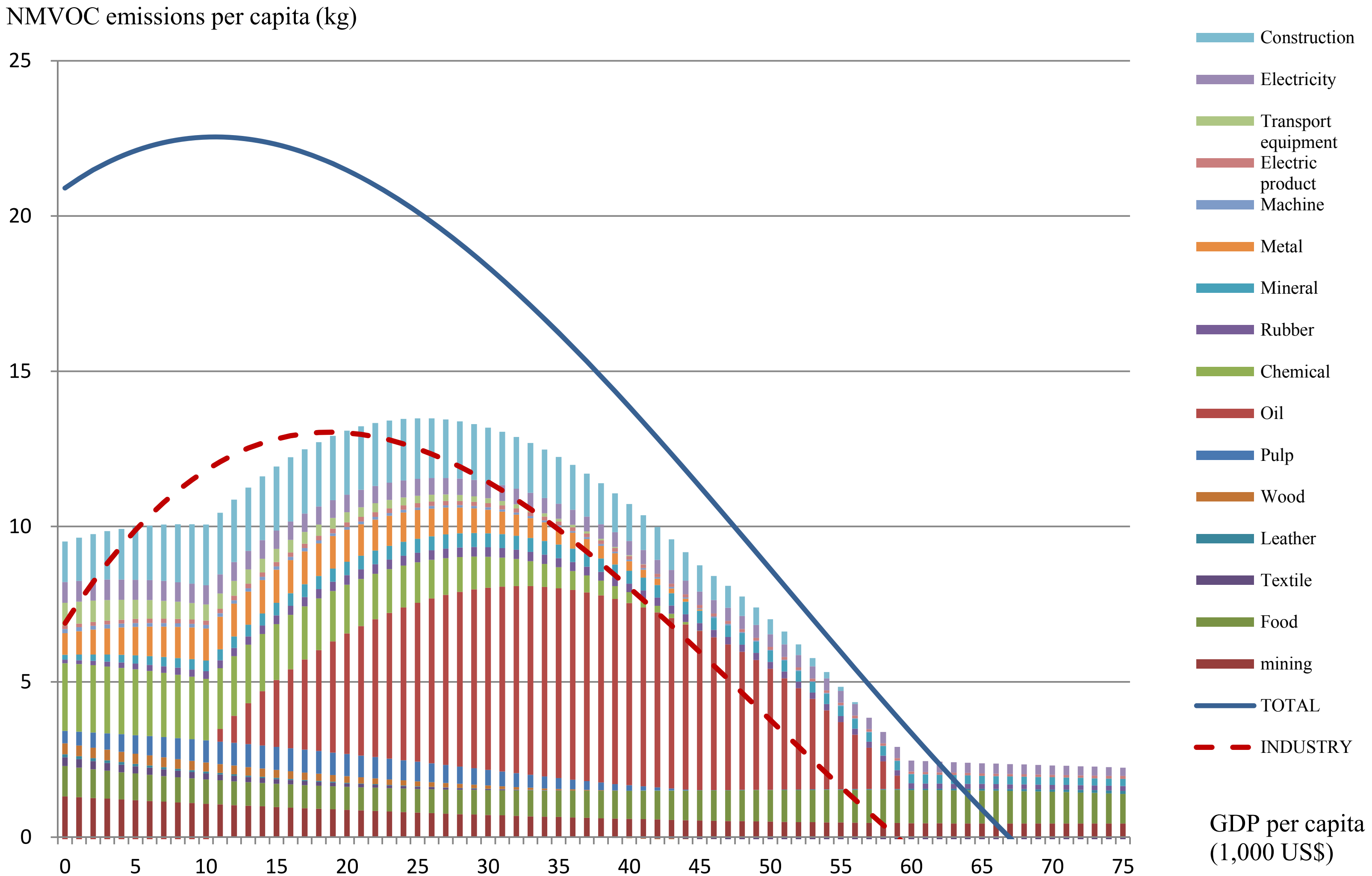


Figure A9. Predicted NMVOC emissions

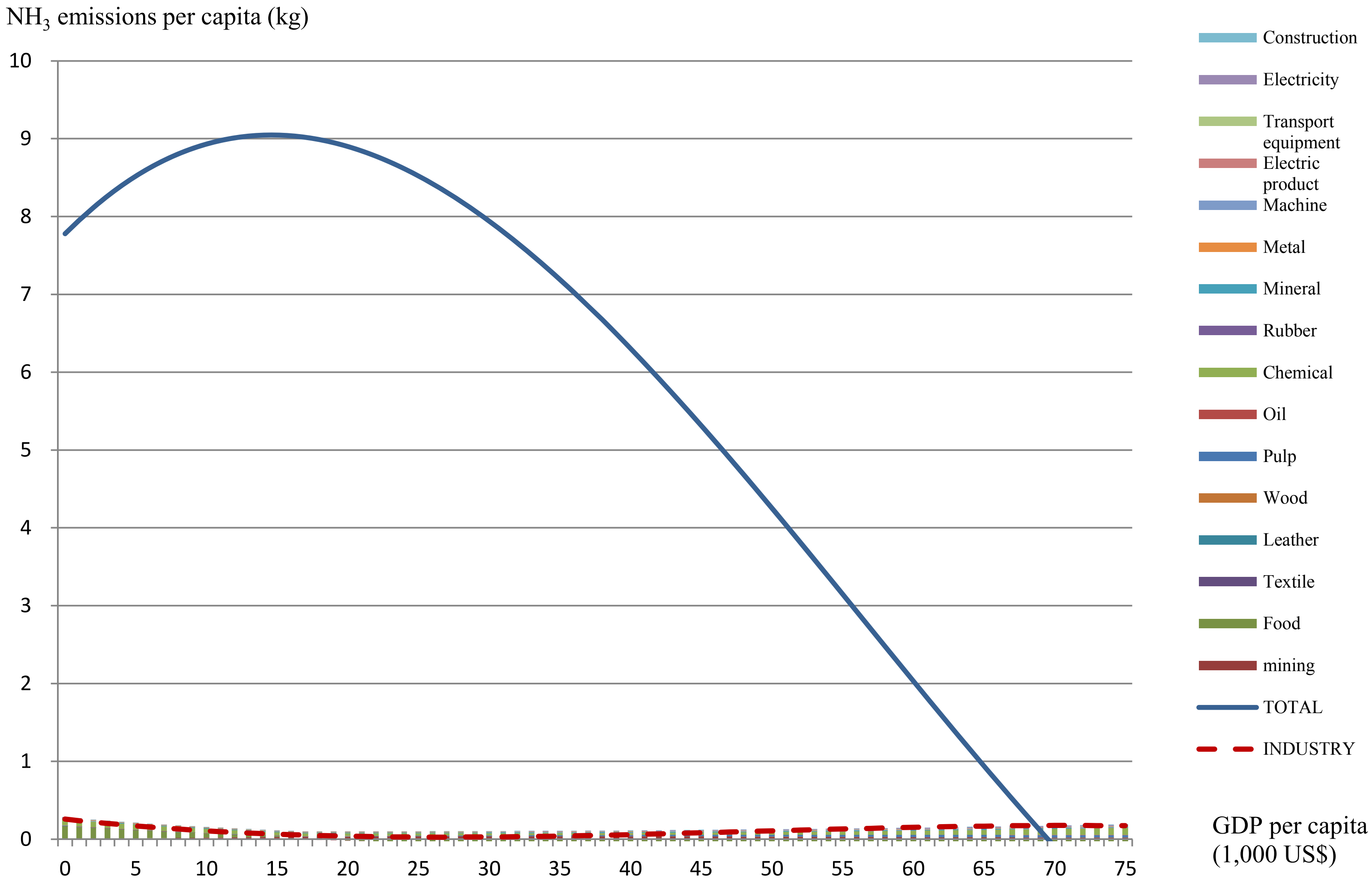


Figure A10. Predicted $NH_3$ emissions