CO2-Emissions and Economic Growth - A bounds-testing cointegration analysis for German industries

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Abstract

We model pollution as an input in the production process and test the long-run relationship between pollution and growth at the industry level. Most empirical studies, especially based on the environmental Kuznets curve, use highly aggregated data. Arguably, the results found may not be generalized for all industries in a given country. Using CO_2- emissions and GDP data for 47 industries observed over the period 1995-2010, we find a long-run relationship between pollution and growth only for a few German industries, e.g. the energy-generating-, the aviation- and agricultural industry. For these industries CO_2-emissions have a negative effect on growth, e.g. through environmental taxes and pollution allowances.

JEL-Classification: Q01, Q32

Keywords: Growth, GDP, CO2 Emissions, Pollution, Bounds-testing

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1 Introduction

Production processes generate some form of pollution (or emissions). This can be a heavy polluting coal-fired power plant as in the energy generating industry, or something simple as using a personal computer in the information and technology industry. Pollution can be therefore a direct (or intended) by-product of production, or an indirect (or unintended) by-product of production by firms in industries.

Firms have an influence on the amount of pollution they generate, e.g. the use of regenerative energy instead of energy based fossil fuels, or the use of more energy efficient machines. However, energy-efficient technologies can be costly and from a firm's point of view it may be more cost-effective to use more polluting (and likely older) technologies at least in the short run.

However, pollution generated by firms in industries imposes costs to the society (e.g. damages to health , Ho and Jorgenson 2007) in form of negative external effects. If these negative external effects are not internalized, firms produce too much of a given product from a socially optimal point of view. Strategies to internalize the external costs (e.g. environmental taxes, command and control regulations, or trade-able pollution permits) cannot stop pollution entirely, but reduce pollution by creating abatement costs to firms. Firms can choose to abate by reducing emissions, and therefore incur costs e.g. through ecological taxes or buying pollution permits. Hence, pollution-levels chosen by firms can be seen as an input to production and being a part of the cost-minimizing decision a firm faces (Brock 1973, Xepapadeas 2005, Bockstael and McConnell 2007).

Firms do sell their products and services, and generate growth in a society. The relationship between economic growth and environmental pollution has been in the discussion of the empirical literature (Grossman and Krueger 1991, Lieb 2003, Stern 2004, Dinda 2004, and Chowdhury and Moran 2012) and the theoretical literature (Brock 1973, Mohtadi 1996, Stockey 1998 Brock and Taylor 2004, von Hauff and Jörg 2013) for many decades. The usual assumption is that economic growth has an impact on the environment by extracting resources during the production process and generating pollution, e.g. CO_2-emissions, SO_2-emissions, NO_x-emissions, and PM10-emissions (fine particle matter).

Most empirical research focuses on the so-called empirical Kuznets curve (EKC). The EKC states that growth (or per capita income growth) can be directly linked to pollution (or emissions) in an economy with the relationship typically mimicking an inverted U-shaped relationship. However, despite the countless papers produced[1], the relationship can often only be found for certain pollutants, or is just an artifact of choosing an inappropriate regression model (Stern 2004).

Furthermore, most of the empirical studies on pollution and economic growth focus on highly aggregated country data and potentially ignore firm or industry developments. What if the EKC relationship found (or not found) is only based on a few industries? For instance, the EKC relationship (or any relationship between economic growth and pollution) is more likely in the energy producing industry, than in the information and technology sector. However, given that firm data on pollution levels are rarely available (and maybe too disaggregated), we choose the next bigger level of aggregation. We use the two-digit and three-digit industry level.

This study has two purposes. First, we test whether industries do use pollution as a direct input in their production. Second, and along with this argumentation we want to give another reason why the EKC relationship cannot be found sometimes, not only because of the pollutant chosen or the econometric technique used, but maybe there just is no direct relationship between pollution and economic growth for many industries.

We use German industries as a case study, because of two reasons. First, Germany has a detailed environmental accounting system in place which offers emission levels at the two-digit and three-digit industry level called the "Umweltgesamtrechnung" (UGR). Second, Germany is also one of the most

[1]See Lieb 2003, Stern 2004, Dinda 2004, Jörg 2007, and Chowdhury and Moran 2012 for detailed literature reviews and especially Stern 2004 for criticisms of the EKC.

progressive countries when it comes to environmental policies and reducing overall CO_2-emissions (Schleich et al. 2001, Bailey 2007).[2] Examples include the "Ökosteuer" (eco-tax) in 1999 as part of the ecological tax reform, and the Energiewende in 2000, as well as voluntary agreements within industries to reduce emissions by using more energy-efficient technologies starting in 1995 (Jochem and Eichhammer 1996, Bailey 2007). These policies could potentially lead to a decoupling of emissions and growth in the long run.

Studies at the industry level are rare and focus only on a few industries and usually use decomposition analysis (e.g. for the German and Colombian manufacturing industry (Martinez 2009), or for the Swedish pulp and paper industry (Lindmark, Bergquist, and Anderson 2011)), or just describe the energy-related CO_2-emissions for a few sectors (Ziesing 1999). However, we are interested in the long-run relationship between pollution and economic growth. Studies related to ours are written by Fujii and Managi (2013) and Zhao, Ma and Yang (2013). Fujii and Managi (2013) focus on nine industries in OECD countries and find significant relationships between economic growth and pollution in these industries (e.g. paper, pulp, and printing, wood and construction industry). Though, more closely related to our research design is the study by Zhao, Ma and Yang (2013). They focus on the Chinese power industry and find a long-run relationship between value added GDP and CO_2-emissions using a bounds-testing approach. However, they focus only on one industry. Given that we use a more complete sample of industries, makes the results presented in this paper more useful in judging the relationship between pollution and economic growth at the industry level.

We have complete emission and GDP data for 47 industries covering the period 1995 to 2010. The industries used in our sample are ranked according to ratio of emissions to their value added output and we chose the top ten polluters

[2] At least during the period covered here, Germany was successful in reducing CO_2 emissions. Since 2012, the process seems to stagnate but is still below the 1990 Kyoto protocol target levels (Umweltbundesamt, `http://www.umweltbundesamt.de/daten/klimawandel/treibhausgas-emissionen-in-deutschland`, last accessed 04/08/2014)

for a more detailed discussion. Our results show that a cointegrating relationship based on a bounds-testing approach can only be found for the energy-generating industry, the airlines industry, the agriculture industry and, surprisingly for the information and communication sector. Previous studies on the EKC for Germany found an EKC relationship (Egli 2004, Stern 2004) but it is likely that these results are mainly driven by a few industries and should not be generalized to all Germany.

These results also imply that most country studies based on highly aggregated data cannot generalize their results for all industries, and at most for just heavy polluters, or industries highly based on energy (or fuel) resources as inputs.

We organize our paper as follows. Section 2 briefly introduces to the idea that pollution can be used as an input in production and links this idea to economic growth. Section 3 introduces to the data and the empirical model used. Section 4 discusses our results, while the paper concludes in section 5.

2 Theoretical Background

Pollution (or emissions) can enter a firm's production function as an input when firms deliberately decide to produce a good or service which creates pollution as a by-product (Bockstael and McConnell 2007). This idea can be traced back to Brock (1973) who argues that firms could produce to lower costs when cleaning up for possible pollution associated with the production is not accounted for.[3] This idea can be used in an aggregated production function. Let the aggregated production function Y be a function of capital K, labor L and pollution Z:

$$Y = F(K, L, Z) \tag{1}$$

assuming that $\partial F/\partial Z > 0$. Dividing (1) by L we get the aggregated production function in per capita terms.

[3]This argument can surely also be made for negative external costs associated with pollution if firms have to account for them.

$$y = F(k, z) \tag{2}$$

Pollution z enters the production function directly and can be determined by technology levels, or set by the policy makers and then applied to all firms (e.g. through a quota on pollution levels).
If we use a typical Solow-model equation for capital accumulation:

$$\dot{k} = sy - (n + \delta)k \tag{3}$$

and assume (2) has a Cobb-Douglas form with $y = k^{\alpha_1} z^{\alpha_2}$, Xepapadeas (2005, p.1230) shows that the steady-state equation of capital $\dot{\hat{k}}$ is a function of pollution z.

$$\dot{\hat{k}} = s\hat{k}^{\alpha_1} z^{\alpha_2} - (n + \delta)\hat{k} \tag{4}$$

and $\dot{\hat{k}} = 0$ in the steady state, we get:

$$\hat{k}^* = \left(\frac{n+\delta}{s}\right)^{\frac{1}{(\alpha_1 - 1)}} z^{\frac{-\alpha_2}{(\alpha_1 - 1)}} \tag{5}$$

with $\partial\hat{k}^*/\partial z > 0$, and $\partial^2\hat{k}^*/\partial z^2 < 0$ such that the capital stock is growing with more pollution but at a decreasing rate.

Similar assumptions can be made in an endogenous growth models where the central planner chooses the optimal level of consumption as a function of the capital stock and pollution in a society (Mohtadi 1996, Xepapadeas 2005, von Hauff and Jörg 2013). Furthermore, this model can also be extended to account for possible feedback effects of pollution on production, e.g. the quality of labor could deteriorate (e.g. through reduced health), similarly if natural resources enter the production function additionally, these could be affected by pollution (or environmental degradation) as well (Bovenberg and Smulders 1995).[4]

[4]Note, this would imply that there could exist a threshold when degradation sets in after reaching a certain level of pollution. Testing for a threshold in CO_2 goes beyond the scope of this study and would likely require a richer data set, e.g. a longer time series, or a cross

The above (and stylized) model implies that pollution and economic growth can be linked in the long run. Furthermore, increased levels of pollution can have a positive effect on economic growth. These two hypotheses can be tested empirically in the sections following.

3 Data and Empirical Strategy

3.1 Data and Descriptive Statistics

We have complete GDP and pollution data on 47 different German industries at the two and three digit level of aggregation (see Table A5 in the appendix). These industries range from the energy-producing sector, manufacturing, agriculture and to different service related industries (see the appendix for a complete list). Germany has a very detailed environmental accounting system (EAS) in place. The EAS data are collected by the "Umweltbundesamt" (environmental protection agency) and called the "Umweltgesamtrechnung" (UGR). The UGR is an annual publication and summarizes information e.g. on energy use, resource use, waste, area use, and information on multiple air pollutants. We use the 2013 report (e.g. the supplemental tables) and choose CO_2-emissions as our air pollutant. The UGR covers the period 1995 to 2011.

The GDP data used here come from the economic accounting system (Inlandsproduktberechnung 2012) and are available at the industry level until 2010. We use value added GDP in current and constant prices for our analysis. Value added GDP should contain all the costs of firms, e.g. also the costs of abating. These costs of abatement can be borne by firms through environmental instruments like environmental taxes or pollution allowances (Muller et al. 2011).

[Figure 1 about here]

country study design. The interested reader may be directed to Chan and Chan (2012). However, they only test if there is a threshold for economic growth in a pollution model.

Figure 1 shows trends in overall CO_2-emissions and GDP for our sample. CO_2-emissions are falling for Germany since the 1990s.[5] Germany signed the Kyoto-protocol and is one of the more progressive states when it comes to implementing environmental policies (Schleich et al. 2001, Bailey 2007). Starting in 1995, industries signed voluntary agreements to reduce CO_2-emissions and implement more efficient and environmentally friendly technologies. Furthermore, the newly elected government consisting of the SPD and for the first time at the federal level the Green party introduced an extensive ecological tax reform in 1999, the "Ökosteuer" (eco-tax) including taxes on the consumption of energy. This is part of a long-term strategy to become more sustainable in the use and generation of energy (Erneuerbare-Energien-Gesetz 2000, Umweltbundesamt 2013, von Hauff and Kleine 2014). This strategy is known as the "Energiewende". In focus of the Energiewende is the promotion of renewable and alternative energy generation (e.g. photovoltaic and wind-powered generators), the more efficient use of energy, and after a few detours the complete phaseout from nuclear energy until 2022.[6] Additionally to these developments, the European Emissions Trading Scheme (ETS) for allowable pollution rights phased-in in 2005 for many energy-intense industries. All these developments can explain why CO_2-emissions are mostly decreasing over time.

GDP itself shows an increasing trend. Clearly visible are peaks and troughs during the construction boom (and the recession following) in the 1990s and the 2008 financial crisis. The two variables move somewhat in opposite directions. While, GDP shows an upward trend, CO_2-emissions show mostly a decreasing trend. The decoupling of these two developments could be because of the envi-

[5] It should be noted that most of the CO_2-emission reductions in the early 1990s are due to a "wall-fall-effect", e.g. many firms from the former East-Germany using outdated production processes closed or updated to newer and more environmentally friendly technologies (Schleich et al. 2001)

[6] The first nuclear powers plant were taken offline in 2011, they very last is supposed to be offline in 2022. Fingers-crossed, given that these terminal dates have changed frequently since 2000. However, after the catastrophe in Fukushima in 2011, the last changes were tied into law (Gesetz zur Änderung des Atomgesetzes 2011).

ronment policies in place in Germany (e.g. voluntary industry agreements, and eco-taxes).[7] This could mean, that pollution is not an input to production, but merely just a by-product of production. However, these developments will be more conclusive once focusing on individual industry developments.

In Table 1 we rank our industries according to the ratio of CO_2-emissions to their value added GDP. CO_2-emissions are from all processes related to the production. Furthermore, we use CO_2-emissions in equivalence units. This includes emissions from all green house gases associated with the production of a good or a service. We use CO_2-emissions in equivalence units for our empirical analysis following. This has the advantage that we do not have to test the relationship between GDP and different pollutants (e.g. SO_2, NO_x, PM10-emissions and others) and can focus our analysis on CO_2-emissions.[8] Furthermore, for most industries the major part of air pollution stems from processes generating CO_2-emissions (see the detailed tables for 1995 and 2010 in the appendix).

To conserve space, we report the ten industries having the highest CO_2/GDP ratios and focus our analysis on these industries. We show these ratio for 1995 and 2010. Not surprisingly, the energy producing industry has the highest CO_2/GDP ratio. Energy is usually produced through the burning of fuels (e.g. natural gas, or coal). This creates high levels CO_2-emissions.[9] Furthermore, the processing industries uses energy-intense production processes. A similar argument can be made for other industries using energy to produce their outputs, however the situation is different for agriculture. Most emissions come from livestock (e.g. methane gases) and the use of fertilizer (e.g. nitrous gases)

[7] Another potential reason could be that production is outsourced to so-called "pollution havens". However, most of our industries produce, at least their final product, in Germany.

[8] However, the information on other typical pollutants as well as on their origin (e.g. from energy-consumption or from the production process) are available in the UGR and could be used in future research.

[9] Though, this relationship should change in the long-run in Germany, nonetheless the Energiewende has to goal to substitute fossil fuels based energy generation with regenerative and alternative sources producing less, or no, emissions.

in the production of agricultural goods and services (Umweltbundesamt 2012). This ranking also relates to the share of total emissions these industries have (column 2 and 4). Based on our sample, the energy producing industry roughly accounts for 22 percent of the CO_2-emissions in 2010, while the processing industry for ten percent and agriculture for 4 percent.

[Table 1 about here]

In Figure 2 we also show trends in CO_2-emissions for the above industries. For most of them CO_2-emissions show a decreasing trend over time.

[Figure 2 about here]

3.2 Empirical strategy

The goal of this study is to assess the long-run relationship between pollution and GDP growth at the industry level. We make use of recent developments in time series modeling to test our hypotheses. We use the method developed by Pesaran, Shin and Smith (2001) to test if there is a long-run (e.g. cointegrating) relationship between CO_2-emissions (our chosen pollutant) and GDP. We explain changes in GDP by past values of GDP and CO_2-emissions. Thus, this kind of time series modeling is also known as auto regressive distributed lags modeling (ARDL). ARDL models use past values (lags) of the dependent (autoregressive) variable to explain changes in the dependent variable.

The method developed by Pesaran et al. has a few advantages over the traditional Engle-Granger method (1987) or the uni-variate method developed by Johanssen (1991). These advantages include simplicity, stationarity of variables and sample size. The first advantage is that it offers a relatively simple test for cointegration, the so-called bounds-test. The bounds-test is an F-test of the joint-hypothesis that the long-run coefficients of GDP and CO_2-emissions are jointly different from zero. If they are different from zero, cointegration

exists. Pesaran et al. provide test statistics in what range (e.g. upper and lower bounds) the computed F-values have to fall for cointegration to exist. Furthermore, the method has the advantage that the time series can be integrated of different orders, e.g. I(0) or I(1). The order of integration can be tested by tests for stationarity (e.g. Augmented Dickey Fuller test, and Philips and Perron test). A final advantage is that the results are asymptotically valid in a relatively short time series, as the one we use.
Our regression model takes following form:

$$\Delta GDP = \alpha_0 + \beta_1 \sum_{i}^{n} L_i.\Delta GDP + \beta_2 \sum_{i}^{n} L_i \Delta CO_2 + \beta_3 L.GDP + \beta_4 L.CO_2 + \epsilon_{it} \tag{6}$$

We model the change in GDP (ΔGDP) as a function of past values of GDP and CO_2-emissions. All variables are transformed into log values. Our hypothesis is that CO_2-emissions and GDP are related in the long run. This implies that β_3 and β_4 are jointly different from zero. Also, if we multiply these coefficients with each other (β_3*β_4) this combination can be understood as a long-run elasticity. Additionally, this kind of modeling allows us to test the effect of CO_2-emissions on GDP, e.g. the significance and sign of β_2. If CO_2-emissions indeed have a positive effect on output, the coefficient should be different from zero and positive. The above model can be estimate by ordinary least squares regressions.

4 Results

We present results for constant GDP (Table 2) and for GDP in current prices (Table 3). The reason is that firms may react to changes in overall prices and make their output decision accordingly. This of course influences their decision on how much to pollute. However, GDP growth is usually based on constant GDP because inflation overstates the actual change in economy-wide output. Thus, we show results for both measurements of changes in GDP. We discuss the results for the industries based on our ranking (Table 1) and show industry-specific trends in CO_2-emissions and GDP for these industries as well (Figure 3 to 9).[10] In Table 2 and 3 we also report the computed F-values for the bounds-testing approach. Pesaran et al. report critical lower and upper bounds for cointegration to exist. We use following critical F-values for our analysis (Pesaran et al., p.300, for k=1): at 10 percent significance F_{lower} = 4.04, F_{upper} = 4.78, at 5 percent significance F_{lower} = 4.94, F_{upper} = 5.83, and for 1 percent significance F_{lower} = 6.84, F_{upper} = 7.84. Based on test of stationarity and information criteria tests for optimal lag lengths, we choose models with a lag length of one.[11]

We find a long-run (e.g. cointegrating) relationship between CO_2-emissions and constant GDP for the energy-producing, the agriculture, the water utilities and the coking industry (Table 2). If we use current GDP (Table 3), we find additionally to these industries, cointegration for the chemical and transport and storage industry. Though, the cointegrating relationship for the coking and energy-producing industry is only significant at the 10 percent level (e.g. close to rejecting). Surprisingly, for the industries where cointegration exists, the change in CO_2-emissions (ΔCO_2) has a negative effect on changes in GDP. This can be explained by environmental taxes in place (e.g. on energy used), and the need to buy pollution allowances through the European Emissions Trading System since 2005. Also, in turn reducing CO_2-emissions would increase GDP. This could be explained by voluntary industry agreements to reduce CO_2-emissions, or the increasing use of more efficient and environmentally friendly technologies, so-called greener technologies (Lehr, Lutz, and Edler 2012, Schreurs 2012, Jännicke 2012, Fujii and Managi 2013)

[10] Cointegration results for the remaining industries can be fond in the appendix.

[11] Information criteria suggest for many models lag lengths between zero or one. If zero is appropriate we still choose a lag length of one to allow for some dynamics in our relatively short time series. Results for the test statistics and unit-root tests can be requested from the authors.

[Table 2 and 3 about here]

Some of the industry developments warrant some additional discussion, e.g. the energy-producing industry, processing and agriculture. These industries are the top polluters in our sample.

The energy producing industries mainly consist of power-plants, oil refineries and the production of heat (Statistisches Bundesamt 2008, Bundesministerium für Wirtschaft und Technologie 2013). Basically, any output produced will have emissions as a consequence. CO_2-emissions are the main emission in this industry. As similar argument can be made for the coking and petroleum industry. Thus, Germany promotes a strategy to reduce CO_2-emissions in the energy sector (e.g. the Energiewende, taxes on energy) and could successfully reduce the emissions in the sector since 1990 until very recently.[12] This could lead to a decoupling of output growth to CO_2-emissions and explain why the cointegrating relationship we find is weak. Instead of seeing CO_2-emissions as an input in production and a deliberate choice made by the firm, CO_2-emissions could be just a by-product of production. Furthermore, trends in GDP and CO_2-emissions seem to follow a common development at most weakly (Figure 3).

[Figure 3 about here]

The processing industry includes the production of investment products, consumer goods as well as repair and installation of machines (Statistisches Bundesamt 2008). We cannot find a long-run relationship between GDP growth and CO_2-emissions, although the trends (Figure 3) move somewhat together. An explanation can be that technology developments in this industry led to decrease in CO_2-emissions and therefore CO_2-emissions cannot be seen as a

[12]Starting in 2012, CO_2-emissions in the energy-sector increased slightly. This can be explained by the cold Winter in 2012 and 2013, as well as the increased use of coal-fired power plants (AG Energiebilanzen 2014).

direct input to production.

However, the long-run relationship between CO_2-emissions and GDP is more pronounced in industries like the transportation industry and the chemical industry (Figure 4). Especially, in transportation CO_2-emissions can be seen as an input to the service where any mode of transportation used needs energy (e.g. through fuel combustion) and the use of energy creates emissions. Emissions from the chemical industry come from the production of organic and inorganic chemicals, and can include various acids (e.g. ammonia) and carbides (Umweltbundesamt 2003), but also from the use of energy and water in the production process. However, improvements in technology but also stricter laws in Germany, could potentially weaken the relationship between CO_2-emissions and GDP in the chemical industry (Umweltbundesamt 2003, Drotloff 2014).

[Figure 4 about here]

Emissions, especially methane and nitrides, are are an integral part of agriculture, e.g. through the use of fertilizers and the production of greenhouse gases through livestock. However, these emissions are falling in the agriculture sector (Figure 5), for instance through the use of bio-gas and bio-mass to produce energy (Faaji 2006, Blottnitz and Curran 2007). This reduction in CO_2-emissions could lead to a decoupling of CO_2-emissions as an input from the production, as in other industries where technology advancements led to more environmentally friendly technologies.

Surprisingly, we find that CO_2-emissions and GDP are cointegrated for the water utilities. If keeping in mind that part of this industry is the extraction, the distribution and the cleaning of water (Statistisches Bundesamt 2008), CO_2-emissions come mainly from the use of energy. This can also explain why the trends seem to move together (Figure 5). Though, this long-term relationship could change in the near future, given that water utilities in Germany increase their activities to reduce their emissions through the use of alternative energy and more efficient energy-related inputs.[13]

[Figure 5 about here]

So far, we discussed industries based on the ranking in Table 1. Though, we have 47 industries available and should mention a few more industries where we find cointegration between CO_2-emissions and GDP. These industries are the aviation industry, the information and technology industry and the automobile and vehicle manufacturing industry. Results are summarized in Table 4.

[Table 4 about here]

The aviation and information and communication industries depend highly on energy to produce their outputs. Emissions in the aviation industry come mostly from airplanes and the use of fuel (e.g. through short and long haul services). This implies that every kilometer (or mile) flown, directly translates into CO_2-emissions (Scheelhaase, Grimme und Schaefer 2010).[14] Whereas, the information and communication industry uses computer equipments, networks and therefore electricity to produce their products and services. Part of this industry is also telecommunication including the use telecommunication infrastructure (e.g. high speed data connections). Even with more energy-efficient systems, the nature of the process will not change. Thus, we can find a significant cointegration between CO_2-emissions and GDP in these two industries. Furthermore, the trends in CO_2-emissions and GDP move together very closely (Figure 6).

[Figure 6 about here]

[13] Examples includes the Veolia-Group (Veolia 2014), or the water utilities in Berlin (Berliner Wasserbetriebe 2014).

[14] A similar argument could be made for any traffic service including the use of fuel. Thus we can find also cointegration between CO_2-emissions and GDP for miscellaneous traffic services (Table 5 and 6).

The automobile and vehicle manufacturing industry (including the production of parts) uses energy to produce their outputs as well, but also creates additional pollution during the production process, e.g. through the use of chemicals and water (Gruden 2008, Mayyas et al. 2012). We find a cointegrating relationship between CO_2-emissions and GDP for these industries. Furthermore, the trends move somewhat together (Figure 7)

[Figure 7 about here]

For the remaining industries in Table 1 we cannot find cointegration between CO_2-emissions and GDP. These industries include the waste, water and recycling industry, the glass, ceramic and other related products industry, and the metal production (see Table 2 and 3 for results). Trends for these industries can be found in Figure 8 and 9. Furthermore, we cannot find cointegration for most of the remaining industries in our sample of 47 industries (see appendix). In conclusion, the long-run relationship between CO_2-emissions and GDP is more likely for industries with high levels of energy as inputs to the production of the goods and services, and through this channel emissions are mainly produced.

[Figure 8 and 9 about here]

5 Conclusion

Environmental pollution is one of the major concerns in modern human development. It is linked to the climate change (Intergovernmental Panel on Climate Change 2014) and to reduced health of people (Ho and Jorgenson 2007). Environmental pollution comes directly from activities by firms and households. In this study, we focus on the relationship between CO_2-emissions and GDP at the industry level. We hypothesis that CO_2-emissions (or any form of emission) can be seen as an input to the production of firms, e.g. through the use of energy. We test for cointegration using the bounds-test developed by Pesaran, Shin and Smith (2001) and find that for most of our 47 industry no cointegration exists. This could imply that pollution (or emissions) are merely a by-product of economic activities and not an input to production. Even then, our results imply that growth is not driven, or linked, with CO_2-emissions. This could give another argument why very often the hypothesized relationship between per capita income growth and pollution, the empirical Kuznets curve, can often not be found (Stern 2004).

However, given we observe German industries from 1995 to 2010, the decoupling of CO_2-emissions and GDP growth can be explained by environmental policies in place. Germany is one of the more progressive countries in promoting energy-efficient technologies, behaviors and the change of the energy mix to more alternative and regenerative energy sources, the Energiewende. This development can show that promoting more environmentally friendly technologies helps not just reducing CO_2-emissions, but also makes production processes cleaner. Especially, Germany could be seen as a working example for an Energiewende from non-regenerative energy to alternative and regenerative energy. This particular strategy is seen as one of the solutions to climate change (Intergovernmental Panel on Climate Change 2014).

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Figures

Figure 1: Trends in overall CO_2-emissions and GDP

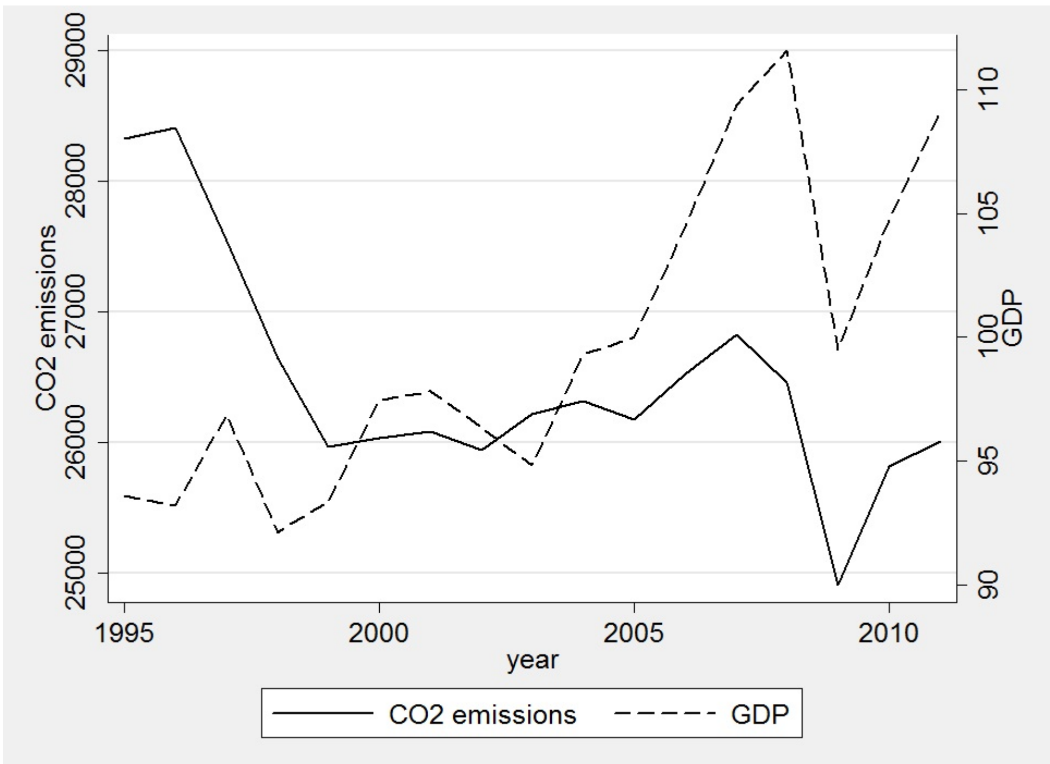


Figure 2: Trends in overall CO_2-emissions by select industries

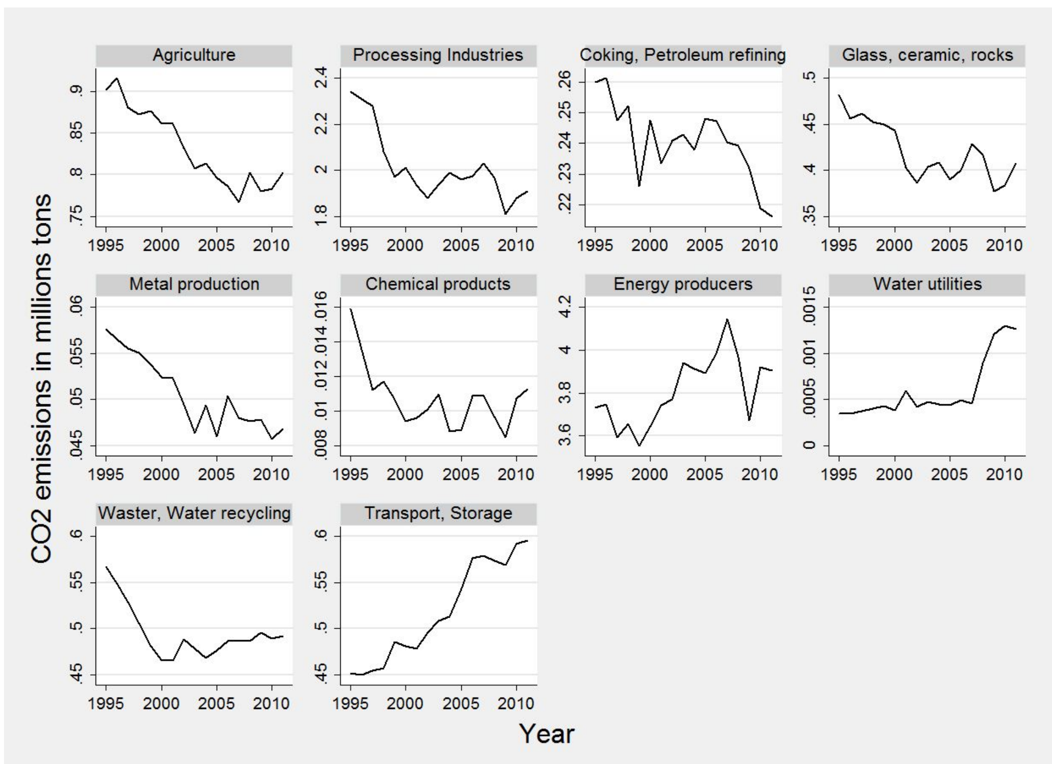


Figure 3: Trends in CO_2-emissions and GDP - Energy providers and processing industry

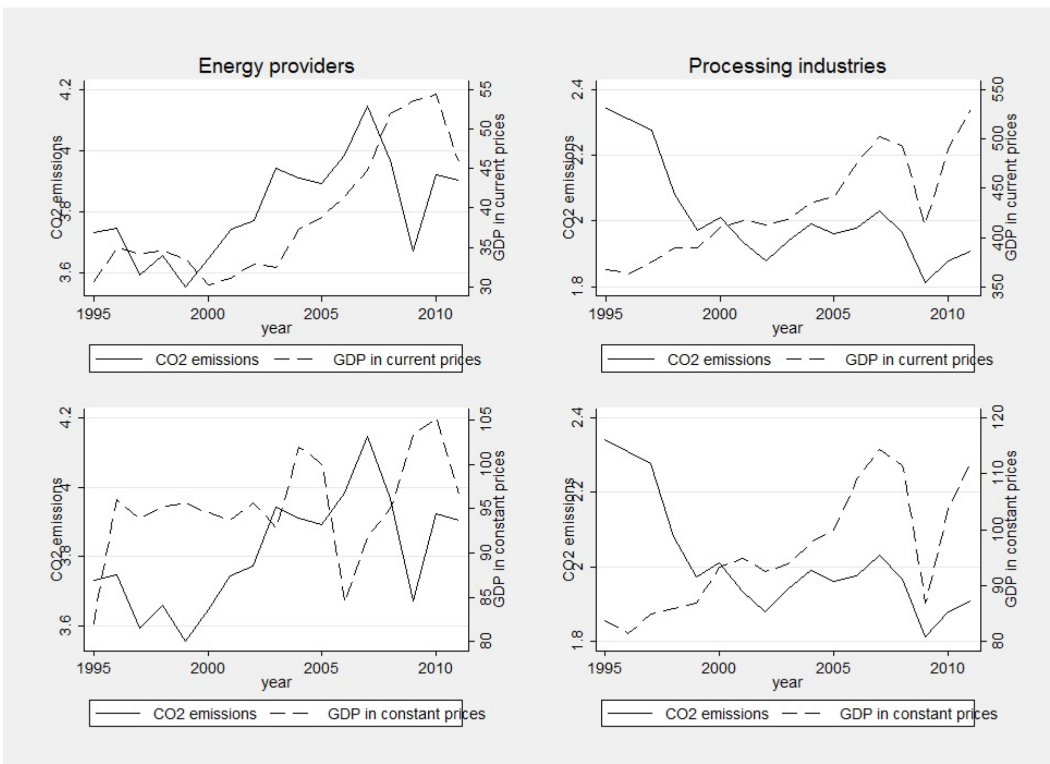


Figure 4: Trends in CO_2-emissions and GDP - Transport and storage, and chemical industry

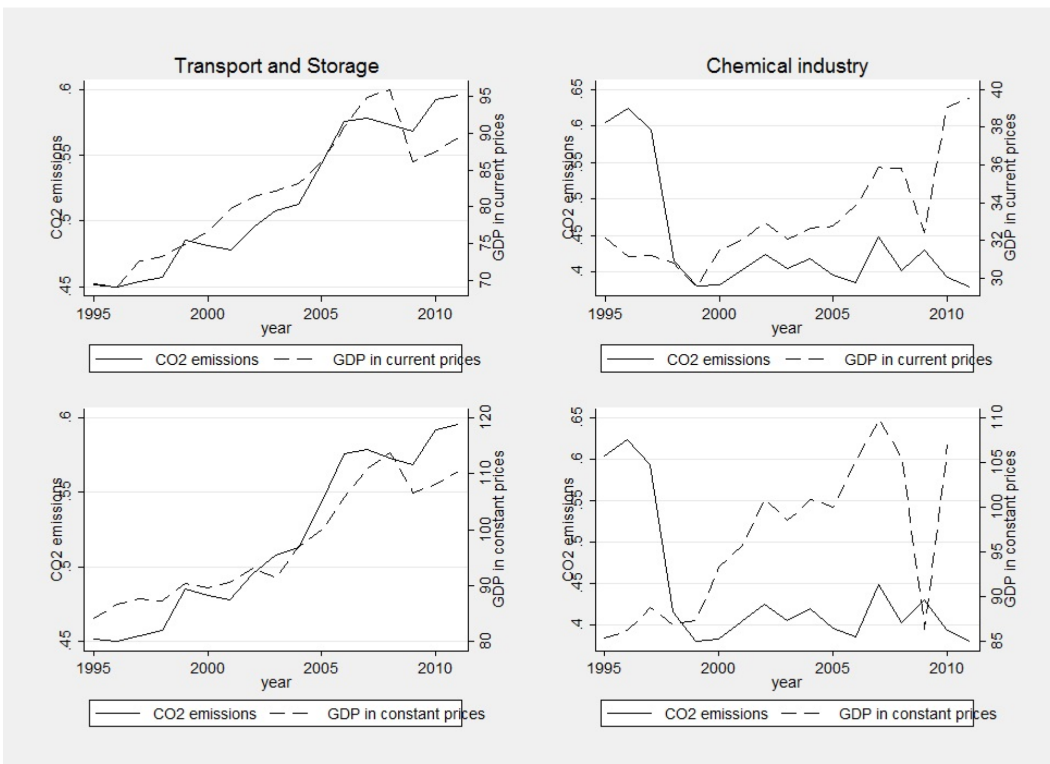


Figure 5: Trends in CO_2-emissions and GDP - Agriculture, and Water utilities

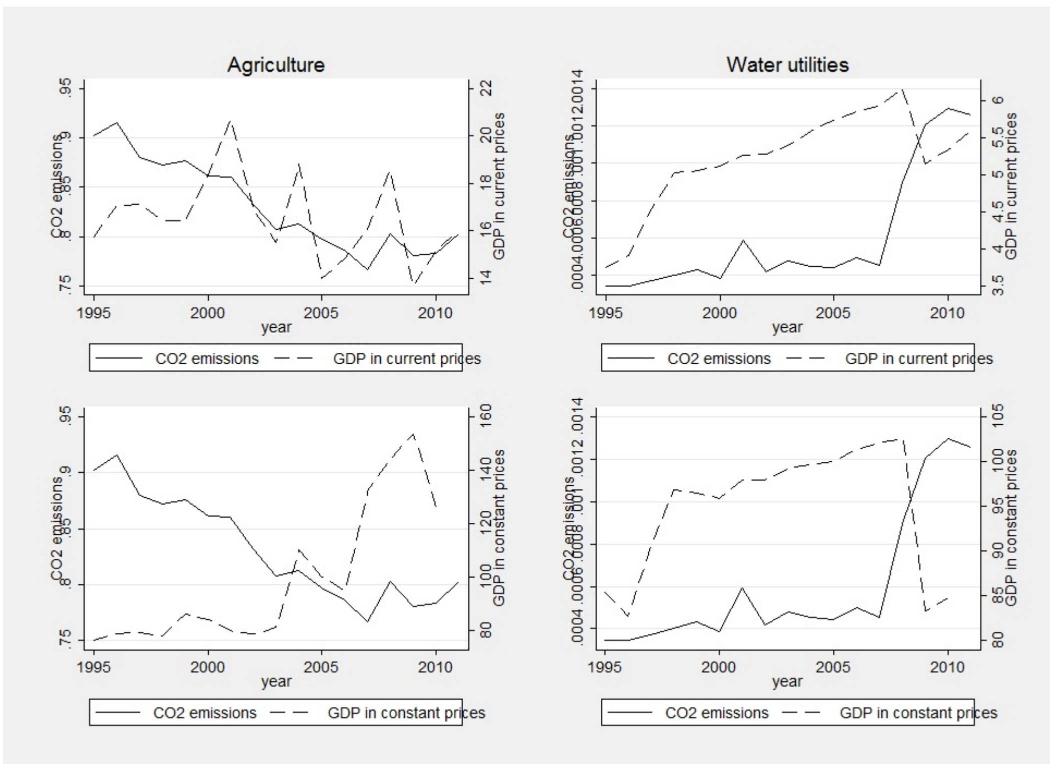


Figure 6: Trends in CO_2-emissions and GDP - Aviation, and Information and Communication

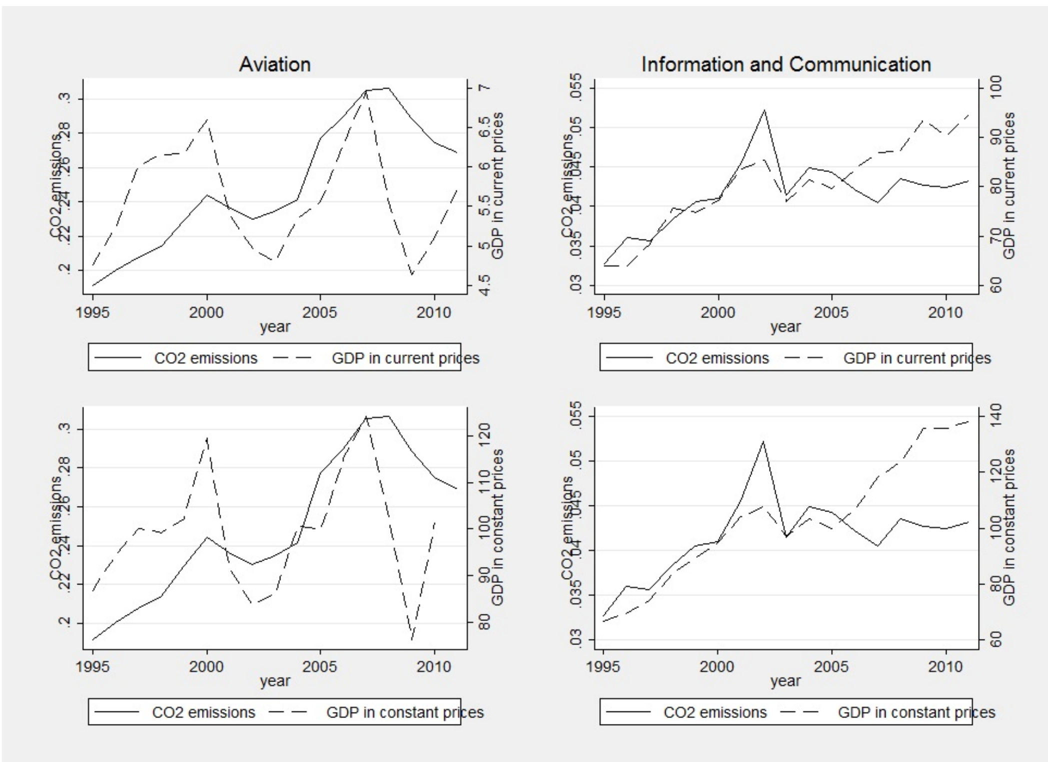


Figure 7: Trends in CO_2-emissions and GDP - Automobiles, parts and misc. vehicles

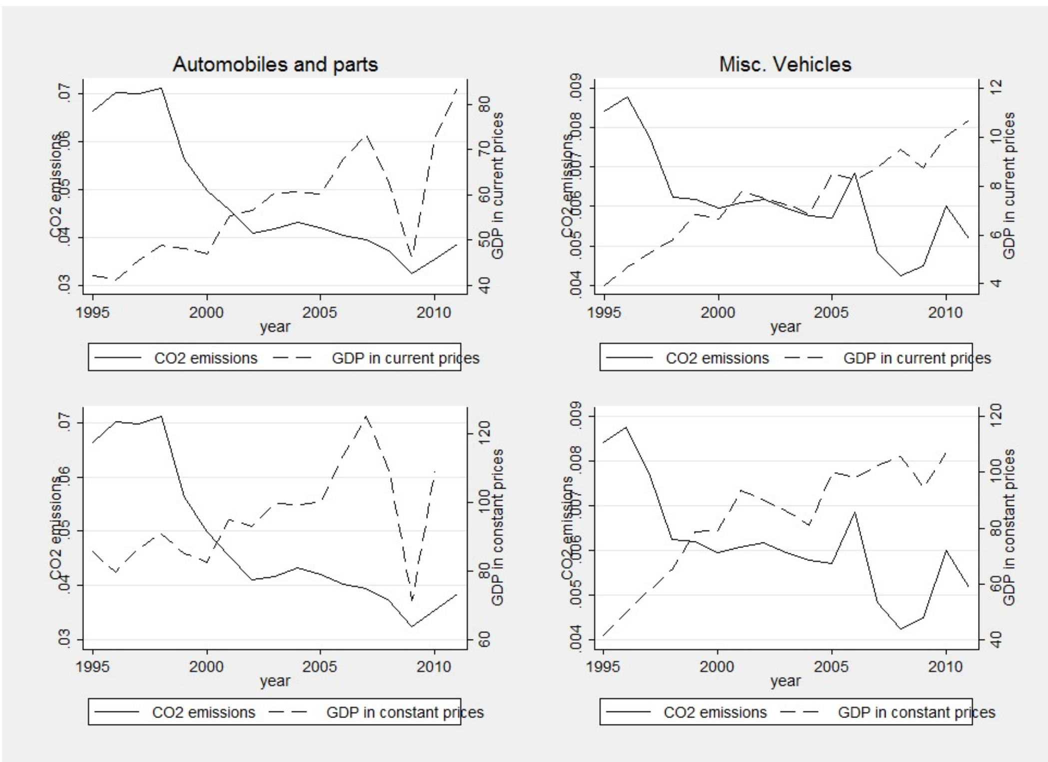


Figure 8: Trends in CO_2-emissions and GDP - Waste and recycling, and glass, ceramic and more

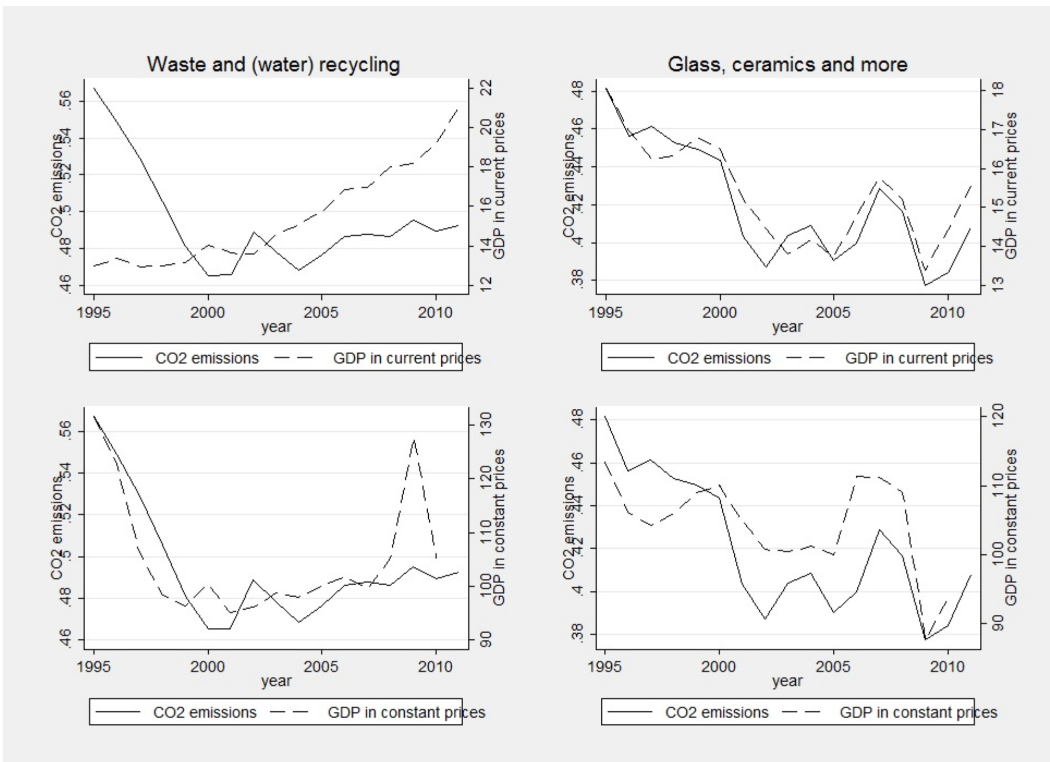
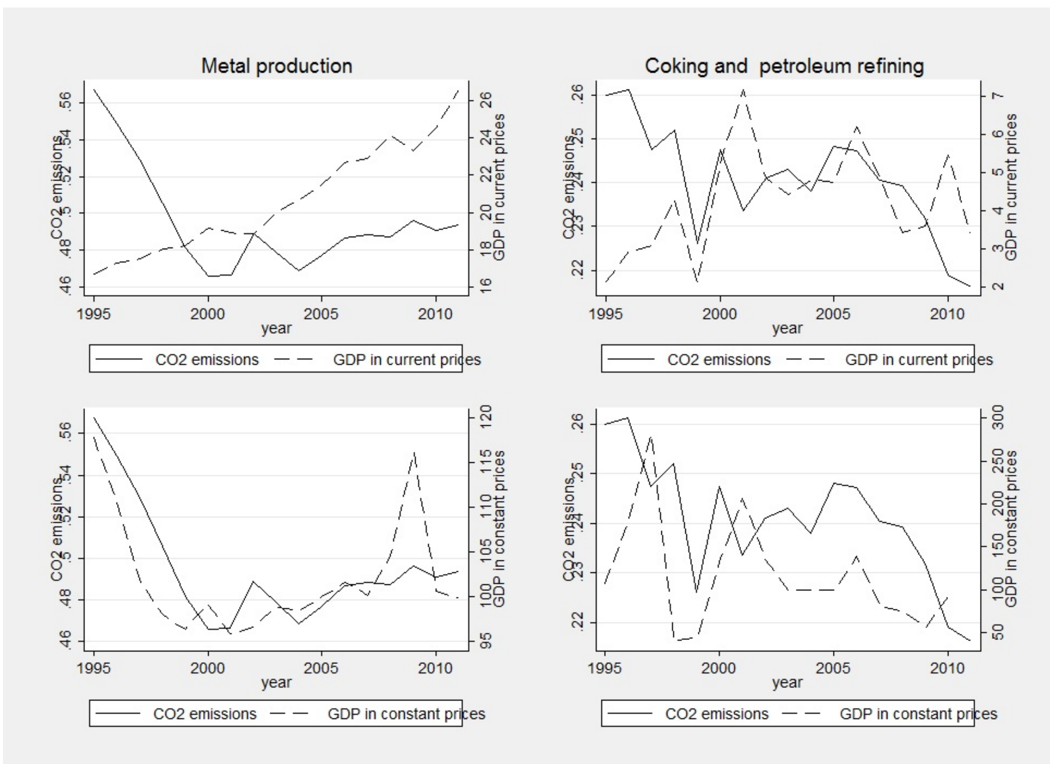


Figure 9: Trends in CO_2-emissions and GDP - Metal producing, and coking and petroleum refining



Tables

Table 1: Top ten industries in 1995 and 2010 - Ratio CO_2 over GDP

Industries	CO_2 / GDP 1995	share on CO_2	CO_2 / GDP 2010	share on CO_2
Energy producers	0.004548505	19.09 %	0.00372741	21.71 %
Processing industries	0.002794013	11.99 %	0.00181341	10.41 %
Agriculture	0.001183965	4.63 %	0.00062064	4.34 %
Chemical products	0.000708558	3.09 %	0.00036709	2.17 %
Water utilities	0.00048176	0.00 %	0.00048794	0.01 %
Waste and water recycling	0.00043098	2.90 %	0.00046585	2.71 %
Glass, Ceramics, industrial rocks and rare minerals	0.000424911	2.47 %	0.00040902	2.13 %
Metal production and processing	0.000481756	2.40 %	0.00051021	2.19 %
Transport and storage	0.000537098	2.31 %	0.00054796	3.28 %
Coking and petroleum refining	0.00024045	1.33 %	0.00023782	1.21 %

Note: CO_2 is in million tons. GDP is in billion Euros and in constant 2005 prices.

Table 2: Unrestricted cointegration models - GDP in constant 2005 prices - 1995 - 2010

	ΔGDP_{t-1}	$\Delta CO2_{t-1}$	GDP_{t-1}	$CO2_{t-1}$	R^2	F-Value	Cointegrated
Energy producers	- .170	-.454	-.965**	.221	0.48	4.08	Yes
Processing industries	-.005	.892	-.730**	-.725*	0.44	3.72	No
Agriculture	.053	2.917	-.778**	-3.251**	0.35	5.41	Yes
Chemical Products	-.234	.422**	-.879***	-.266*	0.51	5.39	Yes
Water utilities	-.073	-.096	-.516*	-.079	0.65	5.98	Yes
Waste and water recycling	.489	.039	-1.076	.703	0.26	3.92	No
Glass, Ceramics, industrial rocks and rare minerals	.868	-.075	-1.587**	.400	0.24	3.81	No
Metal production and processing	.368	.461	-1.153**	-1.017	0.24	2.95	No
Transport and storage	.338	-.580	-1.339***	1.304***	0.40	5.43	Yes
Coking and petroleum refining	.665**	1.938	-1.428***	2.551	0.52	9.02	Yes

Note: significant at *** 1%, ** 5%, * 10%. Robust standard errors are in parentheses and the adjusted R^2 is reported. Models are tested for serial correlation in the error terms. Appropriate lag length is chosen by information criteria. Tests for stationarity are performed using the Dickey Fuller and Philips Perron tests. None of the series is I(2). Every model includes a constant as well.

Table 3: Unrestricted cointegration models - GDP in current prices - 1995 - 2010

	ΔGDP_{t-1}	$\Delta CO2_{t-1}$	GDP_{t-1}	$CO2_{t-1}$	R^2	F-Value	Cointegrated
Energy producers	-.570**	-1.906***	-.358***	2.860***	0.77	16.80	Yes
Processing industries	-.023	.544	-.509*	-.637	0.31	2.02	No
Agriculture	.498*	-3.339**	-1.349***	.918	0.57	6.19	Yes
Chemical Products	-.357	.231	-.087	-.131	0.07	0.68	No
Water utilites	-.038	-.145**	-.399***	.016	0.65	7.79	Yes
Waste and water recycling	-.348	.159	.130	-.191	0.04	1.20	No
Glass, Ceramics, industrial rocks and rare minerals	.717	-.646	-1.027	.735	0.12	2.71	No
Metal production and processing	.105	.463	-.706*	-1.038	0.05	2.07	No
Transport and storage	.162	.305	-.533	.385	0.18	2.58	No
Coking and petroleum refining	-.019	3.132	-1.059**	-3.333	0.34	4.24	Yes

Note: significant at *** 1%, ** 5%, * 10%. Robust standard errors are in parentheses and the adjusted R^2 is reported. Models are tested for serial correlation in the error terms. Appropriate lag length is chosen by information criteria. Tests for stationarity are performed using the Dickey Fuller and Philips Perron tests. None of the series is I(2). Every model includes a constant as well.

Table 4: Unrestricted cointegration models - A few more industries - 1995 to 2010

	ΔGDP_{t-1}	$\Delta CO2_{t-1}$	GDP_{t-1}	$CO2_{t-1}$	R^2	F-Value	Cointegrated
Aviation (current GDP)	.522*	.723	-.975***	-.044	0.50	8.04	Yes
Aviation (constant GDP)	.554	1.398	-1.565***	.289	0.50	8.47	Yes
Information and communication (current GDP)	-.360	.010	.008	-.388*	0.37	4.74	Yes
Information and communication (constant GDP)	.015	-.126	.001	-.416*	0.39	4.45	Yes
Automobiles and parts (current GDP)	.597**	.350	-1.419***	-.788***	0.66	9.63	Yes
Automobiles and parts (constant GDP)	.794**	.473	-1.666***	-.583**	0.48	6.16	Yes

Note: significant at *** 1%, ** 5%, * 10%. Robust standard errors are in parentheses and the adjusted R^2 is reported. Models are tested for serial correlation in the error terms. Appropriate lag length is chosen by information criteria. Tests for stationarity are performed using the Dickey Fuller and Philips Perron tests. None of the series is I(2). Every model includes a constant as well.

Appendix

Table A1: Unrestricted cointegration models - Remaining Industries - GDP in current prices - 1995 - 2010

	ΔGDP_{t-1}	$\Delta CO2_{t-1}$	GDP_{t-1}	$CO2_{t-1}$	R^2	F-Value	Cointegrated
Forestry use	.273	-.069	-1.055*	.119	0.20	2.85	No
Fishery	.322	.065	-1.110***	-.216**	0.42	7.02	Yes
Mining	-.132	-.342	-.427*	-.160	0.42	2.33	No
Food, Beverages and Tobacco	.066	.227	-.368*	-.101	0.44	2.95	No
Clothing, and Leather	-.029	.038	-.325	.046	0.20	1.00	No
Wood products	.150	.099	-.542	-.051	0.30	1.01	No
Paper and Card board	.068	.080	-.281*	-.045	0.34	2.24	No
Printing	.167	-.126	-.237	.124	0.08	0.26	No
Pharmaceutical products	-.029	.029	-.110	-.095	0.28	1.51	No
Plastics	-.334	.005	-.059	.094	0.12	0.16	No
Metals	.119	.418	-.319	-.258	0.30	1.14	No
Digital video, electronic and optical products	.142	.400	-.730**	-.284	0.40	2.82	No
Electronic equipment	-.623	.173	.014	-.002	0.37	0.00	No
Machines	-.143	.488	-.357	-.361	0.23	0.93	No
Misc. vehicles	-.308	.088	-.301	-.133	0.31	1.58	No
Water, distribution and waste	-.330	.060	.058	.061	0.13	0.18	No
Construction	.023	.047	.177	-.308*	0.69	2.85	No
All retail services, and repairs of vehicles	.007	-.006	-.194	-.018	0.22	1.42	No
Retail services and repairs of vehicles	-.728	-.022	.084	.460	0.39	2.94	No
wholesale services without vehicles	-.142	-.042	-.134	.091	0.10	0.46	No
Retail services without vehicles	.064	-.012	-.354	.037	0.26	1.74	No
Misc. traffic and services	.547	.067	-1.285*	.047	0.42	7.03	Yes
services using long-distances pipes							
Maritime logistics	-.355	-.370	-.124	.064	0.28	0.53	No
Storage, and misc. traffic services	.307	-.131	-.348	.280	0.15	2.40	No
Mail delivery	.217	-.180	.021	.271	0.21	2.35	No
Hotels and restaurants	.137	-.026	-.150	-.052	0.12	0.49	No
Financial and insurance services	.283	.339	-.792	-.275	0.38	1.43	No
Estate and apartment services	.223	-.007	.018	-.022	0.07	0.09	No
Free-lancer, and scientific services	.020	-.101	-.241	.050	0.22	1.42	No
Misc. commercial services	.087	-.154	-.058	-.284	0.49	1.86	No
Public administration, defense and social security	.494	.021	-.004	-.022	0.39	0.62	No
Child care and education	-.231	-.000	.032	.038	0.07	0.13	No
Medical and social services	-.768*	.060	.133**	.191*	0.27	3.30	No
Misc. services	-.092	-.051	-.028	.001	0.19	0.61	No

Note: significant at *** 1%, ** 5%, * 10%. Robust standard errors are in parentheses and the adjusted R^2 is reported. Models are tested for serial correlation in the error terms. Appropriate lag length is chosen by information criteria. Tests for stationarity are performed using the Dickey Fuller and Philips Perron tests. None of the series is I(2). Every model includes a constant as well.

Table A2: Unrestricted cointegration models - Remaining Industries - GDP in constant 2005 prices - 1995 - 2010

	ΔGDP_{t-1}	$\Delta CO2_{t-1}$	GDP_{t-1}	$CO2_{t-1}$	R^2	F-Value	Cointegrated
Forestry use	.158	-.119	-.639	-.173	0.12	1.66	No
Fishery	.146	.187	-.301	.051	0.34	1.97	No
Mining	-.401	-.177	-.235	.051	0.40	0.97	No
Food, Beverages and Tobacco	.922**	.588	-1.08**	.317*	0.48	5.62	Yes
Clothing, and Leather	-.589**	-.278**	-.891***	.492***	0.65	9.32	Yes
Wood products	-.182	.129	-.221	-.038	0.29	0.15	No
Paper and Card board	.161	-.029	-.699*	.292	0.08	2.56	No
Printing	.491	-.109	-.766**	.084	0.25	3.37	No
Pharmaceutical products	-.236	-.032	-.070	-.141*	0.09	1.72	No
Plastics	-.362	-.318	-.246	-.040	0.07	0.64	No
Metals	.923	.410	-.989*	-.527	0.30	1.88	No
Digital video, electronic and optical products	.189	.780	-.237	-.690	0.08	0.20	No
Electronic equipment	.104	.232	-1.229**	-.118	0.44	3.24	No
Machines	.499	.444	-1.272**	-.348	0.27	3.67	No
Misc. vehicles	-.337	-.009	-.424*	-.115	0.29	4.62	Yes
Water, distribution and waste	.060	.258	-.716	-.027	0.22	3.81	No
Construction	.325	-.112	-.625	.427	0.28	1.72	No
All retail services, and repairs of vehicles	-.089	-.050	-.110	-.103	0.00	0.87	No
Retail services and repairs of vehicles	.076	-.103	-.142	.031	0.23	1.29	No
wholesale services without vehicles	-.037	-.026	-.016	-.040	0.05	0.12	No
Retail services without vehicles	.188	-.027	-.658	.053	0.28	1.58	No
Misc. traffic and services using long-distances pipes	.153	.113	-.602	-.244	0.30	1.37	No
Maritime logistics	-.808	-1.099	.531	.919	0.31	0.45	No
Storage, and misc. traffic services	.643**	-.487*	-.860***	.780***	0.50	7.21	Yes
Mail delivery	.071	-.292	-.244	.390**	0.23	3.76	No
Hotels and restaurants	-.030	.086	-.351	-.103	0.19	1.01	No
Financial and insurance services	.158	.094	-.303	.049	0.18	0.89	No
Estate and apartment services	-.035	.019	-.087	.002	0.23	1.08	No
Free-lancer, and scientific services	.219	-.209	-.385	.103	0.08	2.49	No
Misc. commercial services	.282	-.229	-.145	-.236	0.37	2.60	No
Public administration, defense and social security	1.085***	-.016	-.259	-.024*	0.45	2.14	No
Child care and education	-.041	-.015	-.800	-.031**	0.39	5.92	Not conclusive
Medical and social services	.026	.109	-.080	-.096	0.01	1.04	No
Misc. services	.269	-.116**	-.116	.038	0.24	1.95	No

Note: significant at *** 1%, ** 5%, * 10%. Robust standard errors are in parentheses and the adjusted R^2 is reported. Models are tested for serial correlation in the error terms. Appropriate lag length is chosen by information criteria. Tests for stationarity are performed using the Dickey Fuller and Philips Perron tests. None of the series is I(2). Every model includes a constant as well. Also, for the shipping industry constant GDP is only available until 2008. Furthermore, for child care and education the model is plagued with serial correlation.

Table A3: Greenhouse pollutants and share on overall CO_2-emissions - 1995

Industry	Total CO_2 equivalence in 1000 tons	CH_4 in %	N_2O in %	NH_3 in %	SO_2 in %	NO_x in %	NMVOC in %	Fine particles in %	**Overall** CO_2 in %	from energy use in %	from processes in %	from traffic in %
Agriculture	90194.47	33.52	49.69	0.63	0.02	0.21	0.03	0.06	15.79	84.56	n.a.	8.49
Forestry	98.85	0.00	0.00	0.00	0.05	0.77	0.22	0.05	100.15	n.a.	n.a.	100.00
Fishery	149.11	0.01	0.00	0.01	0.78	2.36	0.07	0.08	99.26	96.62	n.a.	3.38
Mining	25267.47	61.00	0.00	0.00	0.08	0.04	0.00	0.09	38.23	78.65	18.95	2.38
Processing	234194.2	0.01	0.04	0.01	0.13	0.13	0.37	0.03	84.19	66.16	29.74	3.32
Food, Beverages, and Tobacco	11435.36	0.01	0.00	0.00	0.13	0.15	0.15	0.02	99.30	92.80	n.a.	7.19
Clothing, and Leather	2720.03	0.01	0.00	0.00	0.09	0.16	0.01	0.01	99.26	92.22	n.a.	7.74
Wood products	1701.19	0.01	0.00	0.01	0.13	0.19	0.32	0.13	99.17	66.63	n.a.	8.95
Paper and Card board	8011.15	0.00	0.00	0.00	0.32	0.12	0.01	0.02	99.10	86.80	1.98	
Printing	1389.45	0.00	0.10	0.03	0.03	0.12	8.88	0.23	68.23	57.28	28.59	14.14
Coking and Oil refining	26002.28	0.05	0.00	0.00	0.34	0.18	0.30	0.01	98.61	98.33	1.15	0.52
Chemical products	60461.22	0.00	0.13	0.01	0.10	0.08	0.17	0.01	56.52	55.09	43.48	1.43
Pharmaceutical Products	2151.72	0.00	0.00	0.00	0.09	0.14	0.01	0.02	99.41	94.30	n.a.	5.70
Plastics	2252.51	0.00	0.00	0.00	0.07	0.20	0.02	0.01	99.44	86.88	n.a.	13.13
Glass, ceramics, industrial and rare minerals	48167.93	0.00	0.00	0.01	0.05	0.16	0.01	0.02	94.20	48.51	50.33	0.64
Metals	46942.3	0.01	0.00	0.00	0.12	0.09	0.01	0.06	94.88	56.09	43.16	0.75
Metal products	5764.22	0.01	0.02	0.01	0.06	0.15	2.56	0.07	92.97	84.38	6.01	9.61
Digital video, electronic and optical products	2794.51	0.00	0.00	0.00	0.04	0.11	0.01	0.01	48.77	82.32	n.a.	17.61
Electronic equipment	1590.92	0.01	0.00	0.00	0.11	0.34	0.04	0.03	99.38	68.88	n.a.	31.12
Machines	4210.75	0.00	0.00	0.00	0.08	0.25	0.03	0.02	99.51	79.93	n.a.	20.02
Automobiles and parts	6640.4	0.00	0.00	0.00	0.03	0.14	5.62	0.01	60.16	59.90	20.50	19.57
Misc. Vehicles	840.82	0.00	0.00	0.00	0.10	0.20	0.02	0.02	99.43	87.32	n.a.	12.68
Energy providers	373068.4	0.06	0.00	0.00	0.31	0.08	0.00	0.01	98.07	99.29	n.a.	0.08
Water, distribution and waste	56751.38	72.00	0.01	0.00	0.02	0.10	0.01	0.01	20.82	32.69	n.a.	34.06
Water, and water distribution	34.44	0.00	0.00	0.00	0.07	0.98	0.12	0.07	98.72	n.a.	n.a.	100.00
Waste and water recycling	56716.94	76.00	0.01	0.00	0.02	0.10	0.01	0.01	20.77	32.79	n.a.	33.87
Construction	13968.9	0.01	0.00	0.00	0.08	0.76	0.12	0.11	99.43	52.12	n.a.	46.67
All retail services and repair of vehicles	24137.56	0.07	0.00	0.00	0.08	0.37	0.39	0.03	98.22	60.34	n.a.	37.80
Retail services and repairs of vehicles	3177.73	0.03	0.00	0.00	0.08	0.30	0.06	0.02	99.16	63.82	n.a.	36.12
Wholesale services without vehicles	8074.34	0.14	0.00	0.00	0.07	0.60	1.04	0.04	96.84	42.37	n.a.	54.98
Retail services without vehicles	12885.49	0.04	0.00	0.00	0.08	0.25	0.06	0.02	98.86	70.52	n.a.	27.67
Transport and storage	45148.48	0.04	0.00	0.00	0.22	1.04	0.07	0.29	98.51	63.50	n.a.	36.45
Misc. traffic and services using long distance pipes	8812.05	0.19	0.00	0.00	0.08	1.22	0.17	0.42	95.72	n.a.	n.a.	99.85
Maritime logistics	7322.47	0.01	0.00	0.00	1.07	2.12	0.10	1.10	99.16	95.73	n.a.	4.27
Aviation	19141.61	0.00	0.00	0.01	0.02	0.46	0.02	0.02	99.04	94.81	n.a.	5.17
Storage and misc. Traffic services	4767.83	0.01	0.00	0.00	0.08	1.07	0.06	0.05	99.46	12.15	n.a.	87.73
Mail delivery	2139.15	0.01	0.00	0.00	0.08	1.01	0.06	0.05	99.48	14.66	n.a.	85.24
Hotels and restaurants	5227.53	0.05	0.00	0.00	0.07	0.11	0.06	0.02	98.73	76.92	n.a.	12.23
Information and communication	3274.13	0.02	0.00	0.00	0.06	0.60	0.07	0.04	99.42	33.70	n.a.	64.98
Financial and insurance services	2518.16	0.04	0.00	0.00	0.06	0.11	0.03	0.01	98.92	83.94	n.a.	8.51
Estate and apartment services	1189.11	0.02	0.00	0.00	0.06	0.57	0.08	0.04	99.40	28.85	n.a.	65.48
Free-lancer, and scientific services	6469.25	0.01	0.00	0.00	0.06	0.60	0.08	0.04	99.47	28.02	n.a.	70.30
Misc. Commercial services	927.22	0.03	0.00	0.00	0.06	0.50	0.06	0.03	99.11	46.14	n.a.	49.40
Public administration, defense and social security	10905.53	0.04	0.00	0.00	0.09	0.30	0.10	0.03	98.82	86.26	n.a.	12.07
Child care and education	5406.49	0.06	0.00	0.00	0.06	0.08	0.02	0.01	98.44	97.31	n.a.	2.69
Medical aid and social services	7423.52	0.07	0.00	0.00	0.07	0.11	0.05	0.02	94.21	87.06	n.a.	8.48
Misc. Services	6874.02	0.03	0.00	0.00	0.07	0.38	0.04	0.03	99.04	61.85	n.a.	37.82

Note: Own calculations based on Umweltgesamtrechnung (2013). Column 1 shows CO_2-emissions in equivalence units. Column 2 to 9 show the share of different pollutants on overall CO_2-emissions in equivalence units. Columns 10 to 12 show the origin of actual overall CO_2-emissions.

Table A4: Greenhouse pollutants and share on overall CO_2-emissions - 2010

Industry	Total CO_2 equivalence in 1000 tons	CH_4 in %	N_2O in %	NH_3 in %	SO_2 in %	NO_x in %	NMVOC in %	Fine particles in %	**Overall** CO_2 in %	from energy use in %	from processes in %	from traffic in %
Agriculture	78324.35	31.1	55.71	0.66	0.00	0.20	0.02	0.06	12.52	69.79	n.a.	5.06
Forestry	48.71	0.00	0.00	0.00	0.00	0.55	0.04	0.04	98.54	n.a.	n.a.	93.75
Fishery	71.77	0.01	0.00	0.01	0.73	2.25	0.07	0.08	98.93	91.55	n.a.	8.45
Mining	8948.48	32.00	0.00	0.00	0.05	0.08	0.00	0.17	65.84	74.56	20.13	3.14
Processing	188050.5	0.01	0.01	0.01	0.09	0.11	0.34	0.02	95.01	61.12	30.18	2.88
Food, Beverages, and Tobacco	9658.01	0.01	0.00	0.00	0.04	0.12	0.15	0.02	99.33	88.52	n.a.	6.07
Clothing, and Leather	938.02	0.01	0.00	0.00	0.02	0.12	0.01	0.01	99.25	91.19	n.a.	7.95
Wood products	4178.64	0.01	0.00	0.00	0.02	0.17	0.12	0.06	99.03	18.87	n.a.	1.96
Paper and Card board	9921.4	0.00	0.00	0.00	0.06	0.11	0.04	0.01	99.23	69.19	n.a.	1.26
Printing	978.01	0.01	0.03	0.05	0.00	0.09	10.78	0.31	90.69	63.92	26.16	9.36
Coking and Oil refining	21900.84	0.05	0.00	0.00	0.23	0.13	0.29	0.01	98.63	97.69	1.26	0.99
Chemical products	39290.13	0.00	0.03	0.02	0.09	0.12	0.16	0.01	88.25	46.18	48.32	1.10
Pharmaceutical Products	616.06	0.01	0.00	0.00	0.01	0.21	0.02	0.03	99.02	29.84	n.a.	20.16
Plastics	2189.85	0.00	0.00	0.00	0.03	0.12	0.01	0.01	99.41	88.84	n.a.	9.69
Glass, ceramics, industrial rocks and rare minerals	38402.49	0.00	0.00	0.01	0.06	0.10	0.01	0.01	93.79	45.60	49.90	0.43
Metals	44403.38	0.01	0.00	0.00	0.08	0.06	0.01	0.02	98.54	58.51	40.82	0.61
Metal products	4573.87	0.01	0.01	0.01	0.02	0.11	2.60	0.06	97.77	82.80	5.84	8.94
Digital video, electronic and optical products	1362.2	0.00	0.00	0.00	0.01	0.09	0.01	0.01	44.71	65.02	n.a.	33.00
Electronic equipment	1072.61	0.00	0.00	0.00	0.02	0.17	0.01	0.02	81.02	63.75	n.a.	34.06
Machines	3142.73	0.01	0.00	0.00	0.02	0.17	0.01	0.01	99.34	76.30	n.a.	21.62
Automobiles and parts	3543.01	0.00	0.00	0.00	0.01	0.16	7.36	0.01	99.04	57.94	16.33	23.62
Misc. Vehicles	601.32	0.00	0.00	0.00	0.01	0.16	0.01	0.01	99.45	78.43	n.a.	20.23
Energy providers	392198.3	0.07	0.00	0.00	0.05	0.08	0.00	0.00	97.86	90.69	n.a.	0.09
Water, distribution and waste	49076.84	28.00	0.02	0.00	0.00	0.11	0.00	0.00	52.52	31.43	n.a.	26.56
Water, and water distribution	129.59	0.00	0.00	0.00	0.01	0.53	0.02	0.03	98.77	8.59	n.a.	85.94
Waste and water recycling	48947.26	30.00	0.02	0.00	0.00	0.11	0.00	0.00	52.40	31.55	n.a.	26.26
Construction	9437.3	0.01	0.00	0.00	0.01	0.44	0.05	0.07	99.22	55.49	n.a.	40.26
All retail services and repairs of vehicles	18528.93	0.03	0.00	0.00	0.02	0.25	0.09	0.01	98.75	47.70	n.a.	47.06
Retail services and repairs of vehicles	2361.65	0.02	0.00	0.00	0.02	0.24	0.01	0.01	98.96	50.66	n.a.	46.43
Wholesale services without vehicles	6929.96	0.03	0.00	0.00	0.01	0.40	0.23	0.02	98.37	17.53	n.a.	74.72
Retail services without vehicles	9237.33	0.03	0.00	0.00	0.03	0.13	0.01	0.01	98.99	69.43	n.a.	26.60
Transport and storage	59196.38	0.03	0.00	0.00	0.12	0.63	0.03	0.18	98.29	58.00	n.a.	39.21
Misc. traffic and services using long distance pipes	11724.19	0.15	0.00	0.00	0.00	0.50	0.06	0.22	95.70	0.09	n.a.	93.73
Maritime logistics	6716.04	0.01	0.00	0.00	1.02	2.00	0.09	1.07	99.03	85.58	n.a.	12.80
Aviation	27483.79	0.00	0.00	0.01	0.01	0.41	0.02	0.01	99.00	96.35	n.a.	3.43
Storage and misc. Traffic services	9515.59	0.00	0.00	0.00	0.00	0.46	0.02	0.02	98.65	5.50	n.a.	88.65
Mail delivery	2011.78	0.00	0.00	0.00	0.00	0.44	0.01	0.02	98.67	9.97	n.a.	84.38
Hotels and restaurants	4205.21	0.03	0.00	0.00	0.04	0.07	0.02	0.01	99.09	79.70	n.a.	5.28
Information and communication	4239.59	0.02	0.00	0.00	0.01	0.34	0.02	0.02	98.95	32.90	n.a.	61.74
Financial and insurance services	1930.99	0.04	0.00	0.00	0.02	0.09	0.01	0.01	98.91	76.18	n.a.	13.30
Estate and apartment services	1185.62	0.02	0.00	0.00	0.01	0.28	0.03	0.02	99.02	26.92	n.a.	62.61
Free-lancer, and scientific services	7651.76	0.01	0.00	0.00	0.01	0.28	0.02	0.02	99.11	28.77	n.a.	65.74
Misc. Commercial services	1048.69	0.03	0.00	0.00	0.02	0.18	0.01	0.01	98.98	59.92	n.a.	33.24
Public administration, defense and social security	7179.14	0.03	0.00	0.00	0.05	0.23	0.05	0.01	98.73	77.20	n.a.	20.22
Child care and education	4121.72	0.05	0.00	0.00	0.03	0.06	0.00	0.00	98.79	96.54	n.a.	3.12
Medical aid and social services	7270.63	0.04	0.00	0.00	0.03	0.07	0.01	0.01	92.52	85.61	n.a.	8.71
Misc. Services	6261.97	0.02	0.00	0.00	0.02	0.28	0.03	0.02	99.01	43.10	0.05	52.85

Note: Own calculations based on Umweltgesamtrechnung (2013). Column 1 shows CO_2-emissions in equivalence units. Column 2 to 9 show the share of different pollutants on overall CO_2-emissions in equivalence units. Columns 10 to 12 show the origin of actual overall CO_2-emissions.

List of Industries

Table A5: List of Industries and WZ2008 classification

WZ 2008	German version	translated to
01	Erzeugnisse der Landwirtschaft, Jagd u. DL	Agriculture
02	Forstwirtschaftliche Erzeugnisse u. DL	Forestry
03	Fische, Fischerei- u. Aquakulturerzeugnisse	Fishery
B	Bergbauerzeugnisse, Steine u. Erden	Mining
C	Hergestellte Waren	Processing industries
10-12	Nahrungs- u. Futtermittel, Getränke, Tabakerzeugnisse	Food, Beverages, and Tobacco
13-15	Textilien, Bekleidung, Leder u. Lederwaren	Clothing and leather
16	Holz, Holz-, Kork-, Flecht- u. Korbwaren (ohne Möbel)	Wood products
17	Papier, Pappe u. Waren daraus	Paper and card board
18	Druckereileistungen, bespielte Ton-, Bild- u. Datenträger	Printing
19	Kokerei- u. Mineralölerzeugnisse	Coking and petroleum refining
20	Chemische Erzeugnisse	Chemical products
21	Pharmazeutische Erzeugnisse	Pharmaceutical products
22	Gummi- u. Kunststoffwaren	Plastics
23	Glas, -waren, Keramik, verarbeitete Steine u. Erden	Glass, ceramics, industrial rocks and rare minerals
24	Metalle	Metals
25	Metallerzeugnisse	Metal products
26	DV-geräte, elektronische u. optische Erzeugnisse	Digital video, electronic and optical products
27	Elektrische Ausrüstungen	Electronic equipment
28	Maschinen	Machines
29	Kraftwagen u. Kraftwagenteile	Trucks and parts
30	Sonstige Fahrzeuge	Misc. vehicles
D (35)	Energie u. DL der Energieversorgung	Energy providers
E	Wasser, DL der Wasserversorgung u. Entsorgung	Water utilities
36	Wasser, DL der Wasserversorgung	Water and water recycling
37-39	DL der Abwasser-, Abfallentsorgung u. Rückgewinnung	Waste water, waste and recycling
F	Bauarbeiten	Construction
G	Handelsleistungen, Instandhaltung- u. Reparaturarbeiten an Kfz	All retail services, and repairs of vehicles
45	Handelsleistungen mit Kfz, Instandhaltung u. Reparatur an Kfz	Retail services with vehicles and repairs of vehicles
46	Grosshandelsleistungen (ohne Handelsleistungen mit Kfz)	Wholesale servives without vehicles
47	Einzelhandelsleistungen (ohne Handelsleistungen mit Kfz)	Retail services without vehicles
H	Verkehrs- u. Lagereileistungen	Transport and storage
49.3-5	Sonst. Landverkehrs- u. Transportleistungen in Rohrfernleitungen	Services using long-distance pipes
50	Schifffahrtsleistungen	Maritime logistics
51	Luftfahrtsleistungen	Aviation
52	Lagereileistungen, sonst. DL für den Verkehr	Storage, and misc. traffic services
53	Post-, Kurier- u. Expressdienstleistungen	Mail delivery
I	Beherbergungs- und Gastronomiedienstleistungen	Hotels and restaurants
J	Informations- u. Kommunikationsdienstleistungen	Information and communication
K	Finanz- u. Versicherungsdienstleistungen	Financial and insurance services
L	DL des Grundstücks- u. Wohnungswesen	Estate and apartment services
M	Freiberufliche, wissenschaftliche u. technische Dienstleistungen	Free lancer, scientific services
N	Sonst. wirtschaftliche Dienstleistungen	Misc. commercial services
O	DL der öffentl. Verwaltung, Verteidigung, Sozialversicherung	Public administration, defense and social security
P	Erziehungs- u. Unterrichtsdienstleistungen	Child care and education
Q	DL des Gesundheits- u. Sozialwesens	Medical and social services
R-T	Sonst. Dienstleistungen	Misc. Services

Note: The WZ2008 classification and descriptions of industries are from Statistisches Bundesamt (2008).