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Assessment of the average rate of changes in atmospheric CO emissions in OECD countries

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Abstract: Air quality is crucial for human health and welfare. A large number of studies have indicated strong associations between ambient air pollution levels and adverse health effects. There is a considerable number of literature reports concerning changes in atmospheric greenhouse emissions, while relatively little is known on changes in atmospheric CO emissions. This paper presents the rate of changes in atmospheric CO emissions using the logarithmic method in the assessment of this rate. Studies were conducted based on source data from 32 Organization for Economic Cooperation and Development countries. Analyses covered the period of 2005–2012. It was found that the average rate of changes had a negative average rate for most, although not all analyzed countries. In three of the 32 countries atmospheric CO emissions increased in that period. While the intensity of these changes varied, a definite majority of the countries reduced their CO emissions, whereas Turkey, Poland and Estonia increased their emissions.

Introduction

Air quality is crucial for human health and welfare. A large number of studies have indicated strong associations between ambient air pollution levels and adverse health effects. Studies of long-term exposure to air pollutants have showed an increased risk of chronic respiratory illness, cardiopulmonary mortality, and development of several types of cancer (Kampa and Castanas 2008). Household Air Pollution is a major global cause of morbidity and mortality, estimated to be responsible for 3.5 million premature deaths each year (Lim et al. 2012, Bartington et al. 2017). Over the last several decades, an increasing number of epidemiologic studies it has been concluded that ambient air pollution are causal risk factors for many adverse human health effects, including respiratory illnesses (Götschi et al. 2008, Laumbach and Kipen 2012 and Adam et al. 2015), cardiovascular diseases (Anderson et al. 2012, Shah et al. 2013 and Franklin et al. 2015) and carcinogenic effects (Turner et al. 2011, Pope et al. 2011, Loomis et al. 2013, Masiol 2017). PM are the greatest threat to health and life. It is estimated that the mortality associated with global PM 2.5 emissions in 2010 was 3.15 million people (Lelieveld et al. 2015). True, in the global picture, CO emissions have less impact on human life than PM 2.5. Carbon monoxide is of lesser importance, but it is also harmful. According to the study, in many cities where CO concentrations were very high, there was an increase in the number of deaths caused by myocardial infarction. There was also a correlation between increases in CO exposure and arrhythmias and decreased excitability threshold for ventricular fibrillation. Research is also of importance to inhibit the CO on the immune response of the body, which may contribute to the reduction of resistance to infection (Sroczyński 1996, Report EEA 2011). For this reason many countries have implemented a rational environmental policy to reduce environmental pollution. Many countries are following a strategy for intelligent and sustainable development. Such a strategy aims at economic development, while focusing on its sustainability. This should lead to knowledge-based economy, low-emission, promoting environmentally-friendly technologies, rational resource management, producing new green jobs and at the same time caring for social cohesion. In order to realize the above-mentioned assumptions various policies are being implemented in individual countries in relation to environmental resource management. Examples of such actions may be Guidelines for Reporting Emissions and Projections Data under the Convention on Long-range Transboundary Air Pollution. At its thirty-second session (Geneva, 9–13 December 2013), the Executive Body for the Convention on Long-range Transboundary Air Pollution adopted guidelines for reporting emissions and projections data under the Convention (ECE/EB.AIR/122/Add.1, decisions 2013/3 and 2013/4). The present document contains the guidelines as adopted for application in 2015 and subsequent years. The document is a revised version of the Guidelines for Reporting Emission data under the Convention (ECE/EB.AIR/97), which were approved by the Executive Body in 2008 (ECE/EB.AIR/96, para. 83 (b)). The revised Guidelines were prepared by the Task Force on Emission Inventories and Projections and include technical changes approved at the thirty-seventh session of the Steering Body to the Cooperative Program for Monitoring and Evaluation of the Long-range Transmission of Air Pollutants in Europe (Geneva, 9–11 September 2013), as well as further changes proposed and agreed to by the Executive Body at its thirty-second session. The substances for which there are existing reporting obligations in the Convention and the protocols as further specified by Executive Body decision 2013/4, include: Sulphur (SO_x), Nitrogen oxides, which means nitric oxide and nitrogen dioxide, expressed as nitrogen dioxide (NO_2); Ammonia (NH_3); Non-methane volatile organic compounds (NMVOCs); Particulate matter (PM), which is an air pollutant consisting of a mixture of particles suspended in the air; Cadmium (Cd) and its compounds; Lead (Pb) and its compounds; Mercury (Hg) and its compounds; Polycyclic aromatic hydrocarbons (PAHs). For the purposes of emission inventories, the following four indicator compounds shall be used: benzo(a)pyrene, benzo(b)fluoranthene, benzo(k) fluoranthene, and indeno(1,2,3_cd)pyrene; Dioxins and furans (PCDD/F), which are polychlorinated dibenzo-p-dioxins (PCDD) and polychlorinated dibenzofurans (PCDF), tricyclic, aromatic compounds formed by two benzene rings, connected by two oxygen atoms in PCDD and by one oxygen atom in PCDF, and the hydrogen atoms which may be replaced by up to eight chlorine atoms; Polychlorinated biphenyls (PCBs), which means aromatic compounds formed in such a manner that the hydrogen atoms on the biphenyl molecule (two benzene rings bonded together by a single carbon-carbon bond) may be replaced by up to 10 chlorine atoms; Hexachlorobenzene (HCB), and Carbon monoxide (CO).

Next to carbon dioxide, the three primary air pollutants include sulphur dioxide (SO_2), nitrogen oxides (NO_x) and carbon monoxide (CO) (Streets and Waldhoff 2000).

Within this study it was decided to analyze temporal variability in atmospheric carbon monoxide emissions. Natural sources of this gas include volcanic eruptions as well as wildfires, in which the temperature may reach 1000°C. It is also produced in small amounts in living organisms. Nevertheless, the primary source of CO is anthropogenic. This gas is emitted during high--temperature technological processes, particularly those using coal and crude oil as fuels (power engineering, metallurgical and chemical industries), as well as vehicle exhaust gases (produced by combustion engines). It is also formed in the combustion of coal and other fuels at insufficient levels of oxygen (it is a source of carbon monoxide in heating installations and during fires), at the reduction of steam with coal at a temperature of several hundred degrees Celsius. The sum of all CO sources is 2.5 Pg CO/yr (1 Pg = 10^3 Tg), including fossil fuel use (300 Tg CO/yr), biomass combustion (748 Tg CO/yr), oxidation of biogenic hydrocarbons (683 Tg CO/yr) and methane oxidation (760 Tg CO/yr) (Holloway et al. 2000).

In view of the importance of this gas as a health hazard for humans (Gauderman et al. 2007, McCreanor et al. 2007, Levy et al. 2010, Huang et. al. 2016) it was decided to analyze changes in its atmospheric emissions in selected countries. Due to formal differences between individual investigated countries the adopted approach was to apply the assessment of average rate of changes in these emissions.

Methods

This study is based on unified source data concerning atmospheric CO emissions in selected OECD countries. The objective of OECD is to provide support for the member countries in reaching the highest possible economic growth and standard of living for their citizens. This growth needs to be reached while respecting the environment. Source data used to determine the average rate of changes in CO emissions are derived from the Stat Extracts system, the OECD data base (http://stats.oecd.org/). Data from 32 countries, accumulated and processed using a unified methodology, were analyzed in detail.

In practice, the average rate of change of many processes is determined using geometric and logarithmic methods. The geometric method, due to its structure (the geometric mean of values of the chain index in the investigated period), is easier to apply. However, Adamowicz et al. (2016) claimed that the logarithmic method is recommended for the assessment of environmental processes. For this reason that method was used in this study.

After substitution of all partial elements of the equation the following formula was obtained:

$$\log \bar{A} = \frac{1}{n-1}\sum_{t=2}^{n} log\frac{V_{dt}}{V_{t-1}} \qquad (1)$$

↓

$$\bar{A} = 10^{\left(\frac{1}{n-1}\sum_{t=2}^{n} log\frac{V_t}{V_{t-1}}\right)} \qquad (2)$$

$\bar{A}$ – change emission CO,
V_t – value of analyzed variables in individual years (t),
V_{t-1} – value of a given variable in the previous year.

The last stage of the calculations was to determine the average rate of changes applying the following formula:

$$ARC = (\bar{A} - 1) \times 100\% \qquad (3)$$

ARC – average rate of changes in CO emission (%).

Based on the analyses the direction and rate of changes in CO emissions in individual countries were identified. As a result, a national ranking was prepared, indicating those with the highest CO changes.

Results and discussion

In the analyzed period the greatest amounts of CO were released to the atmosphere by the USA, on average amounting to over 61 million tons/year. In comparison to that volume, over the same period the OECD-Europe countries jointly introduced to the atmosphere approx. 3.5 million tons/year less of this gas. Among European countries the greatest emission was recorded for France, amounting on average to over 4 million tons of CO/year. A slightly lower level of emissions was reported in Germany (on average over 3 million tons/year), followed by Poland ranking third in terms of the emission volume (on average slightly below 3 million tons/year). The lowest emission of carbon monoxide was recorded in Iceland (on average 19 thousand tons/year) (Tab. 1).

Obviously individual countries differ in terms of their size and level of industrialisation. For this reason it was decided to assess the effectiveness of actions undertaken by individual countries to reduce CO emissions based on the average rate of changes in emissions of this gas into the atmosphere.

Analyses showed that atmospheric CO emissions decreased in almost all investigated countries. On average in the OECD--Europe countries CO emissions were reduced by 3% annually. Turkey, Estonia and Poland were exceptions to this trend. A particularly high increase was recorded in Turkey. The average rate of CO emission increase in that country was 8%. In turn, the increase in CO emissions in Poland and Estonia was much smaller, amounting to approx. 1% and below 1%, respectively.

Belgium was the country most effectively reducing atmospheric CO emissions. In that country the annual emission of this gas was decreased on average by almost 9%/year. The amounts of CO introduced to the atmosphere were effectively reduced also in England (by approx. 8%/year) and France (by approx. 7%) as well as Greece, Ireland, Portugal and Israel (by 6%). It seems that the policy aiming at the reduction of CO emissions implemented in those countries should be a model to follow by others.

When comparing averaged changes concerning the reduction of CO emissions in the OECD–Europe countries with those observed in Israel, Australia and the USA, it is clear that more effective environmental policies were implemented in the latter countries concerning reduction of CO emissions. In the analyzed period the average decrease in emissions of that gas in the OECD–Europe countries amounted to approx. 3%, while in Australia and the USA that decrease was greater, amounting to over 4% annually, whereas in Israel it was over 5% (Tab. 2). In turn, in New Zealand, Japan, Korea and Canada the rate of CO emission reduction was smaller in comparison to the calculated averaged rate of these changes for the OECD countries. We need to stress the fact that individual OECD-

Table 1. Atmospheric CO emissions in OECD countries

COUNTRIES	CO th. t/year	COUNTRIES	CO th. t/year	COUNTRIES	CO th. t/year
United States	61947	Spain	2024	Denmark	421
OECD – Europe	26585	Korea	760	Portugal	396
Canada	8961	New Zealand	714	Norway	343
France	4169	Austria	684	Switzerland	259.5
Germany	3391	Netherlands	621	Slovak Republic	240
Australia	3302	Greece	602	Israel	208
Poland	2743	Sweden	595	Slovenia	162
United Kingdom	2654	Belgium	565	Estonia	160
Japan	2567	Finland	476	Ireland	153
Italy	2527	Czech Republic	434	Luxembourg	49
Turkey	2465	Hungary	431	Iceland	19

Table 2. Average rate of changes in atmospheric CO emissions by individual countries

COUNTRIES	$\bar{A}$	Δ (%)
OECD – Europe	-0.02875	-2.87%
Australia	-0.04302	-4.30%
Austria	-0.03997	-4.00%
Belgium	-0.08826	-8.83%
Czech Republic	-0.05469	-5.47%
Denmark	-0.03404	-3.40%
Estonia	0.004036	0.40%
Finland	-0.02312	-2.31%
France	-0.06668	-6.67%
Greece	-0.06356	-6.36%
Spain	-0.01484	-1.48%
Netherlands	-0.02741	-2.74%
Ireland	-0.06267	-6.27%
Iceland	-0.00471	-0.47%
Israel	-0.05637	-5.64%
Japan	-0.0166	-1.66%
Canada	-0.0223	-2.23%

COUNTRIES	$\bar{A}$	Δ (%)
Korea	-0.01858	-1.86%
Luxembourg	-0.05352	-5.35%
Germany	-0.01479	-1.48%
Norway	-0.03833	-3.83%
New Zealand	-0.00575	-0.57%
Poland	0.011506	1.15%
Portugal	-0.05706	-5.71%
Slovak Republic	-0.02853	-2.85%
Slovenia	-0.01844	-1.84%
United States	-0.04033	-4.03%
Sweden	-0.02645	-2.64%
Switzerland	-0.04983	-4.98%
Turkey	0.080934	8.09%
Hungary	-0.03065	-3.06%
United Kingdom	-0.07781	-7.78%
Italy	-0.05469	-5.47%

-Europe countries varied in terms of their approach to the environmental policy aiming at the reduction of CO emissions. The average rate of reducing CO emissions in Belgium, the United Kingdom, France, Greece, Ireland and Portugal was greater than in Israel, while in the Czech Republic, Italy, Luxembourg and Switzerland it was higher than in Australia and USA.

Assuming the average rate of decrease in atmospheric CO emissions by the OECD-Europe countries (-2.87% annually) as the reference point it was found that in Canada, Korea, Japan and New Zealand a lower reduction rate was recorded for atmospheric emissions of this gas in comparison to Europe. However, in relation to individual European countries a lower rate for the reduction of atmospheric CO emissions in comparison to Canada and Korea was recorded in Slovenia, in relation to Japan in Spain and Germany and in comparison to New Zealand a lower rate of CO emission reduction was reported in Iceland, whereas in Estonia and Poland atmospheric emissions of this gas increased. Nevertheless, the greatest increase in emissions of this gas was recorded in Turkey. These analyses showed that the average increase in atmospheric CO emissions in Turkey exceeded 8% (Tab. 2).

We need to agree with the opinion of Parrish et al. (2011), Colette et al. (2011) and Masiol et al. (2017) that a significant drop in the ambient concentrations of many air pollutants has been measured in many developed countries (including the US) as a result of implementation of legislation and regulations through the application of successful abatement technologies and other mitigation measures.

To improve air quality on the local, national and regional levels, some states have been working successfully to gradually reduce and prevent air pollution in the region. One of the vehicles through which this has been achieved is the Convention on Long-range Transboundary Air Pollution, which was signed in 1979. Over the years, it has been extended by eight protocols that identify specific measures to be taken by Parties to cut their emissions of air pollutants. Fifty-one countries have been Party to the Convention, including Poland since 1979 (ratification 1985) and Estonia since 2000. It should be recalled that, apart from Turkey, these countries recorded a positive average rate of changes in CO emission.

An example of air protection policy may be COMMISSION REGULATION (EU) 2015/1185 of 24 April 2015 implementing Directive 2009/125/EC of the European Parliament and of the Council with regard to eco-design requirements for solid fuel local space heaters. Based on this document it was found that annual emissions of carbon monoxide (CO) have been estimated at 1 658 ktons/year respectively in 2010. As a result of specific measures adopted by member states and technological development, these emissions are expected to be 1 433 ktons/year respectively in 2030.

In 2005, in accordance with the Polish Environmental Protection Act of 27 April 2001 (D. 2013, item 1232) the Air Protection Program (APP) was established. The overall goal of the APP is to control the emission of particulate matter and other pollutants (including CO), to reduce the air pollution down to the level recommended by the World Healh Organization (WHO). The APP was established in accordance to the environmental legislation to support people's health and improve their life quality.

One of the most important adjastments in Poland was the Regulation of the Minister of Environment of 24 August 2012, which sets out the emission level of particular substances in air. For example, the 8 hour avarage concentration of CO has been set out to 1000/m^3 according to WHO recommendations (WHO 2006).

In addition, the Air Quality Assessment and Management program is carried out in Poland. The system is based on the measurments of national monitoring network from 46 air quality zones, which consist of 12 agglomerations (above 250 000 inh.), 18 cities (above 100 000 inh.) and the rest of voivodships (16 areas). The zones division has been defined by the Regulation of the Environment Minister. The air quality assessment follows the guidelines and criteria, which take into account 12 pollutants, including CO. The Polish national emission inventory also emphasizes that combustion of fossil fuels is a significant source of energy and also the pollution air emission. It needs to be remembered that in Poland the primary source of CO on the annual scale is connected with combustion in small municipal plants and homes (approx. 62% total CO emission in Poland). (Zasina and Zawadzki 2017). For this reason the key element in the policy to limit CO emission is connected with subsidy programs to replace coal-fired furnaces with more eco-friendly heating sources. This is executed with the participation of local governments, which in their programs to control low emissions allocate funds in their budgets to provide financial support for their residents. Europeisation of local and regional government administration is furthered by the implementation of other EU policies by local administration bodies, e.g. in the field o environmental protection. One of the new tools to implement territorial approaches within the 2014–2020 programming period is Integrated Territorial Investment (ITI). When an urban development strategy or other territorial strategy, or a territorial pact requires an integrated approach involving investments from the ESF, ERDF or Cohesion Fund under more than one priority axis of one or more operational programs, actions may be carried out as an integrated territorial investment. An ITI can be used if challenges and development needs are specific to a geographical area and if a territorial strategy exists addressing the objectives in an integrated way (Kawka 2013). ITI can be an effective tool to reduce air pollution.

Based on the research it was found that the rate of CO emission reductions in EU countries ranged from an almost 9% decrease in Belgium to an over 1% increase in this emission in Poland. This situation seems to result from the implementation and enforcement of pro-environmental legislation in individual countries. For example, regulations concerning air quality in the EU as a rule define target levels or limits for specific substances, but individual countries are free to establish how they would reach these targets. The decline in CO emissions is related to the implementation of air quality policy. This is not due to concrete actions aimed at reducing only CO emissions. In some countries, the rate of gas emission has dropped significantly. Results of these analyses indicate that common legislative solutions for the reduction of atmospheric CO emissions need to be searched for. Models to be followed in the specification of common legal foundations should be provided by these countries in which the greatest rate of such a reduction was recorded, rather than those with the largest decrease in emissions expressed in absolute figures for atmospheric CO emissions, thus it may be e.g. Belgium, the United Kingdom, France, Greece and Ireland. It is advisable to carry out further research identifying the often complex mechanisms of policy implementation related to air protection.

It was found that in some countries ARC was negative (minus). Further research is needed to determine whether these countries have taken many effective measures to reduce CO pollution. In further stages of research it is recommended to search for causes of such situation. Obviously the presented results may provide the basis for the first stage indicating these countries, which thanks to certain actions have been successful and reduced atmospheric CO emissions most effectively (the greatest rate of negative changes), as well as those countries, in which no adequate actions have been undertaken to cope with the problem or in which such actions have not been effective.

Conclusions

This study comprised an analysis of the average rate of changes in atmospheric CO emissions in 32 countries. Additionally, the average rate of reducing atmospheric CO emissions by the OECD-Europe countries was determined. Based on the results it was stated as follows:

1. In the analyzed period the largest amounts of CO were released to the atmosphere by the USA at approx. 61 million tons/year. In the same period the OECD--Europe countries introduced to the atmosphere almost 27 million tons/year. In Europe the largest emitters of this gas included France, Germany and Poland.
2. In countries such as Belgium, Great Britain, France, Greece and Ireland, there has been a decline in CO emissions. In all those countries atmospheric CO emissions decreased at 6% annually. A particularly high effectiveness in this respect was observed in Belgium, in which the average rate of changes in atmospheric emissions of that gas was almost 9%. Further research is needed to determine whether these countries have taken many effective measures to reduce CO pollution. In further stages of research it is recommended to search for causes of such situation.
3. While in most analyzed countries the average rate of changes was observed to have a negative vector, there were some exceptions. In three of the analyzed 32 countries atmospheric CO emissions were found to increase. Within the analyzed period a vast majority of countries reduced their atmospheric CO emissions, although its rate varied, while Turkey, Poland and Estonia increased their emissions. A particularly disturbing trend is connected with the rate of the positive increments in changes observed in Turkey, amounting to over 8% annually.
4. It seems advisable to search for systemic solutions aiming at reducing emissions of this noxious gas. When developing such solutions it is recommended to follow the approach of these countries, which have reduced atmospheric CO emissions most effectively. This effectiveness should be assessed based on the average rate of changes and not on the basis of absolute values presenting quantitative reductions of atmospheric emissions of this gas. Results of this study may be used to identify countries with appropriate policies to decrease CO emissions and to indicate those, in which urgent actions need to be undertaken to support this process, since current actions have not been particularly successful.

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Ocena średniego tempa zmian emisji tlenku węgla do atmosfery w państwach Organizacji Współpracy Gospodarczej i Rozwoju

Streszczenie: W opracowaniu przedstawiono tempo zmian emisji CO do atmosfery z wykorzystaniem logarytmicznej metody oceny tempa. Badania przeprowadzono w oparciu o dane 32 państw będących członkiem OECD. Badaniami objęto okres 2005–2012. Na podstawie wykonanych badań stwierdzono, że w większości analizowanych państw odnotowano średnie tempo zmian charakteryzujące się ujemnym wektorem tych zmian, ale nie dotyczyło to wszystkich. W trzech państwach odnotowano wzrost emisji CO do atmosfery. W analizowanym okresie zdecydowana większość państw w różnym tempie, ograniczała emisję CO do atmosfery, natomiast Turcja, Polska i Estonia zwiększały tempo emisji tego związku chemicznego.