Searching for Correlations Between CO_2 Emissions and Selected Economic Parameters

Ladislav Rozenský[1] | *Czech University of Life Sciences Prague, Prague, Czech Republic*
Pavla Vrabcová[2] | *Czech University of Life Sciences Prague, Prague, Czech Republic*
Miroslav Hájek[3] | *Czech University of Life Sciences Prague, Prague, Czech Republic*
Tereza Veselá[4] | *Czech University of Life Sciences Prague, Prague, Czech Republic*
Petr Hukal[5] | *Czech University of Life Sciences Prague, Prague, Czech Republic*

Abstract

The Emission Trading Scheme is one of the economic instruments of environmental policy and it is used to achieve the goals of reducing greenhouse gas emissions. The Emission Trading Scheme is a common instrument of the European Union, which is mandatory for all member countries. The aim of this paper is to assess the effectiveness of the greenhouse gas emissions trading system in the Czech Republic as one of the important instruments of environmental policy. The presented research model shows that greenhouse gas emissions were only minimally affected by the GDP index level and movement in the monitored time period. The model also shows that the most significant impact on the amount of greenhouse gas production in the given time period was the consumption of renewable energy and the consumption of fossil fuels. By contrast, the price of emission allowances on the market had a minimal effect on the production of greenhouse gases.

Keywords

Economic instruments, emission trading scheme, emission allowances, renewable energy

JEL code

F64, H23, K32, O44

[1] Department of Forestry and Wood Economics, Faculty of Forestry and Wood Sciences, Czech University of Life Sciences Prague, Kamýcká 129, 165 21, Prague 6 – Suchdol, Czech Republic. E-mail: rladislav@seznam.cz.
[2] Department of Wood Processing, Faculty of Forestry and Wood Sciences, Czech University of Life Sciences Prague, Kamýcká 129, 165 21, Prague 6 – Suchdol, Czech Republic: E-mail: vrabcovap@fld.czu.cz.
[3] Department of Forestry Technologies and Construction, Faculty of Forestry and Wood Sciences, Czech University of Life Sciences Prague, Kamýcká 129, 165 21, Prague 6 – Suchdol, Czech Republic. E-mail: hajek@fld.czu.cz.
[4] Department of Forestry Technologies and Construction, Faculty of Forestry and Wood Sciences, Czech University of Life Sciences Prague, Kamýcká 129, 165 21, Prague 6 – Suchdol, Czech Republic. E-mail: sramkova.tereza@gmail.com.
[5] Department of Forestry and Wood Economics, Faculty of Forestry and Wood Sciences, Czech University of Life Sciences Prague, Kamýcká 129, 165 21, Prague 6 – Suchdol, Czech Republic. E-mail: petr@rozvoj.net.

INTRODUCTION

Greenhouse gases arise as a result of human activities (Montzka et al., 2011; Prather et al., 2012), especially due to the burning of fossil fuels (Mittal et Kumar, 2014). To reduce greenhouse gas emissions, environmental policy uses various instruments (OECD, 2007). Economic instruments work in synergy (Phalan et al., 2016) with the other greenhouse gas reduction instruments and relevant legislation (Sorrell, 2003; Directive 2003/87/EC). The individual instruments are chosen by member countries in line with the priorities of their environmental policies (Jordan et al., 2003; Aidt et al., 2004). One of basic instruments in this mix is represented by so-called environmental taxes (Baranzini et al., 2000; OECD, 2007). In the European area, carbon Emission Trading Scheme (ETS) has become a cornerstone of the design of European environmental policy (Convery et al., 2007; Braun, 2009; Hong et al., 2017; Segura et al., 2018). The purpose of ETS is above all to reduce greenhouse gas emissions and to integrate the costs for the elimination of their negative environmental impacts into the costs of their producers (Hong et al., 2017; Segura et al., 2018). Sabzevar et al. (2017) stated that the emission trading price is a base for maximizing company's profits and for controlling the amount of emissions generated.

The European Carbon Emissions Trading Scheme (EU ETS) introduced in 2005 has led to both spot and futures market trading of carbon emissions. However, despite 10 years of trading, we have no knowledge on how profitable the ETS is (Narayan et al., 2015). At present, European countries use emission allowances within the EU ETS as the main CO_2 abatement instrument, but some of them also use carbon taxes, as for example Sweden, Finland, Ireland or Denmark (Leu et Betz, 2016).

Many studies (for example Laing et al., 2014; Hintermann et al., 2015; Muûls et al., 2016) analyzed emission reductions, evolution of allowance prices, and impacts on the economic performance, competitiveness and innovation. Nordhaus (2005, 2011) focused his research mainly on comparing the effectiveness of environmental taxes and ETS, their advantages and disadvantages. Based on this research, he strongly opts for environmental taxes before the ETS and concludes that the carbon market price fluctuation and volatility in one trading period of the EU ETS are not good in terms of longer-term investment planning. As a recommendation for policy makers and regulators, a carbon tax is proposed in the context of fiscal policy as the most appropriate tool for reducing greenhouse gas emissions.

The main ETS supporters for example Fan (2017), who states that in relation to tax, the ETS can increase prosperity on the market with imperfect competition. Moreover, based on his model of strategic and competitive behavior of traders on the Central Atlantic Market, who covers power sector emissions in nine Northeast and Mid-Atlantis States, he notes that when regulators charge tax instead of allowance, the loss caused by deadweight costs in imperfect competition is higher. The Central Atlantic Market is the second largest emission allowance market in the world, which, like the EU ETS, operates on the principle of a free market for emission allowances. Very important in the ETS is the price of tradable permits (Hintermann et al. (2015) find that economic activity and growth announcements as well as oil and gas prices positively influence the prices of allowances. The emissions allowance price has varied considerably over years (Segura et al., 2018). Brink et al. (2016) points to the current market price of emission allowances, which is quite far from the projected price of EUR 20, which is planned as the target price in 2020, and does not therefore seem to meet the desired effect. Deeney et al. (2016) deal with the influence of the European Parliament on the auction price of emission allowances. In April 2013, the European Parliament was expected to pass a draft law for fixing the recognized oversupply issue in the EU ETS (Koch et al., 2014). The Commission's proposal involved postponing until 2019–2020 the release of 900 million EU emission allowances (EUAs).

Oueslati et al. (2017) deal with the specifics of emission allowances and carbon tax.They say energy taxes represent important instruments to increase economic efficiency, to achieve desired environmental outcomes, and raise public revenues. However, the implementation of energy taxes is often hampered by public concerns over their possible effects on unequal income.

Cost-saving from the use of renewable energy sources, which are also represented in our model, is dealt with by Palmer et Burtaw (2005). A renewable energy production tax credit reduces the electricity price at the expense of taxpayers, which limits its effectiveness in reducing carbon emissions, and is less cost-effective in increasing renewables than a portfolio standard. Neither policy is as cost-effective as a cap-and-trade policy for achieving carbon emission reductions (Palmer et Burtraw, 2005).

The effectiveness of environmental policy instruments is often assessed for example through the relationship between the economic growth and the growth of greenhouse gas production. There are many publications dealing with the environmental Kuznets curve (Dinda, 2004; Alam et al., 2016; Özokcu et Özdemir, 2017). Bauer et al. (2015) deal with the impact of fossil fuels policy on reducing greenhouse gas emissions in the United States climatic region. Lim et al. (2014) discussed the context of fossil fuels consumption, economic growth and greenhouse gas production in the Philippines.

The aim of this paper is to assess ETS effectiveness in the Czech Republic using the regression analysis as one of the important instruments of environmental policy.

1 MATERIAL AND METHODS

This chapter introduces research questions and goals and brings details on the individual data that is further worked on in the research section of the paper. Theories and data (CZSO, 2019; ERU, 2019; EUROSTAT, 2019) needed are included in the descriptive part, the objective of which is to assess the environmental effectiveness of emission allowances. For this purpose, the data was created to form time series, from which the charts were then compiled for a more comprehensive understanding of the problem, and the regression analysis was performed that tried to assess the remaining objectives. Another aim was to assess some further factors and how they affect greenhouse gas emissions in the countries under review.

The ETS effects on the amount of CO_2 production were analyzed in details. Because the used model affects some other factors and tools, such as the using of renewable energy sources, or the consumption of fossil fuels, the authors used the regression analysis. By our opinion a suitable research method to assess the synergistic effect of several factors on the research goals.

Greenhouse gas emissions (expressed in tons per year of CO_2 per capita) are the basic dependent variable. The data source is data from the European Statistical Office (Eurostat, 2016). The emission allowance price is an explanatory variable. The emission allowance price was chosen as a variable because the EU ETS is a fundamental obligatory regulatory element. The data was obtained from the European Energy Exchange and from the Energy Regulatory Office. Unit is the average annual emission allowance in EUR per 1 allowance.

Gross Domestic Product (GDP) expressed as a percentage of year-on-year growth for the Czech Republic and a year was obtained from the database of the Czech Statistical Office (CZSO).

The consumption of fossil fuels an explanatory variable which was chosen because the consumption of fossil fuels relates to the greenhouse gas emissions. The data was obtained from the Eurostat database and was calculated per capita and year in tones for the Czech population as of 31 December of the respective year, according to the CZSO database. The consumption of renewable energy is a control explanatory variable in our model. The production of energy from the renewable sources does not generate greenhouse gases. Their substitution for energy from the combustion of fossil fuels containing carbon has the ultimate effect of reducing the greenhouse gas production. The consumption of renewable resources is supported by the country´s policy. This policy is a common EU policy. It is based in particular on state support for the use of renewable energy (Kharlamova et al., 2018). The data was obtained from the Eurostat database and was calculated per capita and year for the population of the Czech Republic as of 31 December of the respective year according to the CZSO database in our calculation model. It is reported by converting the consumption of renewable energies into tons of oil equivalent. In the case of this variable, the theoretical expectations were negative, i.e. with the increasing consumption of renewable energies; there is a decline in greenhouse gas production.

For the data analysis in years 2005–2015 (greenhouse gas emissions, GDP in the Czech Republic in %, emission allowance price, consumption of fossil fuels and consumption of renewable energy sources), regression and correlation analysis was used. The regression analysis allows getting information about the dependence of quantitative characters (Litschmannová, 2011). The *Y* variable, whose behaviour we try to explain, is called a dependent variable (the variable explained). The *X* variable, whose behaviour explains the behaviour of the dependent *Y* variable, is called an independent variable (Hindls et al., 2002). The correlation analysis deals with interdependencies, emphasizing the strength or intensity of the relationship (Bílková et al., 2009). In most cases, the linear regression used was $\eta = \beta_0 + \beta_1 x$. We measured the intensity of dependence using the determination index (Budíková et al., 2010). If the dependency function is proven, the determination index is 1 (and vice versa if the value is 0). The Pearson correlation coefficient for the two variables *X* and *Y* was calculated. Some indicators were also analysed by using the elementary statistical analysis with selected characteristics of position, variability and concentration (median, variance, standard deviation, kurtosis and skewness). Following hypotheses are verified in this paper:

- H_0: there is no linear relationship between the *X* (GDP growth rates in %) and *Y* (GHG emission levels) variables;
- H_0: there is no linear relationship between the *X* (emission allowance price) and *Y* (level of greenhouse gas emissions) variables;
- H_0: there is no linear relationship between the *X* (consumption of fossil fuels) and *Y* (GHG emission level) variables;
- H_0: there is no linear relationship between the *X* (consumption of RES) and *Y* (level of greenhouse gas emissions) variables.

For testing the hypotheses, fixed probability of error of the first type (so-called materiality level) was chosen to be 5%. Tests of the significance of regression parameters were performed to determine if the correlation between the sample variables is strong enough to be considered as proven for the base set.

2 RESULTS

Table 1 shows the basic characteristics of the average price of emission allowance: median, variance, standard deviation, kurtosis and skewness.

Table 1 Elementary statistical analysis – average price of emission allowance in 2005–2015

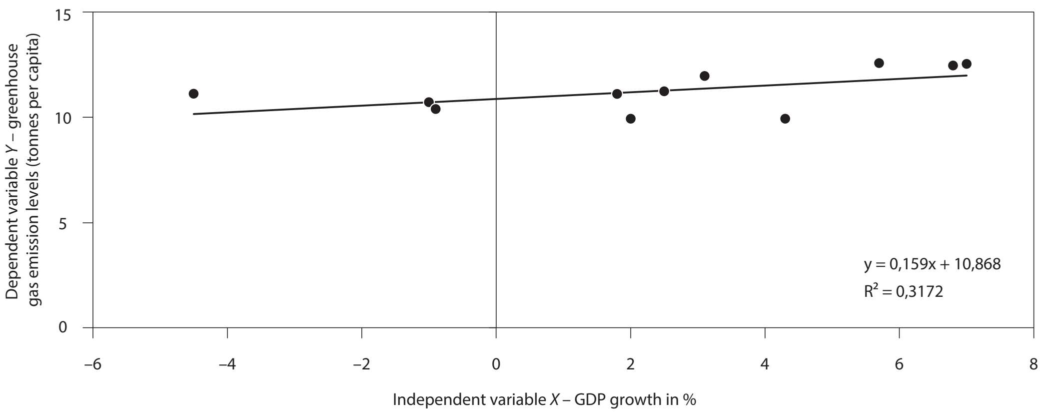
Median	12.720
Standard deviation	6.420
Variance	41.217
Kurtosis	–0.988
Skewness	0.109

Source: Own elaboration

As seen from Table 1, the average price of emission allowance shows considerable variability, which is mainly interpreted by standard deviation (= 6.42). The median, which divides the series of upwardly ranked results into two halves, came out as 12.72. Kurtosis, as a measure of the concentration of the values of random variable around the mean value, is about –0.99, which means the flatter distribution and fewer spikes than the normal distribution. Skewness, which is a measure of symmetry of the given probability distribution, came out as 0.11, indicating a positively skewed division where the values are concentrated rather to the left.

Figure 1 expresses the relationship between the independent variables, namely GDP growth rate (in %) and dependent X variable, which expresses the level of emissions in 2005–2015, including the estimation of the least squares line parameters. Expectations were that the GDP growth would increase the greenhouse gas emissions. This was the construction of a so-called empirical curve describing the observed correlation at the sample level. This curve serves as an estimate of the actual dependence (linear regression function) assumed for the entire base file.

Figure 1 Relationship between the GDP growth rates and greenhouse gas emission levels



Source: Own elaboration

In Figure 1, a theoretical line, i.e. a line drawn by the point graph, was drawn as close to all points as possible – it is the closest regression function with the equation 10.868 + 0.159x. This linear regression function was used to describe the true dependence of the monitored variables at the level of the entire base file. The regression function contained only one regressor, so we tested the zero $H_0 : \beta_1 = 0$ hypothesis against the alternative $H_1 : \beta_1 \neq 0$ hypothesis.The F-test result can be seen in Table 2.

Table 2 Overall *F*-Test design (independent variable: GDP growth rate, dependent variable: GHG emissions)

Source of variability	Sum of squares	Degrees of freedom	Dispersion (mean sum of squares)	*xOBS*	*p*-value
Model	3.188	1	3.188	4.181	0.071
Residual	6.861	6	0.762	×	×
Total	10.049	7	×	×	×

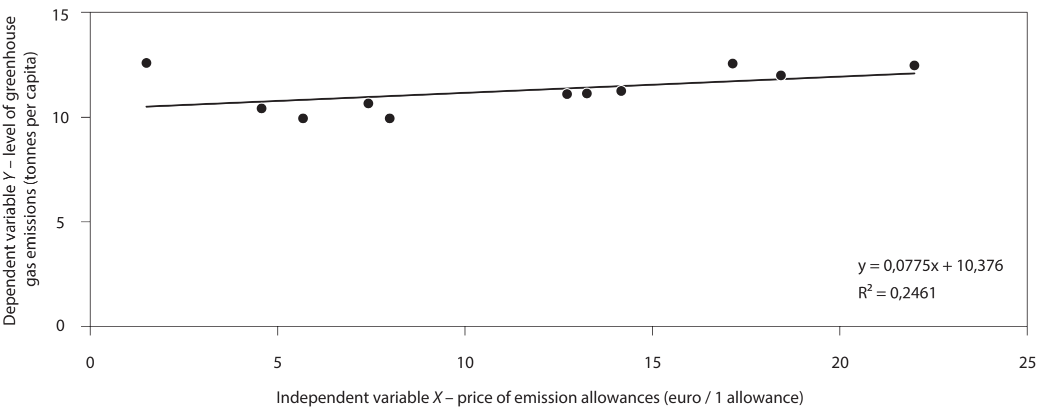
Source: Own elaboration

At the significance level of 0.05 we did not reject the zero hypothesis. Therefore, the GHG emission levels could not be estimated by using the GDP growth rate. The determination index, resp. the modified determination index, determines the quality of the model. The determination index was 0.317;

the modified determination index was 0.241. The model explains for more than 24% of the total variance of the dependent variable, so it cannot be labelled too high.

Furthermore, the relationship between the price of emission allowances and the amount of emissions produced in tonnes per capita in the Czech Republic was examined, see Figure 2.

Figure 2 Relationship between the price of emission allowances and the level of greenhouse gas emissions



Source: Own elaboration

A regression function was found with the equation 10.376 + 0.078*x*. We tested the zero $H_0 : \beta_1 = 0$ hypothesis against the alternative $H_1 : \beta_1 \neq 0$ hypothesis. The *F*-test result can be seen in Table 3.

Table 3 Construction of the total *F*-test (independent variable: emission allowance price, dependent variable: GHG emissions)

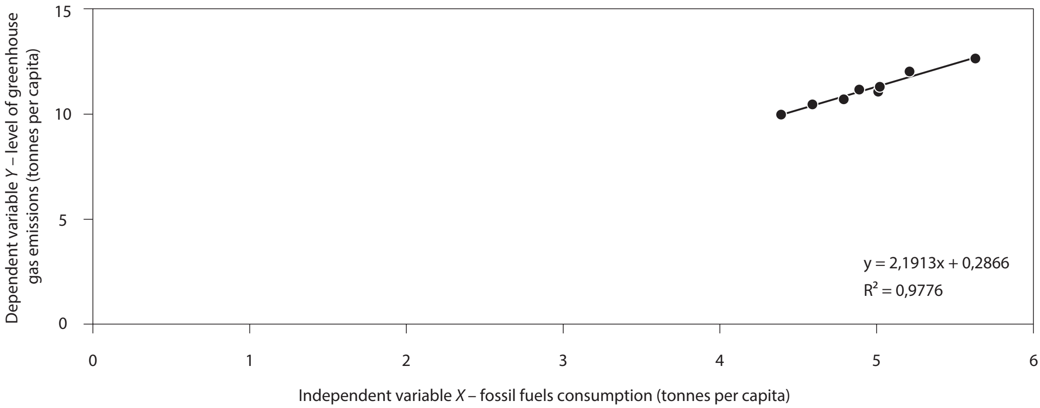
Source of variability	Sum of squares	Degrees of freedom	Dispersion (mean sum of squares)	*xOBS*	*p*-value
Model	2.473	1	2.473	2.938	0.121
Residual	7.575	9	0.842	×	×
Total	10.048	10	×	×	×

Source: Own elaboration

At the significance level of 0.05, the zero hypothesis could not be rejected, the chosen model was not statistically significant. Therefore, the level of significance of the greenhouse gas emission level could not be estimated by using the emission allowance prices. At the significance level of 0.05, we accepted the zero hypothesis, the $\beta 1$ parameter was not statistically significant. The determination index, resp. the modified determination index, determines the quality of the model. The determination index was 0.246; the modified determination index was 0.162. Therefore, the model explains for more than 16% of the total variance of the dependent variable, so it cannot be considered as good.

The relationship between the consumption of fossil fuels in the Czech Republic (tonnes per capita) and greenhouse gas emissions in years 2007–2015 is shown in Figure 3.

Figure 3 Relationship between the fossil fuels consumption and GHG emissions in 2007–2015



Source: Own elaboration

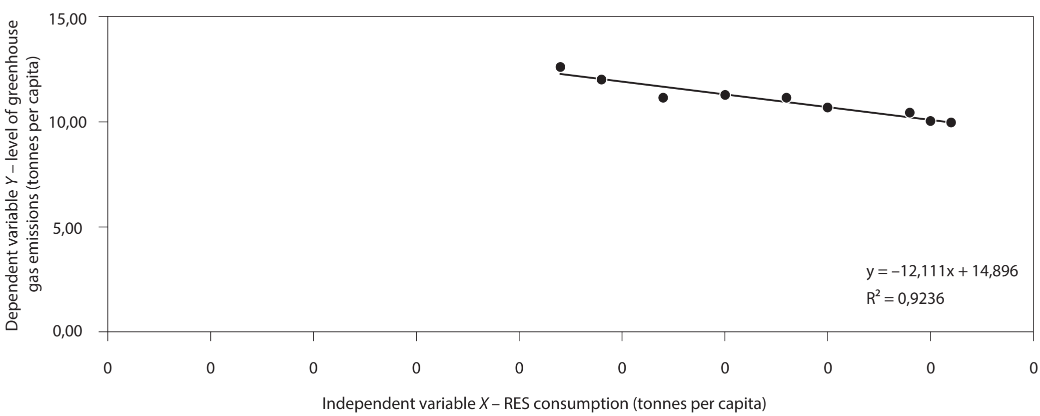
A regression function was found with the equation 0.287 + 2.191x. We tested the zero $H_0 : \beta_1 = 0$ hypothesis against the alternative $H_1 : \beta_1 \neq 0$ hypothesis. The F-test result can be seen in Table 4.

Table 4 Overall *F*-test design (independent variable: fossil fuel consumption, dependent variable: GHG emissions)

Source of variability	Sum of squares	Degrees of freedom	Dispersion (mean sum of squares)	*xOBS*	*p*-value
Model	6.148	1	6.148	305.745	4.93E–7
Residual	0.141	7	0.020	×	×
Total	6.289	8	×	×	×

Source: Own elaboration

Figure 4 Relationship between the RES consumption in the Czech Republic and GHG emissions in 2007–2015



Source: Own elaboration

At the significance level of 0.05 we rejected the zero hypothesis; the chosen model was statistically significant. Hence, greenhouse gas emission levels could be estimated using the fossil fuel consumption. The model explains for more than 97% of the total variance of the dependent variable, so it can be labelled as very good. Pearson's correlation coefficient was 0.989 (indicating a very strong positive correlation). In this case, it can be noted that the increase in the consumption of fossil fuels increases the level of greenhouse gas emissions. The last dependence between the variables is dealt with in Figure 4.

A regression function was found with the equation 14.896 – 12.111x. We tested the $H_0 : \beta_1 = 0$ zero hypothesis against the alternative $H_1 : \beta_1 \neq 0$ hypothesis.The F-test result can be seen in Table 5.

Table 5 Overall *F*-test design (independent variable: RES consumption, dependent variable: GHG emissions)

Source of variability	Sum of squares	Degrees of freedom	Dispersion (mean sum of squares)	*xOBS*	*p*-value
Model	5.808	1	5.808	84.652	3.69E-5
Residual	0.480	7	0.069	×	×
Total	6.288	8	×	×	×

Source: Own elaboration

At the significance level of 0.05 we rejected the zero hypothesis; the chosen model was statistically significant. GHG emission levels could therefore be estimated by using the renewable energy sources. The determination index was 0.924; the modified determination index was 0.913. The model explains for more than 91% of the total dispersion of the dependent variable, so it can be labelled as very good. Pearson's correlation coefficient was –0.961, which indicates a very strong negative correlation, so it can be assumed that greenhouse gas emission levels will decrease with the increasing RES consumption.

In addition to the above analyses, the dependence was examined of final energy consumption in 2010–2015 and emissions of basic pollutants (SO_x in particular) into the air in the Czech Republic (see Table 6).

Table 6 Total *F*-Test design (independent variable: final energy consumption, dependent variable: SO_x)

Source of variability	Sum of squares	Degrees of freedom	Dispersion (mean sum of squares)	*xOBS*	*p*-value
Model	379 764.076	1	379 764.076	0.336	0.593
Residual	4 525 119.965	4	1 131 279.991	×	×
Total	4 904 884.041	5	×	×	×

Source: Own elaboration

At the significance level of 0.05, we did not reject the zero hypothesis. Therefore, final energy consumption levels could not be estimated according to SO_x emissions. At the materiality level of 0.05, we did not reject the zero hypothesis, the β_1 parameter was not statistically significant. The model cannot be considered good.

3 DISCUSSION

Authors admit that relationships between all the variables observed in the article are very complex, moreover the relevant variables are far more than the article is tracked.

Long-term data from the CZSO show that, despite all measures adopted, the Czech Republic together with Estonia, the Netherlands and Luxembourg are four countries with the highest CO_2-per capita production (Eurostat, 2016). This is apparently due to more factors, e.g. by the location of the Czech Republic and by the industrial orientation of Czech economy focused on exports. The analysis shows that, despite the above-mentioned facts, the Czech Republic is able to reduce the CO_2 production in the long term. Although some authors are trying to prove the theory of GDP correlation and increased CO_2 emissions, such as Doda et al. (2013) or Cialani (2017), it seems to be somewhat simplistic. The factors that act on this phenomenon are many and interact with each other. Our model also suggested that the above correlation is minimal. The results of the regression analysis in our model indicate that the development of greenhouse gas production was linked to GDP growth only minimally in the project period. The GHG emission levels cannot be estimated by using the GDP growth rate at the significance level of 0.05. This value was insignificant in our model. This is evidenced, for example, by the fact that the Czech Republic's GDP declined from 3.1% to –4.5% of the long-term average in 2008–2009, probably due to the global economic crisis, while the CO_2 emissions decreased only from 11.96 t to 11.11 t, which is approximately only 7% per capita, and with the GDP growth of 2.9% in 2014, the drop in emissions was even 0.47 t per capita. The hypothesis that the GDP growth will increase the CO_2 emissions was not confirmed for the chosen time period. If the theory of a direct correlation between GDP and CO_2 production can be adopted, this can be besides explained by the overheated economy, depression, economic crisis and by the subsequent slow recession that took place in the period under review and consequently affected the production output and greenhouse gas emissions. The analysis showed that the EU ETS was insignificant in the Czech Republic during the monitored period. In our model, almost no correlation was found between the price of the emission allowance and the amount of CO_2 production. Our model suggests that at the stated emission market prices, it is unlikely that the correlation between the price of emission allowances and the amount of CO_2 production is likely to be demonstrated. This is apparently due to the large number of emission allowances allocated to the issuers, due to the economic crisis and the consequent low demand for emission allowances on the market, which apparently caused the low acquisition cost of this regulatory measure. According to Eurostat, there was no year-on-year increase of greenhouse gases in the EU member states, only Germany and the Czech Republic recorded a long-term decrease (Eurostat, 2016). Among other things, this was probably due to a small, renewed increase in the price of emission allowances. The increase in emissions from the other member states indicates that this price is probably unnecessarily low and does not fulfill its regulatory role properly. Czech Republic appears to be in line with the theory outlined above, still reserving greenhouse gas emission reductions. Thus we agree with Brink et al. (2016) that the projected price of 20 EUR per emission allowance for 2020 is far away from the real price and that this current price probably does not perform well. The analysis thus confirmed that the amount of fossil fuels consumption strongly affects the CO_2 emissions. Greenhouse gas emission levels can be estimated using the fossil fuel consumption – at the significance level of 0.05 we rejected the zero hypothesis, the chosen model was statistically significant. This is due to the carbon content in these fuels and their subsequent release during their combustion. It has been confirmed that with the growing consumption of renewable energy, the CO_2 production is decreasing. Therefore, the GHG emission levels can be estimated by using the renewable energy sources. As stated in the theoretical part, this is due to the substitution effect when high carbon fuels are replaced by so-called pure energy (Boyle, 2004). Statistics from the Eurostat show that the share of renewable energies in the amount consumed is increasing every year in all EU member states. The highest increase in RES consumption is attributable to wood chips. This increase is most striking in the Nordic countries (Eurostat, 2016).

A similar study was conducted by Lin et Li (2011).The authors reviewed the regression analysis of the time series of GDP development, emission allowance prices, carbon taxes, fossil fuel consumption and renewable energy sources for 5 EU member states with the established carbon tax. Their model confirmed a direct link between the GDP and the greenhouse gas production. Unlike the emission allowances, this model showed a significant impact of carbon tax, especially in Finland. It also confirmed the importance of the consumption of fossil fuels and renewable energies in the CO_2 production. The low significance of emission allowances at their low market prices was confirmed by the two studies, whose results are similar as in the Czech Republic. Lin et Li (2011) indicated a more significant role of the carbon tax and its higher environmental effectiveness. The difference in the importance of GDP growth for CO_2 production in both studies may also be due to the study period of Lin et Li (2011) when the economic recession occurred while the results of our model could be distorted by the depression and by the subsequent economic crisis.

CONCLUSIONS

Long-term scientific studies in the EU show that the ETS introduction has led from the start to a drop in CO_2 emissions from large polluters. The data from EUROSTAT, which indicate a too slow decline in CO_2 production, suggests a need of regulatory intervention by EU institutions to ensure that greenhouse gas emissions are further reduced. One possible regulatory intervention is for example a support increase in the price of emission allowances and an immediate reduction in the amount of allowances allocated free of charge in the energy sector. Another option is the introduction of carbon tax as a further tool to reduce greenhouse gas emissions across the EU. The functionality of this tool mix is proven, for example, by the experiences of the Nordic countries since the 1990s.

However, the future development in the EU territory can be predicted as the increasing importance and involvement of environmental taxes in the mix of instruments designed to reduce greenhouse gas emissions, particularly so-called carbon taxes. The Czech Republic has a study on the introduction of carbon tax, including an impact study (Ministry of Finance of the Czech Republic, 2016). However, the introduction of any tax is a very socially sensitive issue, which requires a broad social consensus, and, in the case of environmental taxes, a certain level of environmental awareness of the population. Our research responded to all research questions we asked. It is very likely that the final results could have been affected by the economic crisis occurring at all stages in our time period. This is why it would be appropriate to continue and monitor further time periods in this research project. The basic objective of the paper was to assess whether the ETS emission allowances in the Czech Republic are environmentally effective. The research did not show their environmental effectiveness during the studied period. A proposed solution could be the introduction of carbon tax, as an additional economic tool for reducing greenhouse gases and the intervention by EU authorities aimed at the emission allowance price increased to the planned level of 20 EUR. This conclusion is also reflected in the forthcoming change prepared by the European Commission, which plans to reduce number of freely allocated allowances in the following period (European Commission, 2017). This plan was announced already in 2017 and from the 3rd quarter of 2017 to the 5th month of 2018, there was a step-up increase in the price of emission allowances on the market. Explanation is the ongoing recession of economy and the effort of companies to respond and frontload with allowances for the next period.

ACKNOWLEDGMENT

This paper was supported by IGA (Czech University of Life Sciences Prague, Faculty of Forestry and Wood Sciences), Project No. B08/17 and Project No. QK1920391 financed by Ministry of Agriculture of the Czech Republic called *Diverzifikace vlivu biohospodářství na strategické dokumenty lesnicko-dřevařského sektoru jako podklad pro státní správu a návrh strategických cílů do roku 2030* (Analysis of the consequences of greenhouse gas emissions trading in the Czech forestry).

References

Act No. 695/2004 Coll. on the conditions of trading in greenhouse gas emission allowances and on the amendment of certain laws [online]. <http://aplikace.mvcr.cz/archiv2008/sbirka/2004/zakon_12.html#castka_235>.

AIDT, T. S. AND DUTTA, J. Transitional politics: emerging incentive-based instruments in environmental regulation. *Journal of Environmental Economics and management,* 2004, 47(3), pp. 458–479. DOI:10.1016/j.jeem.2003.07.002.

ALAM, M. M., MURAD, M. W., NOMAN, A. H. M., OZTURK, I. Relationships among carbon emissions, economic growth, energy consumption and population growth: Testing Environmental Kuznets Curve hypothesis for Brazil, China, India and Indonesia. *Ecological Indicators*, 2016, 70, pp. 466–479. DOI: 10.1016/j.ecolind.2016.06.043.

BARANZINI, A., GOLDEMBERG, J., SPECK, S. A future for carbon taxes. *Ecological Economics*, 2000, 32(3), pp. 395–412. DOI: 10.1016/S0921-8009(99)00122-6.

BAUER, N. et al. CO_2 emission mitigation and fossil fuel markets: dynamic and international aspects of climate policies. *Technological Forecasting and Social Change*, 2015, 90(A), pp. 243–256. DOI: 10.1016/j.techfore.2013.09.009.

BÍLKOVÁ, D., BUDINSKÝ, P., VOHÁNKA, V. *Pravděpodobnost a statistika* (Probability and statistics). Plzeň: Vydavatelství a nakladatelství Aleš Čeněk, 2009. ISBN 978-80-7380-224-0. (in Czech)

BOYLE, G. eds. *Renewable Energy.* Oxford University Press, May 2004, 456 p. ISBN-10: 0199261784.

BRAUN, M. The evolution of emissions trading in the European Union – The role of policy networks, knowledge and policy entrepreneurs. *Accounting, Organizations and Society*, 2009, 34(3–4), pp. 469–487. DOI: 10.1016/j.aos.2008.06.002.

BRINK, C., VOLLEBERGH, H. R. J., VAN DER WERF, E. Carbon pricing in the EU: evaluation of different EU ETS reform options. *Energy Policy*, 2016, 97, pp. 603–617. DOI: 10.1016/j.enpol.2016.07.023.

BUDÍKOVÁ, M., KRÁLOVÁ, M., MAROŠ, B. *Průvodce základními statistickými metodami* (Guide to basic statistical methods). Prague: Grada, 2010. ISBN 978-80-247-3243-5. (in Czech)

CIALANI, C. CO2 emissions, GDP and trade: a panel cointegration approach [online]. *International Journal of Sustainable Development*, 2017, 24(3), pp. 193–204. DOI: 10.1080/13504509.2016.1196253.

CONVERY, F. J. AND REDMOND, L. Market and price developments in the European Union emissions trading scheme. *Review of Environmental Economics and Policy*, 2007, 1(1), pp. 88–111. DOI: 10.1093/reep/rem010.

CZSO. *Hrubý domácí produkt* (Gross Domestic Product) [online]. Prague: Czech Statistical Office, 2019. <https://www.czso.cz/csu/czso/hdp_narodni_ucty>.

DAVIET, F. AND RANGANATHAN, J. *The Greenhouse Gas Protocol: The GHG Protocol for Project Accounting.* World Business Council for Sustainable Development (WBCSD), World Resources Institute, 2005.

DEENEY, P. et al. Influences from the European Parliament on EU emissions prices. *Energy Policy*, 2016, 88, pp. 561–572. DOI: 10.1016/j.enpol.2015.06.026.

DINDA, S. Environmental Kuznets curve hypothesis: a survey. *Ecological economics*, 2004, 49(4), pp. 431–455. DOI: 10.1016/j.ecolecon.2004.02.011.

Directive 2009/.../EC of the European Parliament and of the Council of ... amending Directive 2003/87/EC in order to improve and extend the scheme for greenhouse gas emission allowance trading within the Community [online]. <http://register.consilium.europa.eu/pdf/en/08/st03/st03737.en08.pdf>.

Directive 2003/87/EC of the European Parliament and of the Councilof 13 October 2003 establishing a scheme for greenhouse gas emission allowance trading within the Community and amending Council Directive 96/61/EC. Brussels, L 275/32–46.

DODA, B. et al. Emissions-GDP Relationship in Times of Growth and Decline. *Grantham Research Institute on Climate Change and the Environment Working Paper*, 2013, 116 p.

ERU. *Průměrná cena emisní povolenky pro roky 2007–2015* (Average emission permit price for the years 2007–2015) [online]. Prague: ERU, 2019. <https://www.eru.cz/cs/teplo/sdeleni/archiv>.

EUROPEAN COMMISSION. *Emission Trading Scheme (EU ETS)* [online]. European Union: European Commission, 2017. cit. 15.5.2018. <http://ec.europa.eu/environment/climat/emission/index_en.htm>.

EUROSTAT. *Air emissions accounts by NACE Rev. 2 activity* [online]. 2019. <http://appsso.eurostat.ec.europa.eu/nui/show.do?dataset=env_ac_ainah_r2&lang=en>.

FAN, Y. What policy adjustments in the EU ETS truly affected the carbon prices? [online]. *Energy Policy*, 2017, 103, pp. 145–164. DOI: 10.1016/j.enpol.2017.01.008.

HINDLS, R. *Statistika pro economy* (Statistics for economists). 8th Ed. Prague: Professional Publishing, 2007. ISBN 978-80-86946-43-6. (in Czech)

HINDLS, R., SEGER, J., HRONOVÁ, S. *Statistika pro economy* (Statistics for economists). Brno: Professional Publishing, 2002. ISBN 80-86419-26-6. (in Czech)

HINTERMANN, B., PETERSON, S., RICKELS, W. Price and Market Behavior in Phase II of the EU ETS: A Review of the Literature. *Review of Environmental Economics and Policy*, 2015, 10(1), pp. 108–128. DOI: 10.1093/reep/rev015.

HONG, Z. et al. Optimizing an emission trading scheme for local governments: A Stackelberg game model and hybrid algorithm. *International Journal of Production Economics*, 2017, 193, pp. 172–182. DOI: 10.1016/j.ijpe.2017.07.009.

JORDAN, A., WURZEL, R. K. W, ZITO, A. R. *'New' instruments of environmental governance: Patterns and path ways of change.* London: FRANK CASS PUBLISHERS, 2003.
KHARLAMOVA, N. S. AND STAVYTSKYY, A. Estimation of renewable energy sources application in the synergy with european union policy. *Vìsnik. Kiïvs'kogo Nacìonal'nogo Unìversitetu ìmenì Tarasa Ševčenka. Ekonomìka*, 2018, Vol. 3, Iss. 198, pp. 54–65. DOI: 10.17721/1728-2667.2018/198-3/7.
KOCH, N., FUSS, S., GROSJEAN, G., EDENHOFER, O. Causes of the EU ETS price drop: Recession, CDM, renewable policies or a bit of everything? New evidence. *Energy Policy*, 2014, 73, pp. 676–685. DOI: 10.1016/j.enpol.2014.06.024.
LAING, T. et al. The effects and side-effects of the EU emissions tradings cheme. *Wiley Interdisciplinary Reviews: Climate Change*, 2014, 5(4), pp. 509–519. DOI: 10.1002/wcc.283.
LEU, T. AND BETZ, R. Environmental Tax Evaluation What can be learnt so far? *International Energy Policies & Programmes Evaluation Conference,* Amsterdam, 2016, pp. 1–24. DOI: 10.1787/888932765598.
LIM, K., LIM, S., YOO, S. Oil consumption, CO_2 emission, and economic growth: Evidence from the Philippines. *Sustainability*, 2014, 6(2), pp. 967–979. DOI: 10.3390/su6020967.
LIN, B. AND LI, X. The effect of carbon tax on per capita CO_2 emissions. *Energy policy*, 2011, 39(9), pp. 5137–5146. DOI: 10.1016/j.enpol.2011.05.050.
LITSCHMANNOVÁ, M. *Vybrané kapitoly z pravděpodobnosti* (Selected chapters of probability). Ostrava: VŠB-TU, 2011. (in Czech)
MANSUR, E. T. Prices versus quantities: environmental regulation and imperfect competition. *Journal of regulatory Economics*, 2013, 44(1), pp. 80–102. DOI: 10.1007/s11149-013-9219-6.
MINISTRY OF FINANCE OF THE CZECH REPUBLIC. *Analýza k možnostem a dopadům zohlednění environmentálních prvků v sazbách spotřebních a energetických daní v České Republice* (Analysis of the possibilities and impacts of taking into account environmental elements in consumer and energy taxation rates in the Czech Republic) [online]. Prague, 2016. [cit. 20.5.2018] <https://www.mfcr.cz/cs/legislativa/materialy-na-jednani-vlady/1-ctvrtleti-17/materialy-na-jednani-vlady-dne-9-ledna-2-27155>. (in Czech)
MITTAL, M. AND KUMAR, A. Carbon nanotube (CNT) gas sensors for emissions from fossil fuel burning. *Sensors and Actuators B: Chemical*, 2014, 203, pp. 349–362. DOI: 10.1016/j.snb.2014.05.080.
MONTZKA, S. A., DLUGOKENCKY, E. J., BUTLER, J. H. Non-CO_2 greenhouse gases and climate change. *Nature*, 2011, 476(7358), pp. 43–50. DOI: 10.1038/nature10322.
MUÛLS, M. et al. *Evaluating the EU Emissions Trading System: Take it or leave it? An assessment of the data after ten years.* Tech. Rep. 21, Grantham Institute Briefing Paper, 2016.
NARAYAN, P. K. AND SHARMA, S. S. Is carbon emissions trading profitable? *Economic Modelling*, 2015, 47, pp. 84–92. DOI: 10.1016/j.econmod.2015.01.001.
NORDHAUS, W. *Life After Kyoto: Alternative Approaches to Global Warming.* National Bureau of Economic Research, 2005, 34 p. DOI: 10.3386/w11889.
OECD. *Instrument mixes for environmental policy.* OECD Publishing, 2007, 237 p. DOI: 10.1787/9789264018419-en.
OUESLATI, W. et al. Energy taxes, reforms and income inequality: An empirical cross-country analysis. *International Economics*, 2017, 150, pp. 80–95. DOI: 10.1016/j.inteco.2017.01.002.
ÖZOKCU, S. AND ÖZDEMIR, Ö. Economic growth, energy, and environmental Kuznets curve. *Renewable and Sustainable Energy Reviews*, 2017, 72, pp. 639–647. DOI: 10.1016/j.rser.2017.01.059.
PALMER, K. AND BURTRAW, D. Cost-effectiveness of renewable electricity policies. *Energy economics*, 2005, 27(6), pp. 873–894. DOI: 10.1016/j.eneco.2005.09.007.
PHALAN, B. et al. How can higher-yield farming help to spare nature? *Science*, 2016, 351(6272), pp. 450–451. DOI: 10.1126/science.aad0055.
PRATHER, M. J., HOLMES, C. D., HSU, J. Reactive greenhouse gas scenarios: Systematic exploration of uncertainties and the role of atmospheric chemistry. *Geophysical Research Letters*, 2012, 39(9), pp. 1–5. DOI: 10.1029/2012gl051440.
SABZEVAR, N. et al. Modeling competitive firms' performance under price-sensitive demand and cap-and-trade emissions constraints. *International Journal of Production Economics*, 2017, 184, pp. 193–209. DOI: 10.1016/j.ijpe.2016.10.024.
SEGURA, S. et al. Environmental versus economic performance in the EU ETS from the point of view of policy makers: A statistical analysis based on copulas. *Journal of Cleaner Production*, 2018, 176, pp. 1111–1132. DOI: 10.1016/j.jclepro.2017.11.218.
SORRELL, S. AND SIJM, J. Carbon trading in the policy mix. *Oxford review of economic policy*, 2003, 19(3), pp. 420–437. DOI: 10.1093/oxrep/19.3.420.