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MODELING GREENHOUSE GAS EMISSIONS FROM LIVESTOCK FARMING IN POLAND WITH THE USE OF STEPWISE MULTIPLE REGRESSION

Summary

Primarily methane (CH_4) and nitrous oxide (N_2O) are greenhouse gases emitted by agriculture. It is estimated that 18% of global greenhouse gas emissions originates from livestock farming. This paper presents the results of the regression modeling of methane and nitrous oxide from livestock farming in Poland. The study was conducted for the emissions released from animal enteric fermentation (CH_4) and manure management (CH_4 and N_2O). Modeling stepwise allowed a precise determination of the share of livestock population in the emissions. And so, in the case of CH_4 emissions from enteric fermentation Beta coefficients obtained values: for cows - 0.667 and 0.339 for rest of cattle. Modeling CH_4 emissions from manure management pointed to participation of the following variables, in order of importance: pigs population (Beta coefficient equal to 0.986), goats (-0.61), poultry chicken (0.421) and sheep population (0.312). In the case of N_2O emissions released from manure management a high rate has been recorded for cows population (0.812), and significantly lower for pigs (0.227). In each of considered cases a high fitting of the model to the data has been obtained.
***Key words**: Multiple Regression, backward stepwise regression, modeling, methane, nitrous oxide, livestock*

MODELOWANIE EMISJI GAZÓW CIEPLARNIANYCH UWALNIANYCH Z CHOWU ZWIERZĄT GOSPODARSKICH W POLSCE Z WYKORZYSTANIEM REGRESJI KROKOWEJ WIELORAKIEJ

Streszczenie

Gazy cieplarniane emitowane przez rolnictwo to przede wszystkim metan (CH_4) i podtlenek azotu (N_2O). Szacuje się, iż 18% światowej emisji gazów cieplarnianych pochodzi z chowu zwierząt gospodarskich. W artykule zaprezentowano wyniki modelowania regresyjnego w emisji metanu i podtlenku azotu z chowu zwierząt gospodarskich w Polsce. Badania przeprowadzono dla emisji uwalnianych z fermentacji jelitowej zwierząt (CH_4) oraz zarządzania obornikiem (CH_4 i N_2O). Modelowanie krokowe wsteczne umożliwiło dokładne określenie wielkości udziału pogłowia zwierząt w emisjach. I tak w przypadku emisji CH_4 z fermentacji jelitowej otrzymano współczynniki Beta o wartościach: dla krów - 0,667 oraz pozostałego bydła 0,339. Modelowanie emisji CH_4 z zarządzania obornikiem wskazało na udział w kolejności znaczenia następujących zmiennych: pogłowia trzody chlewnej (współczynnik Beta równy 0,986), kóz (-0,61), drobiu kurzego (0,421) oraz owiec (0,312). W przypadku emisji N_2O uwalnianych z zarządzania obornikiem wysoki współczynnik odnotowano dla zmiennej pogłowie krów (0,812) oraz znaczniej niższy dla trzody chlewnej (0,227). W każdym z rozpatrywanych przypadków uzyskano wysokie dopasowanie modelu do danych.
***Słowa kluczowe**: regresja wieloraka, regresja krokowa wsteczna, modelowanie, metan, podtlenek azotu, zwierzęta gospodarskie*

1. Introduction

It is assumed that in regard to the agricultural sector one of the most important factors determining the rate of production of greenhouse gases will be the development of livestock farming. Intensive livestock production has always been and will be a significant burden to the environment.

Greenhouse gases emitted by agriculture are primarily methane (CH_4) and nitrous oxide (N_2O). They are the key pollutions among greenhouse gases being a major contribution to climate changes [9,19] because of their high potential global impact.

Agriculture is responsible for about 50% of global anthropogenic emissions of CH_4 [8].

The main source both of CH_4 and N_2O is animal production [11]. It is estimated that it accounts for 18% of global greenhouse gas emissions (represented as CO_2 -eq) [20]. The sector emits 65% of anthropogenic N_2O and 37% of global anthropogenic CH_4 [21].

The livestock emission are expected to increase to 28000 Gg CO2-eq in 2020 [23]. Emission levels are largely affected by the type and scale of agricultural production (eg. type and number of livectock, area of fertilised cropland ect..) [15]. The share of livestock in total greenhouse gas emissions is greater than that of transport [12]. Livestock represents about 80% of agricultural CH_4 emission [4]. Enteric fermentation of ruminants (cattle, sheep, goats, horses) represents almost 71% of agricultural emissions of CH_4. In turn about 29% of the emissions comes from manure management [26].

Agricultural sources of discussed greenhouse gases are: animal enteric fermentation, manure, agricultural soil and plant residues burning. The proportion is as follows:

- Enteric fermentation - CH_4 (share in total emissions of 2.3%).
- Manure Management - CH_4 (0.8%),
- Manure Management - N_2O (1.3%),
- Direct emissions from soils N_2O (3.1%),
- Indirect emissions from soils - N_2O (1.1%).

The total share of these sources in the total GHGs countries emissions is 8.5%. CH_4 and N_2O emissions have been declining. Released emissions from the agricultural sector in the last two decades illustrates the Figure 1.

Gases emitted by livestock farming shows the Figure 2. Within the CH_4 emissions from enteric fermentation a significant decrease has been observed. The amount of CH_4 released due to manure management remains invariable. N_2O emission shows a downward trend.

Total emissions of CH_4 and N_2O from the agricultural sector in Poland in 2010 amounted to 34,624.13 Gg CO_2 - eq and was lower by 32.0% than in 1988 [3]. 75.2% CH_4 emissions in 2010 is attributed to the processes of livestock enteric fermentation, approximately 24.6% of emissions falls on the manure management, and a small share of about 0.2% came from the combustion of plant residues [3].

In the case of N_2O a major source of emissions in 2010 were agricultural soils, responsible for 77.1% of emissions, while this associated with animal manure management was 22.8%. Participation of combustion plant residues was slight and reached 0.1% [3].

All the information complementary to the knowledge in the field of emissions released from the agricultural sector is a valuable source of knowledge.

The necessity of prediction ability of possible scenarios in the production of greenhouse gases due to growing livestock production is therefore particularly significant. An important challenge of the present time is the adaptation of agriculture to changing climate conditions and support actions to mitigate these changes.

Study of the effect of agricultural production on the environment, particularly greenhouse gas emissions from this sector, is currently the issue undertaken by researchers and political makers in Poland [eg 10, 13, 14, 16, 18] and in the world [eg 1, 2, 6, 7, 27].

2. Materials and methods

The research aimed to quantify indication of complex relationships of variables: livestock populations to greenhouse gas emissions such as CH_4 and N_2O released by enteric fermentation and manure management.

The study was conducted on the basis of the modelling of multiple stepwise regression, which enables to search and describe quantified complex relationships. The constructed multiple regression model allows to examine the impact of many independent variables (X1, X2, ..., Xk) for one dependent variable (Y). The most commonly used variant of multiple regression is linear regression.

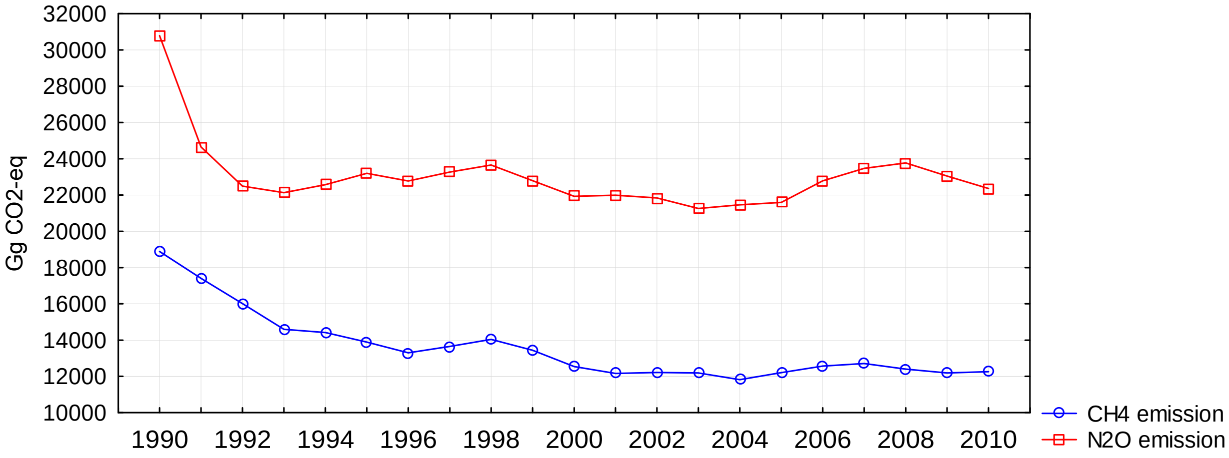

Fig. 1. Total CH_4 and N_2O emissions from the agricultural sector in Poland, source: [24]

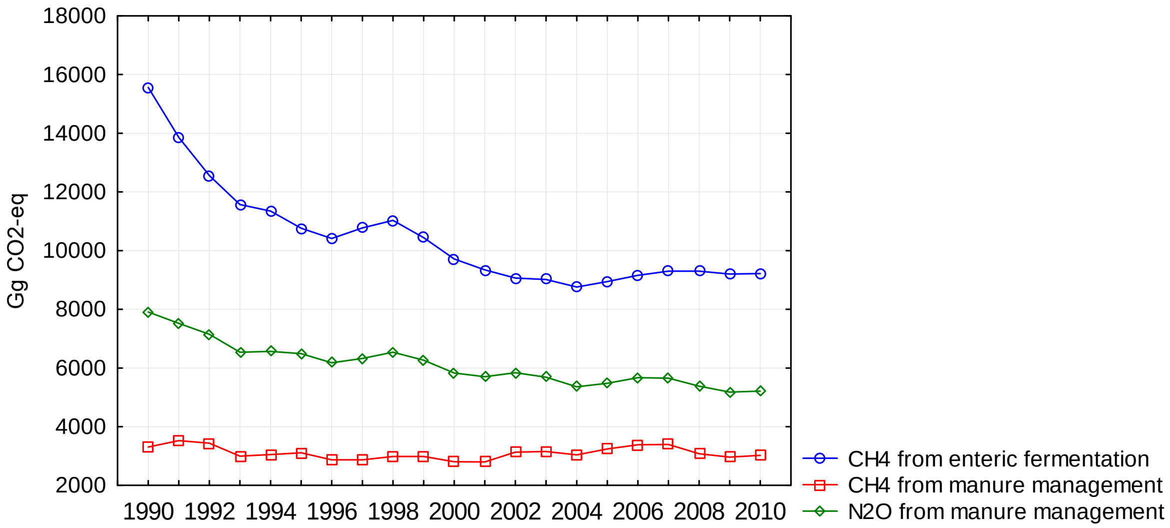

Fig. 2. Emissions from enteric fermentation and animal manure management, source: [24]

It is an extension of linear regression models based on Pearson's correlation coefficient. It assumes the presence of a linear relationship between the two variables. Multiple linear regression model takes the form:

$$Y = \beta_0 + \beta_1 X_1 + \beta_2 X_2 + \dots + \beta_k X_k + \epsilon \quad (1)$$

where:
Y - the dependent variable,
X1, X2,. . . Xk - independent variables,
β1, β2. . . βk – parameters
ε - random component (the rest of the model).

If in the standard multiple regression model insignificant variables are obtained, it should be eliminated by applying the other method to identify the best set of independent variables. The study used stepwise backward regression.

In the first step this method involves constructing a model that includes all potential dependent variables, and then gradually eliminating them in order to maintain the model with the highest coefficient of determination, while retaining significance of parameters. In each step the number of variables is reduced, what consequently leads to the decrease in the coefficient of determination. Removing insignificant variable in the model causes an increase in the number of degrees of freedom for the residual variability, what in association with the fact that there has been a inconsiderable increase in the sum of squared deflection for the residual variability reduces the mean square deflection from the regression model.

Regression modelling was performed for the following cases:

- Study of the impact of livestock population on CH_4 emissions released as a result of enteric fermentation
- Study of the impact of livestock population on greenhouse gases CH_4 and N_2O released through manure management

Input data were taken from international public statistics databases in the case of animal populations from Food and Agricultural Organization (FAO) [5] and emissions from the United Nations Framework Convention on Climate Change (UNFCCC) [24]. Assumed data from the years 1990-2010. Livestock populations in 2011 in Poland contains Table 1. Modelling was carried out in the package Statistica 10.0.

Table 1. Livestock populations in 2011 in Poland; source: [25].

Livestock	**Livestock population** thous. heads
Cattle	5761.9
Sheep	251.0
Poultry	143557.3
Horses	254.4
Goats	111.8
Pigs	13508.7

3. Results and discussion

Initially dependent variable was logarithmed. The analysis of correlation allowed for quick identification of dependencies. The values in Table 2 represent the Pearson correlation coefficients. Statistically significant variables are marked in bold letters ($p < 0.05$).

According to the applied test procedures statistically insignificant variables were not subject to further analysis. Significant variables were used to build the regression model. R^2 values refer to the fitting of the model to the data. Modified R^2 (shown in Table 3 as Adjust R^2) is lower than that because of the inclusion in the analysis the additional degrees of freedom contributed by subsequent variables. Implementation of too many variables can result in overfitting the model to the data. Apart from the coefficient of determination R^2, therefore another parameter should be considered. Particularly significant in comparing models is the Fisher test (test F). The higher value of test F means the better fit for the model [22].

In a case of testing the impact on livestock population for CH_4 emission released from enteric fermentation all independent variables revealed significant linear relationship with the studied dependent variable (Table 2). However, the results obtained from multiple regression (Table 3) indicate the existence of correlations of many insignificant variables. To eliminate them the possibilities of backward stepwise regression were used.

Table 2. Correlation matrix; own calculations

Variable	Cows	Rest of cattle	Pigs	Sheeps	Horses	Goats	Polutry	CH_4 log from enteric ferment	CH_4 log Manure manag.	N_2O log Manure manag.
Cows	1.000									
Rest of cattle	**0.928**	1.000								
Pigs	**0.728**	**0.543**	1.000							
Sheeps	**0.887**	**0.854**	**0.567**	1.000						
Horses	**0.967**	**0.864**	**0.708**	**0.816**	1.000					
Goats	**0.607**	0.410	**0.634**	0.341	**0.64**	1.000				
Poultry	**-0.646**	**-0.579**	**-0.492**	-0.342	**-0.717**	**-0.701**	1.000			
CH_4 log Enteric ferment.	**0.984**	**0.961**	**0.660**	**0.912**	**0.936**	**0.501**	**-0.601**	1.000		
CH_4 log Manure manag.	0.314	0.255	**0.565**	**0.517**	0.215	-0.177	0.259	0.342	1.000	
N_2O log Manure manag.	**0.976**	**0.893**	**0.817**	**0.840**	**0.934**	**0.664**	**-0.678**	**0.959**	0.355	1.000

Table 3. The results of standard backward regression; own calculations

R = 0.996, R^2 = 0.991, Adjust. R^2 = 0.987, F = 216.56, p < 0.000, Estimation Standard error: 0.00771	
Variable	Correlation
Cows	**0.825**
Rest of cattle	0.197
Pigs	-0.02
Sheep	0.097
Horses	-0.08
Goats	-0.08
Poultry	-0.04

Stepwise regression modelling results suggest the importance of two independent variables: cow population and other cattle. The value of Fischer test for Table 4 is substantially higher than previously achieved. What is essential, adjusted R^2 (although lower than that obtained in the first approach) is high and amounts R^2 = 0.987. Regression summary values are shown in Table 4.

To compare the mutual importance of parameters (Beta coefficients), coefficients by variables in the regression equation were normalized. The values of these factors suggest that a greater impact on the emission from the fermentation has cow population than the rest of cattle. Figure 3 presents the experimental results with the data calculated by the multiple regression model with 95% confidence intervals.

Table 4. The results of stepwise multiple regression for the dependent variable CH_4 emissions from enteric fermentation; own calculations

The number of cases N = 21	R= 0.993, R^2= 0.986, Adjust. R^2= 0.984, F(2.18) = 619.09, p < 0.000, Estimation Standard error: 0.00851					
	Beta coefficient	Standard error with Beta	Directional coefficient b	Standard error with b	t(18)	Significance level p
Intercept			3.667528	0.010012	366.3241	0.000000
Cows	0.669654	0.075986	0.000000	0.000000	8.8128	0.000000
Rest of cattle	0.339389	0.075986	0.000000	0.000000	4.4665	0.000298
The regression equation	**Log CH_4 emission enteric ferment. = 0.670 cows+0.339 rest of cattle+3.67**					

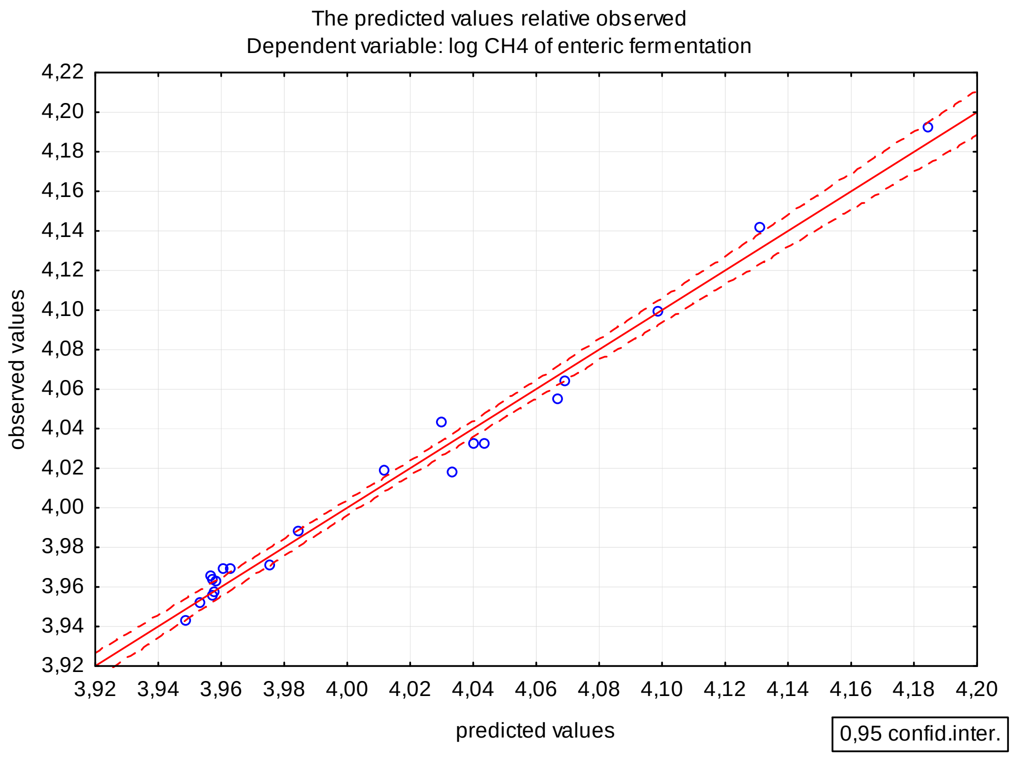

Fig. 3. Scatter plot correlation figure for the observed and predicted by the model results; own calculations on Figure 4 compared the real and predicted values. Their courses are very similar

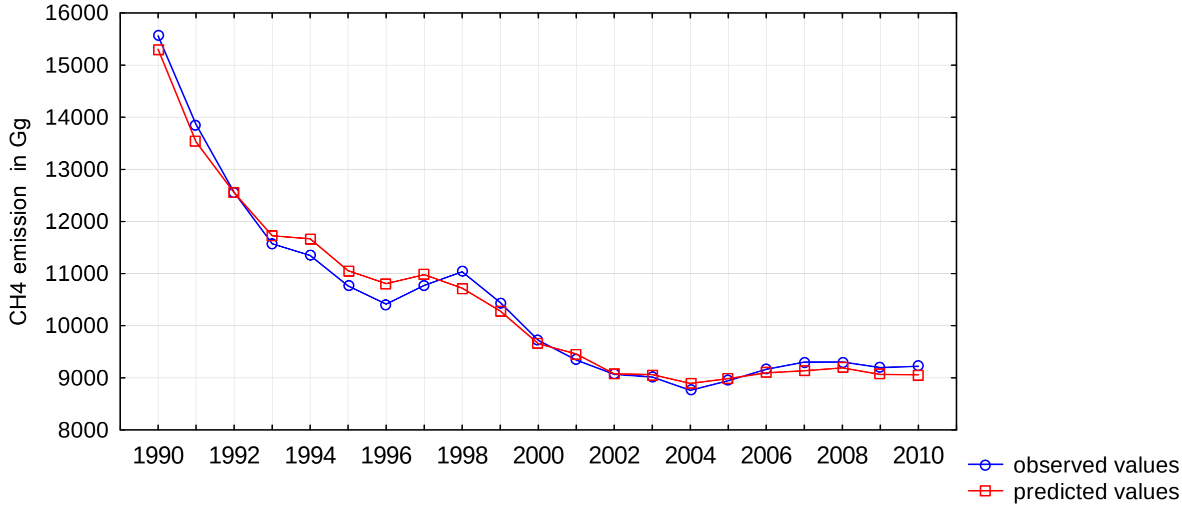

Fig. 4. CH_4 observed and predicted emission from enteric fermentation

In the next phase of the study the impact of livestock populations on gases CH_4 and N_2O released from manure management was analyzed. The analysis was performed according to the procedure described above and the results are summarized in Table 5.

Table 5. The results of multiple regression for the dependent variable CH_4 and N_2O emissions from manure management; own calculations

CH_4 emission						
The number of cases N = 21	$R= 0.968$, $R^2= 0.938$, Adjust. $R^2= 0.922$, $F(4.16) = 60.398$, $p < 0.000$, Estimation Standard error: 0.00808					
	Beta coefficient	Standard error with Beta	Directional coefficient b	Standard error with b	t(18)	Significance Level p
Intercept			3.307217	0.025465	129.8732	0.000000
Pigs	0.985992	0.092009	0.000000	0.000000	10.7163	0.000000
Sheeps	0.311830	0.076313	0.000000	0.000000	4.0862	0.000861
Goats	-0.613858	0.099280	-0.000001	0.000000	-6.1831	0.000013
Poultry	0.421436	0.088521	0.000000	0.000000	4.7609	0.000213
The regression equation	**Log CH_4 emission from manure managment = 0.986 Pigs + 0.312 Sheeps – 0.61 Goats +0.421 Poultry +3.31**					
N_2O emission						
The number of cases N = 21	$R= 0.989$, $R^2= 0.978$, Adjust. $R^2 = 0.976$, $F(2.18)=401.07$, $p < 0.000$ Estimation Standard error: 0.00798					
Intercept			3.463156	0.017295	200.2441	0.000000
Cows	0.811726	0.050955	0.000000	0.000000	15.9304	0.000000
Pigs	0.226536	0.050955	0.000000	0.000000	4.4458	0.000312
The regression equation	**Log N_2O emission from manure managment = 0.812 Cows +0.227 Pigs +3.46**					

Analyzing the impact of animal populations on CH_4 emissions from manure management, Fischer's test as a standard regression accounts F = 49.04, while the stepwise regression approach is higher and amounts to F = 60.4 – it provides a better fit for the model. The most important impact on CH_4 emissions in the resulting model is the pig population and secondly goats. Figure 5 shows the scatter plot for the observed and predicted values.

Figure 6 shows the real and modelled values of CH_4 emission. Their are very similar.

In the case of study the influence of livestock population on N_2O emissions from manure management, Fisher's value from stepwise regression is also higher (F = 401.07) than standard regression (F = 183). More intensive impact on N_2O emissions has the cow population than pigs. Figure 7 shows a scatterplot.

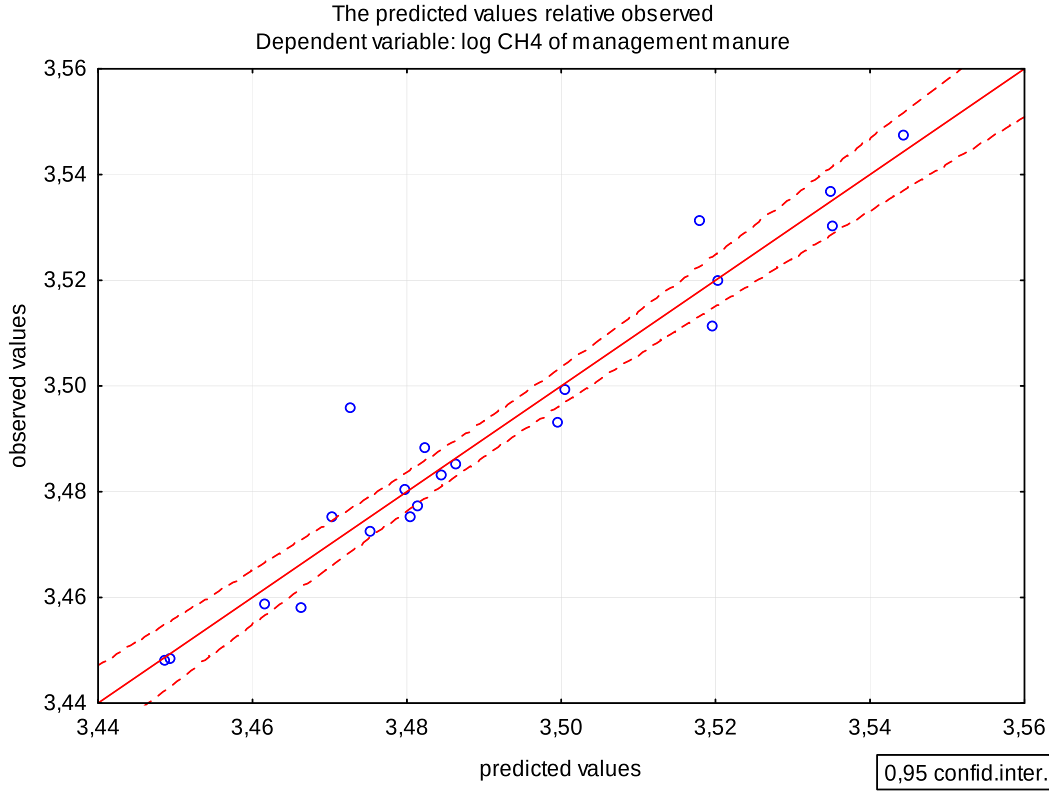

Fig. 5. Scatter plot correlation figure for the observed and predicted by the model results in a case variable CH_4 emission from manure management; own calculations

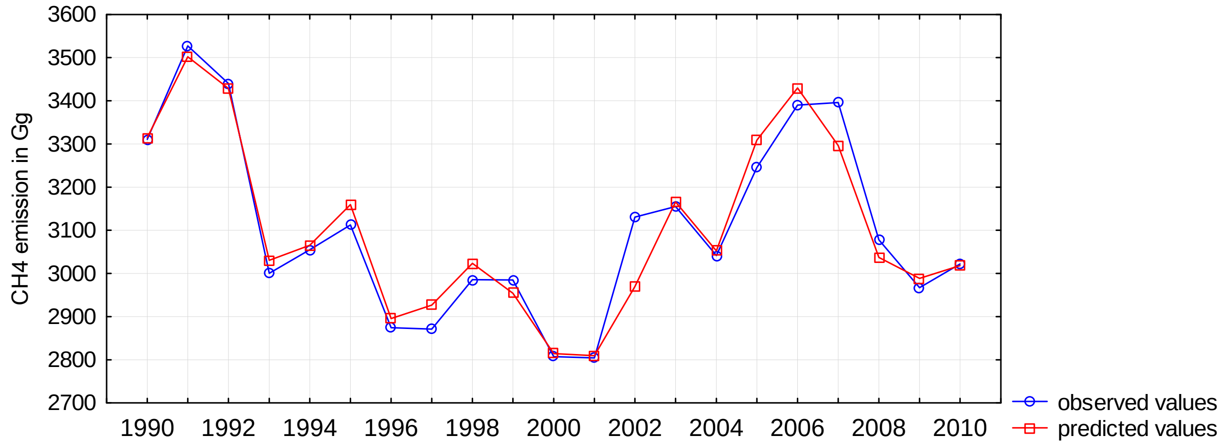

Fig. 6. CH_4 observed and predicted emission from livestock manure management

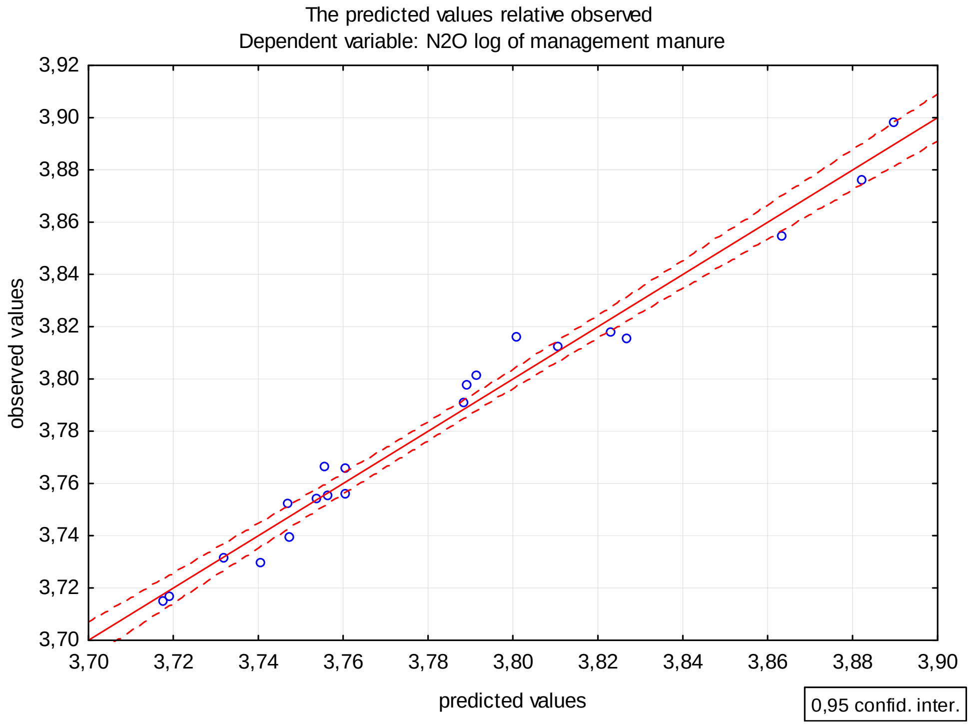

Fig. 7. Scatterplot correlation figure for the observed and predicted by the model results in a case variable N_2O emission from manure management; own calculations

Observed and forecasted values of N_2O emissions are parallel, which proves correct fit of model (Figure 8).

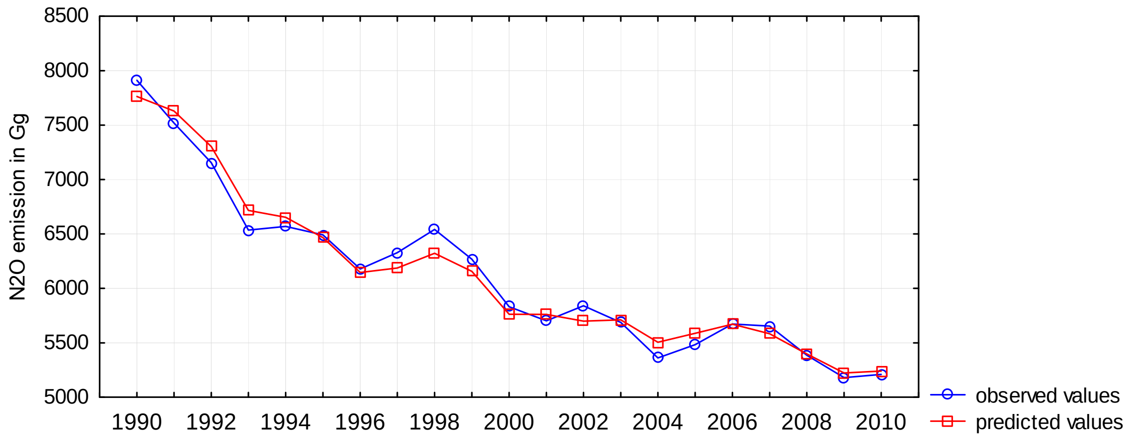

Fig. 8. N_2O observed and predicted emission from livestock manure management

4. Summary

Multiple Regression enables the quantitative description of the impact of some variables for analysed phenomenon. The value of the multiple regression model is used I to serve a purpose of prediction and contains scientific information in the obtained equation.

Stepwise regression was to aim at leaving in the function of regression model a minimum set of independent variables while maximizing the coefficient of determination and minimizing the mean square deflection from the regression model.

The fact is that CH_4 emissions from enteric fermentation are attributed mostly to ruminants, including cattle primarily. The use of step regression modelling enabled an exact determination of the size of this contribution for the cows (0.667) and the rest of cattle (0.339). Beta coefficient for the variable cow population is twice as high and demonstrates the importance of this variable. Adjusted rate reached a high value of $R^2 = 0.987$.

In the next step of the researches, the parameters emitted from manure management, such as CH_4 and N_2O, in both cases indicate a correlation with pigs population. In CH_4 emissions besides the highest part of the pigs population (0.986) the importance of (in the order appropriately received beta coefficient): goats (-0.61), poultry chicken (0.421) and sheep (0.312) is also significant.

The coefficient of determination accounts $R^2 = 0.922$ points a high model fit to the data. N_2O emissions modelling results except for the variable mentioned above, that is the importance of pig population (0.227) reveal the significance of even one more variable - the cows population

(0.812), where the beta coefficient is 3.5 times higher. The regression model explains 98% of variation.

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