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Application of Artificial Intelligence in Environmental Sciences – Forecasting CO₂ Emission in Poland

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1. Introduction

Study on the impact of greenhouse gases emissions on the environment is currently an issue undertaken by scientists and policy makers around the world. The observed increase in the average temperature is often interpreted as a result of normal cyclical changes and long-term phenomenon and global warming is in dispute. In accordance with the precautionary principle efforts are undertaken to stabilize greenhouse gas concentrations in the atmosphere by limiting their anthropogenic emissions and put in place mechanisms to intensify their absorption. During the past 150 years the amount of carbon dioxide in the earth's atmosphere has increased from 280 parts per million to more than 380 parts per million on account of burning of fossil fuels (Srinivasan, 2008). The simulations and forecasts which are being carried out show that the global temperature may increase by 1.6 - 2.0°C in the second half of the 21st century (Timofeev, 2006).

1.1 CO₂ emission in Poland

Poland needs to reduce greenhouse gases emissions by 6%, which means in 2008-2012 the average, annual level must be so lower to compared to 1988 emissions. To attain its objectives, we must limit emissions from all spheres of social life.

In accordance with the European Parliament resolution the European Committee considers that by 2020 the EU will have to reduce greenhouse gas emissions by 15-20%, and for the next 30 years up to 60-80% (compared to 1990).

The main producer of anthropogenic CO₂ in the world is first of all the energy and industry, transport, agriculture and progressive deforestation. The EU directives oblige Poland to maintain specific levels of total national emissions of CO₂, regardless of its source. It is expected that in the coming years, Polish economic development financed from the EU structural and cohesion funds will contribute to the growth of CO₂ emissions.

Particularly important in recent years is the necessity to predict possible scenarios in the greenhouse gases production due to the progressive greenhouse effect. It should be stressed that this is a complex issue because of the diversity and overlapping factors affecting the emission. European Union climate policy is a serious challenge for Poland. To implement this policy in accordance with current recommendations and announced restrictions will

constitute a significant burden on the Polish economy. It should be noted that transport, despite the fact that Poland produces some tons of million of CO₂ is not covered by the ETS. Economic development increases the mobility and traffic loads, causing a steady increase in energy demand, which is the main source of coal and fuel oil.

Polish automotive industry is characterized by a strong growth. A dramatic change occurred with the free market reforms in the 90s. Cars in Poland contribute to emission to atmospheric average 30% pollution and in large cities and agglomerations, their share is much higher and may reach 70% to even 90%. According to Polish Climate Policy, the country should focus primarily on the restructuring of economic sectors towards the diversification of fuels, resulting in a reduction of air pollution.

The transport share in greenhouse gas emissions is increasing. The most difficult in this sector is to carry out activities aimed at emission reductions because of its dependence on petroleum fuels and coal (Resources-use, 2008). You cannot expect on easy successes in reducing greenhouse gas emissions without a change in lifestyles and consumption models, management space use, which conditioning mobility and transport absorptivity. It is predicted a permanent intensity of road traffic in Poland. By 2020, EU countries are obliged to reduce greenhouse gas emissions by 20%. In the same year, we are also supposed to reach the level of 20% of energy generated from renewable sources in the total energy production balance, increase energetic effectiveness of the whole European Union by 20% and increase the share of energy coming from renewable sources in transport by 10%. For the Polish, this may mean instability in the sense of danger of power shortages due to more stringent requirements on emissions of CO₂ and equally ever-increasing demand for energy.

Difficulty in matching the imposed by the European Commission limits may hit the economy functioning. Hard coal plays a very important role in the Polish energy mix, occupying a large share in electricity generation and primary energy consumption, resulting in high and intensity emissions of CO₂.

High CO₂ emission in Poland to result from the fact that the energy sector is based primarily on coal power plants (table 1). Although overall coal consumption in Poland is falling still the share of fossil fuels in electricity production in Poland is near 92% and is the highest among EU countries.

According to current forecasts, the average emissions in Poland in 2008-2012 should not exceed 400 million tons per year. Due to a radical reduction of emission in the 1990s caused by conversion and modernisation of the economy, the cheapest ways of volume reduction concerning the greenhouse gases emission have already been used. The next reductive actions are associated with high capital expenditure and realisations of such investments frequently exceed financial capabilities of companies. It is a fact that the power industry system in Poland is efficient in 33-35%, compared to market-available power blocks with efficiency reaching 50% (Kolasa-Więcek, 2009).

International programs will aim to eliminate power plants based on traditional resources - coal and petroleum. Coal power plants will be gradually phased out in Poland. More and more energy will be generated from alternative sources. The share of renewable energy in total energy production in Poland in 2008 amounted to 7.24% (Environmental protection, 2009), dominated mainly by biomass and hydropower plant. It is expected to increase the participation of wind energy. Undoubtedly, the direction of fuel sources structure development in Poland will result in the emission of energy-fuel sector in the coming years.

| Specification | CO ₂ emission |
|-------------------------------------------|--------------------------|
| Electricity together: | 310 592,29 |
| Fuel combustion: | 310 341,40 |
| - power industry | 187 500,65 |
| - manufacturing and construction industry | 33 724,50 |
| - transport | 37 381,40 |
| Ethereal fuels emission | 250,88 |
| Industrial processes: | 19 040,21 |
| Mineral products | 9 147,39 |
| chemical industry | 4 276,75 |
| metals production | 4 471,88 |
| Other industrial process | 1 144,19 |
| Solvents and other products use | 581,75 |
| Waste | 309,32 |

Table 1. Total CO₂ emission by major sources of emission in 2007 (COS, 2009).

Modern technology can provide Poland with the potential reduction in greenhouse gas emissions, but their development is uncertain. Would be needed life style population changes including technologies that increase energy efficiency in transport and construction. The most important measures have to be taken in improving energy efficiency, its use of low-carbon energy sources and sequestration of CO₂ but it involves a costly investment.

Participation in the emission reduction will have, among others nuclear power plants. It is estimated that in 2020 Poland should have the first nuclear power plant. Much of the traditional coal power plants will end his use period in coming years, and how they will be replaced by is crucial to the country emissivity.

Polish forests are an asset. In industrialized Europe forests occupy a relatively large area in Poland. In recent decades, their surface increasing very slowly but gradually.

There has been observed a theme of making the modeling of CO₂ emissions and spread in many scientific-research institutes in the world, although the modeling in this area is a difficult process even though because of many factors which determine the nature of the phenomenon.

2. Methodology and tools

2.1 ANN in environmental sciences

The character of climatic phenomena is highly complex, with the result that modeling attempts are still taken, which would allow the predictions of high probability. It should be noted that the continuous increase in computing power of modern computers and the development of advanced artificial intelligence tools and statistical tools allow to obtain an application enabling the simulation to gain satisfactory results in modeling.

Present-day, such a far-reaching and widespread interest in neural networks, among both engineers, representatives of science – mathematics, physics and biologists or neurophysiologists stems primarily from research on ways to build more efficient and more reliable information processing equipment, and the nervous system is an unattainable model. There are many successful examples of applications. Just to mention some: electronic systems

diagnosis, biological research interpretation, pattern recognition, speech recognition, medical diagnostics, control theory and optimization issues.

Thanks to the artificial networks it is possible to solve the tasks, which are struggling to cope with traditional computational techniques. Indeed, neural networks, can be used wherever there are problems with the processing and data analysis, with their prediction, classification and control.

The original inspiration for the artificial networks structure was the construction of natural neurons and neural systems. Artificial neural network consists of a large number of items in parallel information processing. These elements are just neurons, although in relation to the real nerve cells their functions are very simplified.

The relatively new insights in environmental sciences provide computational methods based on the idea of artificial intelligence. They are extremely useful in disposing of the noise measurement data information, emerging as a result of overlapping impact of external and internal effects. Thanks to Artificial Neural Networks it is possible to identify the dominant factors.

Theme of modeling the CO₂ emission and dispersion is taken by many research institutes around the World (Auffhammer et al., 2006; IPCC, 2000; Nickerson, 2004; Samoilov & Nakutin, 2009; Sarrat et al., 2007; Schmalensee et al., 1998). Modeling in this area is a difficult process because of for instance the multitude of factors which determine the phenomenon nature (Soon et al., 2001). More importantly, aspects that may seem less related to carbon emissions themselves, such as regulation and private sector strength, or the relative percentage of industry compared to agriculture, or a measure of science and technology are worth exploring so that we may discover a new way to combat this environmental problem (Nickerson, 2004). Modeling is but one approach to understanding climate change. To place more confidence in climate modeling by computer, observational capability must advance (Soon et al., 2001). Simulations carried out by scientists show that even with a dramatic reduction of CO₂ emission, the temperature will not decrease for a certain period of time (Alexiadis 2007).

A significant advantage of the neural network as a forward-looking devices is that through a learning process the network can acquire the ability to predict the output signals based on the observations during the training data. The network is able to predict the output signals, even when using researcher it does not know anything about the nature of the relationship between the conditions with conclusions (Tadeusiewicz, 1993). The neural networks advantage is that they can be used wherever there are problems with the mathematical models creation. Network creator does not have to declare a model sought form and may not even be sure whether any relationship that is possible to a mathematical model even exists. Another important advantage of artificial neural networks is the ability to detect and use any nonlinearities that may occur in the data, even in incomplete data or in the presence of so-called "Noise-information." In order to detect overfitting problems and develop a useful and fair modeling exercise, researchers must follow the technical and practical recommendations and guidelines proposed in the literature on computer science (Bishop, 1995).

Actually, it has been shown that a neural network which is properly designed can approach any continuous function to any desired level of accuracy. Thus in this way the technique is more appropriate than traditional methods in order to model and predict phenomena distinguished by a complex behavior.

Artificial intelligence tools are more and more frequently used in solving issues related to environmental sciences due to, to name just a few, high likelihood of results reception and a possibility to find an alternative solution. There should be also mentioned the disadvantages, which are cited. One of them states that there is no economic theory behind an artificial neural Network. Sometimes this method is criticized because it is considered a black-box without any economic foundation (Álvarez-Díaz, 2009). Another complaint is difficulty in analyzing the impact of input variables to output variable, and moreover it is difficult to verify the statistical importance of predictions. Time-consuming and tedious procedure for the design of neural networks is also emphasized. Another shortcoming is fact that the results can strongly vary depending on the determination of some technical parameters. The last one and more important, the great power of the neural networks to replicate data can be also a serious disadvantage. There is a risk that the network merely mimic data and it cannot generalize new observations (Álvarez-Díaz et al., 2009).

2.2 Research methodology

In this paper, the neural analysis has been made with the use of a neural network of the Flexible Bayesian Models on Neural Networks, Gaussian Processes, and Mixtures, operating in the UNIX/Linux environment (Neal, 2004). Properly designed input-output neural network can learn from the data and provide a reasonable estimate of carbon emissions.

Flexible Bayesian models for regression and classification applications are carried out by this software. The base for these models is multilayer perceptron neural networks or Gaussian processes while in the implementation Markov chain Monte Carlo methods are used. Software modules not only support Markov chain sampling but they also support the distribution and may be useful in other applications.

Flexible Bayesian Neural Networks shows that Bayesian methods allow complex neural network models to be used without fear of the "overfitting" that can occur with traditional neural network learning methods. They can safely be used when training data is limited (Neal, 1996). They can be used to model complex relationships between inputs and outputs or to find patterns in data.

The Bayesian approach treats the issue of model complexity very differently and in particular it allows all of the available data to be used for "training". Since the evidence can be evaluated using training data, we see that Bayesian methods are able to deal with the issue of model complexity, without the need to use cross-validation (Bishop, 1995).

This paper analyses the functional relation between the CO₂ emissions and some factors like:

- CO₂ emissions from the energy industry, transport and other industrial processes in general,
- the size of afforestation,
- hard coal consumption,
- cars and tractors burdensome for clean air (COS, 1991 - 2009).

Analyzed factors are not coincidental, they play and will play a significant role in greenhouse gas emissions in coming years. Training set comprise data from the years 1990-2008 obtained from the CSO database. It was built a network with 4 neurons in the input layer, 8 neurons in the hidden layer and 1 output.

Samples of input signals of training set is shown in the table 2.

| Ordinal number | Afforestation | Number of Vehicles | Hard coal consumption | CO ₂ emissions from transport | CO ₂ emissions |
|----------------|---------------|--------------------|-----------------------|------------------------------------------|---------------------------|
| 1 | 9.98 | 9.51 | 19.45 | 9.43 | 14.02 |
| 2 | 9.98 | 9.6 | 19.2 | 9.55 | 12.64 |
| 3 | 9.98 | 9.63 | 18.42 | 9.67 | 13.1 |
| 4 | 9.98 | 9.65 | 18.36 | 9.49 | 12.27 |
| 5 | 9.98 | 9.7 | 16.76 | 9.68 | 13.1 |
| 6 | 9.98 | 9.73 | 17.47 | 9.6 | 10.76 |
| 7 | 9.99 | 9.79 | 19.43 | 9.56 | 13.19 |
| 8 | 9.99 | 9.84 | 17.64 | 9.71 | 12.1 |
| 9 | 9.99 | 9.88 | 15.61 | 9.98 | 9.68 |
| 10 | 10 | 9.93 | 13.57 | 10.31 | 8.84 |
| 11 | 10 | 10.02 | 11.9 | 10.06 | 7.35 |
| 12 | 10 | 10.08 | 12.15 | 10 | 7.65 |
| 13 | 10.01 | 10.16 | 11.54 | 9.99 | 6.43 |
| 14 | 10.01 | 10.2 | 13.06 | 10.07 | 7.54 |
| 15 | 10.02 | 10.28 | 11.33 | 10.25 | 7.56 |
| 16 | 10.02 | 10.29 | 11.57 | 10.44 | 7.69 |
| 17 | 10.03 | 10.41 | 12.81 | 10.63 | 8.83 |
| 18 | 10.03 | 10.56 | 12.65 | 10.78 | 8.69 |
| 19 | 10.04 | 10.74 | 12.1 | 10.82 | 8.57 |

Table 2. The input signals of training set

The forecasts show a possible direction for the development emissions level, assuming a continuation of current trends and the slight additional measures to prevent climate change. Modelling also shows the other scenarios - optimistic resulting from e.g. introduction of modern technology reducing the emission and pessimistic, assuming such a parameters like expected growth vehicles and thus increasing emissions from transport or other taking into account the increase in coal consumption.

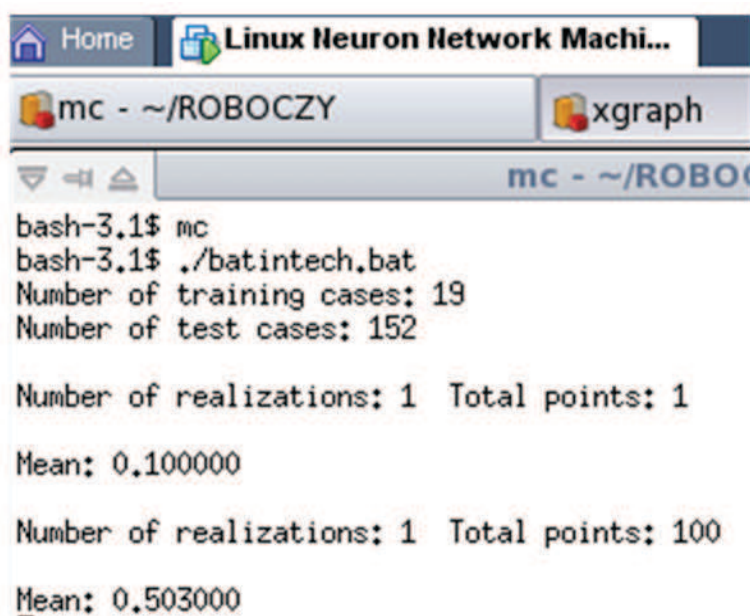
It was analyzed the situation taking into consideration the expected increase in the number of vehicles with the reduction in transport emissions resulting from e.g. the initiation of alternative fuels inter alia biofuels.

To determine the factors most connected with CO₂ emissions and try to find a model describing the relationship between input and output variables the linear regression was used. The above analysis was made using R-Project. R is a modern tool that allows programming, advanced statistical analysis and visualization of research results (Biecek 2008).

3. Results and their interpretation

3.1 Forecasting with FBM

The gained selected (numerical and graphic) parameters of the quality of the network learning, among others, so called recoil index and the trajectory graph of the control values, so called weight hyper-parameters, show proper and relatively optimal course of the process of the network learning. About a balance in the impulses flow through the network, provides the resulting coefficient - 0.503 (Fig. 1), which is within the range of variability 0.2-0.8.



```
bash-3.1$ mc
bash-3.1$ ./batintech.bat
Number of training cases: 19
Number of test cases: 152

Number of realizations: 1 Total points: 1
Mean: 0.100000

Number of realizations: 1 Total points: 100
Mean: 0.503000
```

Fig. 1. Obtained coefficients size

The results of modelling allow for making certain remarks. The forecasts show that limiting or increasing analysed factors affects the volume of CO₂ emission. In consequence, along with an rise in the parameters increasing CO₂ emission.

In Figure 2 the different scenarios of CO₂ emissions were presented.

It appears that "coal consumption" is a very important variable. It is the most important variable and primarily decisive about the CO₂ emission in the analyzed cases.

Based on the modeling results on the figure 2 the observed relationships between variables were presented. For this purpose scatter plots were used, which may even visually help us to assess the force and nature of relationships between variables. The diagrams show the observations for three variables. If the points are arranged in an irregular cloud, then there is no relationship between variables (Figure 2a).

If, however, the points are arranged along a straight line or a curve, it can be discerned a connection between variables.

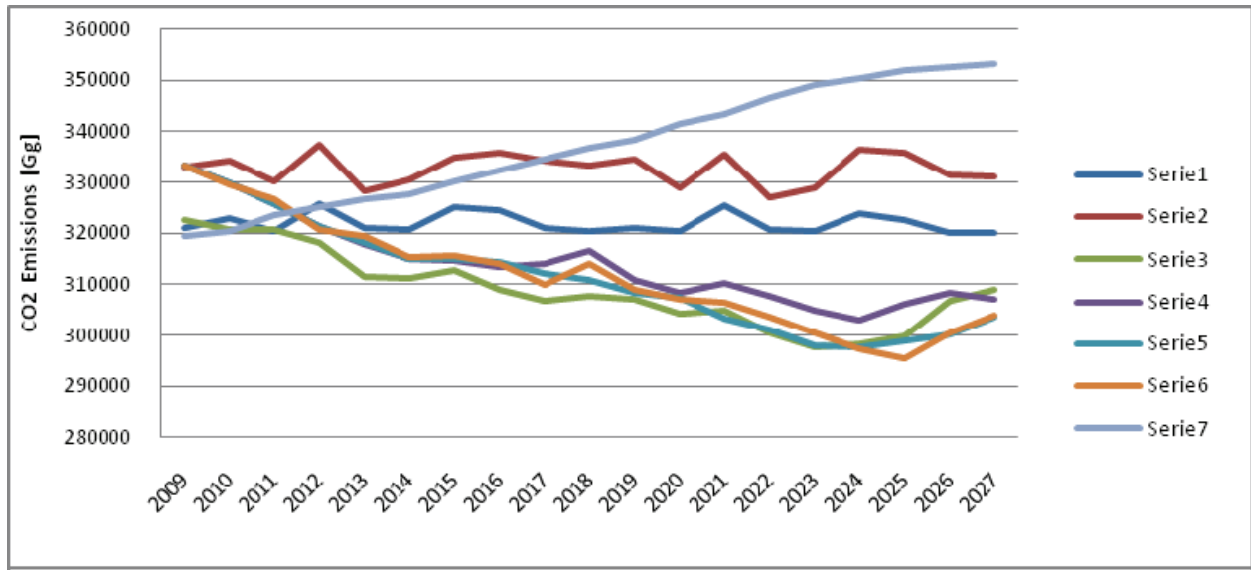
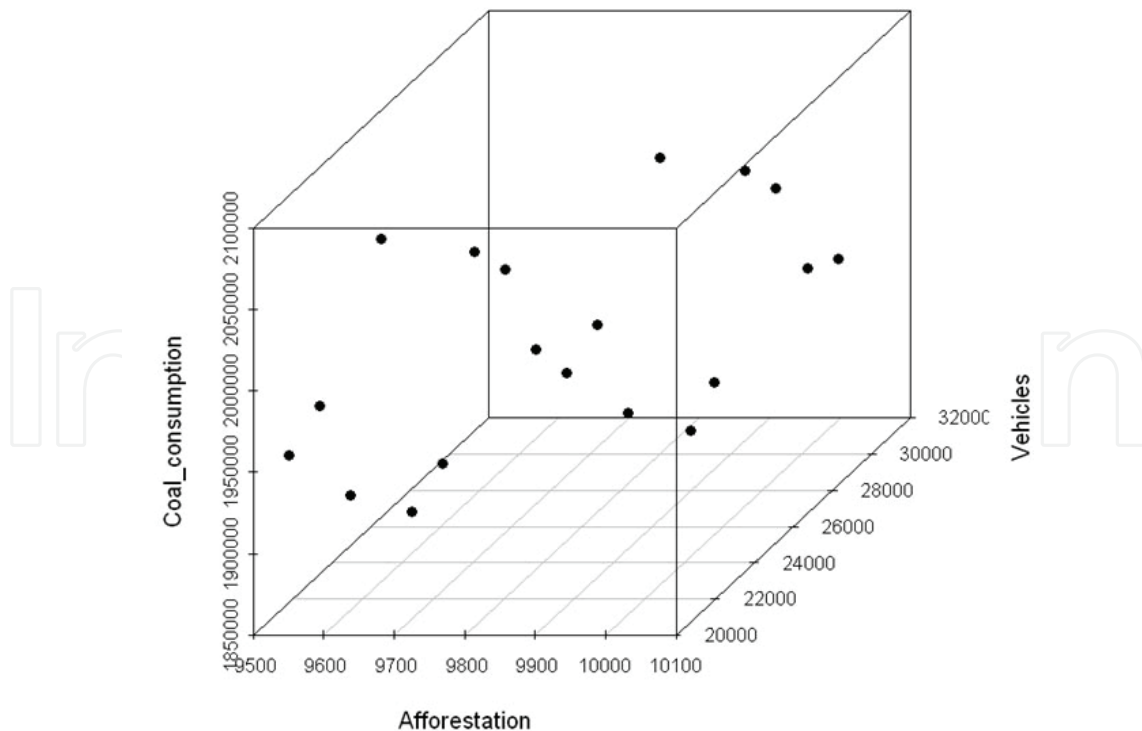


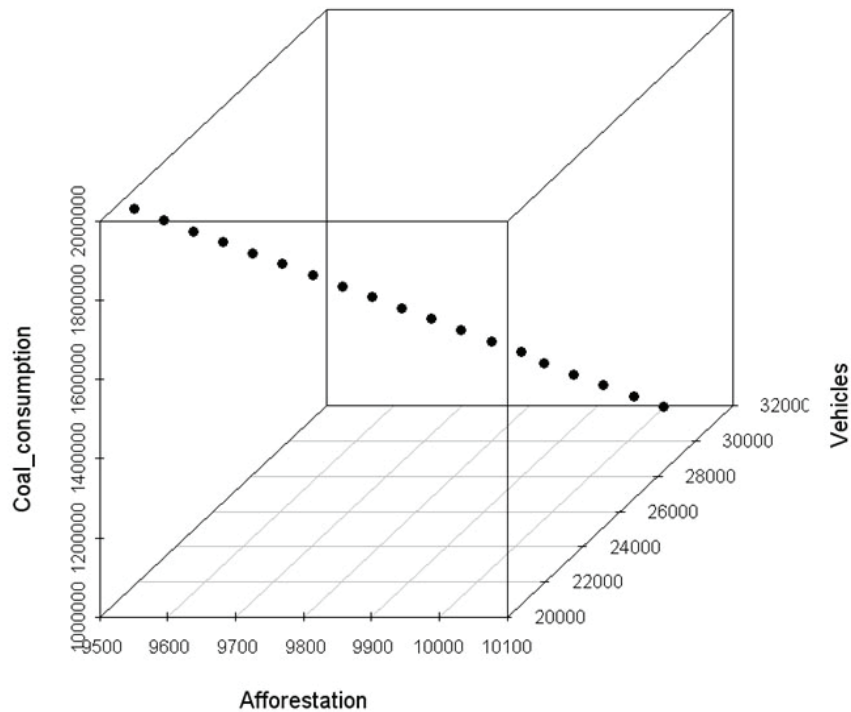
Fig. 2. Forecasting CO₂ emissions taking into account different scenarios: serie 1 - observed trends, serie 2 - CO₂ emissions reduction in transport, Rest parameters with observed trends, serie 3 - reduction hard coal consumption and emissions from transport, serie 4 - reduction hard coal consumption with permanent emissions from transport, 5 - increase of afforestation, 6 - reduction hard coal consumption, reduction emissions from transport from 90 years, permanent number of vehicles, 7 - hard coal consumption increase, emissions from transport and number of vehicles increase.

a)



Points contracting perfectly along a straight are very infrequent. Figure 2b is a excellent example that reflects the existence of a negative linear correlation (case of a reduction in coal consumption).

b)



Graph 2c presents a relationship in case when the analyzed parameters are rising. A strong positive correlation between variables was observed. With an increase in the number of vehicles, emissions from transport and coal consumption, CO₂ emissions rise.

c)

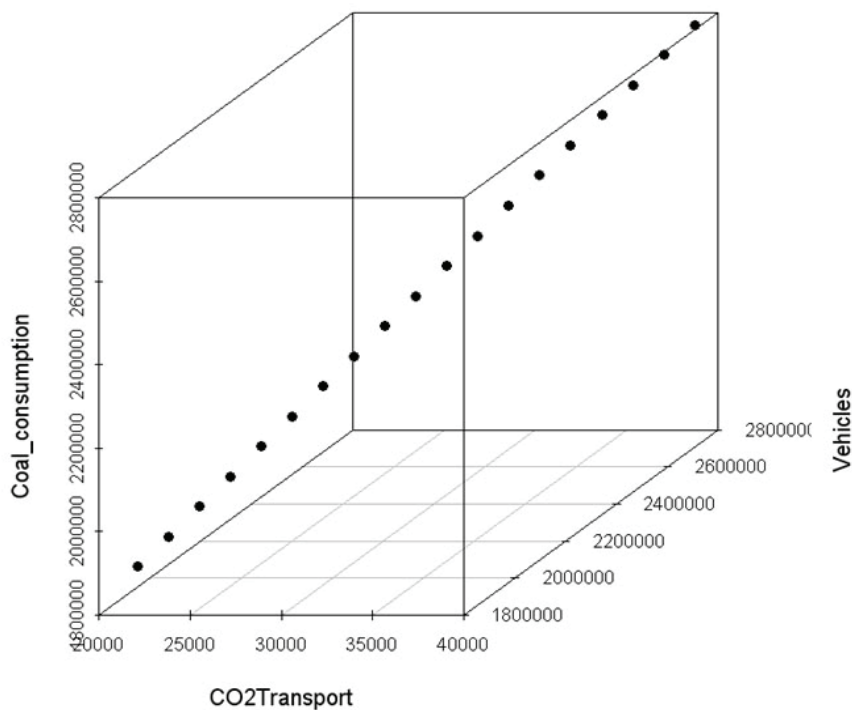


Fig. 2. Scatterplots for chosen parameters

3.1 Modelling using linear regression

The next stage of this study was to define a model describing the relationship between the explanatory variables and the amount of CO₂ emissions. In this case, a linear regression analysis was used. It is a popular and widely used statistical analysis which allows to find the relationship between inputs and outputs. It takes into account the interdependence modeling of the studied traits. This technique is based on estimation of some data from the other. There are known and used many regression techniques. Linear regression assumes that between the input and output variables, there is a linear relationship (Faray, 2002). Using `lm()` function fit a linear model to the data was conducted (fig. 3).

In case 3a with explanatory variable "vehicles" obtained a negative coefficient, which means that this parameter is not significantly different from zero and can be omitted in the model.

Taking into consideration other factors it is a small value.

Coefficient value of R² and Adjusted R² testifies to fit a linear model. Adjusted R² takes into account the number of variables in the model. If the coefficient is closer to 1 the better model fits in the data.

Adjusted R² showing the percentage of variance explained by the model is highest.

a)

```
Call:
lm(formula = CO2emission ~ forests + vehicles + coal + CO2transport,
    data = data.co2)

Residuals:
    Min       1Q   Median       3Q      Max
-9549.1 -4044.2  -458.3  3132.5 18598.0

Coefficients:
              Estimate Std. Error t value Pr(>|t|)
(Intercept) -4.083e+04  5.446e+05  -0.075   0.941
forests      1.813e+01  6.628e+01   0.274   0.788
vehicles     -1.727e+00  3.374e+00  -0.512   0.617
coal         8.728e-02  1.046e-02   8.341  8.4e-07 ***
CO2transport 1.573e+00  1.330e+00   1.183   0.256
---
Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1

Residual standard error: 7348 on 14 degrees of freedom
Multiple R-squared:  0.9324,    Adjusted R-squared:  0.9131
F-statistic: 48.29 on 4 and 14 DF,  p-value: 4.849e-08
```

Statistically non-significant variable was rejected and modeling were carried out again (e.g. 3b).

In case 3b also obtained high coefficients of R² and modified R².

With three independent variables least statistically significant was variable "forests", which was also omitted and modeling were carried out again (e.g. 3c).

Important parameters were variables: a highly significant - "coal" and a less important - "CO2transport".

b)

```
Call:
lm(formula = CO2emision ~ forests + coal + CO2transport, data = data.co2)

Residuals:
    Min       1Q   Median       3Q      Max
-9725.6 -4084.6 -106.1  2859.0 18445.8

Coefficients:
            Estimate Std. Error t value Pr(>|t|)
(Intercept)  2.032e+05  2.569e+05   0.791   0.441
forests      -1.171e+01  3.076e+01  -0.381   0.709
coal          8.886e-02  9.746e-03   9.118 1.66e-07 ***
CO2transport  1.583e+00  1.297e+00   1.221   0.241
---
Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1

Residual standard error: 7165 on 15 degrees of freedom
Multiple R-squared:  0.9311,    Adjusted R-squared:  0.9174
F-statistic: 67.62 on 3 and 15 DF,  p-value: 6.047e-09
```

c)

```
Call:
lm(formula = CO2emision ~ coal + CO2transport, data = data.co2)

Residuals:
    Min       1Q   Median       3Q      Max
-9870.8 -3614.3   611.5  2393.4 18955.3

Coefficients:
            Estimate Std. Error t value Pr(>|t|)
(Intercept)  1.064e+05  3.750e+04   2.839   0.0119 *
coal          8.975e-02  9.211e-03   9.744 3.94e-08 ***
CO2transport  1.160e+00  6.539e-01   1.774   0.0950 .
---
Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1

Residual standard error: 6971 on 16 degrees of freedom
Multiple R-squared:  0.9305,    Adjusted R-squared:  0.9218
F-statistic: 107.1 on 2 and 16 DF,  p-value: 5.455e-10
```

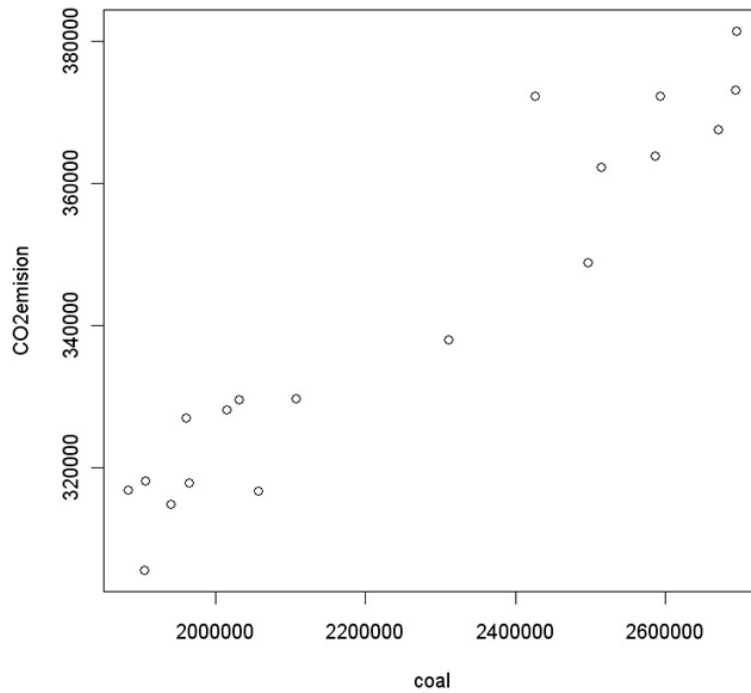
Fig. 3. The results of fitting the model to data.

With higher results (fig. 3c), the model is as follows:

$$\text{Emisja CO}_2 = 1,064e^{+05} + 8,975e^{-03} * \text{coal} + 1,160e^{-01} * \text{CO2transport} \quad (1)$$

Figures show a graphic interpretation of evaluation model coefficients, which clearly show that the explanatory variable of the highest importance is the coal consumption (variables are arranged along a straight line – e.g. 4a).

a)



b)

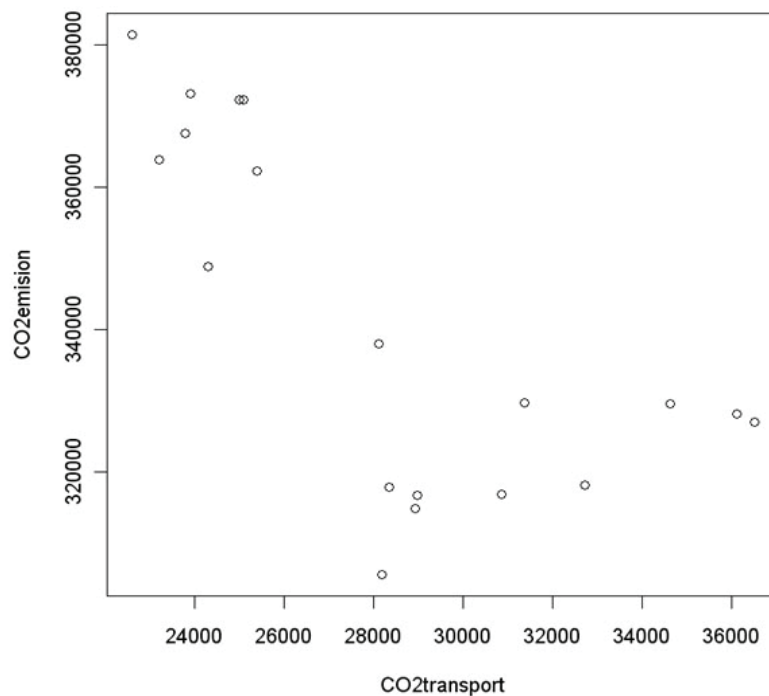
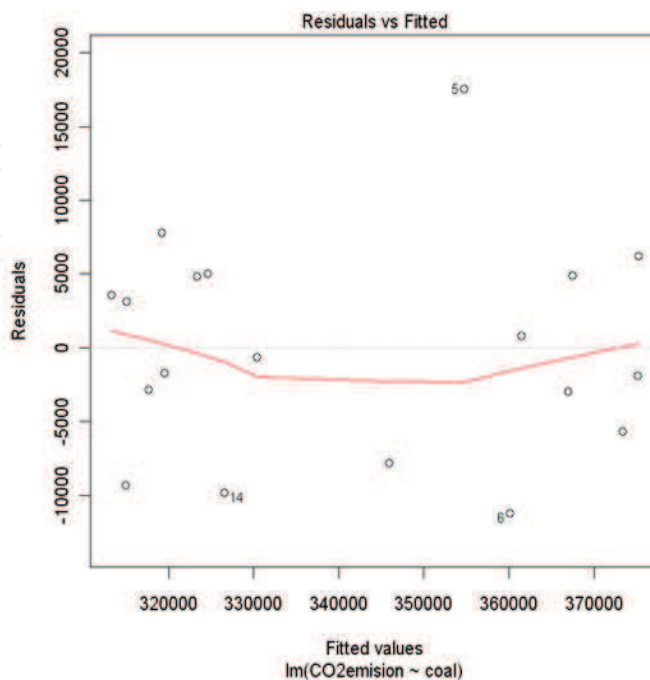


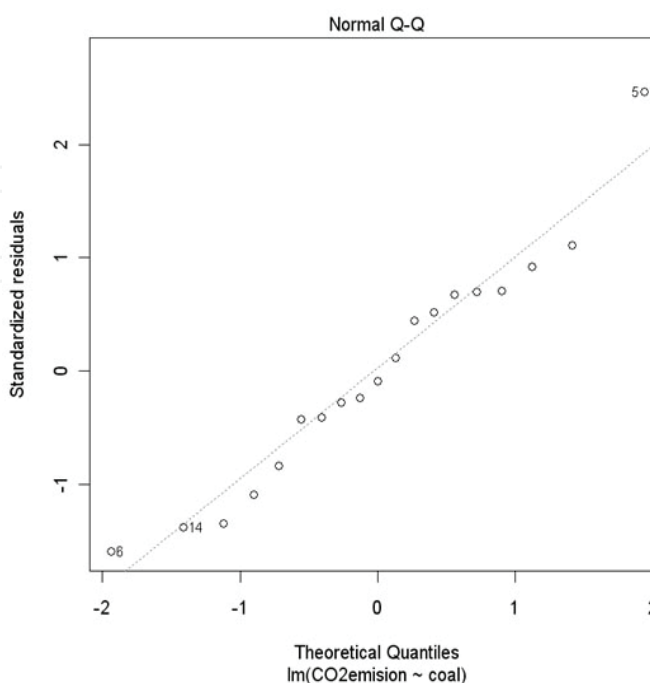
Fig. 4. Scatter diagram showing the emission of CO₂ a) depending on the size of coal consumption, b) depending on CO₂ emissions from transport

We can examine the model assumptions, verifying the properties of residues. If the stipulations are achieved, the random noise should have a normal distribution with equal variances. That's why diagnostic graphs were used (fig. 5). This is a good method when the model is adequate.

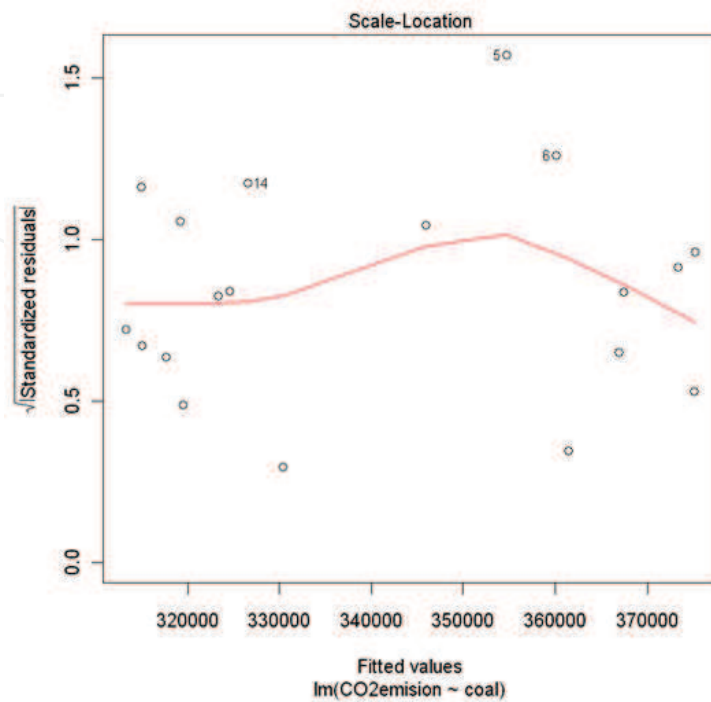
a) The chart “Residuals vs Fitted” shows that the average value of residuals is close to 0 and the variance is homogeneous. On the horizontal axis shown values are matched by the model and the vertical axis are shown the elements of the residuals of standardized modules.



b) Figure “Normal Q-Q” it is a fractile graph for a normal distribution. The horizontal axis shows the values corresponding to the normal distribution quantiles residuals, and the vertical axis for the standardized empirical quantile of residuals. Contracting points along a straight line suggests that the model can be considered adequate and the distortion has a normal distribution.



c) Graph "Scale-Location" present, as in the case a) on the horizontal axis shown values are matched by the model and the vertical axis - the elements of the residuals of standardized modules. Results was observed in the form of derogations unevenly spaced points.



d) Graph "Residuals vs Leverage" takes into account the confidence range. It is very useful chart for detecting abnormal values.

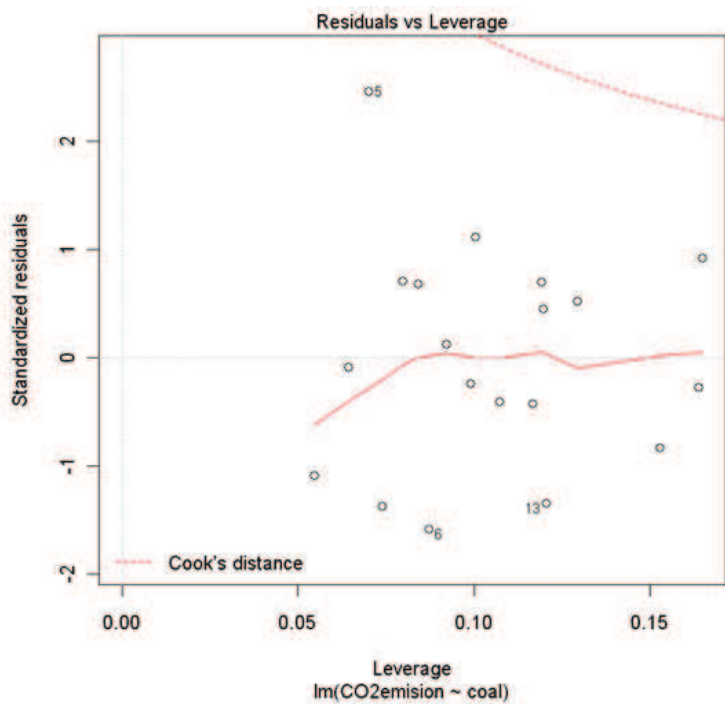


Fig. 4. Diagnostic diagrams for the tested model

4. Conclusion

Phenomena occurring in the natural environment are usually random or stochastic processes. Conventional calculation and statistic methods are sometimes inefficient when solving certain environmental problems. In the recent years, scientists all over the world have been trying to use methods based on artificial neural networks to solve environmental issues. The success of generating forecasts by a neural network is determined by having a representative collection of data which manifest the phenomenon being modelled. This investigation and model allowed to make an analysis of sensitivity in order to calculate the impact of each input parameter of the neural network on the total emission. From the experimental results it is possible to argue that coal consumption has the greatest impact on CO₂ emissions in Polish situation.

Taking into consideration all the parameters in the model it is not easy and often impossible. Often, a determining factor is the availability of data.

The resultant match factor Adjusted R², provides high-fit model to the data. In the test case linear regression proved to be a good tool for estimating the correlation of the tested variables.

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Artificial Neural Networks - Application

Edited by Dr. Chi Leung Patrick Hui

ISBN 978-953-307-188-6

Hard cover, 586 pages

Publisher InTech

Published online 11, April, 2011

Published in print edition April, 2011

This book covers 27 articles in the applications of artificial neural networks (ANN) in various disciplines which includes business, chemical technology, computing, engineering, environmental science, science and nanotechnology. They modeled the ANN with verification in different areas. They demonstrated that the ANN is very useful model and the ANN could be applied in problem solving and machine learning. This book is suitable for all professionals and scientists in understanding how ANN is applied in various areas.

How to reference

In order to correctly reference this scholarly work, feel free to copy and paste the following:

Alicja Kolasa – Więcek (2011). Application of Artificial Intelligence in Environmental Sciences – Forecasting CO2 Emission in Poland, Artificial Neural Networks - Application, Dr. Chi Leung Patrick Hui (Ed.), ISBN: 978-953-307-188-6, InTech, Available from: <http://www.intechopen.com/books/artificial-neural-networks-application/application-of-artificial-intelligence-in-environmental-sciences-forecasting-co2-emission-in-poland>

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