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CHANGE IN THE STRUCTURE OF ELECTRICITY GENERATION IN THE USA, CHINA, JAPAN AND THE EU, AND A FORECAST OF ELECTRICITY CONSUMPTION

1. INTRODUCTION: GENERATION CAPACITY

In 2015, the world's total electricity-generating capacity was 3098 GW. Fossil fuels such as gas, oil and coal accounted for over 60%, while 13% came from hydropower. Nuclear power supplied 9%, whereas renewable energy, e.g. wind and solar power, was at 7% (Fig. 1) [1].

In the USA, the largest increase in electricity generation capacity, from 1990 until 2015, was noted in energy sectors which use fossil fuels and wind power. In the sector of fossil fuels generation capacity increased by 300 GW and now stands at 820 GW. In the field of wind energy intensive growth is noticeable since 2005 and total capacity stands currently at 64 GW [1].

In 1990, China's energy sector was based on two main pillars: fossil fuels – 101 GW and hydropower – 36 GW. Within the 24 years which followed all areas apart from the nuclear energy sector experienced rapid growth in generation capacity. Currently, China has a generation capacity of 1,201 GW accounting for about 38% of world electricity-generating capacity [1].

Japan, due to its location and poor resource base has an approximately 13% share of the world's nuclear energy production, at the level of 42 GW. Since 1990, there has been an increase in generation capacity of about 120 GW. The greatest increase has taken place in the fossil fuels sector and solar energy sector – 192 GW and 23 GW, respectively [1].

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In 2015 (411 GW capacity) the European Union reported lower electricity-generating capacity from fossil fuels in comparison to 2005 and 2010. A decrease in the generation capacity of the nuclear energy sector may be observed. Conversely, rapid growth in areas such as wind energy (153 GW) and other renewable energy sources (153 GW) has been recorded [1].

Poland's current electricity generation capacity is at 33 GW, 85% of which is supplied by the fossil fuel sector. Wind energy in Poland has a generation capacity of 3 GW, which amounts to 8% of the total (Figs 2 and 3) [1, 2].

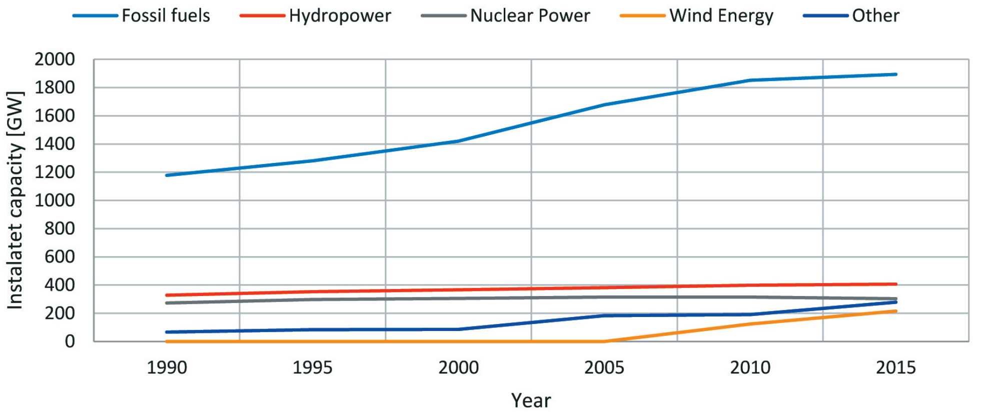

Fig. 1. Global changes in the electricity-generating capacity mix since 1990 to 2015 (compiled on the basis of [1])

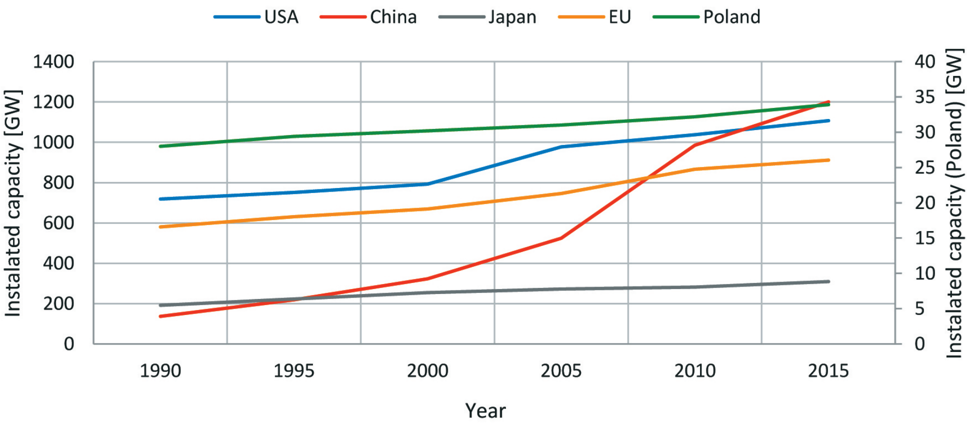

Fig. 2. Changes in the structure of the generation capacity mix in the US, China, Japan, the EU and Poland (right axis) since 1990 (compiled on the basis of [1])

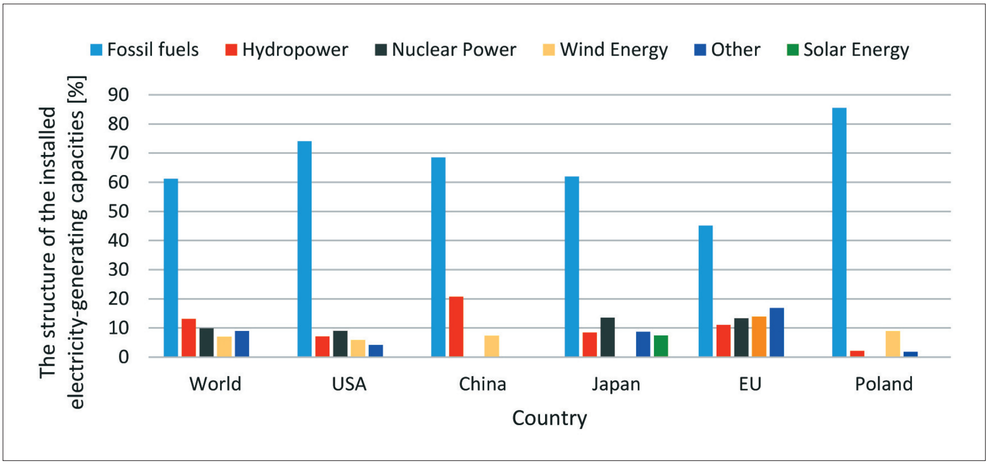

Fig. 3. Installed electricity-generating capacities by source in 2014 (compiled on the basis of [1])

In 1990, 1 GW of power provided 5.5 TWh of electricity. At present, this amount rose to over 7 TWh (Tab. 1). This change is related to extended use of power units and an increased demand for electricity. In comparison with countries such as: the USA, Japan, China or groups of countries such as the EU, only Poland has recorded an increase in electricity generated from 1 GW of power [1–3].

Table 1

Changes in the amount of electricity generated from 1 GW (compiled on the basis of [1])

Year	World	USA	China	Japan	EU	Poland
1990	5.5 TWh	4.2 TWh	4.3	4.2	4.1	4.45
2015	7.2 TWh	3.6TWh	4.28	3.2	3.3	4.6

2. ELECTRICITY GENERATION BY SOURCE AND CO_2 EMISSIONS

In 2015, the world produced 22,433 TWh of energy. Almost 40% of the energy was produced from coal, which is comparable to the 1990 levels. The largest increase was recorded for natural gas, where there was an increase from 10% in 1990 to 21% in 2015. The use of hydropower in 2015 was at 16%. Worldwide CO_2 emission in 2015 stood at 35 billion tons, an increase by 13 billion tons compared to 1990. Emissions from the world's electricity sector constitute 49% of global CO_2 emission and continue to rise every year, demonstrating a long-term growth trend. This is due to the ageing of the power units and the development of electricity based on fossil fuels in countries such as the USA and China (Fig. 4) [1–4].

2.1. USA

In the United States there was a significant increase in natural gas-fired electricity generation, from 363 TWh in 1990 to 1272 TWh in 2015, which translates to a growth of up to 30% of the domestic electricity production. The number of gas power plants rose from 1670 in 2004 to 1770 in 2015. There are more gas power stations on the East Coast than in other regions and in 15 states they are the primary source of electricity. The price of producing 1 MWh of electricity from natural gas is USD 50, making natural gas the least expensive source of electricity apart from hydropower and nuclear power. A reduction in the use of coal and nuclear energy is noticeable and heavy oil was virtually abandoned in the electricity sector. The USA produce about 5 billion tons of CO_2, an increase of approximately 1 billion tons within the last 25 years [1, 4, 5, 21, 22].

2.2. China

In 2015 China produced about 5,147 TWh, which amounted to approximately 22% of global electricity production (Fig. 5). The greatest problem of the China's electricity system are transmission grids. There are many local power plants there which are not connected to the national distribution system. Despite large investments, the connections between the "islands" are inefficient or practically nonexistent. The Chinese government plans to consolidate the electricity network by 2020. Electricity production in China is currently based on two fundamental pillars: coal electricity and hydropower, which generate 3681 TWh and 1029 TWh, respectively. China, the world leader in coal mining, produced 2.38 billion tons of coal in 2006. It should be emphasised that China has increased its electricity production almost tenfold since 1990, contributing to an increase in CO_2 emissions from 2.4 billion tons to 10.2 billion tons, which is about 30% of the world's total production. It is worth mentioning that Asia (without China) generates 10% of world's CO_2 emissions. The decrease in greenhouse gas emissions was clearly visible during the Asian crisis (Fig. 6). It is expected that by 2035 China will increase the energy consumption of natural gas to 492 bcm per annum. [1, 4, 5, 23–26].

2.3. Japan

Before the Fukushima Daiichi nuclear disaster, which was due to an earthquake in 2011, Japan produced 1042 TWh. Use of nuclear energy was restricted in the aftermath of the disaster. This required reducing energy consumption to the lowest level possible and finding the cheapest and most effective energy source to compensate for the lost electricity-generating capacity. Due to Japan's geographical location and a lack of a raw material base in the form of coal and oil reserves, the Japanese government made a decision to increase natural gas consumption. In 2011, Japan had 19 terminals with a total maximum capacity of 247 billion cubic meters. 2018 will see the completion of the projects related to the construction of the new terminals and capacity will rise to 265 billion cubic meters. Currently, 43% of the electricity in Japan comes from gas power plants. This is an increase compared to 2010, when only 28% of electricity was generated from gas. Japan produces 1.2 billion tons of CO_2, only a 10% increase compared to 1990 [1, 4–9, 27].

2.4. The European Union and Poland

The share of energy generated from coal is falling in the EU while renewable energy is increasing in importance. In 2011 there was a decline in gas consumption both for power generation and municipal purposes. This may be explained in particular by increased use of renewable energy sources and the gas – coal price relation, which is influenced by changes in the US market and increased supplies of coal to the European market. Import of coal from the United States reduces coal price, which in turn increases the competitive advantage of coal over natural gas on the European market. In the EU there has been an increase in electricity production from 2.366 TWh to 3.040 TWh with a simultaneous decrease of CO_2 emissions from 4 million tons in 1990 to 3.4 billion tons in 2015. Poland generates approximately 156 TWh of energy, with as much as 80% produced from the the coal-based energy sector. As a result of the falling share of coal-based energy and rising prominence of wind power and waste incineration there was a decline in production of CO_2 emissions from 0.3 billion tons to 0.302 billion tons [1–4, 10].

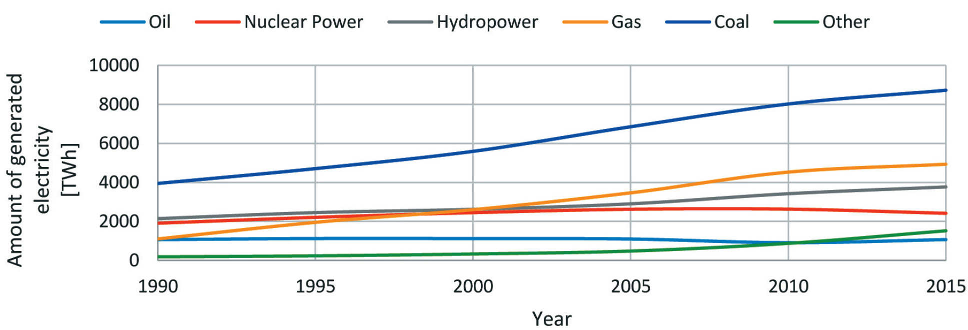

Fig. 4. Amount of generated electricity by source (compiled on the basis of [1])

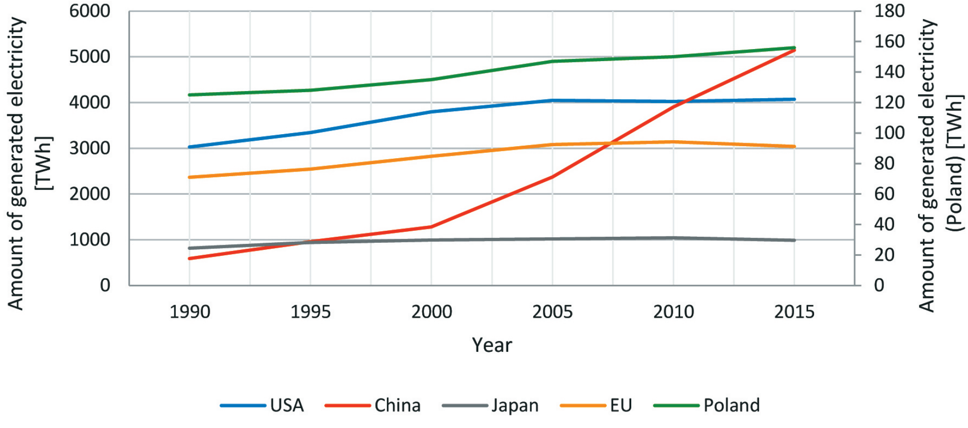

Fig. 5. Changes in the structure of energy generation
in the U.S., China, Japan, the EU and Poland (right axis) since since 1990
(compiled on the basis of [1])

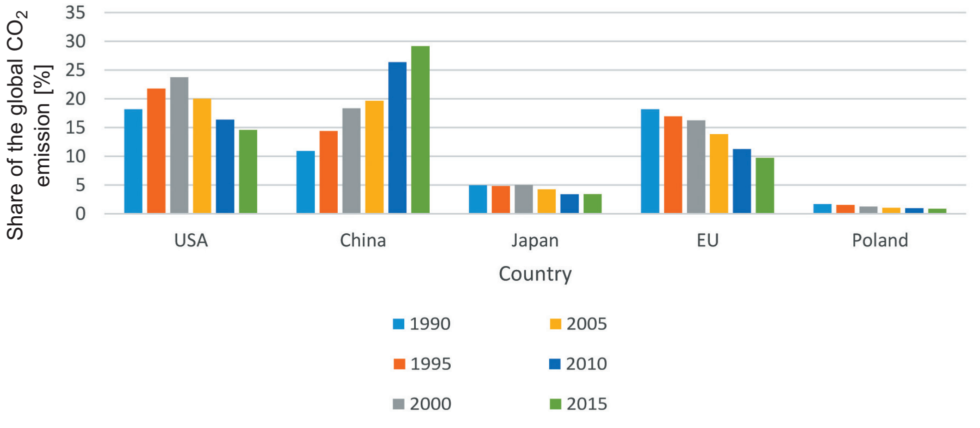

Fig. 6. CO_2 emissions by country
(compiled on the basis of [4])

3. FORECASTING OF ELECTRICITY CONSUMPTION

Forecasting enables appropriate planning of modernisation works performed on the power grids as it is possible to predict the period of highest energy consumption, i.e. grid load. Making decisions concerning the development of the distribution system becomes easier and faster due to data on future consumption. The information obtained during the analysis allows predicting the amount of energy needed and managing the system in an easy way, which is important from the point of view of a country's energy security.

The aim of the paper is to forecast electricity consumption for 1 day, 7 days and 12 days based on the data collected from three months, such as power consumption and ambient temperature (Fig. 7). Dummy variables, such as days of week, holidays and hours of the day, were used for forecasting. On the basis of the data two models were created: model 1, which used dummy variables (weekdays and holidays) and ambient temperature, and model 2, which used measurement time (hour) and ambient temperature. Calculations were made in the following programs: Statistica and Gretl.

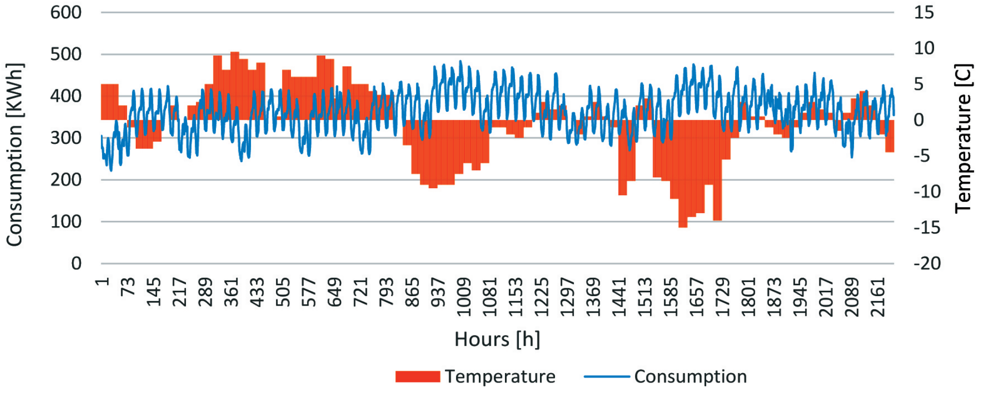

Fig. 7. The association between consumption and temperature

3.1. Regression analysis

Regression analysis is a statistical method which examines the relationships between data and uses them to predict unknown values on the basis of other values [11].

Assumptions [11–14, 29]:

- The model has a linear form $Y=\beta x+\varepsilon$,
  where:
  - β – parameter,
  - ε – error variable.

  The matrix x is known and is not random.
  The rank $x = k$ $\quad T > k + 1$,
  where:
  - k – the number of parameters,
  - T – number of observations.
- The expected value of the error variable is zero.
- The variance of the error variable is constant and equals σ^2.

Forecasts made by means of regression analysis for 24 hours, 7 days and 12 days (Figs 8–10).

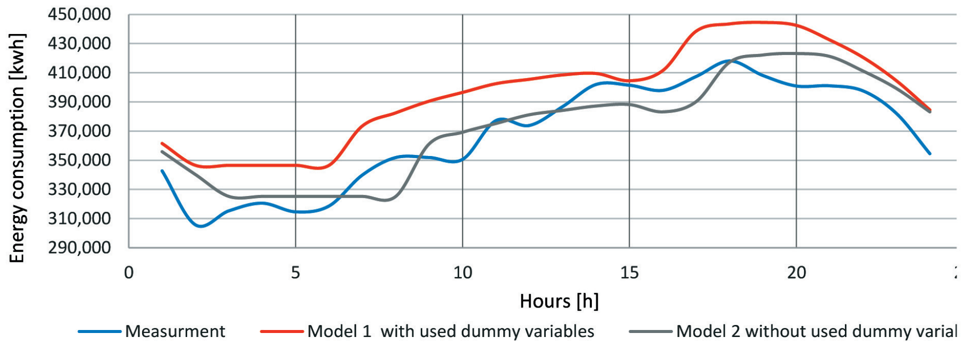

Fig. 8. Forecast with regression and models 1 and 2 for 24 hours

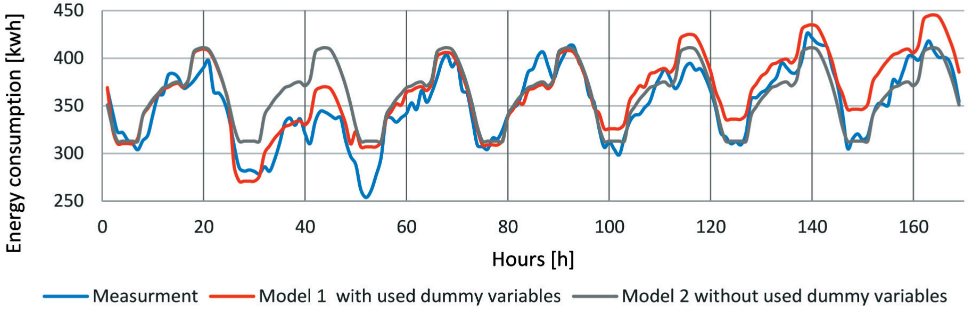

Fig. 9. Forecast with regression and models 1 and 2 for 7 days

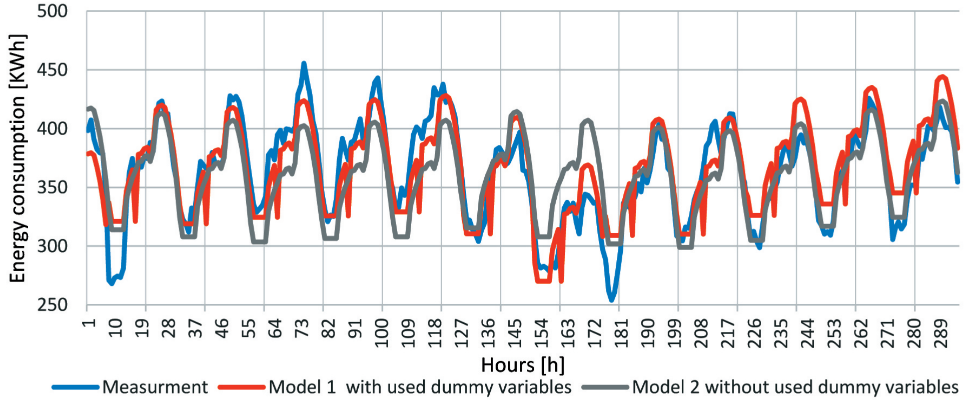

Fig. 10. Forecast with regression and models 1 and 2 for 12 days

3.2. Artificial neural networks (ANNs)

An artificial neural network is composed of artificial neurons (or nodes), the basic constituents that together form an artificial neural network.It is a 'transducer' which receives input signals, multiplies them by appropriate values of weights depending on the significance of the input signal and generates an output value. Signals multiplied by the weights are added up and adjusted in the summation function. This is used to determine the strength of neuron excitation. Signals which cross the activation threshold are routed to the non-linear activation function in order to generate an appropriate output signal [15].

Neural network training is used when we do not have information on the associations between all inputs and outputs. It is performed by determining weights which give the best solution. There are two types of ANN learning: supervised and unsupervised.

In supervised learning, training examples are supplied at the input and supervisory signals are supplied at the output. The network automatically selects the weights in order to learn the function describing the association between the input signals and the output signal. In unsupervised learning, output is generated on the basis of the received input signals. This process is carried out without example weights (Tab. 2) [15–20].

Table 2

Simulation parameters

Parameter name	Value
Number of hidden layers	3
Error function	Sum of squared errors
Activation functions – hidden neurons	exponential, logistic
Activation function – output neurons	exponential, logistic
Reduction of hidden layer weights	Min. –0.0001, max. –0.001
Reduction of output layer weights	Min. –0.0001, max. –0.001

Forecasts made using ANNs for 24 hours, 7 days and 12 days (Fig. 11–13).

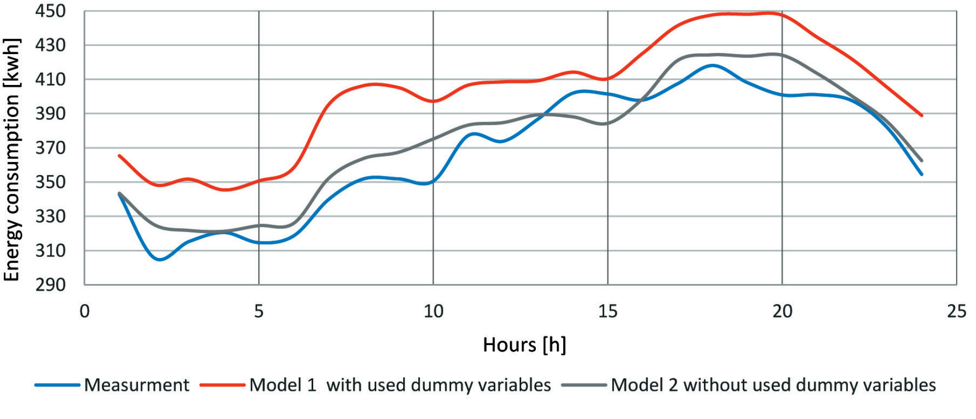

Fig. 11. Forecast with ANN and models 1 and 2 for 24 hours

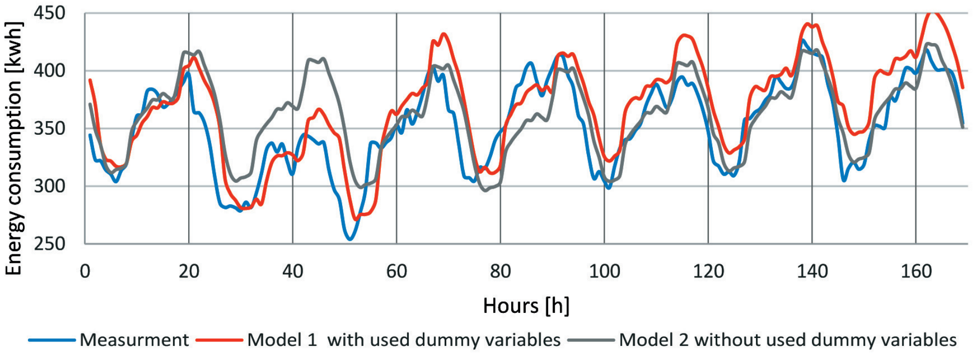

Fig. 12. Forecast with ANN and models 1 and 2 for 7 days

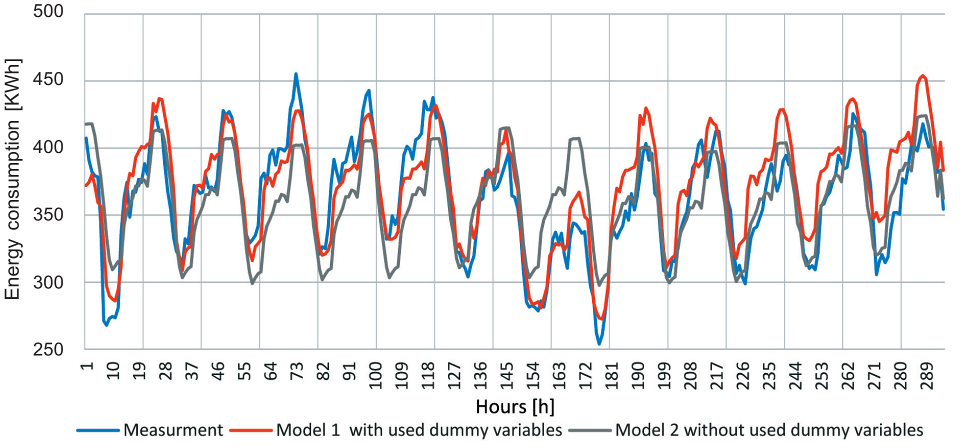

Fig. 13. Forecast with ANN and models 1 and 2 for 12 days

4. CONCLUSIONS

1. One may notice a worldwide trend of investing in the fossil fuel and wind energy sectors to increase power generating capacity. China makes the biggest investments in enlarging its electricity output. More than 80% of Poland's electricity generation capacity comes from fossil fuels.
2. China consumes the largest amount of energy in the world (Fig. 5) and consequently generates the largest amount of CO_2. In contrast to China, countries (or groups of countries) such as the United States, the EU, Japan and Poland increase electricity consumption while reducing emissions of CO_2 at the same time.
3. ANNs were found to be better for forecasting electricity consumption since they gave a lower MAPE error and allowed for extending the forecast without a significant negative influence on forecasting quality (Tab. 3).

Table 3
MAPE Error

	Method					
	ANNs [%]			Regression [%]		
Model type	1	7	12	1	7	12
Model 1	3	5.01	4.8	8.4	7	7
Model 2	2.78	6.5	6	2.9	6	6.72

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