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An artificial neural network approach for the estimation of the primary production of energy from municipal solid waste and its application to the Balkan countries

Vladimir M. Adamović [a,*], Davor Z. Antanasijević [b], Aleksandar R. Ćosović [a], Mirjana Đ. Ristić [c], Viktor V. Pocajt [c]

[a] Institute for Technology of Nuclear and Other Mineral Row Materials, Bulevar Franše d'Eperea 86, 11000 Belgrade, Serbia
[b] University of Belgrade, Innovation Center of the Faculty of Technology and Metallurgy, Karnegijeva 4, 11120 Belgrade, Serbia
[c] University of Belgrade, Faculty of Technology and Metallurgy, Karnegijeva 4, 11120 Belgrade, Serbia

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ABSTRACT

Although the use of municipal solid waste to generate energy can decrease dependency on fossil fuels and consequently reduces greenhouse gases emissions and areas that waste occupies, in many countries municipal solid waste is not recognized as a valuable resource and possible alternative fuel. The aim of this study is to develop a model for the prediction of primary energy production from municipal solid waste in the European countries and then to apply it to the Balkan countries in order to assess their potentials in that field. For this purpose, general regression neural network architecture was applied, and correlation and sensitivity analyses were used for optimisation of the model. The data for 16 countries from the European Union and Norway for the period 2006–2015 was used for the development of the model. The model with the best performance (coefficient of determination R^2 = 0.995 and the mean absolute percentage error *MAPE* = 7.757%) was applied to the data for the Balkan countries from 2006 to 2015. The obtained results indicate that there is a significant potential for utilization of municipal solid waste for energy production, which should lead to substantial savings of fossil fuels, primarily lignite which is the most common fossil fuel in the Balkans.

1. Introduction

High rate of population growth and even higher rates of urbanisation and industrialisation led to increased energy consumption worldwide and at the same time significantly increased waste generation (Ouda et al., 2016). One of the possible ways to cover some of this expanding energy demand and deal with growing waste issue is to produce energy from municipal solid waste (MSW) (Abila, 2014), using processes like anaerobic digestion (Li et al., 2018; Yano and Sakai, 2016), landfills (Lee et al., 2017; Mboowa et al., 2017), pyrolysis (Chen et al., 2015), ethanol fermentation (Wu et al., 2015) and incineration (Li et al., 2016; Lu et al., 2017).

In 2015, fossil fuels accounted for 86.02% of the global primary energy consumption (thereof oil 33.12%, coal 28.88% and natural gas 24.01%) (BP, 2017). The common use of fossil fuels to meet energy demand is nowadays associated with growing greenhouse gasses (GHG) emissions and the resulting climate change caused by global warming (Bilgen, 2014).

Abbreviations: ANNs, artificial neural networks; DMC, domestic material consumption; EP, energy productivity; EPMSH, electricity prices by medium size household; EPMSI, electricity prices by medium size industries; ET, energy taxes; EU, European Union; EUROSTAT, the European Union statistical office; FEC, final energy consumption; GDP, gross domestic product; GHG, greenhouses gases; GMSW, generated municipal solid waste; GRNN, general regression neural network; GRNN-CA, general regression neural network model optimized by correlation analysis; GRNN-CA/SA, general regression neural network model optimized by correlation and sensitivity analyses; HDI, human development index; *IA*, index of agreements; ISF, individual smoothing factor; *MAE*, mean absolute error; *MAPE*, mean absolute percentage error; MSW, municipal solid waste; NMER, number of main electricity retailers; PPEAP, primary production of energy from all products PPEMSW, primary production of energy from municipal solid waste; R^2, coefficient of determination; *RMSE*, root mean squared error; RRMSW, recycling rate of municipal solid waste; SREGFEC, share of renewable energy in gross final energy consumption; SUP, share of urban population; toe, tonnes of oil equivalent.

* Corresponding author.
E-mail address: v.adamovic@itnms.ac.rs (V.M. Adamović).

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At the United Nations Framework Convention on Climate Changes which was held in Paris, France, in December 2015 on the 21st Conference of the Parties, 196 countries agreed to limit global warming to less than 2 °C compared to pre-industrial levels. This aim can be achieved only by reduction of the GHG emissions achieved through the use of low carbon fuels (Murphy and McDonnell, 2017).

Utilization of renewable energy sources, accompanied with implementation of energy efficiency measures, is essential in supply of low-carbon energy (International Energy Agency, Eurostat, 2004). According to International Energy Agency's classification of renewables and waste (International Energy Agency, Eurostat, 2004) MSW is a combustible fuel, which can be renewable or non-renewable. Renewable waste is the portion of MSW which is biological (biodegradable) material and non-renewable waste is the portion of MSW which is non-biological (non-biodegradable) material (European Commission – Eurostat, 2015).

MSW can be a significant source of water, soil and air pollution and consequently represents a huge risk for public health, but also, if properly managed, MSW can become a useful raw material and a significant energy source. Using municipal solid waste to generate energy is beneficial for multiple reasons, such as decreased dependency on fossil fuels and reduction of greenhouse gases emissions from fuel combustion.

It is well known that incineration of municipal solid waste with aim to generate heat or/and electricity (waste-to-energy process), releases lower emissions of GHG, sulphur oxide, nitrogen oxide and particular matter compared to combustion of methane from landfills (Chandel et al., 2012; Kaplan et al., 2009) or coal combustion (Kaplan et al., 2009). In addition, to reduce GHG and other pollutants emissions, utilization of MSW for energy production also reduces the volume of MSW that ends up in landfills. However, in many countries, especially in developing countries, such as the majority of Balkan countries, not even existing potentials for the use of municipal solid waste in the primary energy production is known, which is crucial if higher usage of municipal solid waste as fuel is to be achieved.

Energy statistics on supply, transformation and consumption usually are the basis for any energy, economic or environmental policy-related decisions. Decision makers need to have reliable information about production, trade, stocks, and consumption of energy sources, but basic energy data are not always available and reliable due to diminishing statistical expertise caused by budget cuts and simultaneous increase of data requests, liberalisation of energy markets which led to difficult gathering of basic information and other factors (International Energy Agency, Eurostat, 2004). One of solutions to stop current erosion in data quality, coverage and timeliness is development of proper prediction models of supply (Gils et al., 2017; Sveinbjörnsson et al., 2017), transformation (Volkart et al., 2017) and consumption (Aydin, 2014) for any particular energy source.

It should be taken into account that municipal solid waste as a nonhomogeneous fuel is greatly different from conventional fossil fuels and therefore the calculation of the net calorific value (lower heating value) is very complex and can lead to substantial errors. Consequently, development of a model for the prediction of energy produced from MSW is more complex than for conventional sources of energy.

Relatively accurate predictions of energy consumption (Antanasijević et al., 2015; Ekonomou, 2010; Szoplik, 2015), as well as the predictions of various aspects of the application of MSW for energy recovery (Dong et al., 2003; Nabavi-Pelesaraei et al., 2017; Ogwueleka and Ogwueleka, 2010; Shu et al., 2006) were obtained using artificial neural networks (ANNs). In their studies, Dong et al. (2003); Shu et al. (2006) and Ogwueleka and Ogwueleka (2010) applied ANNs to predict of the lower heating value of MSW, whilst Nabavi-Pelesaraei et al. (2017) used ANN and Life Cycle Assessment (LCA) to analyse the energy consumption and environmental impact of MSW recycling system in Teheran, Iran.

ANNs are a non-linear computing system based on the concept of learning by example as the human brain does (Freeman and Skapura, 1991) and it can use various broadly available socio-economic, industrial, demographic and environmental indicators as its inputs.

This paper presents the development of a model for the prediction of annual primary production of energy from MSW (PPEMSW) at the national level for 16 European Union (EU) countries and Norway, using general regression neural network (GRNN), an improved technique in neural networks based on the nonparametric regression. GRNN relies on one-pass learning algorithm, which does not need iterative training, and therefore, unlike the other artificial neural networks architectures, GRNN has no problems related to network overtraining. One of the main advantages of GRNN in comparison with other ANN techniques is the speed of training (Kisi, 2006; Thwin and Quah, 2005). Also, it is considerably simpler than other ANN techniques and it has ability to make accurate predictions even with small or incomplete data series (Gheyas and Smith, 2011).

The main aim was to obtain accurate, but low complex model, which can be easily applied on developing countries, e.g. eleven Balkan countries, that lack or have highly uncertain data related to the amount and heating value of municipal solid waste.

Unlike previous studies that dealt with the prediction of net calorific values of MSW (Dong et al., 2003; Ogwueleka and Ogwueleka, 2010; Shu et al., 2006) and energy consumption related to the local MSW management (Nabavi-Pelesaraei et al., 2017), the topic of this research was modelling of the annual primary production of energy from MSW at the national level and application of the obtained model to the countries that mostly do not utilise MSW for the production of energy.

2. Materials and methods

2.1. Primary production of energy from MSW (PPEMSW)

The first step of this study is the development of a model for the prediction of PPEMSW in EU countries and Norway.

Primary production of energy from all products refers to the sum of the first energy form of all products, which includes: energy contents (in case of coal, crude oil, natural gas, biomass and waste), heat (in case of nuclear, geothermal and solar thermal) and electricity (in case of solar photovoltaic, wind, hydro, tide, wave and ocean) (European Commission – Eurostat, 2015). Primary production of energy from MSW represents the heat produced after combustion and corresponds to the net calorific value of the MSW. In case of anaerobic digestion of wet waste, primary energy production corresponds to the net calorific value (heat content) of the biogases produced, including the gases consumed in the installation for the fermentation processes but not of flare (European Commission – Eurostat, 2015). It is usually expressed in tonnes of oil equivalent (toe) or in terajoules (TJ), to allow comparison with primary production of energy from different types of fuel. The tonne of oil equivalent is a standardized energy unit defined as a net calorific value of 10^7 kcal (41,868 MJ), which is roughly the net energy equivalent of a tonne of crude oil (International Energy Agency, Eurostat, 2004).

The data on PPEMSW for 16 EU countries and Norway is available in Eurostat (the EU statistical office) database (Eurostat, 2017a) and descriptive statistics are presented in Table 1. The data for the period 2006–2015 has been used. In order to allow comparison of countries with different size of population, primary