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A grey neural network and input-output combined forecasting model. Primary energy consumption forecasts in Spanish economic sectors

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ABSTRACT

A combined forecast of Grey forecasting method and neural network back propagation model, which is called Grey Neural Network and Input-Output Combined Forecasting Model (GNF-IO model), is proposed.

A real case of energy consumption forecast is used to validate the effectiveness of the proposed model.

The GNF-IO model predicts coal, crude oil, natural gas, renewable and nuclear primary energy consumption volumes by Spain's 36 sub-sectors from 2010 to 2015 according to three different GDP growth scenarios (optimistic, baseline and pessimistic).

Model test shows that the proposed model has higher simulation and forecasting accuracy on energy consumption than Grey models separately and other combination methods.

The forecasts indicate that the primary energies as coal, crude oil and natural gas will represent on average the 83.6% percent of the total of primary energy consumption, raising concerns about security of supply and energy cost and adding risk for some industrial production processes. Thus, Spanish industry must speed up its transition to an energy-efficiency economy, achieving a cost reduction and increase in the level of self-supply.

1. Introduction

Information regarding energy consumption disaggregated by economic branch and by type of energy source is very limited. For example, the *Energy Consumption Survey* elaborated by the Spanish Statistical Institute [1] gives information on the different types of fuels used by mining and quarrying and manufacturing industries, but biannually.

In fact, the most common source of this kind of disaggregated information used to be input-output tables which summarize production and utilization of the output of different sectors and sub-sectors of the economy. Since it is needed to take much time and resources for compiling an input-output table, there is time lags in theirs publications and the information is not available at the desired frequency. For example, the *World Input-Output Database*[2] provides environmental accounts including energy use, among others, for several countries (as Spain) at disaggregated level, but only has information until 2009. The World Input-Output Database (WIOD) is a serie of world and national input-output tables for 40 countries from 1995 to 2011 [3].

Despite these limitations, disaggregated information by economic branch is required not only to characterize each sector, but also to monitor and to forecast sectoral energy consumption. In this sense, accurate and reliable forecasts of the energy consumption for each sector are very important to establish stable energy policies.

However, under a situation of small amount of information available, the estimation and forecast by traditional approaches (as regression methods) are impossible as a dimensionality problem arises.

In this context, the Grey systems theory, established initially by Julong Deng in 1982 [4], focuses on the study of problems where the sample is small and the information poor. It deals with uncertain systems with partially known information which is generated, excavated and extracted from what is available. Grey models have been successfully used in several fields as hydrology, geology, medicine, energy or regional economics among others (see an introduction to Grey models in [5] and a review of their applications in [6] and more recently in [7]). For example in the energy

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field, these models have been used for the estimation of CO_2 emissions by sectors in China [8], energy consumption and economic growth [9] or wave energy [10]. Energy consumption forecasting is also one of the key usage fields of Grey models. For instance, the grey GM(1,1) model is improved using artificial neural network sign estimation [11] and with the concept of average system slope [12] for forecasting electricity consumption. [13] used a trigonometric grey prediction model to forecast Chinese electricity consumption. [14] developed a grey rolling prediction model to predict electricity demand and [15] extended the model to singular spectrum analysis. Recently [16], use the called Optimized Grey Modeling, which is an optimized Grey forecasting model, to forecast the total electric demand of Turkey.

In the above commented references, only a single Grey model is used to forecast an energy variable. However, it is the argument of this paper that it is possible to increase the estimation and forecast accuracy by combining several Grey models. A combination of individual forecasts would be supposed to perform better than the individual forecast as it benefits of the availability of multiple information because each of the considered forecasts capture different aspects of the available information [17].

The mix of three different Grey forecasting models and their combination by using a neural network model is proposed. There are several ways to combine forecasts [18], but a neural network model as a combined method [19] is used because it would be able to account potentially complex nonlinear relationships not easily assessed by linear combining methods [20]. In fact a neural network back propagation (BP) model, which has better nonlinear and self-learning ability, is used. This model has been successfully applied it in primary energy related CO_2 emissions estimation by sector in China [8].

Thus, a combined forecast model of the GM (1,1), WPGM (1,1), pGM(1,1) and BP neural network, which is called Grey Neural Network and Input-Output Combined Forecasting Model (GNF-IO model) is proposed. Forecasting results obtained from three different Grey forecasting models and their combination are used as input values of a back propagation (BP) neural network model.

GNF-IO model integrated the advantages of GM(1, 1), WPGM(1, 1), pGM(1, 1), BP neural network and input-output analysis. The GM(1,1) requires only a few number of historical data and is used to predict exponential signals in real time. WPGM(1,1) model is an unbiased Grey-forecasting model, it does not exist inherent error which GM(1,1) model has. Thus it removes the invalid phenomenon which appears when the growth rate of initial data is larger. PGM(1,1) model is a weighted grey prediction model with a time-varying parameter, which solves the problem that in many dynamic systems the jumping sometimes appear during a relatively short-time which will cause the initial sequence great fluctuation. The predict results of GM(1,1), WPGM(1,1), pGM(1,1) are used as inputs to the BP neural network, solving the problem that the randomly selection of inertial value of inputs will impact the forecasting accuracy. BP neural network adapts the nonlinear function to approximate the object so that the prediction is more accurate than other methods.

A real case of energy consumption prediction is used to validate the effectiveness of the proposed model. Through GNF-IO model five kinds of primal energy consumed by 36 Spanish economic subsectors are forecast. Specifically, GNF-IO model is used to forecast the five kinds of primal energy consumed (coal, crude oil, natural gas, renewable and nuclear) by Spanish economy at sub-sectoral level for the period 2010–2015.

In this model, input-output analysis method is applied to make a sector forecast. Economic sector forecast is more complex by the fact that each sector has their own property and there have interactions from other sectors. Input- Output can provide good information by sector forecast needed. In this paper, the last *Spanish Symmetrical Input-Output* tables covering years 1995, 2000 and 2005 (Spanish Statistical Office, INE [21]) and the *World Input-Output Database* ([2]) are used. Input-output models discover the direct and indirect links between industries and can determine the demand for energy after the growth of any industry. GNF-IO model requires GDP growth forecasts from 2010 to 2015 as previous input to predict primary energy use by Spanish economic sectors for this period. The *Spanish Saving and Energy Efficiency Plan 2011–2020*[22] shows both the primary energy consumptions by sources and some economic sectors (industry, transport, building & equipment, public services and agriculture & fisheries) and its evolution by 2020. However, this survey no shows the energy consumption at sub-sectoral level and the forecasts have been done under unrealistic GDP growth trend. Thus, in this paper GDP forecasts provided by several international and national organisms are used and three forecasting scenarios are generated: the baseline, optimistic and pessimistic.

The forecasting results show that the proposed GNF-IO model has better forecasting performance than any the single Grey model and other combination procedures.

The present study contributes to the literature on this topic on three ways: (*i*) It provides a model forecasting (GNF-IO model) that integrates the advantages of GM(1,1), WPGM(1,1), pGM(1,1), BP neural network and input-output analysis, (*ii*) it delivers an empirical investigation about the use of grey models and combining of forecasting in the energy field, (*iii*) it provides findings that may be useful for policy makers in order to establish long-term stable energy policies for Spain.

In the following parts of this paper, Section 2 provides a literature review about the Grey Neural Network and combining forecasts; Section 3 analyses five kinds of primary energy consumption structure by 36 Spanish economic sub-sectors; Section 4 describes the basic concepts of the used Grey Models and the BP neural network and present the GNF-IO model structure; Section 5 applies GNF-IO model to forecast Spanish primary energy consumption by economic sectors and subsectors; simulation and forecasting accuracy of the model is tested in this section. Section 6 concludes and provides suggestions.

2. Literature review

The systems are called Grey due to the amount of know information. In a Grey System, the information is only partially known. The term origin emerges in contrast to concepts as “black or white boxes” for which the level of information is totally unknown or completely known, respectively [23].

The fundamental principles of Grey systems are based on six axioms: information differences, non-uniqueness solution, best use of minimal information, recognition base, new information priority over old information and absolute Greyness or absolute incompleted information [7].

The Grey system theory principles constitute the base of Grey forecasting models [24]. The Grey forecasting model presents interesting advantages especially for temporal limited information scenarios. It will be able to characterize an unknown system given relative little discrete data such as only four observations [25]. From a first order differential equation, the Grey forecasting model can estimate the unknown system [26]. The theory of the Grey system is useful when other methodologies such as relational analysis or model estimation are insufficient to characterize the system. Grey