Models for Predicting Non-Renewable Energy Competing with Renewable Source for Sustainable Energy Development: Case of Asia & Oceania Region

Muhammad Ikram[a]

[a]*School of Business Administration, Al Akhawyan University in Ifrane, Avenue Hassan II, P.O. Box 104, 53 000 Ifrane, Morocco*

i.muhammad@aui.ma

Abstract

Accurate energy forecasting is of great significance to meet the energy demands, clean energy plans and sustainable energy development strategies. Therefore, this study develops the integrated grey framework to forecast the growth trends of renewable and non-renewable energy production and consumption in Asia & Oceania region from 2017 to 2025 by using novel grey forecasting models namely Even grey model (EGM), Discrete Grey Model (DGM), Optimized Discrete Grey Model (ODGM) and Non-homogeneous Discrete Grey Model (NDGM). Mean absolute Percentage Error (MAPE) was employed to measure the performance of grey models. Data were collected from the International Energy Agency (IEA) from 1980 to 2016. The results reveal that the energy consumption and production from coal as a non-renewable energy source is comparatively higher than any other energy source and depicted an increasing trend until 2025. Whereas renewable, nuclear, and other renewable sources of energy production and consumption showed the uprising trend with slow pace. Moreover, the consumptions of petroleum started with 23.07 quadrillion BTU in 1980, however, the production ended at 18.577 quads BTU in 2015. While the production and consumption of petroleum will reach approximately 21.0465 and 93.750 quads BTU respectively, in 2025 and are projected to increase in Asia & Ocean region. All the four grey models showed the excellent performance. Whereas NDGM performance was recorded slightly higher. The study is first of its kind to develops the grey integrated forecasting framework to predict the renewable and non-renewable production and consumption in the region of Asia and Oceania. This study provides useful information for policymakers, decision-makers, and energy experts in sustainable energy planning, simultaneously help to make the environment more sustainable.

Keywords: Asia & Oceania; Consumption; Grey forecasting models; Non-renewable energy; NDGM; Production; Renewable energy; Sustainable development

1. Introduction

With the increasing number of challenges regarding the issue of environment results of Greenhouse gas (GHG) emissions from non-renewable energy sources like fossil fuels lead to high and unpredictable energy costs. It also affect the geopolitical atmosphere which encompassing the production of fossil fuels, renewable energy sources have risen as a significant part in the global energy mix consumption (D'Adamo et al., 2021; Rehman et al., 2020). As indicated by the International Energy Outlook (US Energy Information

Administration, 2017), the renewable energy sources are anticipated to be the largest growing source of world energy. In particular, world renewable energy source used for electricity production will increase by 3% on the average every year and the renewable energy consumption elevating by 2.6 % every year from 2007 to 2035. As per the International Energy Outlook report by(US Energy Information Administration, 2017), the overall renewable energy consumption around the globe has expanded. The growth level in the 21st century's main decade was 4.40%, especially associated with growth levels of 3.18 % and 12.89 % for hydropower and non-hydropower. While in the year of 2011, renewable energy sources provided an expected 16.7 % of total energy consumption worldwide and around the globe in renewable energy sources expanded by 17% because of reduced price and technological advancements in renewable energy resources (Deb et al., 2017). New advancements in renewable resources (comprising modern biomass, solar, small hydro, biofuels, wind, and geothermal) are truly reasonable for local energy production in remote and rural regions, where the transportation expenses of unrefined petroleum or flammable gas i.e. natural gas are frequently restrictively high, similar to those of power transmission (D'Adamo et al., 2021a; Ren et al., 2015).

Most of the developing nations have initiated to recognize, execute projects and implement such approaches and policies to strengthen the framework of the continuing rural renewable energy markets (Gupta et al., 2019). Along these lines, these markets expanded more and are progressively alluring to potential stakeholders (Singh et al., 2019). The International Energy Agency (International Energy Agency and Agency, 2011) appraises that yearly interest in the rural energy area requires to expand more than fivefold to accomplish the extensive utilization of new renewables energy by the year 2030. These components indicate a more promising time to come for renewable energy resources (Ketsetzi and Capraro, 2016).

In spite of the fact that the anticipated development in renewable energy source can be allocated in part to government strategies, for example, renewable energy generation duty credits, installation discounts, portfolio guidelines. Moreover, the production of business sectors for renewable energy certificates, there has likewise been a distinct fascination for cleaner, other energy sources by the overall population (Apergis et al. 2010; Menyah and Wolde-Rufael 2010; Menegaki, 2011).

Thus, following this, the renewable share of global electricity production will go up from 18 % in the year 2007 to 23 % in 2035. Wind energy and hydroelectricity are expected as the biggest share in total renewable electricity production at 26 % and 54 % respectively (Bhattacharya et al. 2016; Tugcu et al., 2012). Given the development of renewable energy source in the debate of a sustainable development, it is essential to comprehend the elements between renewable energy consumption and financial development, which this investigation tries to address and give extra power by merging the time series and cross-sectional data information by enabling heterogeneity cross-wise over nations will be used (Ikram et al., 2021b; Shukla et al., 2019).

The objective of this kind of study in the energy sector is to examine how the dispersion of innovation impacts or competes with the dissemination of different advances. Furlan and Mortarino (2018) conducted a study on Italian case with the competition of coal and firewood and examined in a dispersion system through a logistic model. Nadimi and Tokimatsu (2017), utilized a diffusion model, considering through competitors' costs, for the depiction of renewables in South Korea. Similarly, Wu et al. (2019) utilized a Lotka–Volterra model to investigate about the development of PV solar and wind advancements in most advanced countries. Wang et al. (2018), examined the variations in Germany from atomic power to renewables (photovoltaic and wind). In this paper, we try to examine simultaneously all energy sources by concentrating on the challenges among renewable energy and non-renewable energy systems. Specifically, we consider the overall consumption (in Mtoe) from renewable and non-renewable energy sources. For non- renewable energy sources, we allude to coal, oil, gas, and nuclear energy (COGN) sources, while for the case of renewable energy, we allude to wind, hydroelectric and solar energy.

Given this vulnerability, the figures published in 2013 by the EIA state that world energy consumption will elevate by 56 % somewhere in the range of the year 2010 and 2040 (Tabasi et al., 2016), for the most part, due to non-OECD nations, and the energy market will grow. The diverse energy systems perform as competitors in this market. The passage of new technological advancements may counteract for the exit of advances for drained energy sources. Simultaneously, new advances may encourage the development of the market potential size, particularly for rising nations. Ordinarily, it requires significant investment before another mechanical advancement comes up to show a considerable industry share (Appolloni et al., 2021; D'Adamo et al., 2020). For a considerable length of time, this has been the situation of green technologies that, have confronted trouble in being embraced because of mechanical disparities with the previous electric framework and because they firmly depend on incentive plans to be economically focused. In addition to this, the competitive impacts would likewise influence the time section of new advances and life cycle of prior innovations (Sushil, 2015).

This study aims to perform an accurate forecast of energy production and consumption of renewable and non-renewable sources from 1980 to 2025 in Asia & Oceania region, by using four advanced mathematical novel grey forecasting models of Even Grey Model GM (1,1), Discrete Grey model GM (1,1), Non-homogenous Discrete Grey Model (NDGM) and Optimized Discrete Grey model (ODGM). This paper contributes in various ways and fills the gap in litaerature. This study develops the intergrated grey forecasting framework to analyze the total energy consumption and production growth for future in Asia & Ocenia region. The main advantage of grey prediction models that ensure accuracy and superiority over other statistical models. In addition, grey models shows higher performance on small set of data and incomplete information. This study is first of its kind to assess the future trends of total energy production and consumption in context of Aisa & Oceania region.

It has been estimated that NDGM model is the most effective model among four forecasting models. This model is effective for the current research as it eliminates uncertainty, ambiguity, and data bias. This model eliminates uncertainty and bias by offering deeper analyses of renewable and non-renewable energy. This research is its first kind to utilized four models to forecast energy production and consumption of renewable and non-renewable sources. Moreover, this study is a pioneer to investigate the future of the Asia & Oceania region in terms of energy production and consumption by renewable and non-renewable sources.

our grey methodology utilizes available data making replication of this study and future work more reliable to both practitioners and scholars. The outcomes of this study provide the valuable information to policy makers, energy experts climate scientists, governments and other reserachers to understand the future growth of renewable and non-renewanable energy production and consumption in Asia & Oceania region, and simultaneously help to make the environment more sustainable.

The rest of the paper is organized as follows. Section 2 presents the literature review. Section 3 discusses the development steps of EGM, DGM, NDGM, and ODGM. Section 4 represents the exciting results with discussion. Finally, a conclusion is presented in the last section of the paper.

2. Background

As per National Bureau Statistics (NBS) of China the overall energy consumption in the year 2017 expanded by 2.9 % from 4.36 Giga tons (billion tons of standard coal proportional) in 2016 (Ali et al., 2017). China's objective for decreasing its energy force (energy consumption per unit of GDP) is 3.4%, with a decrease of 3.7% in 2017 and the portion of coal in overall energy consumption reduced to 1.7 % (Armeanu et al., 2017; Ito 2017; Jacobson et al., 2017;

Koçak and Şarkgüneşi 2017; Squalli 2017) . Whereas the natural gas, nuclear and wind energy expanded by 1.5% in the year 2017 and meanwhile the energy consumption expanded by 6.6% reported in 2017 by the Chinese National Energy Administration (NEA) and furthermore the development of 5.5% in mechanical energy consumption. Likewise, the planted energy generation limit of the nation developed by 137 GW to over 1,800 GW for the period of approximately about 13 GW of hydropower limit and almost 46 GW of thermal volume were planted (Giest and Mukherjee 2018; Vasconcelos et al. 2018).

The energy policy of India heavily relies on the nation's increasing energy deficits and specifically, focuses on the progress of another type of energy sources especially solar system nuclear and wind energy. Generally, in energy independence, at 66 % India ranked at 81 levels in the year 2014. After China and America in context to primary energy consumption, India contributes the third biggest share of 5.6% in the year 2017. The overall primary energy consumption from coal (424 Mtoe; 56.26%), renewable power (21.8 Mtoe, 2.89%), hydroelectricity (30.7 Mtoe, 4.07%), natural gas (46.6 Mtoe, 6.18%), nuclear energy (8.7 Mtoe, 1.15%), crude oil (221.1 Mtoe, 29.34%) is 753.7 Mtoe except for traditional biomass use in year 2017 (Ikram et.al 2020). India's net imports of unrefined petroleum are almost 198.8 million tons and its items LNG 25.7 Mtoe, coal 129.8 Mtoe totaling to 354.3 Mtoe of primary energy, which is equivalent to 47 % in 2017 of total primary energy consumption (Giest and Mukherjee, 2018). While India produces 75 % of its electricity from petroleum and furthermore minimal exporter of electricity for 2017. By 2030, India is for the most part reliant on petroleum imports to fulfill its energy needs and its reliance on non-renewable energy sources surpass 53% of the nation's overall energy consumption (Central Statistics Office et al., 2016). The primary energy supply for Indonesia relies upon non-renewable energy source like petroleum, gas, and coal in which 41% of energy consumption depended on oil, 29% is based on coal and 24% depends on natural gas in 2015 (Faizah and Husaeni 2018; Nugraha and Osman 2018).

Renewable energy most notably hydropower and geothermal resources have a portion of 6%, on the contrary, statistical figures don't cover the conventional utilization of biomass as an energy resource in rural zones for heating process, cooking, and lighting which is assessed to incorporate 21% up to 29% of overall energy demand. Additionally, in recent years the electricity consumption has expanded by 7 % every year. It is determined that until the year 2020 the energy demand increased by 1.6 % for each 1 % expansion in GDP. It was hard for Indonesia to fulfill this demand growth with adequate system investments. Moreover, it has turned out to be increased frequency and term of intensity blackouts that result in expensive to neighborhood businesses and industrial demand (Siagian et al., 2017).

The energy in Japan alludes to consumption and production of electricity, import, and exports. While the primary source of energy consumption of Japan was 477.6 Mtoe in the year 2011, which is a decline of 5% over the preceding year. While the overall electricity production for the period of 2015 was 1041 TWh in which natural gas added 409 TWh, from coal 343 TWh, 91 TWh from hydro, 103 TWh from oil, 41 TWh from wind and solar source, whereas biofuels and waste contributed 41 TWh, and 9 TWh from atomic (Iwafune, Mori, Kawai, and Yagita, 2017). Finally, the consumption for 2015 was 957 TWh, on average around 7500 kWh per capita by and large without imports and exports. As of now, Japan is producing approximately 10% of its electricity from renewable energy resources. And by end of 2030, the renewable resources will contribute 24% in overall energy production. While Japan expects in the following 15 years putting $700 billion into renewable energy resources (International Energy Agency, 2017). In this study we choose the Aisa & Oceania region and analyzed the future trends of energy due to higher total energy production and consumption. Figure 1 showed that Asia & Oceania region produced comparatively higher energy in quad Btu by using fossil fuels and renewable sources from 1980-2015.

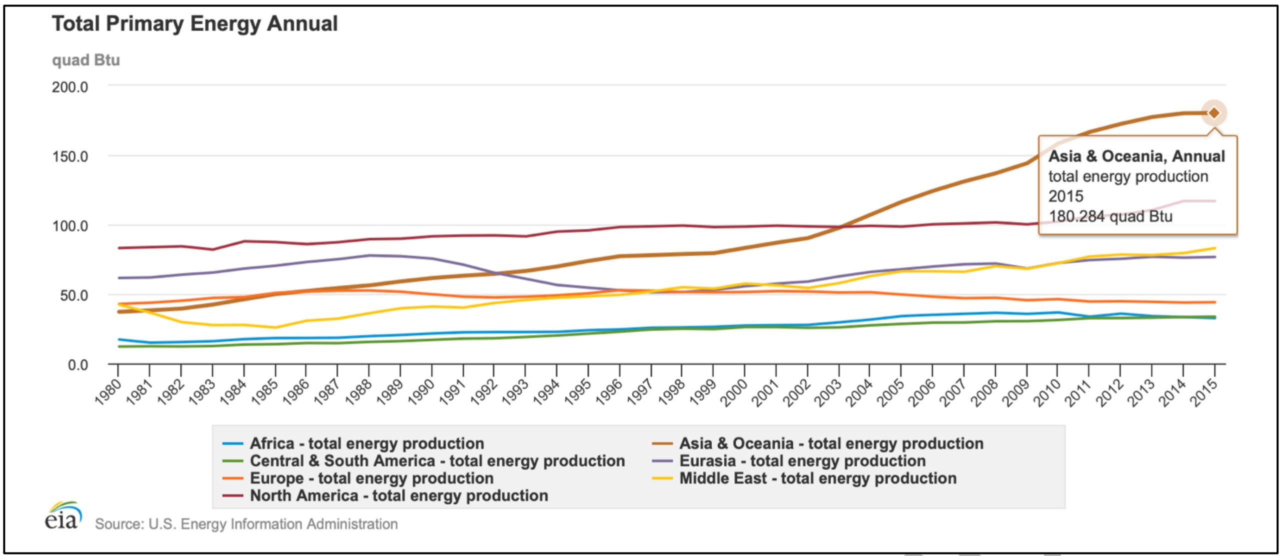

Figure 1: Total Energy Production in quadrillion BTU world data 1980-2015 (Continental Regions)

Russia is the second biggest production market of dry natural gas and the world's biggest maker of unrefined petroleum including lease condensate and furthermore delivers considerable measures of coal. The economy of Russia is exceedingly reliant on its oil, hydrocarbons and natural gas revenues, which represents more than 33% of the federal budget revenues in 2017 (BP, 2017). As per the British Petroleum (BP) statistical review, nation devoured 26.74 quadrillion Btu (British thermal units) of energy, the vast majority of which was natural gas 52%, oil 22%, coal represented 13% and nuclear, renewable and others are represented 13% of energy consumption in Russia for 2016 (BP, 2017). A wide range of energy utilized around 82 % in the United States is derived from non-renewable energy sources. In 2014, the biggest source of the nation's energy generation is 35 % which originated from petrol, pursued by coal 18%, natural gas 28 %, nuclear power 8 % and sustainable resources of 10% (Liu and Lv, 2019). Figure 2 showed that Asia & Oceania region consumed comparatively higher energy in quad Btu by from 1980-2015.

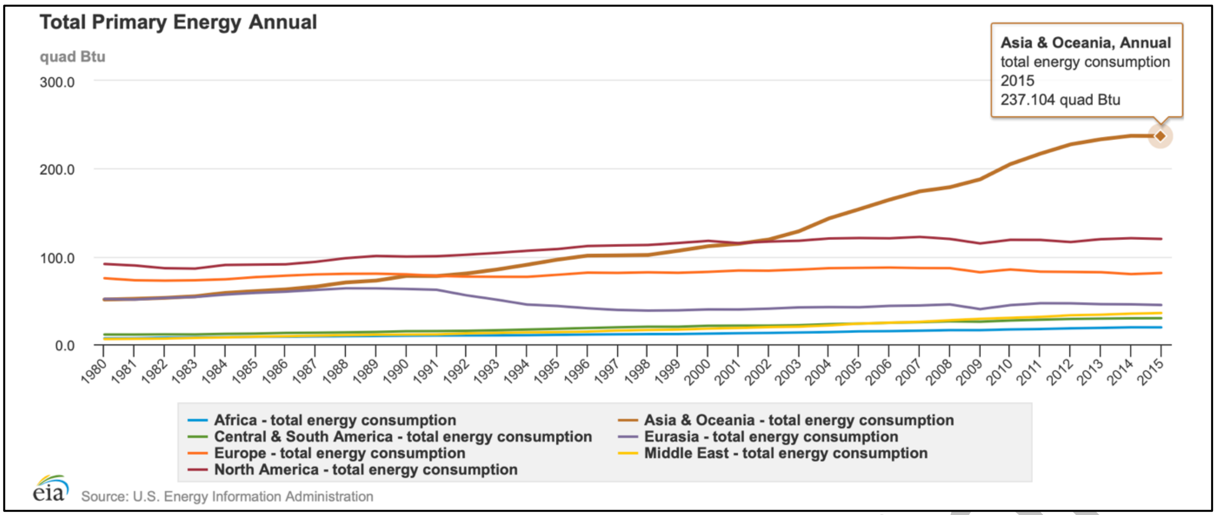

Figure 2: Total Energy consumption in quadrillion BTU world data 1980-2015 (Continental Regions)

3. Methodology

3.1 Grey Forecasting Models

3.1.1 Even Grey Model GM (1, 1)

Professor Deng introduced the idea of a grey system as a scientific theory for forecasting unsure system was initially introduced by Deng Julong in 1982 which includes little and poor data (Sheikh et al., 2019). By and large, the forecasting models of grey systems have showed more accuracy and superiority over statistical models (Ikram et al., 2021). For forecasting, grey system have various models, in which EGM, DGM, ODGM and NDGM have used in this study to assess the production and consumption of total energy in region of Asia & Oceania.

There are various grey forecasting models, fractional grey model with accumulation order is another model of the grey system theory that specifically focuses on the most recent set of information rather than considered an old and a new set of data with equal weight (Liu, Yang, and Forrest 2017). In grey system theory, GM (1, 1) plays a vital and significant part which is employed for prediction with a limited set of data or when the sample size is comparatively small. There are number of applications for grey prediction models such as GM(1,1) which have been used in many disciplines for investigation, for example, research publication analysis (Javed and Liu, 2018), electricity demand in China (Pi et al., 2010; Wang and Ye, 2017) predicition of sectoral based GHG emission (Rehman et al., 2021), wind speed prediction (El-Fouly et al., 2006), and output of industrial area (Feng et al., 2012; Hsu 2011; Ou 2012).

The fundamental of GM (1,1) based on one variable with grey model to calculate prediction values with the first order sequence of original data. GM (1,1) has been categorized into four types. Even grey model is the most reliable grey forecasting model among four GM (1,1) models having increasing non-exponential data sequence demonstrated by (Dudin et al., 2017; Ye et al., 2017) which is shown in equation (i)

$$\hat{x}^{(0)}(k)=\left(1-\mathrm{e}^{a}\right)\left(k^{(0)}(1)-\frac{b}{a}\right)\mathrm{e}^{-a(N-1)}, \quad K=1,2,\ldots n \tag{1}$$

$x^{(0)}$ represents the original data sequence values is given in the above-mentioned equation (1) whereas, further $-a$ parameters denote index development and follows presented by $\hat{x}^{(0)}$ and $\hat{x}^{(1)}$, moreover, b is knowns as quantity of grey actuating. These parameters are the parameters of an Even GM (1,1) model. The prior studies investigated; that the forecasts seem to be most reasonable in data set sequence for the initial two data set values after the value of last data sequence.

$$\hat{x}^{(1)}(k)=\left(x^{(0)}(1)-\frac{b}{a}\right)\mathrm{e}^{-a(k-1)}+\frac{b}{a}, \quad k=1,2,\ldots n \tag{2}$$

3.1.2 Discrete Grey Model GM (1, 1)

Although the EGM showed the satisfactory and authentic, however progressively improved results are needed, thus DGM is also utilized in this study for better results. In grey forecasting models the accuracy of predicted results is a significant issue of GM (1,1) models. Many researchers focus on settling this issue to get progressively precise outcomes and minimize the errors. used the McLaurin series to undertake a comparative analysis of EGM and DGM. Their findings demonstrate that DGM and optimized models showed the higher accuracy level over EGM and recorded the more effective grey forecasting model. In this study the MAPE (%) for DGM ended up being fundamentally superior to EGM as demonstrated in table 10 and 11. Moreover if $x^{(0)}$ is data sequence of original data and $x^{(1)}$ is prediction accumulated successions, then the DGM is followed by(Liu et al., 2017b):

$$\hat{x}^{(1)}(N) = [x^{(0)}(1) - \frac{\beta 2}{1-\beta 1}]\beta 1^{N} + \frac{\beta 2}{1-\beta 1} \quad (3)$$

3.1.3 Nonhomogeneous Discrete Grey Model (NDGM)

The NDGM system is designed on the basis of law of approximation non-homogenous exponential growth in accordance with assumptions of a sequence of real data (Wu et al., 2014). Zeng and Li (2016), recommended that the actual data sequence is a concurrence with a homogenous pattern like GM (1,1). The accuracy level of NDGM model is considerably improved over other grey models so far as mean sequence value and value set of intervals (Ikram et al., 2019). NDGM model has been utilized in various fields, for example, in a study the electricity consumption of Turkey was predicted and analyzed the NDGM as best fit and more accurate prediction model over other grey forecasting models (Kusakci and Ayvaz, 2016). Whereas, Duan et al., (2018) forecast the crude oil consumption in China and investigated that NDGM showed superior performance.

$x^{(0)}$, represents the original data sequence and $x^{(1)}$ follows the accumulated data sequence in NDGM model so, we can write as follows:

$$\hat{x}^{(1)}(L+1) = \beta_1 \hat{x}^{(1)}(L) + \beta_2 . L + \beta_3 \quad (4)$$

$$\hat{x}^{(1)}(1) = x^{(1)}(1) + \beta_4 \quad (5)$$

Where, $\hat{x}^{(1)}$(L), is the forecasting value of $x^{(1)}$ along with parameters β_1, β_2, β_3, and β_4 So, we can write the above equation in matrix form as this: if L=1, 2, and 3…. n-1

$$\begin{bmatrix} x^{(1)}(2) \\ x^{(1)}(3) \\ \vdots \\ x^{(1)}(n) \end{bmatrix} = \begin{bmatrix} \beta_1 \\ \beta_2 \\ \beta_3 \end{bmatrix} \begin{bmatrix} x^{(1)}(1) & 1 & 1 \\ x^{(1)}(2) & 2 & 1 \\ \vdots & \vdots & \vdots \\ x^{(1)}(n-1) & L-1 & 1 \end{bmatrix} \tag{6}$$

The input data shows constant sequence in single case to satisfy NDGM parameters β1, β2, β3, and β4 by applying the following relation:

$$\hat{\beta} = (B^{\mathrm{T}}B)^{-1}B^{\mathrm{T}}Y = [\beta_1, \beta_2, \beta_3]^{\mathrm{T}} \tag{7}$$

The following formula to be used to calculate β4 for minimizing the sum of square error:

$$\beta_4 = \frac{\sum_{L=1}^{n-1}\left[x^{(1)}(L+1) - {\beta_1}^{L}x^{(1)}(1) - \beta_2 \sum_{j=1}^{L} j{\beta_1}^{L-j} \frac{1-{\beta_1}^{L}}{1-\beta_1}.\beta_3\right].{\beta_1}^{L}}{1-\sum_{L=1}^{n-1}({\beta_1}^{L})^2)} \tag{8}$$

For further knowledge about NDGM model, its parameter and properties, Liu *et. al.* (2010) is referred.

3.1.4 Optimize discrete Grey Model (ODGM)

Grey forecasting model is one of the most dynamic mathematical modeling methods which demonstrates the precise evaluation and accuracy level for small data set (Ikram et al., 2021b; Javed and Liu, 2018). To take care of a small data set information-based issues, an advanced Discrete Gray Model (ODGM) has been built up. The major principle of this forecasting model ODGM has five steps which are explained as:

- In the first step, we take data from the year 1980 to 2015 of total energy production and consumption, and ODGM original sequence model is presented in the first equation (9) as

$$Y^{(0)} = \{Y^{(0)}(1),\ Y^{(0)}(2), \dots \dots \dots \dots Y^{(0)}(n-1)Y^{(0)}(n)\} \tag{9}$$

- In the second step, the aggregated generated operating sequence presented in equation (10)

$$Y^{(1)} = \{y^{(1)}(1), y^{(1)}(2), \dots\dots y^{(1)}(n-1), y^{(1)}(n)\} \tag{10}$$

and transformational succession of heat emission $Y^{(1)}$presented in equation (11) is as follows:

$$y^{(1)} = \sum_{k}^{i=1} y^{(0)}(i), \quad k = 1,2,3, \ldots . . n \tag{11}$$

- The third step is as follows:

$\beta = (\beta_{1,}\beta_2)^T$, is the parameter series of heat emission,

Where,

$$\beta = \begin{bmatrix} y^{(1)}(1) & 1 \\ y^{(1)}(2) & 1 \\ \vdots & \vdots \\ y^{(1)}(n-1) & 1 \end{bmatrix} \tag{12}$$

and,

$$y^{(k+1)} = \beta_1 y^{(1)}(k) + \beta_{2,} \qquad k = 1,2,3,, \ldots \ldots \ldots n-1. \tag{13}$$

In the ODGM model, we calculate the parametric equation (14) through the ordinary least square (OLS) technique which is presented in equation (15) as $\hat{\beta}$.

$$y^{(1)}(k+1) = \beta_1 y^{(1)}(k) + \beta_2, \quad k = 1,2,\ldots,n-1 \tag{14}$$

$$\hat{\beta} = (\beta_1,\beta_2)^T = (B^T B)^{-1} B^T Y \tag{15}$$

Where B^T denotes the transpose of B matrix.

Furthermore, by applying an iterative datum $\hat{y}^{(1)}(1)$ is not equal to $y^{(1)}(1)$, then to express the equation difference between $\hat{y}^1(1)$ and $y^1(1)$, that is $\hat{y}^1(1) = y^1(1) + \beta$, a changed has occurred in the β_3. As indicated by the least-square technique can comprehend to β_3 with an unstrained optimized model which is presented in equation (16).

$$\min_{\beta_3} \sum_{n}^{k=1} [\hat{y}^{(1)}(k) - y^{(1)}(k)]^2 \tag{16}$$

- In the fourth step, forecasted or predicted values of $y^{(1)}(K+1)$ and $y^{(0)}(K+1)$ could be appeared in equation (17) and (18) as:

$$\hat{y}^{(1)}(k+1) = \beta_1^k (\hat{y}^{(1)}(1) + \beta_3) + \frac{1-\beta_1^k}{1-\beta_1} \cdot \beta_2, \quad k = 1,2,\ldots,n-1 \tag{17}$$

$$\hat{y}^{(0)}(k+1) = \hat{y}^{(1)}(k+1) - \hat{y}^{(1)}(k) = \left(\beta_1^k - \beta_1^{k-1}\right)\left(\hat{y}^{(1)}(1) + \beta_3 - \frac{\beta_2}{1-\beta_1}\right), \quad k = 1,2,\ldots,n-1 \qquad (18)$$

In addition to this, $\hat{y}^{(0)}(1), \hat{y}^{(0)}(2), \ldots. \hat{y}^{(0)}(n)$, denotes the simulated values and $\hat{y}^{(0)}(n+1), \hat{y}^{(0)}(n+2), \ldots\ldots \hat{y}^{(0)}(n+m)$ denotes the forecasting sequence of values.

- The last and final step is the estimation of Mean Absolute Percentage Error (MAPE) %, which is performance measuring criteria of the ODGM in equation (19)

$$MAPE(\%) = \frac{1}{n}\sum_{n}^{k=1}\left|\frac{y^{(0)}(k) - \hat{y}^{(0)}(k)}{y^{(0)}(k)}\right|$$

(19)

Where in equation (19), $y^{(0)}(k)$ represents the original sequence of data and $\hat{y}^{(0)}(k)$ denotes the forecasting sequence data values. Moreover, we can interpret the MAPE % accuracy and level clearly in table 1 for better understanding and comparison of our results for interpretation. The methodological framework operationalized in this study is presented in figure 3.

Table 1: MAPE for model evaluation. Source: (*Lewis, 1982*)

MAPE %	Forecasting accuracy
Greater than 50 %	Weak and inaccurate
20–50 %	Reasonable
10–20 %	Good
Less than 10%	Highly Accurate

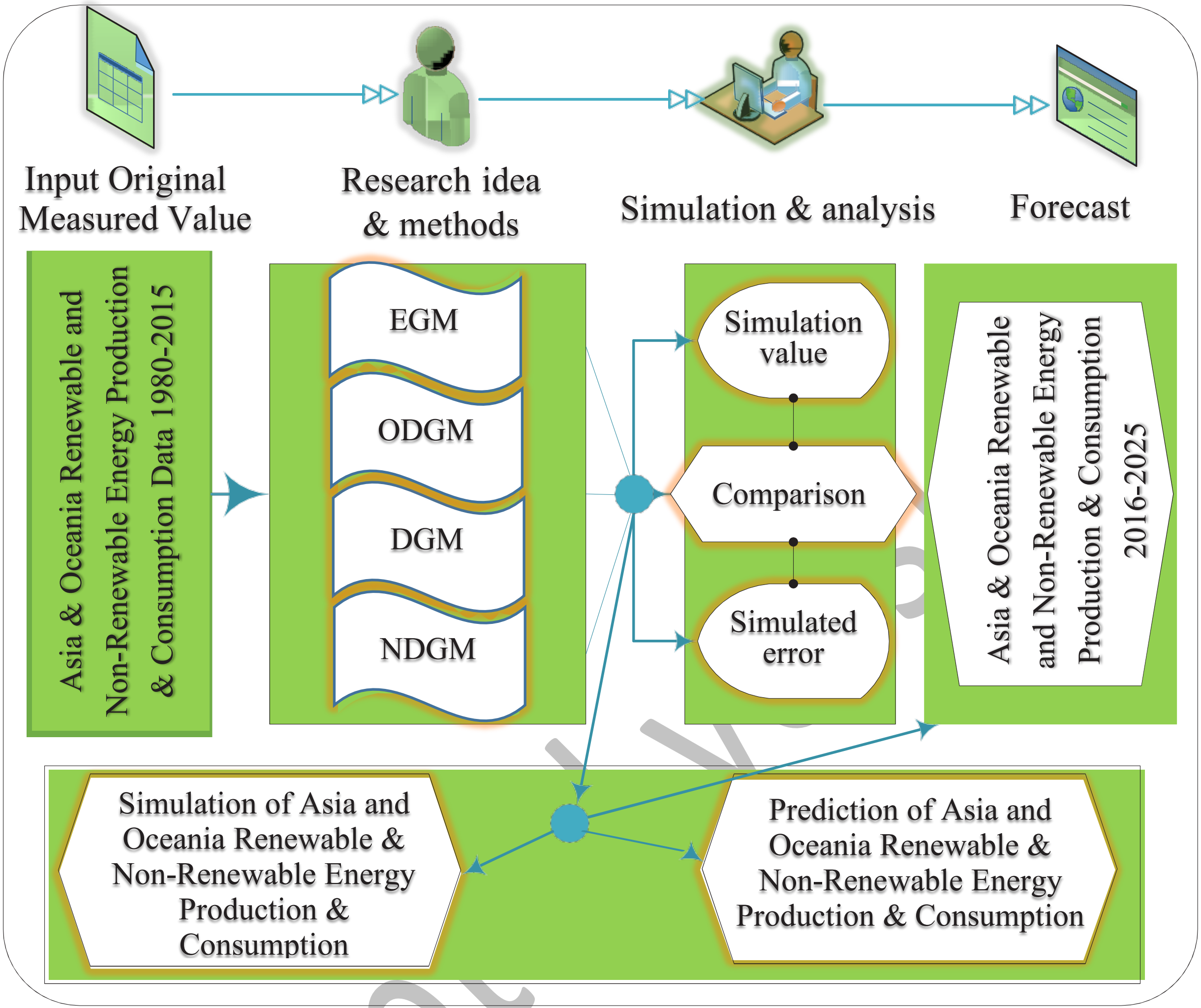

Figure 3: Grey integrated forecasting framework operationalized in this study.

4. Results and Discussion

The data used in this study was obtained from International Energy Agency (IEA) from 1980 to 2015, covering the data on coal, petroleum, natural gas, nuclear and renewable energy production and consumption for Asia and Oceania Region. In this study, we employed four different grey model approaches that are EGM, ODGM, DGM, and NDGM to forecast renewable and non-renewable energy production and consumption. The calculated simulated values are shown below in table 2 to 9.

In Tables 2 and 3, results for primary energy production and consumption of coal are presented. Based on the EGM model parameters, parameters for coal production are a= -

0.055961, *b*= 16.124707 while coal consumption are a= -0.015465, b= 17.099964 which are calculated in the methodology section and are shown in equation (20) and (21) as:

$$x^0(N) = 16.124707(1 - \mathrm{e}^{-0.055961})\mathrm{e}^{0.055961\,(N-1)} \tag{20}$$

$$x^0(N) = 17.099964(1 - \mathrm{e}^{-0.015465})\mathrm{e}^{-0.015465\,(N-1)} \tag{21}$$

Moreover, for the production of energy by coal, the NDGM time response formula-based forecasting equation parameters are obtained as β1= 1.015251and β2= 3.749037 and for the consumption of coal β1= 1.015557and β2= 2.659392represented in 3 & 4 respectively. The MAPE accuracy of production of coal as a primary energy source is estimated to be 92.37%, 92.29%, 92.39% & 92.48% and consumption of coal MAPE accuracy is 91.38%, 91.44%, 91.46 %and 91.50% under EGM, ODGM, DGM, and NDGM model respectively which can be seen in table 22 &23 presented at the end of the result section.

$$\hat{x}^{(1)}(N) = [x^{(0)}(1) - \frac{16.622100}{1-1.057521}]1.012530^{\,N} + \frac{16.622100}{1-1.057521} \tag{22}$$

$$\hat{x}^{(1)}(N) = [x^{(0)}(1) - \frac{16.622100}{1-1.057521}]1.012530^{\,N} + \frac{16.622100}{1-1.057521} \tag{23}$$

In Asia and Oceania region, the production of coal as a non-renewable energy source, we used the data from the year 1980 to 2015 and applied four grey models. In the case of EGM, the simulated value of coal showed the inclined trend from 1980 to 2015 which started from 18.38 quadrillion BTU to 118.2701 quadrillion BTU. Similarly, the other three models ODGM, DGM & NDGM have shown approximately the same results with little fluctuation and their values also start from 18.38 in 1980 and in 2015 the simulated value of coal production reached to 118.3384, 118.38381 & 118.360659 quadrillions BTU respectively. While the predicted values of EGM model from 2016 to 2025 are 125.0773, 132.2763, 139.8896, 147.9411, 156.456, 165.461, 174.9843, 185.0558, 195.7069, and 206.971 respectively. The forecasted values of ODGM, DGM, & NDGM also showed the same result approximately with the considerable inclined trend like EGM, but the only difference can be seen in the predicted value of 2025 that is 207.21481, 207.10073 and 207.159694 respectively. The exponential growth of production of coal as primary energy source is presented in figure 4(a).

Coal, a non-renewable resource, is one of the major sources for the development of human society and rich, worldwide. Presently, china is one of the largest producer of the coal which accounts nearly 45 % of the global market, where 95 % of the coal comes from underground mines (Jiang et al., 2019). The economy of South Ais is heavily dependent on coals consumption as energy source to fulfill their demand at industrial and commercial scale. Although this region has already invested on cleaner energy technology such as green technologies to mitigate the CO_2 emission but still, they remain far from replacing the conventional energy production sources.

Table 2: Production of Coal as energy source of ASIA and Pacific

Years	Coal (Quad btu)	EGM (1,1)	ODGM (1,1)	DGM (1,1)	NDGM (1,1)
1980	18.381973	18.38197	18.381973	18.381973	18.381973
1981	19.04611	17.64241	17.616609	17.679447	17.647149
1982	20.20202	18.65784	18.631671	18.696383	18.663124
1983	21.627481	19.73172	19.705222	19.771815	19.737591
1984	23.589511	20.8674	20.84063	20.909106	20.873916
1985	25.487371	22.06845	22.04146	22.111815	22.075661
1986	26.510643	23.33862	23.311481	23.383705	23.346592
1987	27.847535	24.6819	24.65468	24.728755	24.690694
1988	28.87642	26.1025	26.075274	26.151174	26.112177
1989	30.637886	27.60486	27.577722	27.655411	27.615497
1990	31.618875	29.19369	29.166741	29.246173	29.205366
1991	32.540804	30.87397	30.847318	30.928437	30.886767
1992	33.639558	32.65095	32.62473	32.707467	32.664968
1993	34.691794	34.53022	34.504556	34.588827	34.545543
1994	36.529659	36.51764	36.492696	36.578405	36.534386
1995	39.603691	38.61946	38.595392	38.682426	38.63773
1996	41.197919	40.84225	40.819245	40.907471	40.862166
1997	40.935701	43.19297	43.171236	43.260503	43.214668
1998	40.987628	45.67899	45.658748	45.748883	45.702606
1999	41.14735	48.3081	48.289589	48.380396	48.333779
2000	44.729484	51.08853	51.072018	51.163277	51.116433
2001	47.864712	54.02899	54.01477	54.106231	54.059289
2002	49.55404	57.13869	57.127082	57.218466	57.17157
2003	56.142989	60.42738	60.418724	60.50972	60.46303
2004	63.438059	63.90534	63.90003	63.99029	63.943985
2005	70.054144	67.58349	67.581927	67.671064	67.625344
2006	75.282124	71.47334	71.475974	71.56356	71.518645
2007	80.637425	75.58707	75.594395	75.679955	75.636089
2008	84.409289	79.93757	79.950117	80.033129	79.990581
2009	90.135353	84.53847	84.556815	84.636701	84.595769
2010	97.755027	89.40418	89.428949	89.505075	89.466084
2011	105.81709	94.54995	94.581814	94.653481	94.616792

2012	110.39602	99.99188	100.03159	100.09803	100.064034
2013	111.3489	105.747	105.79537	105.85575	105.824883
2014	109.21573	111.8334	111.89126	111.94466	111.917393
2015	105.47239	118.2701	118.3384	118.38381	118.360659
2016		125.0773	125.15702	125.19335	125.174874
2017		132.2763	132.36852	132.39457	132.381394
2018		139.8896	139.99555	140.01002	140.002806
2019		147.9411	148.06204	148.06351	148.062994
2020		156.456	156.59332	156.58025	156.587221
2021		165.461	165.61618	165.58687	165.602201
2022		174.9843	175.15892	175.11157	175.136189
2023		185.0558	185.25152	185.18413	185.219063
2024		195.7069	195.92565	195.83607	195.882425
2025		206.971	207.21481	207.10073	207.159694

Additionally, for the energy production by coal, by NDGM forecasting equation parameters are presented as β1= 1.128, β2= 2664.166, β3= 20927.409 and β4= -247.952 while consumption of coal is displayed as β1= 1.128, β2= 2664.166, β3= 20927.409, and β4= -247.952 in the time-series formula of NDGM which can be estimated by MATLAB.

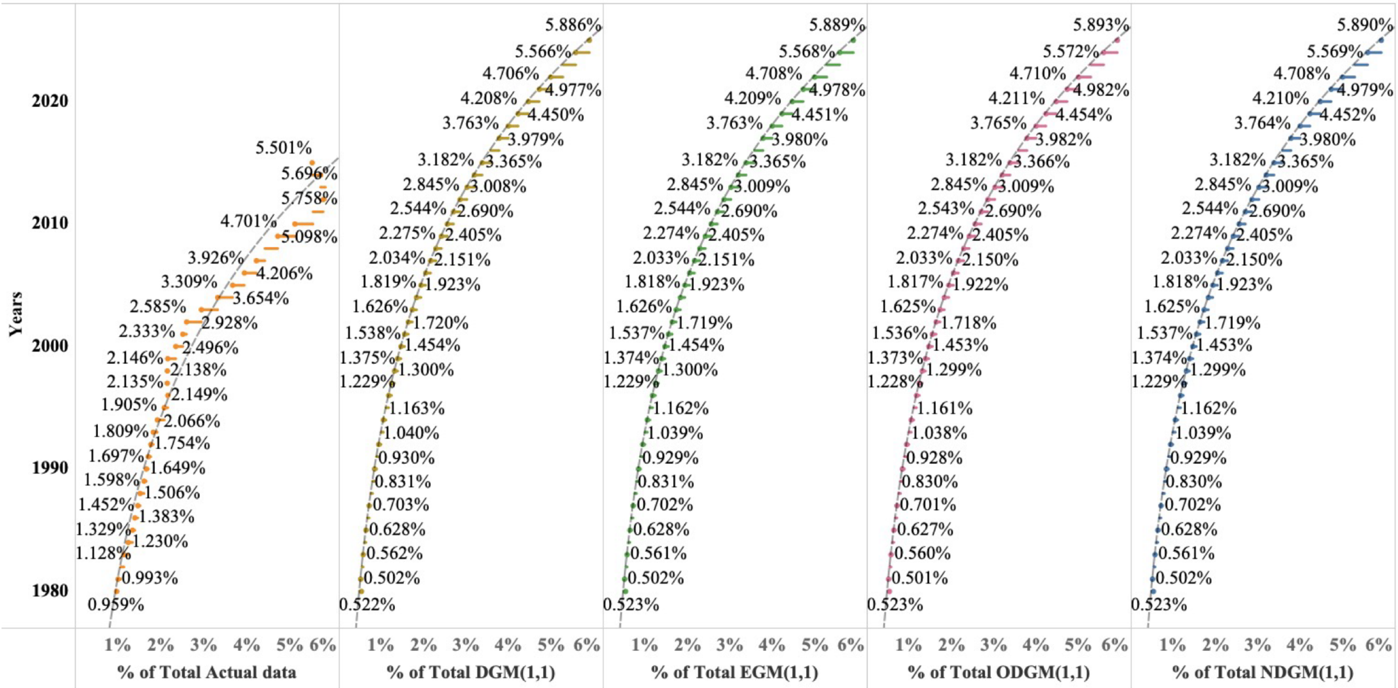

Figure 4(a): The exponential growth of production of coal as primary energy source

For more convenience and a clear view, the comparison between original data and NDGM simulated data from 1980 to 2025 are shown in table 2. The case of consumption of coal, the figure 4 (a) has also shown the increasing trend from 1980 to 2015 when grey models have been applied. The simulated values start 19.817607 and reached 120 quadrillion BTU in EGM, ODGM, DGM and NDGM model. But original values in the consumption of coal are little different than simulated values which can be noted in the last four columns of the table. From 1980 to 1990, the simulated values calculated by these models were low with a minor difference than original and then started to increase from 1991 to 2015. The forecasted values for the consumption of coal have been calculated for the year 2016 to 2025. These predicted values are elevating from 127 and reached a level of 208 quadrillion BTU in all the four grey models.

In contrast to Vietnam, Indonesia was fifth largest coal producer and second biggest exporter of coal in the world, and there is a prediction of increase of coal production and consumption for short period of time (Ghazouani et al., 2020). Whereas the increasing the demand of coal from Malaysia, the Philippines, and Vietnam is boosting production, along with government infrastructure investments and other efforts to increase domestic coal consumption. Moreover, the high papulation growth mounting the demand of electricity turn into increase the consumption of coal. Additionally, some see Indonesia as looking to capitalize on reduced coal production in other countries; Indonesia may be able to ramp up production to satisfy remaining international demand (Cucchiella et al., 2015).

Table 3: consumption of coal as energy resource

Years	coal	EGM (1,1)	ODGM (1,1)	DGM (1,1)	NDGM (1,1)
1980	19.81761	19.81761	19.817607	19.817607	19.81761
1981	20.38173	18.69287	18.647204	18.697676	18.75099
1982	21.36193	19.74541	19.698896	19.750761	19.80554
1983	22.51243	20.85722	20.809902	20.863158	20.91939
1984	24.71025	22.03164	21.983569	22.038208	22.09589
1985	25.79029	23.27218	23.22343	23.279438	23.33856
1986	26.57656	24.58257	24.533219	24.590576	24.65111
1987	28.03162	25.96675	25.916879	25.97556	26.03748
1988	30.12354	27.42887	27.378576	27.438548	27.50182
1989	29.97268	28.97331	28.922713	28.983935	29.04851
1990	33.1628	30.60472	30.553938	30.61636	30.68219
1991	31.3529	32.32798	32.277163	32.340727	32.40774
1992	32.31762	34.14828	34.097577	34.162213	34.23034
1993	34.42441	36.07108	36.020661	36.086288	36.15545
1994	36.20537	38.10214	38.052206	38.11873	38.18882
1995	39.63999	40.24757	40.19833	40.265643	40.33654
1996	40.59938	42.5138	42.465493	42.533474	42.60506

1997	39.79136	44.90764	44.860523	44.929033	45.00115
1998	39.80328	47.43626	47.390632	47.459514	47.532
1999	41.93095	50.10727	50.063437	50.132516	50.20518
2000	45.93609	52.92867	52.886987	52.956066	53.0287
2001	48.588	55.90894	55.869784	55.938644	56.01102
2002	51.71778	59.05702	59.020808	59.089205	59.16106
2003	59.46343	62.38236	62.349549	62.417212	62.48826
2004	66.63646	65.89494	65.866029	65.932657	66.00258
2005	74.09314	69.6053	69.580836	69.646099	69.71454
2006	80.92908	73.52458	73.505157	73.568688	73.63526
2007	86.97162	77.66455	77.650807	77.712204	77.77648
2008	89.41071	82.03763	82.030269	82.08909	82.1506
2009	95.30174	86.65694	86.65673	86.71249	86.77072
2010	101.8503	91.53636	91.544122	91.596288	91.65068
2011	109.8602	96.69052	96.707159	96.755149	96.80508
2012	113.2994	102.1349	102.161389	102.204567	102.2494
2013	105.8822	107.8858	107.923235	107.960906	107.9998
2014	104.3296	113.9606	114.010045	114.041451	114.0737
2015	101.7856	120.3774	120.440148	120.464463	120.4892
2016		127.1555	127.232905	127.249231	127.2654
2017		134.3153	134.40877	134.416128	134.4228
2018		141.8782	141.98935	141.986677	141.9827
2019		149.867	149.997471	149.983613	149.9678
2020		158.3056	158.457244	158.430951	158.4019
2021		167.2194	167.394145	167.354056	167.3104
2022		176.635	176.835081	176.779727	176.7198
2023		186.5808	186.808482	186.736268	186.6585
2024		197.0867	197.344376	197.253578	197.1561
2025		208.1841	208.474489	208.363242	208.2441

Results of petroleum production with 95.31%, 94.47%, 95.47%, and 95.50% MAPE accuracy and consumption of petroleum with 96.07%, 96.18%, 96.18%, and 96.19% MAPE accuracy for EGM, ODGM, DGM, and NDGM respectively are presented in tables 10 & 11. Likewise, the identical results were derived where the NDGM model has shown slightly more forecasting validity as compared to EGM, OGDM, and DGM model as presented in table 4. Based on the EGM model, the values of parameters for primary energy production of petroleum are *a*= -0.012467 and *b*= 11.952605 while for the consumption of petroleum are a= -0.026035 & b= 3.160246 which can be seen in equations 24 and 25 respectively.

$$x^{(0)}(N) = 11.952605(1 - \mathrm{e}^{-0.012467})\mathrm{e}^{0.012467\,(N-1)} \tag{24}$$

$$x^{(0)}(N) = 3.160246(1 - \mathrm{e}^{-0.026035})\mathrm{e}^{-0.026035(N-1)} \tag{25}$$

Likewise, the production and consumption of coal as a primary source of energy, the production of petroleum is not as high. As the original data is starting from 10.6046738 to 17. 4171233 quadrillion BTU. Also, simulated values and original values are approximately the same. The increasing trend has been observed from 1980 to 2015 while forecasted values have been calculated for the year 2016 to 2025 under the four grey models which started about 18 quads BTU and reached the level of approximately 21 quad BTU. Under the ODGM model, the forecasted value is 18.81704, 19.053377, 19.292682, 19.534992, 19.780346, 20.028782, 20.280337, 20.535053, 20.792967 and 21.054121 quads BTU. The exponential growth of consumption of coal for Asia and Oceania region is presented in fig. 4(b).

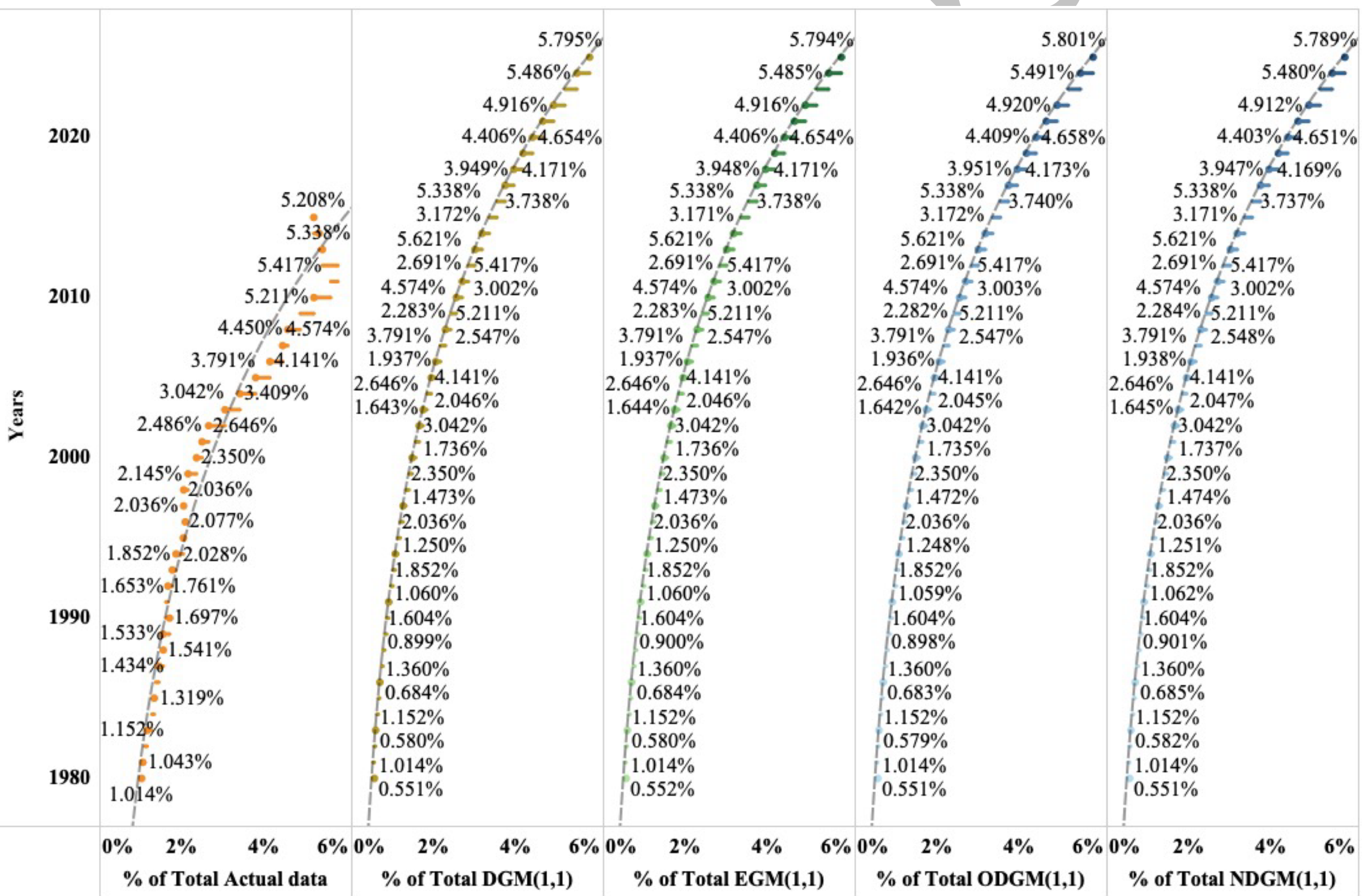

Figure 4(b): The exponential growth of consumption of coal as primary energy source

Table 4: Production of petroleum as primary energy source

Years	Petroleum	EGM (1,1)	ODGM (1,1)	DGM (1,1)	NDGM (1,1)
1980	10.6046738	10.604674	10.604674	10.60467	10.604674
1981	10.5406716	12.160451	12.157066	12.1642	12.16061
1982	10.17532	12.312999	12.309756	12.31661	12.313162
1983	10.8047423	12.467461	12.464363	12.47093	12.467628

1984	11.7578069	12.623861	12.620911	12.62719	12.624031
1985	12.4144036	12.782222	12.779426	12.7854	12.782397
1986	12.8652372	12.94257	12.939932	12.9456	12.942749
1987	12.844553	13.10493	13.102454	13.10781	13.105113
1988	13.1303982	13.269326	13.267017	13.27204	13.269514
1989	13.5302466	13.435784	13.433647	13.43834	13.435977
1990	13.9642466	13.604331	13.60237	13.60671	13.604528
1991	14.3693367	13.774992	13.773212	13.7772	13.775194
1992	14.3477256	13.947794	13.946199	13.94982	13.948001
1993	14.4689305	14.122764	14.12136	14.12461	14.122975
1994	14.8127718	14.299928	14.29872	14.30159	14.300145
1995	15.2994698	14.479315	14.478308	14.48078	14.479537
1996	15.7566147	14.660953	14.660151	14.66222	14.661179
1997	16.0805903	14.844869	14.844278	14.84593	14.8451
1998	16.1915305	15.031092	15.030718	15.03195	15.031329
1999	16.1937499	15.219651	15.2195	15.22029	15.219893
2000	16.6679664	15.410575	15.410652	15.411	15.410823
2001	16.4817493	15.603895	15.604205	15.60409	15.604149
2002	16.525678	15.79964	15.80019	15.7996	15.799899
2003	16.3434794	15.99784	15.998636	15.99757	15.998105
2004	16.5326965	16.198527	16.199574	16.19801	16.198798
2005	16.6915605	16.401731	16.403036	16.40097	16.402008
2006	16.7574126	16.607484	16.609053	16.60647	16.607768
2007	16.658514	16.815819	16.817658	16.81454	16.816109
2008	16.9103592	17.026767	17.028883	17.02522	17.027063
2009	16.8189272	17.240361	17.242761	17.23854	17.240663
2010	17.5414026	17.456634	17.459325	17.45453	17.456944
2011	17.2117288	17.675621	17.678609	17.67323	17.675937
2012	17.312577	17.897355	17.900647	17.89467	17.897678
2013	17.1260442	18.12187	18.125474	18.11888	18.1222
2014	17.2256306	18.349202	18.353125	18.34591	18.349539
2015	17.4171233	18.579386	18.583635	18.57578	18.57973
2016		18.812457	18.81704	18.80852	18.812808
2017		19.048452	19.053377	19.04419	19.048811
2018		19.287407	19.292682	19.2828	19.287774
2019		19.52936	19.534992	19.52441	19.529735
2020		19.774348	19.780346	19.76904	19.774731
2021		20.02241	20.028782	20.01674	20.0228
2022		20.273583	20.280337	20.26755	20.273982
2023		20.527907	20.535053	20.52149	20.528314
2024		20.785422	20.792967	20.77862	20.785837
2025		21.046167	21.054121	21.03897	21.046591

Likewise, the DGM based forecasting, equation 26 and 27 display the parameters β1=1.019459 and β2=3.202163 for petroleum production and β1=1.026376 and β2=11.085871 for the consumption of petroleum.

$$\hat{x}^{(1)}(N) = [x^{(0)}(1) - \frac{3.202163}{1-1.019459}]1.019459^{N} + \frac{3.202163}{1-1.019459} \quad (26)$$

$$\hat{x}^{(1)}(N) = [x^{(0)}(1) - \frac{11.085871}{1.026376}]1.026376^{N} + \frac{11.085871}{1.026376} \quad (27)$$

Additionally, in the petroleum, on the basis of NDGM forecasting equation, we obtained these parameters as β1= 0.869, β2= 3459.439, β3= 31145.425 and β4= -1332.496 for energy production but for energy consumption case we have β1= 1.128, β2= 2664.166, β3= 20927.409 and β4= -247.952.

Likewise, the consumption of petroleum as an energy source is higher than production. The simulated values are starting from 23.07 and leveled up to 67.40 under EGM, ODGM, DGM, and NDGM. The exponential growth of production of petroleum as primary energy source for Asia & Oceania can be seen in figure 4(c).

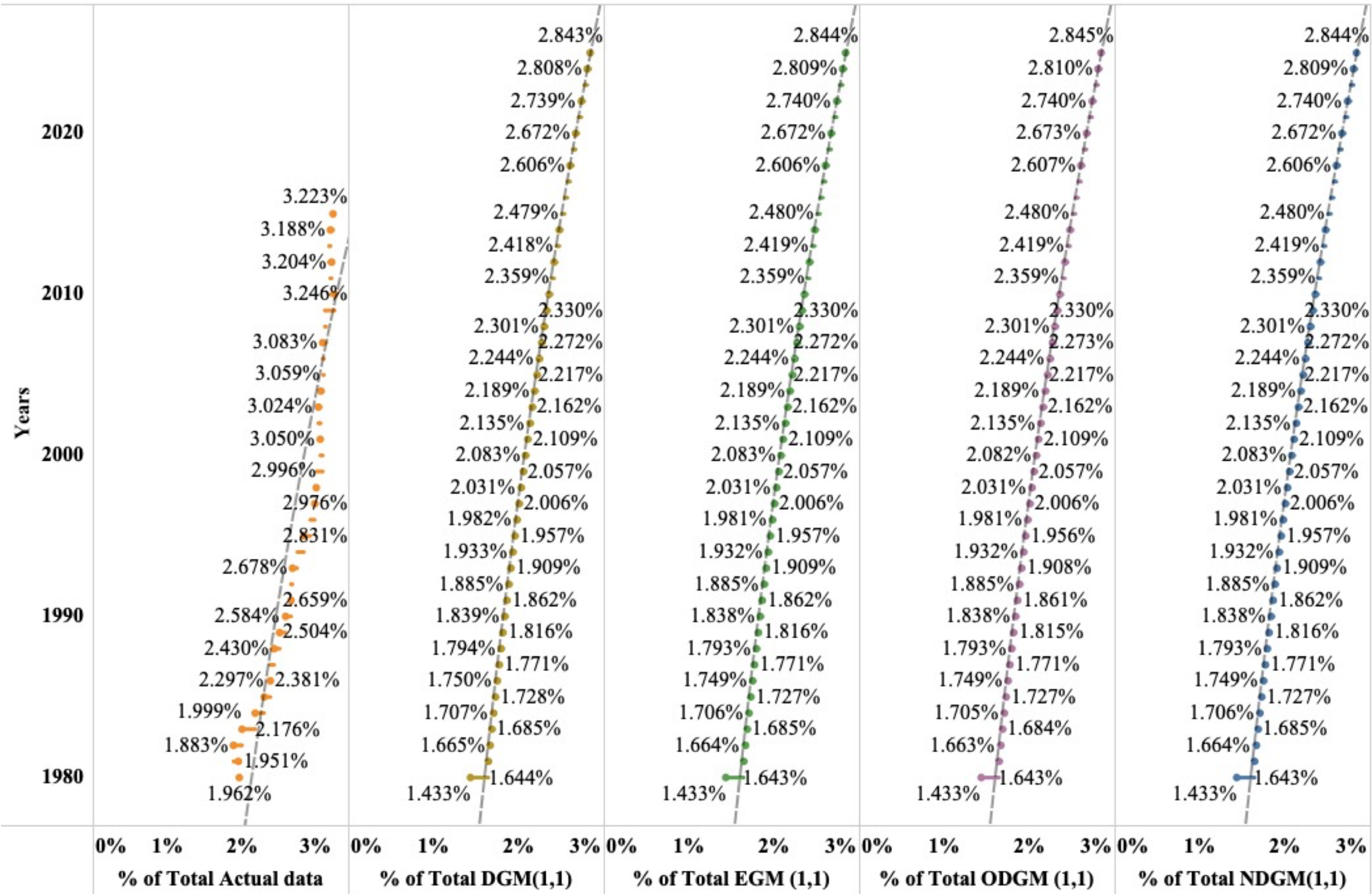

Figure 4(c): The exponential growth of production of petroleum as primary energy source

According to original data set the value of petroleum consumption goes down from 1980 to 1986 t mentioned in the quadrillion's BTU while the simulated figures 4(d) has shown decay only from 1980 to 1982 then it started to increase gradually from 1983 to 2015 and reached to 65.53138 in original data and 67.402077 in simulated figure calculated by grey models. Then forecasted values started from 69 and elevated to 87 quads BTU.

Thailand relies heavily non-renewable energy sources such as coal, though petroleum and natural gas make up a greater share of the energy mix than coal. The country energy imports shifting to large amounts of oil and gas, however, leading some public officials to see greater use of coal as a means of improving the country's energy supply (Cucchiella et al., 2015).

Table 5: Consumption of petroleum as primary energy source

Years	Petroleum	EGM (1,1)	ODGM (1,1)	DGM (1,1)	NDGM (1,1)
1980	23.07248	23.072481	23.072481	23.072481	23.072481
1981	22.42345	21.956859	21.954503	21.958883	21.963411
1982	21.8195	22.693254	22.691061	22.695414	22.699913
1983	21.66351	23.454346	23.452331	23.456649	23.461112
1984	22.54497	24.240964	24.23914	24.243417	24.247837
1985	22.33017	25.053964	25.052347	25.056574	25.060943
1986	23.04018	25.894231	25.892835	25.897006	25.901316
1987	23.86161	26.762678	26.761522	26.765627	26.769868
1988	25.72763	27.660252	27.659353	27.663382	27.667546
1989	27.28955	28.587929	28.587305	28.591249	28.595326
1990	28.65302	29.546719	29.546389	29.550239	29.554217
1991	29.95497	30.537664	30.53765	30.541394	30.545263
1992	31.39265	31.561845	31.562167	31.565794	31.569541
1993	32.91449	32.620374	32.621056	32.624553	32.628167
1994	35.1075	33.714405	33.71547	33.718825	33.722292
1995	36.88645	34.845128	34.8466	34.8498	34.853107
1996	38.57801	36.013773	36.01568	36.01871	36.021841
1997	40.14354	37.221613	37.223981	37.226827	37.229767
1998	39.5542	38.469961	38.47282	38.475465	38.478198
1999	41.55416	39.760177	39.763556	39.765984	39.768493
2000	42.70621	41.093664	41.097596	41.099789	41.102055
2001	42.87161	42.471874	42.476392	42.478332	42.480336
2002	43.98441	43.896307	43.901445	43.903113	43.904835
2003	45.92503	45.368513	45.374308	45.375683	45.377103
2004	48.7445	46.890095	46.896585	46.897645	46.898739
2005	49.91749	48.462707	48.469933	48.470656	48.471402
2006	51.08029	50.088062	50.096066	50.096428	50.0968
2007	52.84308	51.767929	51.776754	51.77673	51.776703
2008	52.39362	53.504136	53.513828	53.513392	53.512939
2009	53.10751	55.298572	55.30918	55.308304	55.307396
2010	56.75809	57.15319	57.164765	57.163419	57.162027
2011	58.3391	59.070009	59.082603	59.080758	59.078849
2012	60.83004	61.051115	61.064783	61.062407	61.059949
2013	61.89543	63.098663	63.113465	63.110523	63.107481
2014	63.12764	65.214883	65.230878	65.227336	65.223673
2015	65.53138	67.402077	67.419328	67.415149	67.410828
2016		69.662626	69.6812	69.676345	69.671325
2017		71.99899	72.018956	72.013384	72.007623
2018		74.413711	74.435142	74.428811	74.422265

2019	76.909418	76.93239	76.925255	76.917878
2020	79.488826	79.513418	79.505432	79.497176
2021	82.154744	82.181038	82.172152	82.162966
2022	84.910071	84.938155	84.928318	84.918148
2023	87.757808	87.787772	87.776929	87.765721
2024	90.701053	90.73299	90.721087	90.708781
2025	93.743009	93.777019	93.763995	93.750532

Moreover, in Table 10 & 11 MAPE accuracy results for primary production of natural gas as 96.07%, 96.18%, 96.18% & 96.19% and energy consumption of as 94.98%, 95.40%, 95.39% & 95.40% for EGM, ODGM, DGM and NDGM respectively. Moreover, we acquired the same results for both production and consumption and NDGM has shown slightly more forecasting effectiveness when compared to EGM, ODGM and DGM model, as portrayed in figure 3. Based on the results of the EGM model, parameters for energy production of natural gas are shown as;

a= -0.049796 and *b*= 1.905146 while parameters for energy consumption are represented as a= -0.050127, b=0.853664 in equation 28 and 29 respectively.

$$x^{(0)}(N) = 1.905146(1 - \mathrm{e}^{-0.049796})\mathrm{e}^{0.049796(N-1)} \quad (28)$$

$$x^{(0)}(N) = 0.853664(1 - \mathrm{e}^{-0.050127})\mathrm{e}^{0.050127(N-1)} \quad (29)$$

Similarly, by looking at table 6 for natural gas as a primary source of energy production in Asia and Oceania, its production in 1980 started from 2.6 quads BTU to 19.339352 in the original figure while in simulated figures, it is 21.17 quads BTU using grey modeling technique. And it is clearly visible that it started to elevate during 1980 to 2015 which will keep on increasing with every next year and until 2025 it will touch the figure of 33 quadrillion BTU approximately estimated by grey forecasting technique. The exponential growth petroleum consumption as primary energy source from 1980 to 2025 is presented in figure 4(d).

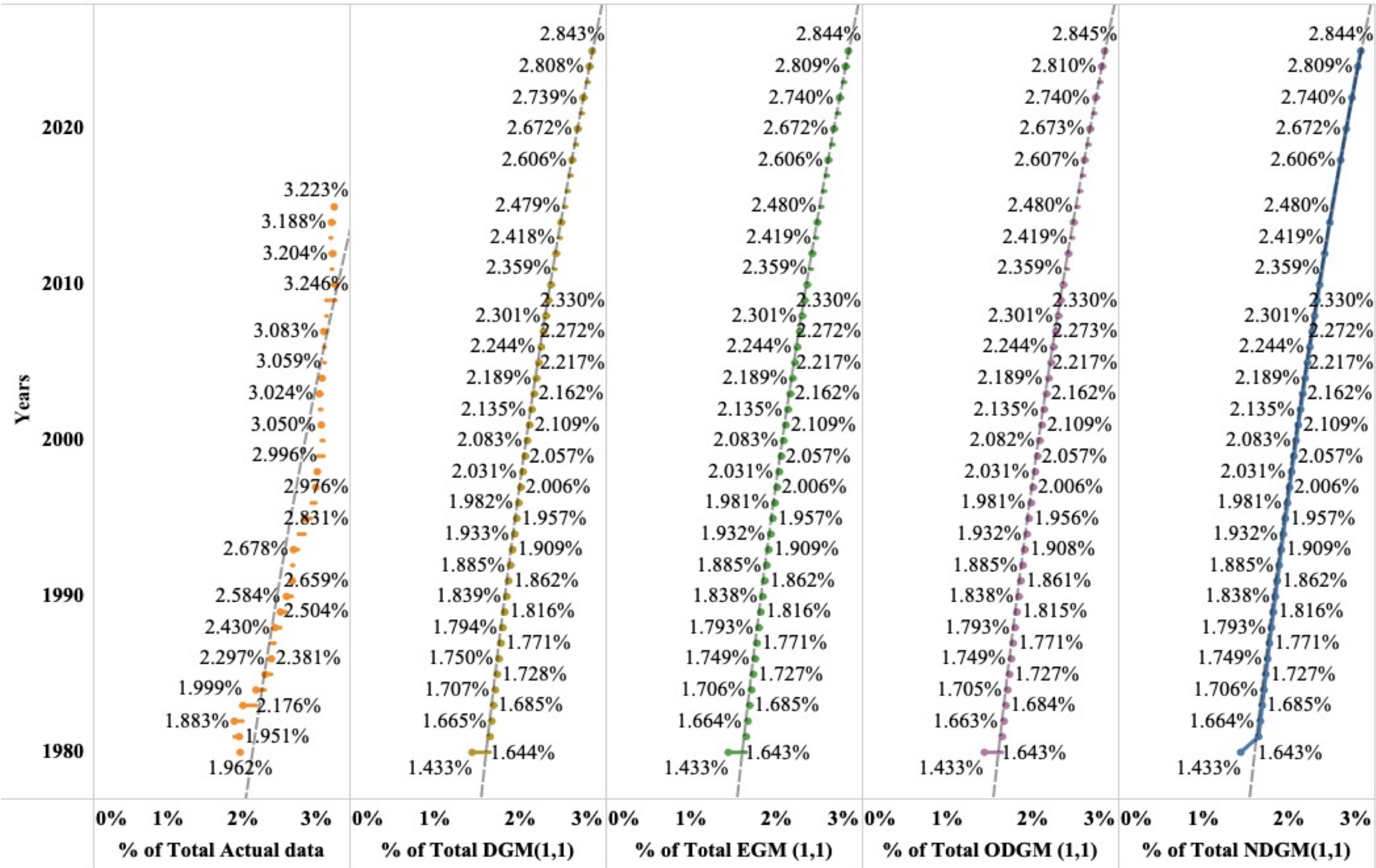

Figure 4(d): The exponential growth petroleum consumption as primary energy source

Conversely, there is a positive relationship between nonrenewable consumption and economic growth for Indonesia, Malaysia, South Korea, Thailand, and the USA (Salari et al., 2021). This segment of results signifies that these countries are rely on fossil fuels to fulfill their energy demand, and infrastructural development for energy consumption from renewable sources is still at a nascent stage. In other words, the share of renewable energy consumption the energy mix is still not enough to have a significant impact on economic growth.

Table 6: Natural Gas as primary energy production of Asia &Oceania

Years	Natural Gas	EGM(1,1)	ODGM(1,1)	DGM(1,1)	NDGM(1,1)
1980	2.698	2.698	2.698	2.698	2.698
1981	2.8693591	3.894637	3.893085	3.89796	3.895462
1982	2.919	4.093483	4.091971	4.096937	4.094392
1983	3.24	4.302482	4.301018	4.306072	4.303482
1984	3.789	4.522151	4.520744	4.525881	4.523249
1985	4.219	4.753036	4.751695	4.756911	4.754239

1986	4.538	4.995709	4.994445	4.999735	4.997025
1987	4.807	5.250772	5.249597	5.254954	5.252209
1988	5.177	5.518857	5.517783	5.5232	5.520425
1989	5.383	5.800631	5.79967	5.80514	5.802338
1990	6.012	6.09679	6.095958	6.101472	6.098647
1991	6.449	6.40807	6.407383	6.41293	6.410088
1992	6.791	6.735244	6.734717	6.740288	6.737434
1993	7.197	7.079121	7.078774	7.084355	7.081496
1994	7.781	7.440556	7.440407	7.445987	7.443128
1995	8.213342	7.820444	7.820516	7.826078	7.823229
1996	8.868345	8.219728	8.220043	8.225571	8.222739
1997	9.196345	8.639398	8.63998	8.645457	8.642652
1998	9.220345	9.080495	9.081371	9.086777	9.084008
1999	9.827345	9.544112	9.545311	9.550625	9.547904
2000	9.986345	10.0314	10.032953	10.03815	10.035489
2001	9.988	10.54357	10.545507	10.55056	10.547974
2002	10.702	11.08189	11.084246	11.08913	11.08663
2003	11.31674	11.64769	11.650507	11.65519	11.652793
2004	11.701829	12.24238	12.245697	12.25015	12.247869
2005	12.425795	12.86743	12.871293	12.87548	12.873334
2006	13.335945	13.52439	13.528849	13.53272	13.53074
2007	14.417851	14.2149	14.219998	14.22352	14.221718
2008	15.019993	14.94066	14.946456	14.94958	14.947982
2009	15.824016	15.70348	15.710026	15.7127	15.711334
2010	17.762257	16.50524	16.512605	16.51478	16.513669
2011	17.801152	17.34794	17.356185	17.3578	17.356976
2012	17.759679	18.23367	18.242861	18.24386	18.243349
2013	18.236944	19.16461	19.174834	19.17514	19.174987
2014	18.938755	20.14309	20.15442	20.15396	20.154201
2015	19.339352	21.17152	21.184049	21.18275	21.183421
2016		22.25246	22.26628	22.26406	22.2652
2017		23.3886	23.403798	23.40056	23.402222
2018		24.58273	24.599429	24.59507	24.597309
2019		25.83784	25.856141	25.85056	25.853426
2020		27.15703	27.177054	27.17014	27.173689
2021		28.54357	28.565449	28.55708	28.561375
2022		30.0009	30.024774	30.01482	30.019926
2023		31.53264	31.55865	31.54697	31.552961
2024		33.14259	33.170888	33.15733	33.164284
2025		34.83473	34.865491	34.84989	34.857892

Similarly using the DGM based forecasting equation, parameters for production of natural gas are β1=1.051046 and β2=3.760237, while consumption parameters have resulted as β1=1.051392 and β2=3.299401 in equation 30 & 31.

$$\hat{x}^{(1)}(N) = [x^{(0)}(1) - \frac{3.760237}{1-1.051046}]1.051046^{N} + \frac{3.760237}{1-1.051046} \tag{30}$$

$$\hat{x}^{(1)}(N) = [x^{(0)}(1) - \frac{3.299401}{1-1.051392}]1.051392^{N} + \frac{3.299401}{1-1.051392} \tag{31}$$

When it comes to analyzing the consumption of natural gas, it is also high as compared to its production in last years but its consumption and production remain almost equal from

1980 to 1983 which is around 7 quads BTU. Afterward, it reached the level of 28 quads BTU approximately, according to the simulated figure estimated by EGM, ODGM, and DGM, and NDGM. Then again, the prediction has been done by using grey modeling techniques and under NDGM the forecasted values are 30.05532, 31.96611, 33.99838, 36.15985, 38.45875, 40.90379, 43.50428, 46.2701, 49.21176, and 52.34043 quads BTU for the year 2016 to 2025. Notably, while natural gas has increasingly supplanted coal elsewhere in the world, demand for coal has far outpaced that for natural gas in Southeast Asia, an imbalance that appears likely to persist (Liu et al., 2021). The exponential growth of natural gas as primary energy production source for Asia & Oceania region from 1980 to 2015 is presented in figure 4(c).

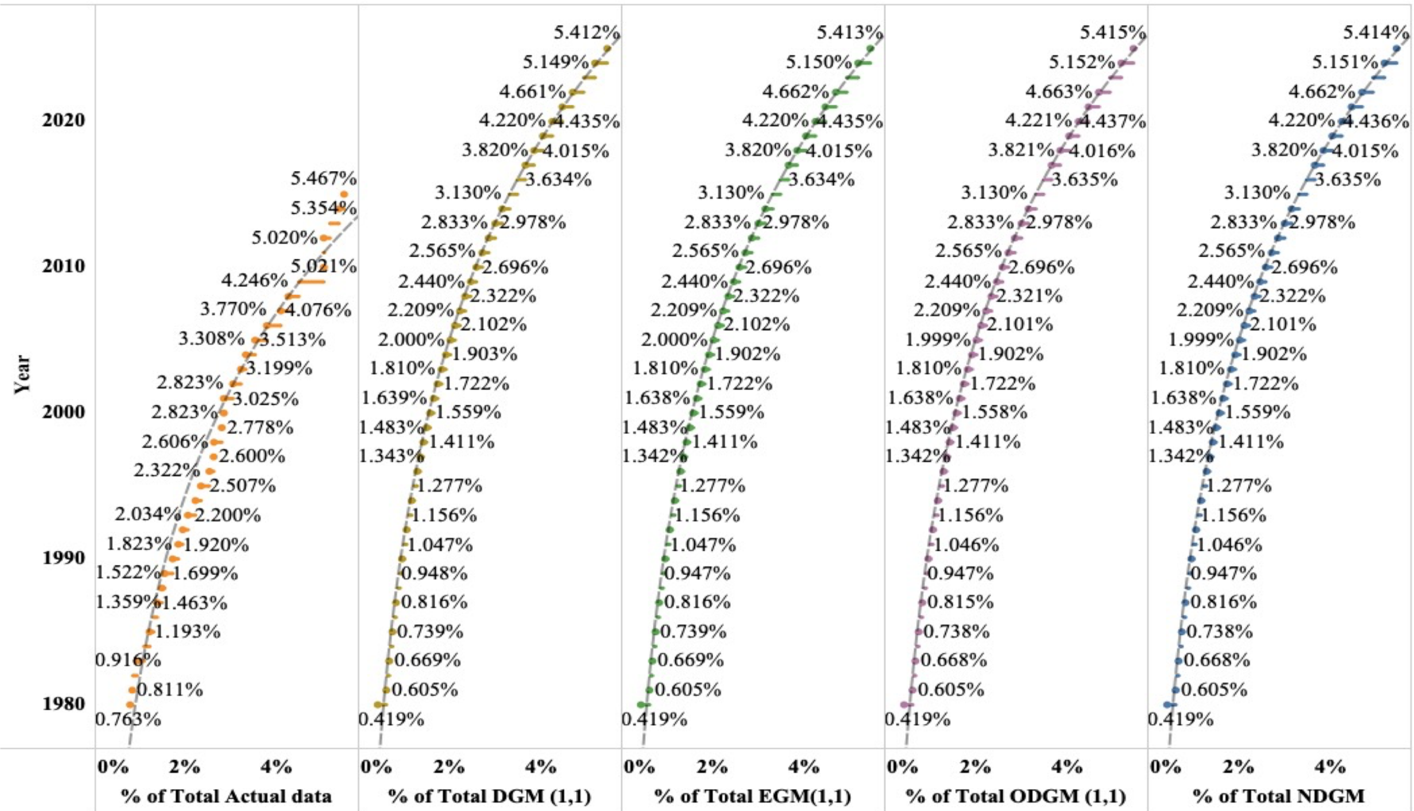

Figure 4(e): The exponential growth of natural gas as primary energy production source

Table 7: consumption of natural gas as primary source of energy

Years	Natural Gas	EGM (1,1)	ODGM (1,1)	DGM (1,1)	NDGM (1,1)
1980	2.771	2.771	2.771	2.771	2.771
1981	2.9023591	3.472181	3.471194	3.473315	3.47557
1982	2.957	3.692915	3.691995	3.694194	3.696532
1983	3.223	3.927683	3.926841	3.929119	3.931542
1984	3.829	4.177375	4.176625	4.178984	4.181493
1985	4.269	4.44294	4.442297	4.444739	4.447334
1986	4.547	4.725389	4.724869	4.727393	4.730077
1987	4.879	5.025793	5.025416	5.028023	5.030795

1988	5.301	5.345294	5.345079	5.347771	5.350632
1989	5.589	5.685107	5.685077	5.687852	5.690803
1990	6.162	6.046523	6.046701	6.04956	6.0526
1991	6.677	6.430914	6.431328	6.434271	6.437399
1992	6.953	6.839743	6.840421	6.843446	6.846661
1993	7.4	7.274561	7.275537	7.278642	7.281943
1994	8.016	7.737022	7.738329	7.741513	7.744898
1995	8.47534195	8.228883	8.23056	8.23382	8.237286
1996	9.16034503	8.752012	8.754101	8.757435	8.760978
1997	9.61334503	9.308398	9.310944	9.314347	9.317964
1998	9.72034503	9.900155	9.903208	9.906676	9.910361
1999	10.472345	10.52953	10.533145	10.536672	10.54042
2000	10.925345	11.19892	11.203152	11.206732	11.21054
2001	11.144	11.91086	11.915778	11.919403	11.92325
2002	12.085	12.66806	12.673734	12.677395	12.68128
2003	12.6777395	13.4734	13.479903	13.48359	13.48751
2004	13.2858732	14.32994	14.337352	14.341053	14.34499
2005	14.2277034	15.24092	15.249342	15.253045	15.25698
2006	15.7417722	16.20982	16.219344	16.223034	16.22695
2007	17.6813754	17.24032	17.251047	17.254707	17.25859
2008	18.4110878	18.33633	18.348376	18.351988	18.35582
2009	19.3910132	19.50201	19.515506	19.519048	19.52281
2010	21.5860605	20.7418	20.756875	20.760325	20.76399
2011	23.141088	22.06041	22.077208	22.080539	22.08407
2012	24.1898126	23.46284	23.481526	23.484709	23.48809
2013	24.9413294	24.95443	24.975173	24.978175	24.98136
2014	25.8099703	26.54084	26.563829	26.566615	26.56957
2015	25.6881209	28.2281	28.253538	28.256069	28.25875
2016		30.02263	30.05073	30.05296	30.05532
2017		31.93124	31.962239	31.964121	31.96611
2018		33.96118	33.995338	33.996819	33.99838
2019		36.12017	36.157762	36.158783	36.15985
2020		38.41642	38.457736	38.458233	38.45875
2021		40.85864	40.90401	40.903911	40.90379
2022		43.45612	43.50589	43.505119	43.50428
2023		46.21873	46.273275	46.271745	46.2701
2024		49.15696	49.216691	49.214309	49.21176
2025		52.28198	52.347336	52.344	52.34043

Table 10 presents the MAPE accuracy level for nuclear, renewable energy production as 95.87%, 95.84%, 95.85%, and 95.8% and for the consumption, we have MAPE accuracy as 95.84%, 95.81%, 95.82%, and 95.85% by four grey models respectively in table 11. Moreover, the identical results were derived for both cases where the NDGM model has shown slightly more forecasting validly as compared to EGM, ODGM, & DGM, as displayed in figure 4. According to EGM model, the resulted production parameters *a*= -0.046797 and *b*= 4.183374 and consumption parameters a= -0.046861, b= 4.179405 are represented in equation 32 & 33.

$$\hat{x}^{(0)}(N) = 4.183374(1 - \mathrm{e}^{-0.046797})\mathrm{e}^{0.046797(N-1)} \quad (32)$$

$$\hat{x}^{(0)}(N) = 4.179405(1 - \mathrm{e}^{-0.046861})\mathrm{e}^{0.046861(N-1)} \tag{33}$$

If we look at table 8, we see that the like coal and petroleum production and consumption energy sources, the original figures of nuclear and renewable energy production are not very high. Also, the simulated values calculated under all the four models are nearly equal to real data set, but minor difference started to increase from 2003 to 2015 e.g., in DGM model, the simulated between these years are 12.50309, 13.10205, 13.72971, 14.38743, 15.07666, 15.7989, 16.55575, 17.34886, 18.17995, 19.05086, 19.9635, 20.91985, 21.92201. While the original data between these years are 11.27745829, 12.51722195, 13.39359366, 14.25100375, 14.53881447, 15.57246454, 16.27170286, 18.20745574, 17.78564721, 18.15227122, 19.89955787, 22.05920123, and 23.37927224. Moreover, the prediction has been done for the year 2016 to 2025. Though all the predicted values during these years are the same with a very minor difference for the year 2025, value under the EGM model is 34.98812 and for ODGM, DGM and NDGM are 35.01284, 35.00254, and 35.00782 respectively.

In many Asia-pacific countries the consumption of natural gas has emerged as a positive source on other energy sources like coal and oil to reduce the impact of greenhouse. There is uprise shift can be seen in the consumption of natural gas in the whole Asia-Pacific region from 5.9 billion cubic meters (bcm) in 1965 to 722.5 bcm in 2016, an increase of nearly 123-fold, with an average annual growth rate of 9.7%. Furthermore, in 2016, the Asia-Pacific region as a whole contributes approximately 20.4% of the total world consumption of natural gas and has become the third largest global natural gas consumption region (Gong et al., 2020). Further, the APEC countries are on the track to promote the the adoption of green technology that helps in the production of renewable energy. The renewable energy production is increasing significantly in this region, with a growth rate of 2.5% annually. Furthermore, total install capacity will reach at 6235 GW by 2040 with renewable energy's share reaches 35% (APEC, 2016). In this study the exponential growth of natural gas consumption as primary energy production sources can be seen in figure 4(f).

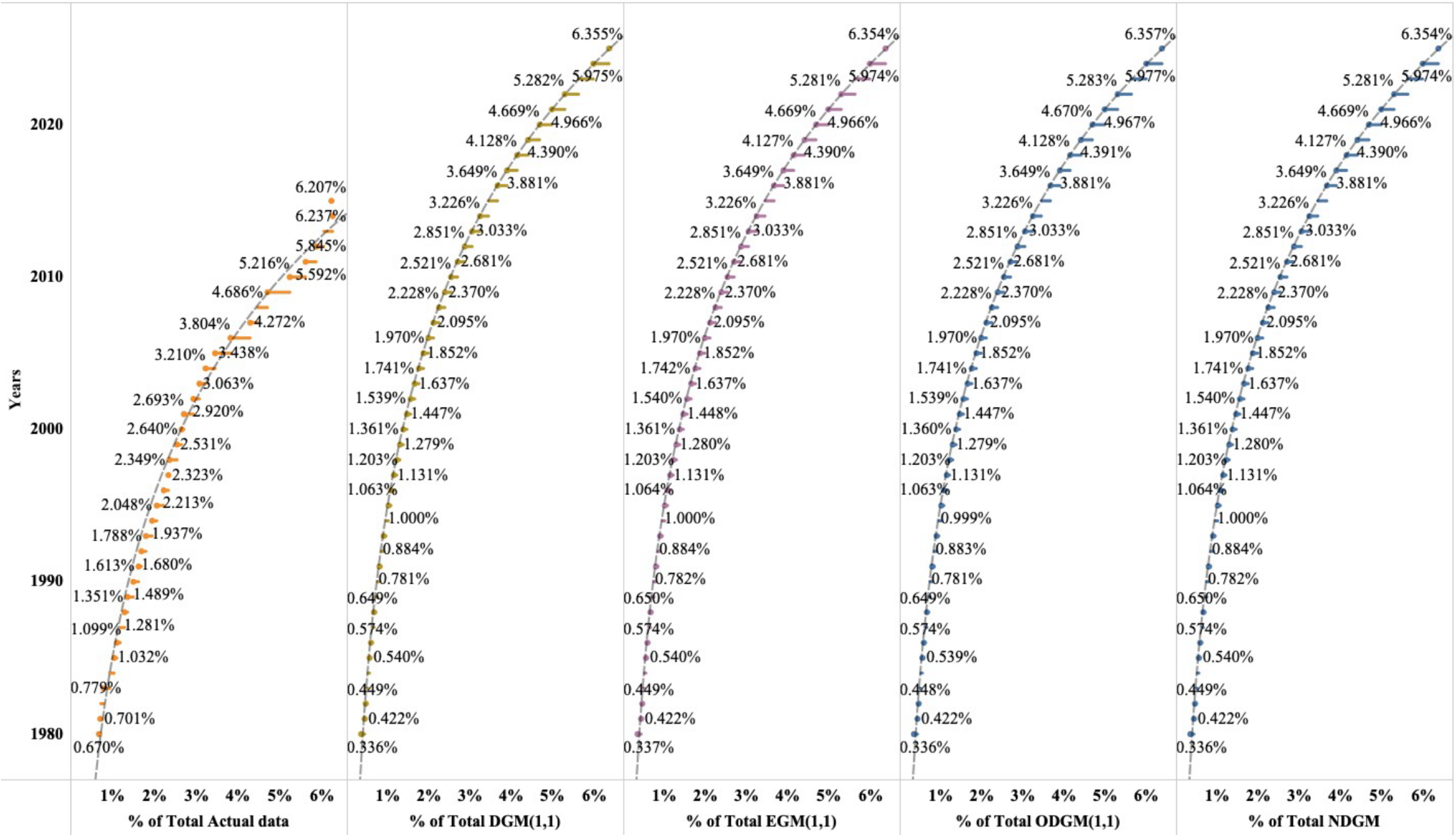

Figure 4(f): The exponential growth of natural gas consumption as primary energy source

Table 8: Nuclear, Renewables, and other as primary energy production

Years	Nuclear, Renewables, and Other	EGM (1,1)	ODGM (1,1)	DGM (1,1)	NDGM (1,1)
1980	3.770356485	3.770356	3.770356	3.770356	3.770356
1981	4.038232725	4.463441	4.462469	4.466169	4.464275
1982	4.289941774	4.677284	4.676363	4.680121	4.678198
1983	4.758248628	4.901371	4.900509	4.904322	4.902371
1984	5.080240645	5.136195	5.135399	5.139264	5.137286
1985	5.609354026	5.382269	5.381548	5.38546	5.383458
1986	5.943899436	5.640132	5.639495	5.643451	5.641427
1987	6.361237594	5.910349	5.909806	5.9138	5.911756
1988	6.592226571	6.193512	6.193073	6.197101	6.19504
1989	6.917651101	6.490242	6.489918	6.493973	6.491898
1990	7.293311752	6.801188	6.800991	6.805067	6.802982
1991	7.538053663	7.127031	7.126975	7.131064	7.128972
1992	7.512310933	7.468485	7.468583	7.472678	7.470583
1993	8.136148793	7.826299	7.826566	7.830657	7.828564
1994	8.567319056	8.201255	8.201707	8.205784	8.203698
1995	9.261492594	8.594175	8.594829	8.598883	8.596809
1996	9.408723952	9.00592	9.006794	9.010812	9.008757
1997	9.75804338	9.437391	9.438506	9.442475	9.440445
1998	10.26378883	9.889534	9.89091	9.894817	9.892819
1999	10.37183555	10.36334	10.365	10.36883	10.36687
2000	10.62397684	10.85984	10.86181	10.86555	10.86364

2001	11.35210871	11.38014	11.38244	11.38606	11.38421
2002	11.28079043	11.92536	11.92802	11.93151	11.92972
2003	11.27745829	12.4967	12.49975	12.50309	12.50138
2004	12.51722195	13.09541	13.09888	13.10205	13.10043
2005	13.39359366	13.72281	13.72674	13.72971	13.72819
2006	14.25100375	14.38027	14.38468	14.38743	14.38602
2007	14.53881447	15.06922	15.07417	15.07666	15.07538
2008	15.57246454	15.79118	15.7967	15.7989	15.79778
2009	16.27170286	16.54773	16.55386	16.55575	16.55479
2010	18.20745574	17.34053	17.34732	17.34886	17.34807
2011	17.78564721	18.17131	18.1788	18.17995	18.17937
2012	18.15227122	19.0419	19.05015	19.05086	19.0505
2013	19.89955787	19.95419	19.96325	19.9635	19.96337
2014	22.05920123	20.91019	20.92013	20.91985	20.91999
2015	23.37927224	21.91199	21.92287	21.92201	21.92245
2016		22.96179	22.97367	22.97219	22.97295
2017		24.06188	24.07484	24.07267	24.07378
2018		25.21468	25.22879	25.22587	25.22736
2019		26.42271	26.43805	26.43432	26.43623
2020		27.68861	27.70527	27.70065	27.70302
2021		29.01517	29.03323	29.02765	29.03051
2022		30.40528	30.42485	30.41822	30.42161
2023		31.86199	31.88316	31.87541	31.87938
2024		33.38849	33.41138	33.4024	33.407
2025		34.98812	35.01284	35.00254	35.00782

Renewable energy source refers to a source that doesn't deplete and can be replenished anytime. It is produced from the natural environment that doesn't pollute the environment while non-renewable energy sources not only pollute the environment but their formation takes billions of years and cannot be readily available from natural resources (Singh and Sushil, 2017; Ikram et al., 2021). For the nuclear, renewable production, by using the DGM based forecasting equation parameters resulted as β1=1.047905and β2=4.28555while its consumption parameters are estimated as β1=1.047972 and β2=4.281645 shown in equations 34 and 35 respectively.

$$\hat{x}^{(1)}(N) = [x^{(0)}(1) - \frac{4.28555}{1-1.047905}]1.047905^{N} + \frac{4.28555}{1-1.047905} \quad (34)$$

$$\hat{x}^{(1)}(N) = [x^{(0)}(1) - \frac{4.281645}{1-1.047972}]1.047972^{N} + \frac{4.281645}{1-1.047972} \quad (35)$$

Additionally, by NDGM forecasting equation parameters for production are estimated as β1= 1.133901, β2= -457.165268, β3= 4931.3784 and β4= 13.453014 and for the case of consumption we have β1= 1.133901, β2= -457.165268, β3= 4931.3784 and β4= 13.453014 respectively in the time series formula of NDGM.

In table 9, the original values for the year 1980 are starting from 3.775144 and remained the same until the year 1984 and continuing this way, the figures were nearly identical for many years that can be noticed in the table. Similarly, the values for EGM, ODGM, DGM, and NDGM for the year 1984 to 1987 were almost the same. Under the four grey models, the simulated values are starting from 1980 to 2015 and reached the level of 23 quadrillion British thermal units. The exponential growth of renewable production and consumptions as primary energy source can be seen in figure 4(g) and figure 4(h). The forecasted values calculated by the NDGM (1, 1) are 23.00587, 24.1095, 25.26608, 26.47814, 27.74834, 29.07948, 30.47448, 31.9364, 33.46844, and 35.07399 from the year 2016 to 2025. It can be noticed that the original value ended at 23.42615 quadrillion BTU and the predicted value is starting from 23 and ends at 35 until 2025. But under the EGM model, the first forecasted value is 22.9954 which is nearly equal to original and is different than the value predicted by ODGM, DGM, and NDGM.

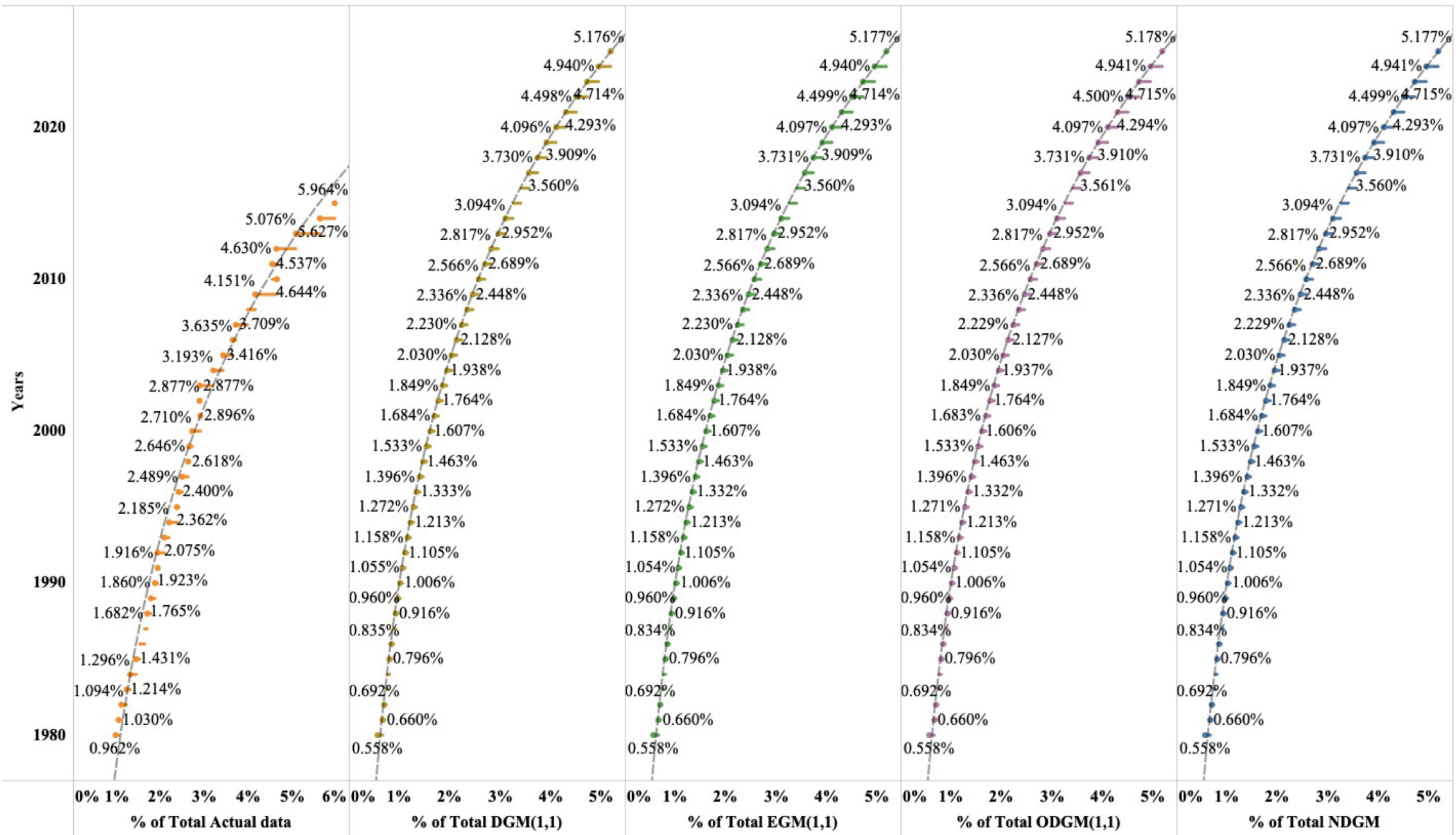

Figure 4(g): The exponential growth of nuclear, renewable and others production as primary energy sources

According to China's National Bureau of Statistics (NBS) the total energy consumption in China has increased to 2.9% which is about 4.36 gigatons (Yang and Shi, 2017). Since 2016, China is aiming to reduce the energy-intensive consumption (measured as energy consumption per unit of GDP) at 3.4%, with a reduction of 3.7% in 2017, and the share of coal in total energy consumption declined by 1.7 % (Enerdata, 2017). Moreover, China is emphasis on increase in production and consumption of gas, hydropower, nuclear, and wind energy increased by 1.5% in 2017, the electricity consumption increased by 6.6%. The Chinese National Energy Administration (NEA) stated that in 2017, there was a 5.5% growth in industrial power consumption.

The installed power generation capacity of the country grew by 137 GW to above 1,800 GW; during the year, with nearly 13 GW of hydropower capacity and nearly 46 GW of thermal capacity installed (Agency, 2017).

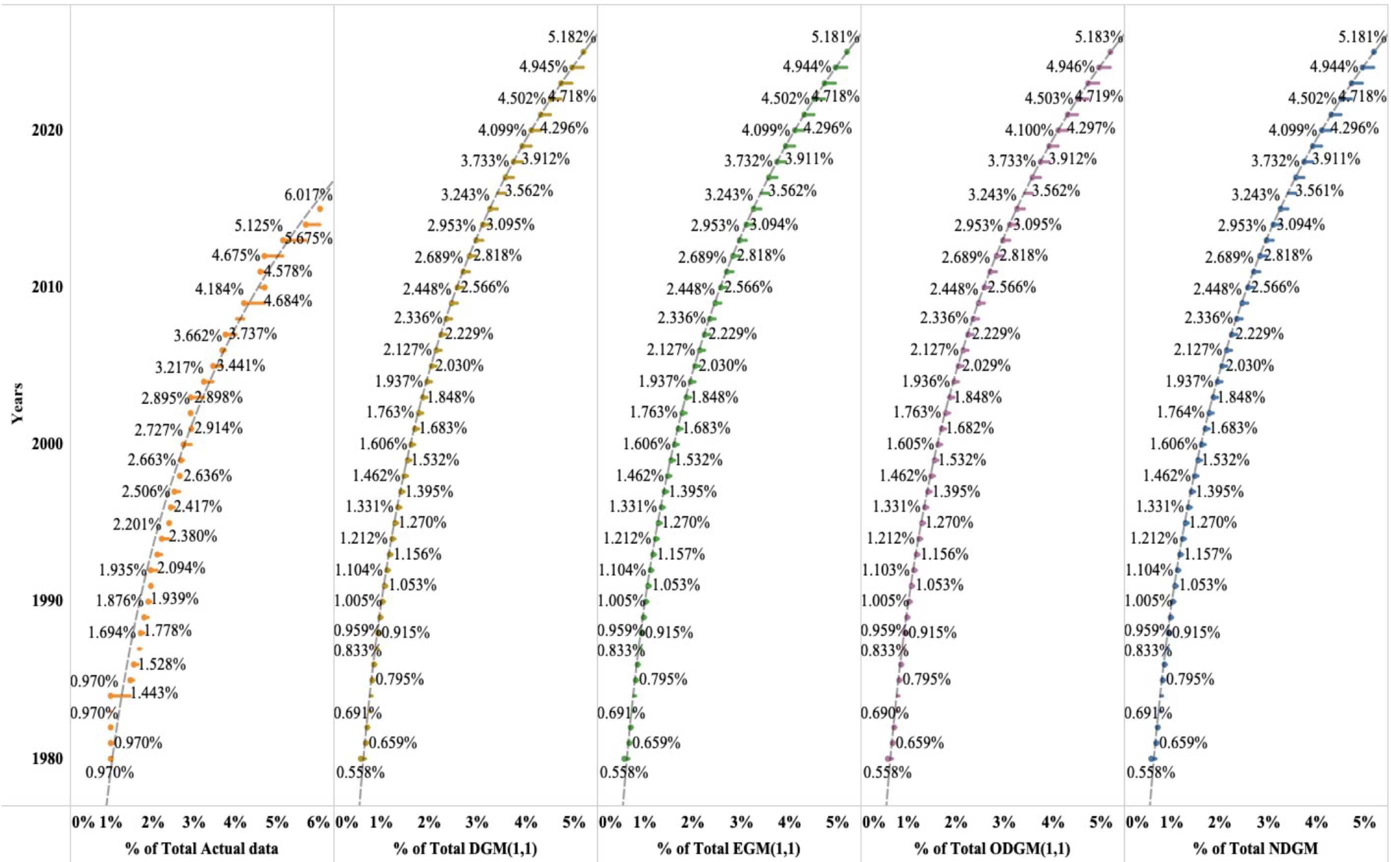

Figure 4(h): The exponential growth of nuclear, renewable and others consumption as primary energy sources

Table 9: consumption of Nuclear, Renewable etc. as primary source of energy

Years	Nuclear, Renewables, and Other	EGM (1,1)	ODGM (1,1)	DGM (1,1)	NDGM (1,1)
1980	3.775144	3.775144	3.775144	3.775144	3.775144
1981	3.775144	4.459998	4.459009	4.460833	4.462745
1982	3.775144	4.673974	4.673036	4.674889	4.676831
1983	3.775144	4.898215	4.897337	4.899217	4.901187
1984	3.775144	5.133215	5.132403	5.134309	5.136306
1985	5.616498	5.37949	5.378753	5.380682	5.382705
1986	5.948367	5.63758	5.636926	5.638878	5.640923
1987	6.366689	5.908052	5.907492	5.909463	5.911528
1988	6.595607	6.191501	6.191045	6.193033	6.195115
1989	6.922137	6.488548	6.488208	6.490209	6.492306
1990	7.302814	6.799847	6.799634	6.801646	6.803754
1991	7.547134	7.126081	7.126009	7.128028	7.130143
1992	7.53165	7.467967	7.468049	7.470071	7.472189
1993	8.150618	7.826255	7.826506	7.828527	7.830644
1994	8.569566	8.201732	8.20217	8.204184	8.206294
1995	9.264216	8.595224	8.595864	8.597867	8.599965
1996	9.409703	9.007594	9.008456	9.010441	9.012521
1997	9.756396	9.439748	9.440851	9.442813	9.444868
1998	10.26202	9.892636	9.894001	9.895933	9.897956
1999	10.36794	10.36725	10.3689	10.3708	10.37278
2000	10.6158	10.86464	10.8666	10.86845	10.87038
2001	11.34523	11.38589	11.38818	11.38997	11.39185
2002	11.27091	11.93214	11.9348	11.93653	11.93834
2003	11.28113	12.50461	12.50766	12.50931	12.51105
2004	12.52238	13.10454	13.10801	13.10958	13.11122
2005	13.39654	13.73325	13.73718	13.73865	13.74019
2006	14.25539	14.39213	14.39655	14.39791	14.39934
2007	14.5489	15.08261	15.08756	15.0888	15.0901
2008	15.57431	15.80623	15.81175	15.81285	15.814
2009	16.28959	16.56456	16.5707	16.57164	16.57262
2010	18.23372	17.35927	17.36607	17.36684	17.36764
2011	17.82249	18.19211	18.19962	18.2002	18.2008
2012	18.19859	19.0649	19.07318	19.07355	19.07393
2013	19.95086	19.97957	19.98867	19.9888	19.98894
2014	22.09218	20.93813	20.9481	20.94798	20.94785
2015	23.42615	21.94267	21.95359	21.95318	21.95275
2016		22.9954	23.00733	23.00662	23.00587
2017		24.09865	24.11166	24.11061	24.1095
2018		25.25482	25.26899	25.26757	25.26608
2019		26.46646	26.48187	26.48005	26.47814
2020		27.73623	27.75297	27.75071	27.74834
2021		29.06693	29.08508	29.08235	29.07948
2022		30.46146	30.48113	30.47789	30.47448
2023		31.9229	31.94419	31.94039	31.9364
2024		33.45445	33.47747	33.47307	33.46844
2025		35.05949	35.08435	35.07929	35.07399

To check the accuracy level of EGM, ODGM, DGM, and NDGM, MAPE % is being used here for our calculations which identifies the overall accuracy ratios as 94.05%, 94.07%, 94.34%, and 94.39% respectively for energy production given in table 10. The MAPE % comparison of EGM, ODGM, DGM and NDGM of total energy production for Asia & Oceania region can be seen in figure 5.

Table 10: MAPE % for energy production

Energy Production	EGM	ODGM	DGM	NDGM
Coal	7.63	7.71	7.61	7.52
Natural Gas	7.33	6.31	6.33	6.30
Petroleum & other liquids	4.69	5.53	4.53	4.50
Nuclear, Renewables and others	4.13	4.16	4.15	4.12
Average MAPE %	5.95	5.93	5.66	5.61
Overall accuracy Level %	**94.05**	**94.07**	**94.34**	**94.39**

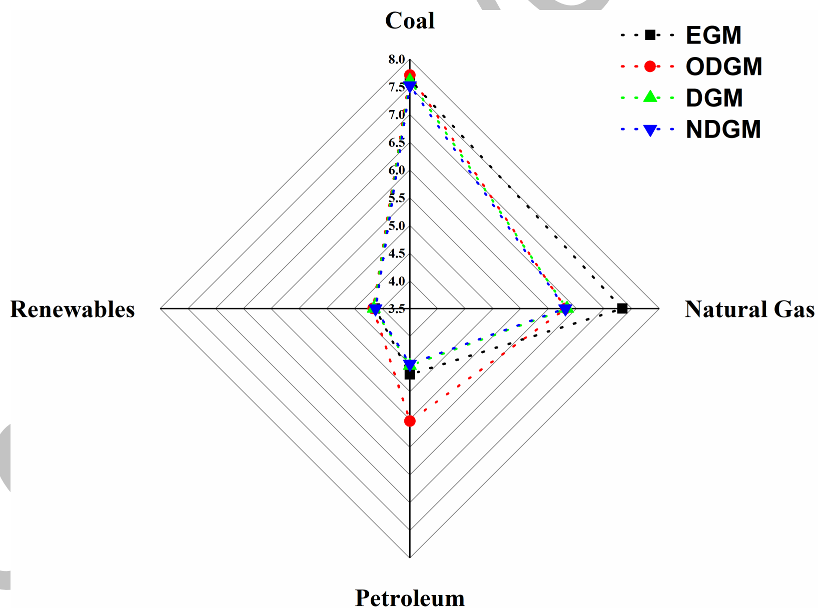

***Figure 5*:** MAPE % comparison of EGM, ODGM, DGM and NDGM for total energy production

While for the case of energy consumption, the overall MAPE % accuracy ratios are calculated as 94.57%, 94.71%, 94.71% & 94.73 % for EGM, OGM, DGM, and NDGM model respectively in table 11. It can be analyzed from both tables that NDGM is a best fit grey model due to a high percentage and slightly more effective to forecast renewable and nonrenewable energy consumption and production output for Asia and Oceania as compared to EGM, ODGM, and DGM model. The MAPE % comparison of EGM, ODGM, DGM and NDGM of total energy consumption for Asia & Oceania region can be seen in figure 6.

Table 11: MAPE % for energy consumption

Energy Consumption	EGM	ODGM	DGM	NDGM
Coal	8.62	8.56	8.54	8.50
Natural Gas	5.02	4.60	4.61	4.60
Petroleum & other liquids	3.93	3.82	3.82	3.81
Nuclear, Renewables and others	4.16	4.19	4.18	4.15
Average MAPE %	5.43	5.29	5.29	5.27
Overall accuracy Level %	**94.57**	**94.71**	**94.71**	**94.73**

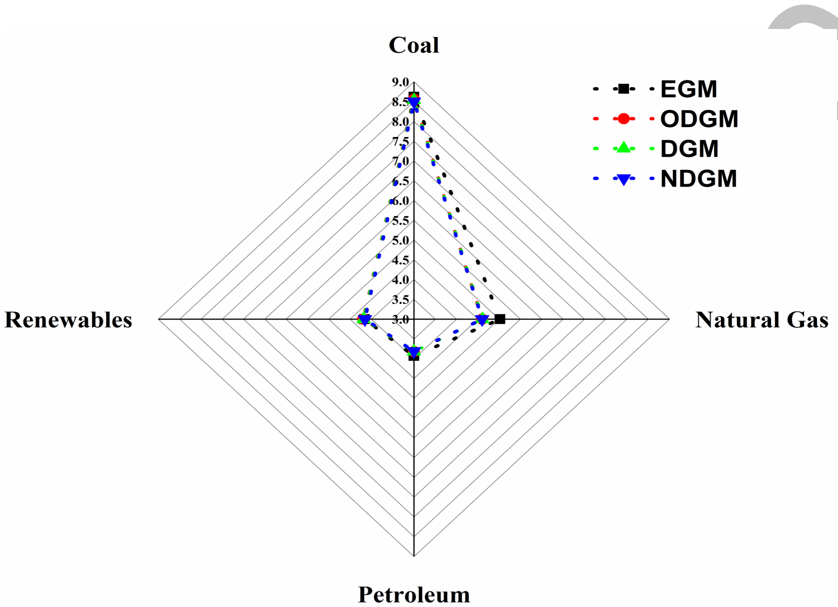

Figure 6: MAPE % comparison of EGM, ODGM, DGM and NDGM for total energy consumption

5. Conclusion and policy implication

5.1 Conclusion

This study developed a framework to measure the accurate estimation of energy consumption and production by renewable and non-renewable sources of Asia & Oceania region by using advance mathematical grey models namely Even, Discrete, Non-homogeneous Discrete and Optimized Discrete grey prediction models for the period of 2016 -2025. Further the MAPE % performance criteria was employed to measure the accuracy level of the models. This study confirms that the accuracy level of the NDGM model is better than the other three forecasting Even GM (1,1) and Discrete GM (1,1) grey and Optimized Discrete Grey models

(ODGM). The consumption and production of coal as a non-renewable energy source is comparative very high than any other energy source and depicted increasing trend overall in NDGM approach. And the difference between simulated and original data was found to be identical. While petroleum production remained consistent for many years, but the consumption of petroleum was comparatively higher than the production. As consumptions started with 23.07 quadrillion BTU in 1980, however, the production ended at 18.577 quads BTU in 2015. While the production and consumption of petroleum will reach approximately 21. 0465 and 93.750 quads BTU respectively, in 2025 and are projected to increase.

In the production of natural gas, though its production and consumption were not balanced both started with a figure around 2.60. However, the production and consumption in 2015 were 21.183421 and 28.25875, while a forecasted value under the NDGM for 2025 were 34.857892 & 52.34043 respectively. In nuclear and other renewable energy sources, through NDGM approach, the production was high as compared to its consumption. However, in all other cases, the situation was inverse because their consumption was high then its production. Surprisingly, its production and consumption as a primary energy source in 1980 started with 3.77 in 2015 it was 21.92 and forecasted values is almost the same under the NDGM model i.e., 35 quads BTU.

5.2 Policy Implications

To summarize, our study showed an increasing trend which is a serious threat in future. Therefore, this study formulates the policy recommendations to minimize the usage of non-renewable resources. The integration of resource and environmental concerns is important. For this purpose, we need to upgrade the effectiveness and quality of energy development and change the amount of energy consumed to meet our energy-saving and emission-reduction targets (Cucchiella et al., 2015). In addition, we need to transform the energy system and move from over-reliance on nonrenewable sources to greater dependency on modern and renewable sources. Although renewable sources cannot entirely replace non-renewable sources in the short term; therefore, with the advent of new technologies, new energy sources can be incorporated through production and lifestyles. The extensive need for new energy sources is one of the most effective means of alleviating this growing burden on carbon management to increase this supply–demand disparity and minimize the carbon emission.

Nuclear, solar and wind energies are indeed environmentally friendly and renewable sources of energy. Considering the challenge of the depletion of non-renewable resources, such as coal, petroleum, and natural gas, etc., and the degradation of the atmosphere, renewable energy options can eventually replace these sources in the future due to the economic and environmental advantages of the former. We are optimistic that renewable technology will lead to new advancements in the future (Sushil et al., 2016). Moreover, policymakers must consider the United Nations Sustainable Development Goals (SDGs) while developing the policies and procedures towards environmental sustainability.

There are some limitations of this study. we employed four grey forecasting models such as EGM, DGM, ODGM and NDGM to predict the future trends of total energy consumption and prediction of Asia & Oceania region. Moreover, this study forecast the growth trends in Asia & Oceania region until 2025. As climate change is an emergent issue, the future research can be conducted by undertaking the comparative analysis between different regions. Further the other grey forecasting models can be utilized such as grey wolf optimizer prediction model, variable speed, and adaptive structure model and grey fractional model. The future research can also be conducted by considering the doubling time models to analyze how much total time will it take the Asia & Oceania region to increase the production of their renewable energy.

Ethics Declarations

Ethics approval

This study used secondary data and did not involve any human or animal subjects.

Conflict of Interest
The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Availability of Data and Materials
The data used in the current study is available publicly at International Energy Agency (IEA) website.

Funding

The author(s) received no financial support for the research, authorship, and/or publication of this article.

References

Agency, I. E. (2017). Global Energy & CO2 Status Report. *Global Energy & CO2 Status Report*, *March*, 1–15.

Ali, C. H., Qureshi, A. S., Mbadinga, S. M., Liu, J.-F., Yang, S.-Z., & Mu, B.-Z. (2017). Biodiesel production from waste cooking oil using onsite produced purified lipase from Pseudomonas aeruginosa FW_SH-1: Central composite design approach. *Renewable Energy*, *109*, 93–100.

Apergis, N., Payne, J. E., Menyah, K., & Wolde-Rufael, Y. (2010). On the causal dynamics between emissions, nuclear energy, renewable energy, and economic growth. *Ecological Economics*, *69*(11), 2255–2260.

Appolloni, A., D'Adamo, I., Gastaldi, M., Santibanez-Gonzalez, E. D. R., & Settembre-Blundo, D. (2021). Growing e-waste management risk awareness points towards new recycling scenarios: The view of the Big Four's youngest consultants. *Environmental Technology & Innovation*, *23*, 101716. https://doi.org/10.1016/j.eti.2021.101716

Bhattacharya, M., Paramati, S. R., Ozturk, I., & Bhattacharya, S. (2016). The effect of renewable energy consumption on economic growth: Evidence from top 38 countries. *Applied Energy*, *162*, 733–741.

BP. (2017). *British Petroleum Report*. https://www.bp.com/content/dam/bp/business-sites/en/global/corporate/pdfs/investors/bp-annual-report-and-form-20f-2017.pdf

Central Statistics Office, Ministry of Statistics and Programme Implementation, & Government of India. (2016). Central Statistics Office Ministry of Statistics and Programme Implementation Government of India www.mospi.gov.in. *Mospiold. Nic. In/Mospi_New/Upload/Energy_Statistics_2017. Pdf*, 104. http://mospi.nic.in/sites/default/files/publication_reports/ElderlyinIndia_2016.pdf

Cucchiella, F., D'Adamo, I., & Gastaldi, M. (2015). Financial analysis for investment and policy decisions in the renewable energy sector. *Clean Technologies and Environmental Policy*, *17*(4), 887–904. https://doi.org/10.1007/s10098-014-0839-z

D'Adamo, I., Falcone, P. M., Huisingh, D., & Morone, P. (2021). A circular economy model based on biomethane: What are the opportunities for the municipality of Rome and beyond? *Renewable Energy*, *163*, 1660–1672. https://doi.org/10.1016/j.renene.2020.10.072

D'Adamo, I., Gastaldi, M., & Morone, P. (2020). The post COVID-19 green recovery in practice: Assessing the profitability of a policy proposal on residential photovoltaic plants. *Energy Policy*, *147*, 111910. https://doi.org/10.1016/j.enpol.2020.111910

D'Adamo, I., Gastaldi, M., & Rosa, P. (2021). ASSESSING ENVIRONMENTAL AND ENERGETIC INDEXES IN 27 EUROPEAN COUNTRIES. *International Journal of Energy Economics and Policy*, *11*(3), 417–423. https://doi.org/10.32479/ijeep.11169

Deb, C., Zhang, F., Yang, J., Lee, S. E., & Shah, K. W. (2017). A review on time series forecasting techniques for building energy consumption. In *Renewable and Sustainable Energy Reviews*. https://doi.org/10.1016/j.rser.2017.02.085

Duan, H., Lei, G. R., & Shao, K. (2018). Forecasting crude oil consumption in China using a grey prediction model with an optimal fractional-order accumulating operator. *Complexity*, *2018*.

https://doi.org/10.1155/2018/3869619
Dudin, M. N., Reshetov, K. Y., Mysachenko, V. I., Mironova, N. N., & Divnenko, O. V. (2017). " Green Technology" and Renewable Energy in the System of the Steel Industry in Europe. *International Journal of Energy Economics and Policy*, *7*(2), 310–315.
El-Fouly, T. H. M., El-Saadany, E. F., & Salama, M. M. A. (2006). Grey Predictor for Wind Energy Conversion Systems Output Power Prediction. *IEEE Transactions on Power Systems*, *21*(3), 1450–1452. https://doi.org/10.1109/TPWRS.2006.879246
Enerdata. (2017). *World Energy Consumption Statistics*. Global Energy Statistical Yearbook 2017.
Faizah, S. I., & Husaeni, U. A. (2018). Development of Consumption and Supplying Energy in Indonesia's Economy. *International Journal of Energy Economics and Policy*, *8*(6), 313–321.
Feng, S. J., Ma, Y. D., Song, Z. L., & Ying, J. (2012). Forecasting the energy consumption of China by the grey prediction model. *Energy Sources, Part B: Economics, Planning, and Policy*, *7*(4), 376–389.
Furlan, C., & Mortarino, C. (2018). Forecasting the impact of renewable energies in competition with non-renewable sources. *Renewable and Sustainable Energy Reviews*, *81*, 1879–1886.
Ghazouani, T., Boukhatem, J., & Yan Sam, C. (2020). Causal interactions between trade openness, renewable electricity consumption, and economic growth in Asia-Pacific countries: Fresh evidence from a bootstrap ARDL approach. *Renewable and Sustainable Energy Reviews*, *133*, 110094. https://doi.org/10.1016/j.rser.2020.110094
Giest, S., & Mukherjee, I. (2018). Behavioral instruments in renewable energy and the role of big data: A policy perspective. *Energy Policy*, *123*, 360–366.
Gong, C., Gong, N., Qi, R., & Yu, S. (2020). Assessment of natural gas supply security in Asia Pacific: Composite indicators with compromise Benefit-of-the-Doubt weights. *Resources Policy*, *67*, 101671. https://doi.org/10.1016/j.resourpol.2020.101671
Gupta, S., Chen, H., Hazen, B. T., Kaur, S., & Santibañez Gonzalez, E. D. R. (2019). Circular economy and big data analytics: A stakeholder perspective. *Technological Forecasting and Social Change*, *144*, 466–474. https://doi.org/10.1016/j.techfore.2018.06.030
Hsu, L.-C. (2011). Using improved grey forecasting models to forecast the output of opto-electronics industry. *Expert Systems with Applications*, *38*(11), 13879–13885.
Ikram, M., Mahmoudi, A., Shah, S. Z. A., & Mohsin, M. (2019). Forecasting number of ISO 14001 certifications of selected countries: application of even GM (1,1), DGM, and NDGM models. *Environmental Science and Pollution Research*, *26*(12), 12505–12521. https://doi.org/10.1007/s11356-019-04534-2
Ikram, M., Sroufe, R., Zhang, Q., & Ferasso, M. (2021). Assessment and prediction of environmental sustainability: novel grey models comparative analysis of China vs. the USA. *Environmental Science and Pollution Research*, *28*(14), 17891–17912. https://doi.org/10.1007/s11356-020-11418-3
Ikram, M., Zhang, Q., Sroufe, R., & Ferasso, M. (2021). Contribution of Certification Bodies and Sustainability Standards to Sustainable Development Goals: An Integrated Grey Systems Approach. *Sustainable Production and Consumption*, *28*, 326–345. https://doi.org/10.1016/j.spc.2021.05.019
International Energy Agency, & Agency, I. E. (2011). Key World Energy. In *Statistics*. https://doi.org/http://dx.doi.org/10.1787/weo-2011-en
Ito, K. (2017). CO2 emissions, renewable and non-renewable energy consumption, and economic growth: Evidence from panel data for developing countries. *International Economics*, *151*, 1–6.
Jacobson, M. Z., Delucchi, M. A., Bauer, Z. A., Goodman, S. C., Chapman, W. E., Cameron, M. A., Bozonnat, C., Chobadi, L., Clonts, H. A., & Enevoldsen, P. (2017). 100% Clean and Renewable Wind, Water, and Sunlight All-Sector Energy Roadmaps for 139 Countries of the World, Joule 1 (2017) 1–14. doi: 10.1016/j. joule. 2017.07. 005. *URL Https://Doi. Org/10.1016/j. Joule*, *5*.
Javed, S. A., & Liu, S. (2018). Predicting the research output/growth of selected countries: application of Even GM (1, 1) and NDGM models. *Scientometrics*, *115*(1), 395–413.
Jiang, P., Yang, H., & Ma, X. (2019). Coal production and consumption analysis, and forecasting of related carbon emission: evidence from China. *Carbon Management*, *10*(2), 189–208. https://doi.org/10.1080/17583004.2019.1577177
Ketsetzi, A., & Capraro, M. M. (2016). Renewable energy sources. In *A Companion to Interdisciplinary*

Stem Project-Based Learning: For Educators by Educators (Second Edition). https://doi.org/10.1007/978-94-6300-485-5_17

Koçak, E., & Şarkgüneşi, A. (2017). The renewable energy and economic growth nexus in Black Sea and Balkan countries. *Energy Policy*, *100*, 51–57.

Kusakci, A. O., & Ayvaz, B. (2016). Electrical energy consumption forecasting for Turkey using grey forecasting technics with rolling mechanism. *Conference Proceedings of 2015 2nd International Conference on Knowledge-Based Engineering and Innovation, KBEI 2015*. https://doi.org/10.1109/KBEI.2015.7436013

Lewis, C. D. (1982). Industrial and business forecasting methods. *Journal of Forecasting*, *2*(2), 194–196.

Liu, F., & Lv, T. (2019). Assessment of geographical distribution of photovoltaic generation in China for a low carbon electricity transition. *Journal of Cleaner Production*, *212*, 655–665.

Liu, G., Dong, X., Kong, Z., Jiang, Q., & Li, J. (2021). The role of China in the East Asian natural gas premium. *Energy Strategy Reviews*, *33*, 100610. https://doi.org/10.1016/j.esr.2020.100610

Liu, S., Yang, Y., & Forrest, J. (2017a). Grey Data Analysis. In *Computational Risk Management* (Issue Deng 1990). Springer Singapore. https://doi.org/10.1007/978-981-10-1841-1

Liu, S., Yang, Y., & Forrest, J. (2017b). *Grey Data Analysis*. Springer.

Menegaki, A. N. (2011). Growth and renewable energy in Europe: a random effect model with evidence for neutrality hypothesis. *Energy Economics*, *33*(2), 257–263.

Menyah, K., & Wolde-Rufael, Y. (2010). CO2 emissions, nuclear energy, renewable energy and economic growth in the US. *Energy Policy*, *38*(6), 2911–2915.

Nadimi, R., & Tokimatsu, K. (2017). Analyzing of Renewable and Non-Renewable Energy consumption via Bayesian Inference. *Energy Procedia*, *142*, 2773–2778.

Nugraha, A. T., & Osman, N. H. (2018). CO2 emissions, economic growth, energy consumption, and household expenditure for Indonesia: Evidence from cointegration and vector error correction model. *International Journal of Energy Economics and Policy*, *9*(1), 291–298.

Ou, S.-L. (2012). Forecasting agricultural output with an improved grey forecasting model based on the genetic algorithm. *Computers and Electronics in Agriculture*, *85*, 33–39.

Pi, D., Liu, J., & Qin, X. (2010). A Grey Prediction Approach to Forecasting Energy Demand in China. *Energy Sources, Part A: Recovery, Utilization, and Environmental Effects*, *32*(16), 1517–1528. https://doi.org/10.1080/15567030902780360

Rehman, E., Ikram, M., Feng, M. T., & Rehman, S. (2020). Sectoral-based CO2 emissions of Pakistan: a novel Grey Relation Analysis (GRA) approach. *Environmental Science and Pollution Research*, *27*(23), 29118–29129. https://doi.org/10.1007/s11356-020-09237-7

Rehman, E., Ikram, M., Rehman, S., & Feng, M. T. (2021). Growing green? Sectoral-based prediction of GHG emission in Pakistan: a novel NDGM and doubling time model approach. *Environment, Development and Sustainability*, *23*(8), 12169–12191. https://doi.org/10.1007/s10668-020-01163-5

Ren, Y., Suganthan, P. N., & Srikanth, N. (2015). Ensemble methods for wind and solar power forecasting - A state-of-the-art review. In *Renewable and Sustainable Energy Reviews* (Vol. 50, pp. 82–91). https://doi.org/10.1016/j.rser.2015.04.081

Salari, M., Kelly, I., Doytch, N., & Javid, R. J. (2021). Economic growth and renewable and non-renewable energy consumption: Evidence from the U.S. states. *Renewable Energy*, *178*, 50–65. https://doi.org/10.1016/j.renene.2021.06.016

Sheikh, A. H. A., Ikram, M., Ahmad, R. M., Qadeer, H., & Nawaz, M. (2019). Evaluation of key factors influencing process quality during construction projects in Pakistan. *Grey Systems: Theory and Application*, *9*(3), 321–335. https://doi.org/10.1108/gs-01-2019-0002

Shukla, S. K., Sushil, & Sharma, M. K. (2019). Managerial Paradox Toward Flexibility: Emergent Views Using Thematic Analysis of Literature. *Global Journal of Flexible Systems Management*, *20*(4), 349–370. https://doi.org/10.1007/s40171-019-00220-x

Siagian, U., Yuwono, B., Fujimori, S., & Masui, T. (2017). Low-Carbon Energy Development in Indonesia in Alignment with Intended Nationally Determined Contribution (INDC) by 2030. *Energies*, *10*(1), 52. https://doi.org/10.3390/en10010052

Singh, A., & Sushil. (2017). Developing a conceptual framework of waste management in the organizational context. *Management of Environmental Quality: An International Journal*, *28*(6),

786–806. https://doi.org/10.1108/MEQ-07-2016-0045
Singh, A., Sushil, Kar, S., & Pamucar, D. (2019). Stakeholder role for developing a conceptual framework of sustainability in organization. *Sustainability (Switzerland)*, *11*(1), 208. https://doi.org/10.3390/su11010208
Squalli, J. (2017). Renewable energy, coal as a baseload power source, and greenhouse gas emissions: Evidence from US state-level data. *Energy*, *127*, 479–488.
Sushil. (2015). Valuation of Flexibility. *Global Journal of Flexible Systems Management*, *16*(3), 219–220. https://doi.org/10.1007/s40171-015-0100-6
Sushil, B., Kanika, T., & Singh, S. P. (2016). *Managing Flexibility, People, Process, Technology and Business. eBook ISBN 978-81-322-2380-1*. India: Springer.
Tabasi, S., Aslani, A., & Forotan, H. (2016). Prediction of energy consumption by using regression model. *Computational Research Progress in Applied Science & Engineering*, *2*.
Tugcu, C. T., Ozturk, I., & Aslan, A. (2012). Renewable and non-renewable energy consumption and economic growth relationship revisited: evidence from G7 countries. *Energy Economics*, *34*(6), 1942–1950.
US Energy Information Administration. (2017). International Energy Outlook 2017 Overview. In *U.S. Energy Information Administration* (Vol. IEO2017, Issue 2017). https://doi.org/www.eia.gov/forecasts/ieo/pdf/0484(2016).pdf
Vasconcelos, A. L. S., Cherubin, M. R., Feigl, B. J., Cerri, C. E. P., Gmach, M. R., & Siqueira-Neto, M. (2018). Greenhouse gas emission responses to sugarcane straw removal. *Biomass and Bioenergy*, *113*, 15–21.
Wang, H., Di Pietro, G., Wu, X., Lahdelma, R., Verda, V., & Haavisto, I. (2018). Renewable and sustainable energy transitions for countries with different climates and renewable energy sources potentials. *Energies*, *11*(12), 3523.
Wang, Z.-X., & Ye, D.-J. (2017). Forecasting Chinese carbon emissions from fossil energy consumption using non-linear grey multivariable models. *Journal of Cleaner Production*, *142*, 600–612. https://doi.org/10.1016/j.jclepro.2016.08.067
Wu, L. F., Liu, S. F., Cui, W., Liu, D. L., & Yao, T. X. (2014). Non-homogenous discrete grey model with fractional-order accumulation. *Neural Computing and Applications*, *25*(5), 1215–1221. https://doi.org/10.1007/s00521-014-1605-1
Wu, W., Ma, X., Zeng, B., Wang, Y., & Cai, W. (2019). Forecasting short-term renewable energy consumption of China using a novel fractional nonlinear grey Bernoulli model. *Renewable Energy*, *140*, 70–87.
Yang, S., & Shi, L. (2017). Prediction of long-term energy consumption trends under the New National Urbanization Plan in China. *Journal of Cleaner Production*, *166*, 1144–1153. https://doi.org/10.1016/j.jclepro.2017.08.092
Ye, B., Yang, P., Jiang, J., Miao, L., Shen, B., & Li, J. (2017). Feasibility and economic analysis of a renewable energy powered special town in China. *Resources, Conservation and Recycling*, *121*, 40–50.
Zeng, B., & Li, C. (2016). Forecasting the natural gas demand in China using a self-adapting intelligent grey model. *Energy*, *112*, 810–825.

Key Questions

1. What are the future trends of renewable and non-renewable energy production and consumption in Asia & Oceania region?
2. How to transform the energy system and move from over-reliance on non-renewable sources to greater dependency on modern and renewable sources?
3. Do grey forecasting models ensure accuracy and higher performance?

Dr. Muhammad Ikram works as Assistant Professor of Management at School of Business Administration (SBA) Al Akhawayn University in Ifrane, Morocco. He worked as Postdoc. researcher at College of Management, Institute of Business Analytics and Supply Chain Management, Shenzhen University. Dr. Ikram holds a Ph.D. degree in Management Sciences and Engineering from Nanjing University of Aeronautics and Astronautics (NUAA), China. Dr. Ikram is head of AYRS Research Group of CSR and Director (Industry-Academia Linkages) of Greysys foundation. He has more than 30 publications in the prestigious scientific journals indexed/ranked includes SSCI, SCI, Scopus, ABS, and ABDC. One of his papers awarded the most cited paper in Sustainable Production and Consumption journal. Dr. Ikram serves as Articles' editor in SAGE Open and Guest Editor of Environmental Science and Pollution Research journal. His teaching and research interests include Corporate Social Responsibility (CSR), Sustainable Development Goals (SDGs), Organizational Behavior, Corporate Sustainability, Integrated Management System (IMS), Grey Modeling, Operation Management, Energy Economics, Environmental Sustainability, and Supply Chain Management.