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Simulation of Flow Pattern through a Three-Bucket Savonius Wind Turbine by Using a Sliding Mesh Technique

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Abstract

Vertical axis wind turbine (VAWT) type Savonius rotor is self-starting, inexpensive, less technicality & high productivity wind machine, which can accept wind from any direction without orientation, and provides high starting torque. The investigations of aerodynamic parameters and the flow pattern of the turbulent flow through the rotor have high aspect on Savonius wind turbine performance. The flow pattern through a three buckets Savonius rotor model of 10cm diameter inside smoke wind tunnel with high-speed camera was investigated experimentally. The commercial code FLUENT 6.3.26 used to simulate the turbulent flow ($M<0.3$,$Re>2000$) by RNG K−ε turbulent model. Two-dimensional model carried out the simulation of the flow pattern, velocities and pressures of airflow within a Savonius wind rotor placed in Smoke wind tunnel. The domain of the airflow dived for two zone, first zone up and down stream flow meshed by fixed structured grid generation. The second zone is around Savonius rotor; the flow pattern created by a pitched blade rotor was calculated by using a sliding mesh technique with unstructured grid generation. Three time steps between two blades of rotor is taken, which give three angular orientations of blades.

The CFD results show good agree with experimental results of flow pattern. It is concluded that the sliding mesh method is suitable for the prediction of flow patterns around wind turbine. Then after ensured from the reliability of CFD simulation, it can be used for studying the velocity contour and the pressure distribution around the turbine.

1.Introduction

Computational fluid dynamics models are now regularly used to calculate the flow patterns in the Savonius wind rotor turbine. To model the turbine, it is common to prescribe experimentally obtained velocity data in the outflow of the turbine, see e.g. Bakker and Van den Akker [1]. This has the disadvantage that it is often necessary to extrapolate the data to situations for which no experiments were or can be performed. Only recently have methods become available to explicitly calculate the flow pattern around the turbine blades without prescribing any experimental data. The sliding mesh method is a novel way of dealing with the turbine blades-wind interaction. The main advantage of the sliding mesh method is that no experimentally obtained boundary conditions are needed, as the flow around the turbine blades is being calculated in detail [2]. This allows modeling of Savonius wind rotor turbine systems for which experimental data is difficult or impossible to obtain. The purpose of this paper is to report on initial studies to the suitability of this novel method for the prediction of the flow pattern, velocity contour, and the pressure distribution through the wind turbines. We will first discuss the sliding mesh method, then present computational results and a comparison with experimental data, and finally the simulated velocity contour and pressure distribution will be discussed over a three time steps of three blade Savonius wind turbine.

2. Sliding Mesh Method

Dynamic sliding mesh simulations are required in several engineering applications such as wind turbine analysis and require an efficient implementation of non-conformal mesh joining. A variety of capabilities to handle such mesh configurations exist and include finite element-based multipoint constraint methods [3], interface capture and tracking methods [4] and cell centered finite volume methods (CCFVM) in which a flux matching protocol is employed [5], where care is required to reconstruct a conservative area representation between the two blocks [6].

With the sliding mesh method the wind tunnel is divided in two regions that are treated separately:, first zone up and down stream flow meshed by fixed structured grid generation, The second zone is around Savonius rotor; the flow pattern created by a pitched blade rotor was calculated by using a sliding mesh technique with unstructured grid generation. See Figure 1

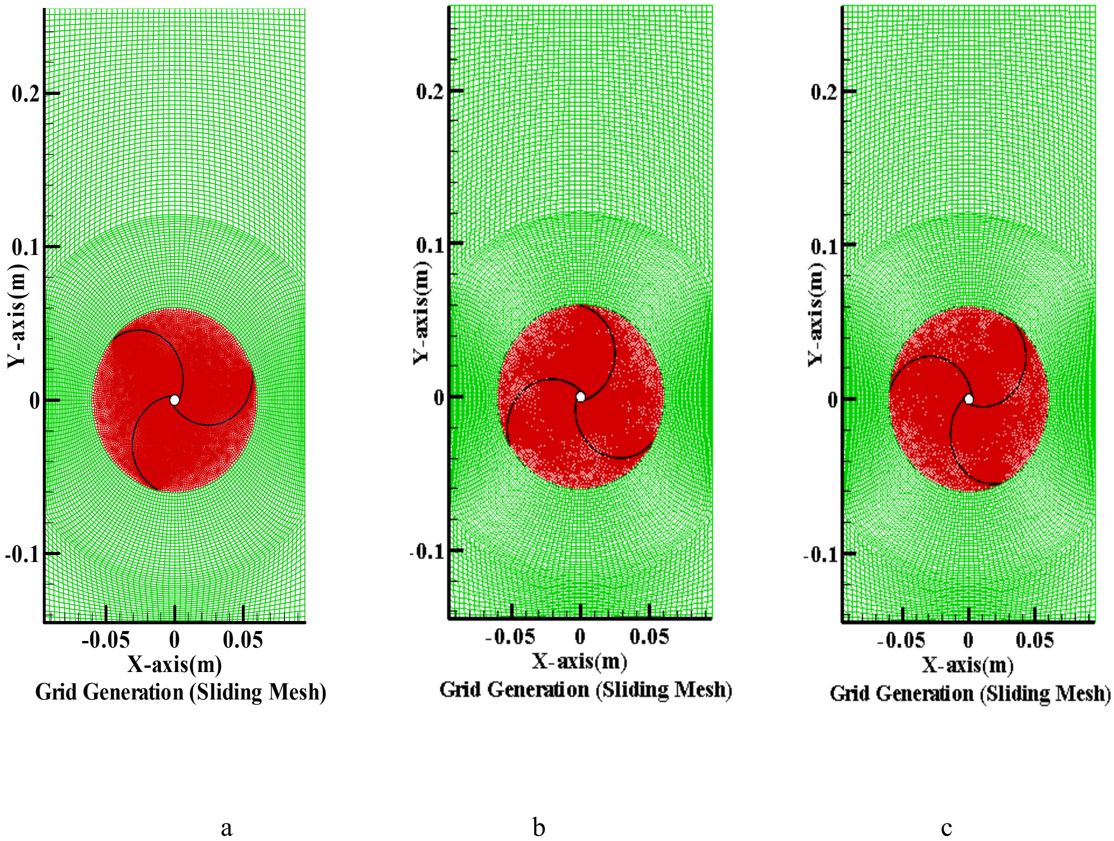


Figure 1. Grid Used in The Sliding Mesh Method With Different Time Steps: (a) at Time (t)=0.02062 s, (b) at Time (t) =0.08247 s, (c) at Time (t) =0.1649 s.

3.Turbulent Sliding Mesh

In the wind tunnel region the standard conservation equations for mass and momentum are solved. In the rotating turbine region a modified set of balance equations is solved:

$$\partial/(\partial x\_j)(u\_j - v\_j) = 0$$
……………..…….. (1)

$$\partial/\partial t\, pu\_i + \partial/(\partial x\_j)\, p(u\_j - v\_j)\, u\_i = -\partial p/(\partial x\_i) + (\partial \tau\_ij)/(\partial x\_j)$$ ……………...……. (2)

Where: u is the wind velocity in a stationary reference frame
v is the velocity component arising from mesh motion
p is the pressure and
τ_{ij} is the stress tensor

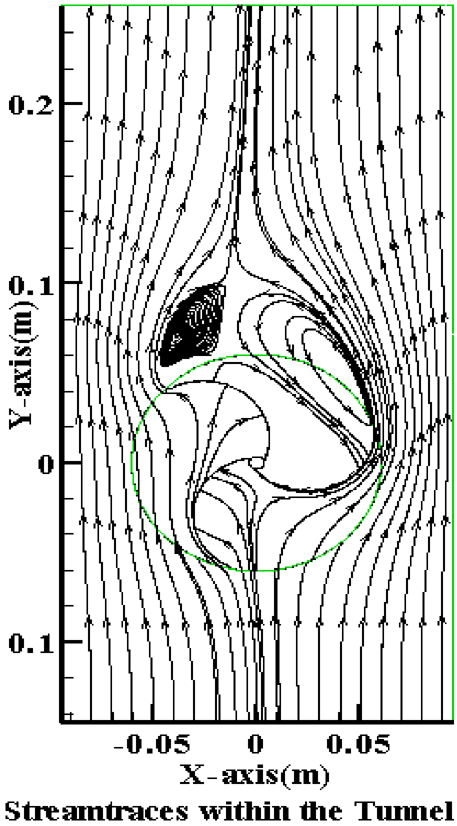
The first equation is the modified continuity equation and the second equation is the modified momentum balance. At the sliding interface a conservative interpolation is used for both mass and momentum, using a set of fictitious control volumes. No-slip boundary conditions are used at the turbine blades, the shaft, and the tunnel walls. No experimental data is prescribed in the outflow of the turbine. All fluid motion strictly arises from the rotation of the turbine blades. The grid was generated with a proprietary program named GSMMBIT 2.2.30. The total number of mesh was approximately 50000. All simulations were performed using Fluent™ from Fluent, Inc. More details of the numerical methods can be found in Murthy *et al.* [7] and in reference [8].

4. Simulation Design

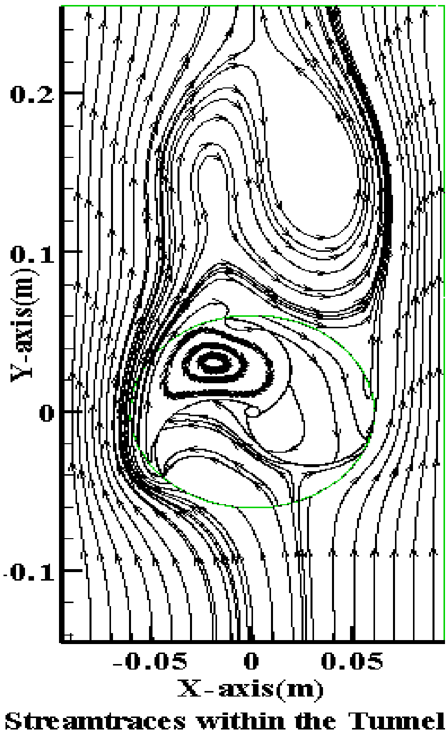
Time dependent simulations were performed for the flow created by a pitched blade turbine in a wind tunnel with a diameter of T=10cm. The turbine diameter was D = T/3. The blade width was W = 0.2D. The turbine rotational speed was $N = 4.68s^{-1}$ and the viscosity was fixed to obtain turbine Reynolds numbers ($Re = \rho.N.D.2/\mu$) more than Re = 2000. In this range the flow was turbulent. In that case the k-ε RNG turbulence model was used [3]. In the simulations a three time steps at t=0, t=0.08247 s, and at t=0.1649 s were used, resulting in 46.8 revolutions. Local and average velocities were tracked as a function of time to determine when periodic steady state was reached. The local velocities close to the turbine converged fastest, while the average tangential velocity in fluid bulk converged slowest.

5. Experimental validation of CFD Simulation

To verify the CFD simulation results it should be compared the results from simulation with the experimental results. Figure 2 shows the results of velocity field and the stream lines that found experimentally by smoke tunnel and theoretically by simulation for three different time steps. The flow pattern is shown by means of velocity vectors. The vectors point in the direction of the air velocity at the point where they originate. The experimentally measured velocities are shown on the right while the sliding mesh results are shown on the left. At this Reynolds number the turbine creates a mainly radial flow pattern. Two-circulation loops form, above and below the turbine. The flow is very weak away from the turbine. The model results can be seen to compare quite well with the experimental visualization.


0.2
0.1
0
0.1
Y-axis(m)
-0.05
0
0.05
X-axis(m)
Streamtraces within the Tunnel

(a)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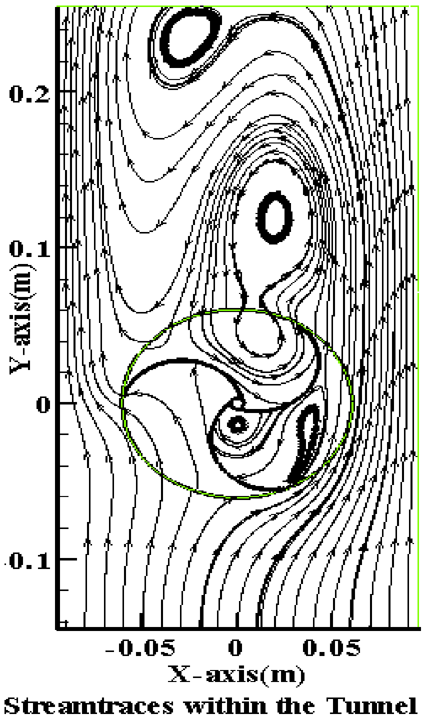
Streamtraces within the Tunnel

(b)



(c)

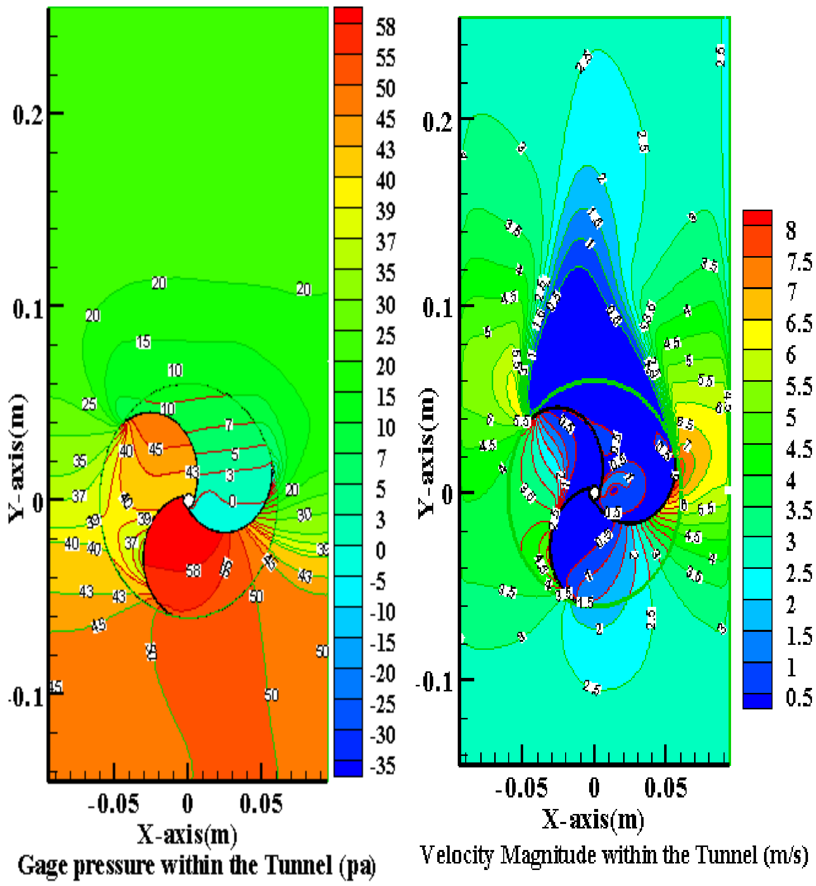
Figure 2. Comparison Between Experimental Data (right) and Sliding Mesh Results (left) With Different Time Steps: (a) at Time (t)=0.02062 , (b) at Time (t) =0.08247 s, (c) at Time (t) t=0.1649 s.

5.Simulation Results of Velocity Contour and Pressure Distribution

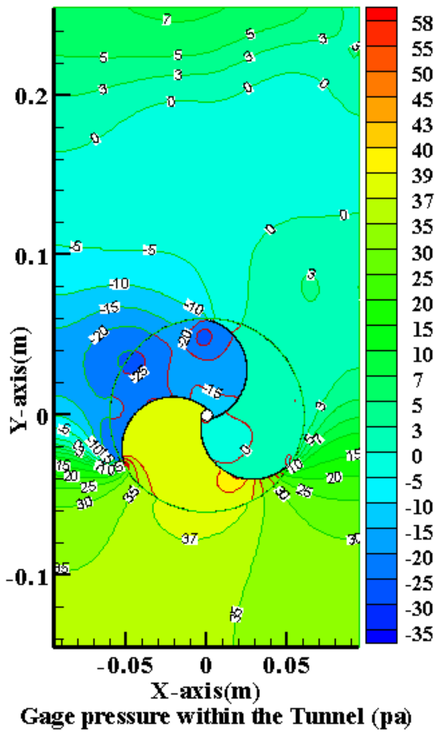
After it is ensured from the reliability of CFD simulation results, that the experimental results were in good correlation with theoretical model that was simulated with FLUENT software, so that it can be used for simulate the velocity contour and pressure distribution around the Savonius turbine without needing to the experimental data.

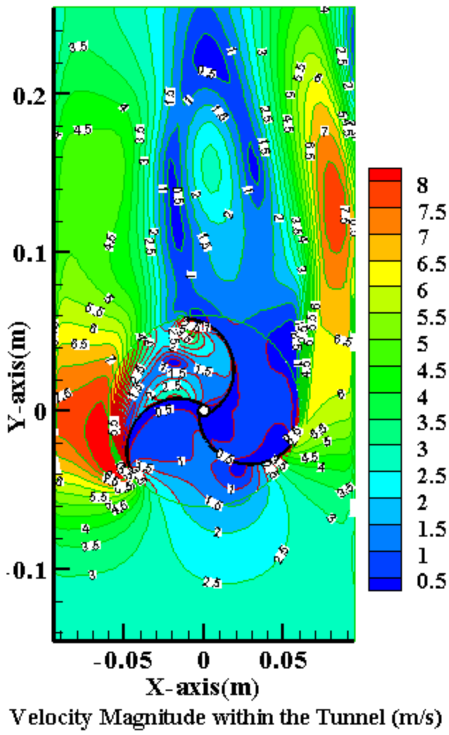
This study appears the two dimensional turbulent fluid flow RNG k-ε models that are taken to simulate the velocities and pressures for three time steps within Savonius Wind Turbine by using FLUENT software. The simulations compromises the analysis of the flow in the upstream, downstream of scoops and between the scoops by solving the continuity and momentum equations for incompressible Air flow through moving frame at unsteady state.

Figure 3 shows the local velocity magnitude and the pressure distribution in a plane down stream and up stream of the turbine blade. It's found that the velocity magnitude alternate as pressure distribution as according to the location from the turbine blades for the three selective time steps. Also the velocity intensity increases as the time increase while the pressure distribution decrease as the time step increase.

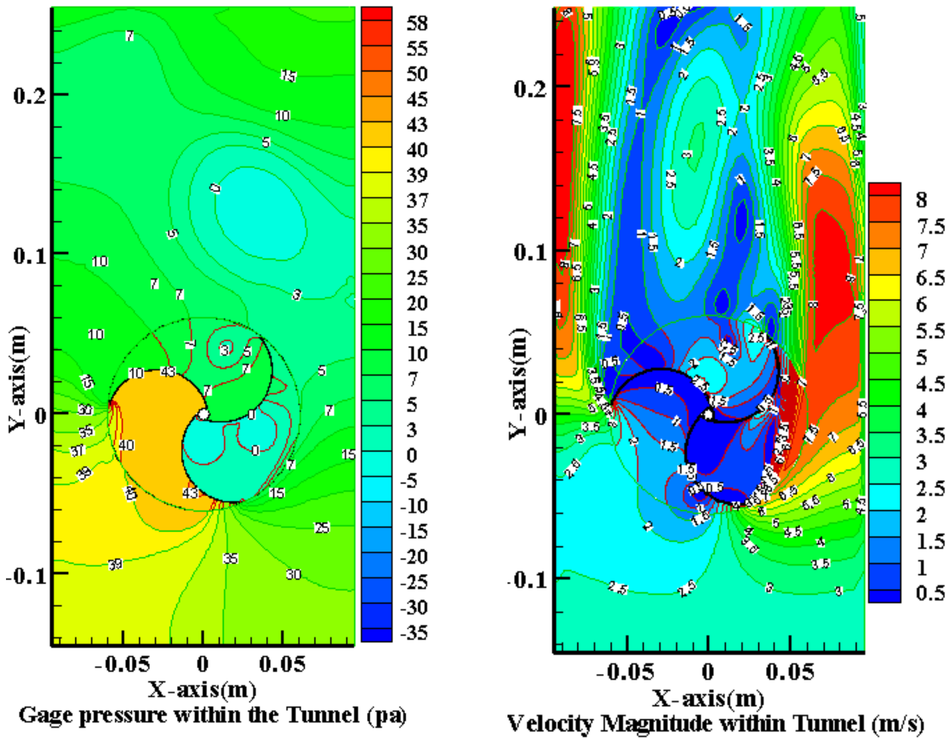


(a) At First Time Step (t=0.02062 s)





(b) At Second Time Step (t=0.08247 s)



(c) At third time step (t=0.1649 s)

Figure 3 Simulated velocity magnitudes (right) and simulated pressure distribution (left) with different time steps: (a) at time (t) =0.02062 , (b) at time (t) =0.08247 s, (c) at time (t) t=0.1649 s.

6.Discussion

Sliding mesh methods can be used to accurately predict the time dependent turbulent flow pattern in wind turbine of Savonius rotor type, without the need for experimental data as turbine boundary conditions. A drawback is the long calculation time, which is about an order of magnitude longer than with steady state calculations based on experimental turbine data. Furthermore, grid dependency studies will have to be performed to determine the minimum grid resolution necessary to resolve turbulent tip vortices. An important application for the sliding mesh method might be the development of new, optimized wind turbine designs for specific industrial applications and prediction of flow patterns, velocity magnitude, and pressure distribution within the turbine for which no experimental data are available.

Refrences

[1] Bakker A., Van den Akker H.E.A., (1994). Single-Phase Flow in Stirred Reactors Chemical Engineering Research and Design. *Trans. Chem.* 72, A4, 583-593.

[2] André Bakker, Richard D. LaRoche, Min-Hua Wang, and Richard V. Calabrese. (2000).

Sliding Mesh Simulation of Laminar Flow in Stirred Reactors., [Online] Available: http://www.bakker.org/cfm.

[3] Gartling, D. (2005). Multipoint constraint methods for moving body and non-contiguous mesh simulations. *Int. J. Numer. Meth. Fluids*, 47, 471-489.

[4] Tezduyar, (2001). T. E. "Finite element methods for ow problems with moving boundaries. *Comp. Meth. Engrg.* 8, 83-130.

[5] Lilek, Z, Muzaferija, S., Peric, M, S., & Seidl, V. (1988). An implicit finite-volume method using non-matching blocks on structured grid. *Num. Heat Transfer Part B*, 32, 385-401.

[6] Moen, C.D., Hensinger, D. M. & Cochran, B. (2000). Consistent areas for thermal contact between non-matching unstructured meshes. *Extended abstract for the Aerospace Sciences meeting, Reno, NV, January*.

[7] Murthy J.Y., Mathur S.R., Choudhury D. (1994). CFD Simulation of Flows in Stirred Tank Reactors Using a Sliding Mesh Technique Mixing. *Proceedings of the Eighth European Conference on Mixing, Institution of Chemical Engineers, Symposium Series* 136, 341-348, ISBN 0 85295 329 1.

[8] Fluent User's Guide, Fluent, Inc., (1995).

Projection of Carbon Dioxide Emissions by Energy Consumption and Transportation in Malaysia: A Time Series Approach

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Abstract

Climate change is one of the most complex challenges threatening our planet. Since the beginning of the industrial era, mankind has been emitting large amounts of greenhouse gases into the atmosphere. This study empirically investigates the carbon dioxide emissions (CO_2) of electricity consumption and energy use in Malaysia using time series data for the period of 1970-2008. There are five major sources that contribute to the total CO_2 emissions in Malaysia: gaseous fuel consumption, liquid fuel consumption, solid fuel consumption, electricity heat production and transportation. In this study, a comprehensive modeling tool, consisting of ARIMA models in time series, was utilized to project the total CO_2 emissions from year 2009 to year 2020. It was projected that without any mitigation measures taken by the country, 500 mega tons of CO_2 will be released in 2020, a 43.3% increase compared to the amount of CO_2 emitted in 2005. In addition, this study also reviews the mitigation steps taken in order to reduce CO_2 emissions contributed by electricity generation and transportation. The projection of CO_2 emission and its associated impact is hoped to provide an important message to consumers on the significance of reducing future CO_2 emissions in Malaysia.

Keywords: Carbon dioxide emissions, Projection, Time series

1. Introduction

Climate change has been a widely discussed environmental issue over the past few decades. Climate change and global warming refer to an increase in average global temperatures, believed to be caused by natural events and human activities, which primarily increase "greenhouse" gases such as Carbon Dioxide (CO_2). Studies done by Chakraborty *et al.* (2000) and Spence (2005) reported that global CO_2 emissions have increased 30% and temperature has risen by 0.3- 0.6 °C during the 20th century. Presently, burning coal used in electricity generation and petroleum used for motor transport (Mohammad, 2005; EPA 2012) are identified as two main sources of CO_2 emissions. According to a report from the Ministry of Natural Resources and Environment (NRE), Malaysia, CO_2 emissions from energy usage in industries constituted the highest percentage (35%) followed by transportion (21%) (NRE, 2011).

Many countries including Malaysia are playing an active role in reducing CO_2 emission through national mitigation and intergovernmental mechanisms such as the United Nations Framework Convention on Climate Change (UNFCC) (Nor Shaliza *et al,* 2010). For instance, the Prime Minister of Malaysia announced during the 2009 UNFCCC conference in Copenhagen (Bernama, 2009) that Malaysia is adopting an indicator of a voluntary reduction of up to 40 percent in terms of emissions intensity of Gross Domestic Product (GDP) by the year 2020 compared to 2005 levels.

In order to predict the CO_2 emission in the future, a time series model is used. Time series data are commonly used today. Time series models are widely used for predictions in the economic and industrial areas. For instance, there are some studies done in China by Chu *et al.* (2012), United States by Ozkan (2012) and United Kingdom by Chitnis & Hunt (2012) which were all focused on energy use and CO_2 emissions forecasting models.

The objective of this study explores the five main sources of CO_2 emissions; namely, gaseous fuel consumption, liquid fuel consumption, solid fuel consumption, electricity heat production and transportation. Time series model is used to predict the CO_2 emission in 2020. In addition, mitigation steps to reduce CO_2 emissions in Malaysia are also discussed.

2. Materials

The study was conducted in Universiti Sains Malaysia from June 2011 to June 2012. This study used secondary data collected from the Carbon Dioxide Information Analysis Center (CDIAC) with the bench marking assessment study on CO_2 emissions data from Green Technology Corporation of Malaysia (GreenTech), the Energy Commission of Malaysia and the Department of Statistic of Malaysia (DOS). The study is based on reliable data on CO_2 emissions factors; gaseous fuel consumption, liquid fuel consumption, solid fuel consumption, electricity heat production and transportation data in Malaysia from 1971 to 2008 (refer to Fig. 1). It is evident that Malaysia is still very much dependent on fossil fuels, mainly natural gas, coal and oil, to meet its commercial energy demand and electricity generation. With the escalating energy demand required to sustain the country's growth in the future, it is inevitable that CO_2 emissions continue to rise, as long as fossil fuels remain as the main contributor in the energy mix of energy production. The scope and boundary of each category is defined as follows:

- CO_2 emissions from gaseous fuel consumption refer mainly to emissions from the use of natural gas as an energy source.
- CO_2 emissions from liquid fuel consumption refer mainly to emissions from the use of petroleum-derived fuels as an energy source.

- CO_2 emissions from solid fuel consumption refer mainly to emissions from the use of coal as an energy source.
- CO_2 emissions from electricity heat production (EHP) are the sum of three International Energy Agency (IEA) categories emissions: (1) Main Activity Producer Electricity and Heat which contains the sum of emissions from main activity producer electricity generation, combined heat and power generation and heat plants. (2) Unallocated auto producers, which contain emissions from the generation of electricity and/or heat by auto producers. Auto producers are defined as undertakings that generate electricity and/or heat, wholly or partly for their own use as an activity which supports their primary activity. They may be privately or publicly owned. In the 1996 IPCC Guidelines, these emissions would normally be distributed between industry, transportation and ""other"" sectors. (3) Other Energy Industries contains emissions from fuel combusted in petroleum refineries, for the manufacture of solid fuels, coal mining, oil and gas extraction and other energy-producing industries.
- CO_2 emissions from transportation contain emissions from the combustion of fuel for all transportation activities, regardless of the sector, except for international marine bunkers and international aviation.

3. Model Construction and Development

To estimate the total CO2 emissions from energy consumption and transportation in Malaysia, a time series approach is applied in this study. Autoregressive Integrated Moving Average (ARIMA) model is a generalization of an autoregressive moving average (ARMA) model. The letter “I" (Integrated) indicates that the modelling time series has been transformed into a stationary time series. ARIMA represents three different types of models: It can be an autoregressive (AR) model, or a moving average (MA) model, or an ARMA which includes both AR and MA terms. These models are fitted to time series data either to better understand the data or to predict future points in the series (forecasting). ARIMA models were popularized by George Box and Gwilym Jenkins in the early 1970s (Peter & Richard, 2002).

3.1 ARIMA(1,1,0) = differenced first-order autoregressive model:

This is a first-order AR (1), model with one order of nonseasonal differencing. (In the output of the Forecasting procedure in Statistic graphics, this coefficient is simply denoted as the AR (1) coefficient). This would yield the following prediction equation:

$$\hat{Y}(t) = Y(t-1) + \phi\{Y(t-1) - Y(t-2)\} \quad (1)$$

3.2 ARIMA (0,1,1) = simple exponential smoothing with growth:

This is a first order MA(1), which is a weighted moving average of a fixed number of forecast errors produced in the past. This would yield the following prediction equation:

$$\hat{Y}(t) = Y(t-1) + \theta\, e(t-1) \tag{2}$$

3.3 A "mixed" model--ARIMA (1,1,1):

The features of autoregressive and moving average models can be "mixed" in the same model. For example, an ARIMA (1,1,1) model would have the prediction equation:

$$\hat{Y}(t) = Y(t-1) + \phi\,\{Y(t-1) - Y(t-2)\} - \theta\, e(t-1) \tag{3}$$

Nomenclature

$\hat{Y}$	Forecast value
Y	Response series
t	Indexes time
ϕ	Autoregressive Coefficient
θ	Moving Average Coefficient
e	Lagged forecast Error

ARIMA models form an important part of the Box-Jenkins approach to time-series modelling. The first (and most important) step in fitting an ARIMA model is the determination of the order of differencing needed to stationarize the series. The Box-Jenkins procedure consists of four main stages: Identification, Estimation, Diagnostic checking and Forecasting.

4. Results

The Box-Jenkins methodology was selected in the analysis of this study. In the first stage of Box-Jenkins procedure, identification, the first difference of the data was transformed into a stationary time series and the model was determined by analyzing the autocorrelation function (ACF) and partial autocorrelation function (PACF). In order to determine the appropriate Box-Jenkins model, it is necessary to analyze the behavior (pattern) of the autocorrelation and partial autocorrelations functions. The autocorrelation coefficient measures the relationship or correlation between a set of observations and a lagged set of observations in a time series. A partial correlation coefficient is the measure of the relationship between two variables when the effect of other variables has been removed or is held constant.

In Fig 2 and Fig 3, both ACF residual and PACF residual do not show constant over the time and therefore, it is not stationary. In order to meet the basic criteria of stationary, the first difference-stationary data were used in model identification.

All the potential models comprising AR (1), MA (1), ARMA (1,1), AR (2) and MA (2) were analyzed using Graph Repository Transformation Language (GReTL) software. The results are shown in Table 1. Based on the Akaike Information Criterion Selection for best model, the P-value for ARIMA (1,1) is the most significant with the smallest Akaike criterion value among the other models. Therefore, ARIMA (1, 1) was selected as the best estimation model for this analysis.

Additionally, the Q-Q plot (Fig 4) is for the residual data. It is used to test for normality. Here we can see that the Q-Q plot approximately follows the QQ-line visible on the plot. This is a good indicator of normality within the residuals. This Q-Q plot confirms that the residuals of ARIMA (1,1,1) model are normally distributed and indicates that the model fits the data well. Based on the time series data, the ARIMA (1,1,1) is the best identified forecasting model to predict the total CO_2 emissions in Malaysia .

5. Forecasting and Scenario Discussion

The total CO_2 emissions in Malaysia are projected using Equation 3. The predicted total CO_2 emissions (2009 – 2020) in Malaysia are shown in Fig 5.

As a rapidly developing economy in Asia, Malaysia, a middle-income country, has transformed itself since the 1970s from a producer of raw materials into an emerging multi-sector economy. In this scenario, CO_2 emissions are estimated to increase due to dramatic economic development and high demand for better standard of living. Energy demand growth is directly related to the population growth. According to the Population and Housing Census final report (2010), Malaysia's population stood at 28.3 million at the end of 2010 compared with 23.3 million in 2000. During the last decade, Malaysia has seen an almost 20 percent increase in energy generating capacity from 13,000MW in the year 2000 to 15,500MW in 2009. Referring to the list of countries by carbon dioxide emissions per capita; Malaysia was at No. 51 in world rank with 7.7 metric tons of CO_2 per capita, and was the third largest contributor (after Brunei and Japan) among Asian countries (CDIAC, 2012).

There is an increasing trend of energy consumption year by year in Malaysia. This study shows an increasing overall total CO2 emission from the five major contributing sources over the period of 1971-2008. Forecasted value for total CO2 emissions (2009-2020) also shows an increasing trend. It is projected that CO_2 emission for 2020 will reach 500 mega tons based on 95 percent of confidence interval prediction.

5.1 Mitigation Steps to Reduce CO_2 Emissions

In Malaysia, electricity generation is mostly fossil-based, in particular natural gas and oil. Although the burning of natural gas produces fewer emissions than oil and coal, the burning processes of fossil fuels in power plants are one of the major contributors to industrial air pollution. To ensure the reliability and security of energy supply, the Four-fuel Diversification Strategy was introduced in 1981 as an extension of the 1979 National Energy Policy. Subsequently the Five-fuel Diversification Strategy was introduced in 1999. The rationale for this policy initiative was to reduce Malaysia's overdependence on oil in overall energy consumption and on gas in the electricity generation sector (Nor Shaliza et al. 2010). In the electricity generation sector, this policy aimed for a gradual change in fuel use from 75% gas, 9% coal, 10% hydro and 6% petroleum in 2000 (KTAK, 2005) to 40% gas, 30% hydro, 29% coal and only 1% petroleum by 2020 (Masjuki, 2002).

Mitigation steps are taken by the country to reduce the total CO_2 emissions contributed by electricity generation and transportation. There are several possible strategies to reduce the amount of CO_2 emitted from fossil-fuel power plants. Potential approaches include increasing plant efficiency, employing fuel balancing or fuel switching, making enhanced use of renewable energy and employing CO_2 carbon capture and sequestration (Hashim, 2005). As a proactive step taken by the government in promoting renewable energy as an additional energy mix source in Five-fuel Diversification Strategy, it has also created the awareness of the importance of sustainable development in Malaysia. Among the various sources of renewable energy, biomass seems to be a very promising alternative for Malaysia. In line with the promotion of using biomass energy, a Biomass Power Generation and Cogeneration project (BioGen) was commissioned in October 2002 (Rahman & Lee, 2006). The ultimate objective of this BioGen project was to reduce the growth rate of greenhouse gases emission from fossil-fired combustion processes. In addition, several energy efficiency programmes and activities were implemented to ensure optimum use of the energy resources. These include Low Energy Office (LEO), Malaysia Industrial Energy Efficiency Improvement Programme (MIEEIP), Centre for Education and Training on Renewable Energy and Energy Efficiency (CETREE) and others. (KTAK, 2005).

In the transportation sector, alternative transportation fuels such as hydrogen-powered fuel-cell as well as bio-fuel and natural gas potentially offer significant environmental benefits which accounted for almost 20% in reduction of greenhouse gasses. Natural gas reserves in Malaysia are the largest in South East Asia and the 12th largest in the world. With a production rate of 1000 million cubic feet per day, natural gas could still be contributing to the energy mix for the next 87 yrs as compared to about 12 yrs for oil (Cai *et al.* 2008). The government should take this opportunity to promote natural gas vehicles to address environmental concerns. In the Ong et al. (2011) study, four transportation mitigation scenarios were suggested; modal shifting from passenger cars to public transports, modal shifting from motorcycles to public transports, fuel switching for passenger cars to natural gas vehicles, and passenger cars renewal. A study done by (Cai *et al.* 2008) stated a few mitigation options in order to reduce CO2 emissions, including transmissions technologies, vehicle technologies, engine technologies, bus rapid transit and finally fuel switching. However, cost information should be an important consideration when devising mitigation options. The extent of emission reduction potential that can be achieved will be limited by the costs of bringing about the reduction.

In another approach, the reduction of CO_2 emissions can be achieved by the Clean Development Mechanism (CDM). The CDM transfers reduction of CO_2 into Certified Emission Reductions (CER). The CERs can be sold to the governments of and private companies in industrialized countries as part of their obligation towards commitments under the Kyoto Protocol and UNFCC. Malaysia itself already has 22 registered CDM projects with most of the CERs coming from biomass plants. As at March 2007, two of the 22 CDM projects had sold 320,000 tonnes of CERs valued at about RM10 million. According to the National Green Technology Center, agricultural and natural-resources-rich Malaysia has 100 million tonnes of carbon credit potential, which translates to RM4.8 billion in potential revenue (The Star, 2008). Based on data released by the United Nations Environment Programme (UNEP) resource centre, as of March 2009, there are a total of 4,660 future CDM projects registered, with Malaysia having 156 projects or 4% of the list in the pipeline (Oh & Chua, 2010).

6. Conclusions and recommendations

Economic development and population growth are closely linked with energy consumption since higher economic development is expected when more energy is consumed. The ARIMA (1,1,1) model projected that without any mitigation measures undertaken by the country, 500 mega tons of CO_2 will be released in 2020, which means a 43.3% increase compared to the amount of CO_2 emitted in 2005. Most of these emissions can be avoided through improved energy efficiency. In this regard, greater use of energy efficient, renewable energy and green technologies or options along with behavioral changes, can help to substantially reduce CO2 emissions from the energy sector. This move will contribute to the Malaysian Government's commitment of achieving up to 40% reduction of CO2 emissions intensity by the year 2020. To help achieve this, future research should include studies related to energy efficiency, renewable energy, green technology or even clean development mechanism.

References

Bernama (2009). Najib proffers conditional 40% carbon cuts at Copenhagen. Online: http://www.themalaysianinsider.com/index.php/malaysia/46861-najib-proffers-conditional-40pc-carbon-cuts-at-copenhagen. Accessed on 3 Jan 2011

Cai, W., Wang, C., Chen, J., Wang, K., Zhang, Y., & Lu, X. (2008). Comparison of CO2 emissions scenarios and mitigation opportunities in China's five sectors in 2020, *Energy Policy*, 36, 1181–1194.

CDIAC (2010). Malaysia- carbon dioxide emissions. Online: http://www.indexmundi.com/facts/malaysia/co2-emissions. Accessed on 1 Nov 2011.

CDIAC (2012). List of countries by carbon dioxide emissions per capita. Online: http://en.wikipedia.org/wiki/List_of_countries_by_carbon_dioxide_emissions_per_capita. Accessed on 3 June 2012.

Chakraborty, S., Tiedemann, A.V., & Teng, P.S. (2000). Climate change: Potential impact on plant diseases, Environmental Pollution, Vol. 108, pp: 317–326.

Chitnis, M., & Hunt, L. C. (2012). What drives the change in UK household energy expenditure and associated CO 2 emissions? implication and forecast to 2020. *Applied Energy, 94*, 202-214.

Chu, C., Yang, Y., Bai, X., Peng, Q., & Ju, M. (2012). Time series analysis of energy consumption and carbon emission for binhai new area of Tianjin. *Applied Mechanics and Materials,* vol. 174-177, pp: 3571-3575. 2nd International Conference on Civil Engineering, Architecture and Building Materials, CEABM 2012; Yantai; 25 May 2012through27 May 2012.

EPA (2012). Inventory of U.S. Greenhouse Gas Emissions and Sinks (1990-2010). Online: http://www.epa.gov/climatechange/ghgemissions/usinventoryreport.html**.** Accessed on 29 June 2012

Hashim, H., Douglas, P., Elkamel, A. & Croiset, E. (2005). Optimization model for energy planning with CO2 emission considerations, *Industrial and Engineering Chemistry Research*, 44, 879–890.

KTAK. (2005). Energy Policy of Malaysia. Ministry of Energy, Water and Communication.

Masjuki, H.H., Mahlia, T.M.I., Choudhury, I.A., & Saidur, R. (2002). Potential CO2 reduction by fuel substitution to generate electricity in Malaysia, Energy Conversion and Management, 43, 763–770.

Mohammad, F (2005). Fossil Fuel (oil and gas) Scenario for Malaysia. *National Convention for Energy Professional 3 "Achieving Sustainable Development through Fossil Fuel Conservation".* 15 Sep 2005: Kuala Lumpur

Nor Shaliza, M. S., Zainura, Z. N, Haslena, H., Zaini, U & Juhaizah, T. (2011). Projection of CO2 Emissions in Malaysia. *Environmental Progress and Sustainable Energy. Wiley Online Library.* 30(4), 658–665.

NRE (2011). Malaysia 2nd National Communication to UNFCCC report. Online: http://www.nre.gov.my/Environment/Documents/SECOND%20NATIONAL%20COMMUNICATION%20TO%20THE%20UNFCCC%20%28NC2%29.pdf. Accessed on 20 May 2012.

Oh, T. H., & Chua, S. C. (2010). Energy efficiency and carbon trading potential in malaysia. *Renewable and Sustainable Energy Reviews, 14*(7), 2095-2103

Ong, H. C., Mahlia, T. M. I., & Masjuki, H. H. (2011). A review on emissions and mitigation strategies for road transport in malaysia. *Renewable and Sustainable Energy Reviews, 15*(8), 3516-3522.

Ozkan, F., & Ozkan, O. (2012). Panel data analysis for the CO 2 emissions, the industrial production and the energy sector of the OECD countries. *Energy Education Science and Technology Part A: Energy Science and Research, 29*(2), 1233-1244.

Peter, J. B. & Richard, A. D. (2002). Introduction to time series and forecasting. 2nd edition. Springer: New York.

Population and Housing Census final report (2010). Department of Statistic Malaysia.

Rahman Mohamed, A., & Lee, K.T. (2006). Energy for sustainable development in Malaysia: Energy policy and alternative energy, *Energy Policy*, 34, 2388–2397.

Spence, C. (2005). Global warming: Personal solutions for a healthy planet (1st Edition), New York: Palgrave Macmillan.

The Star (2008). Huge Potential in Carbon Trading. The Star newspaper. p. 11.

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Table 1: Akaike Information Criterion Selection Table

Model Type	AR (1)	MA (1)	ARMA (1,1)	AR (2)	MA (2)
p	1	0	1	2	0
d	1	1	1	1	1
q	0	1	1	0	2
Coefficient	0.559402	0.347233	ϕ (1)= 0.987193 θ (1)= -0.810188	ϕ (1)= 0.396182 ϕ (2)= 0.332597	θ (1)= 0.614831 θ (2)= 0.446255
Std. Error	0.144015	0.154863	AR (1)= 0.0719502 θ (1)= 0.20285	ϕ (1)= 0.156628 ϕ (2)=0.167373	θ (1)= 0.150549 θ (2)= 0.156496
P value	0.00010	0.02495	AR (1)= <0.00001 θ (1)= 0.00006	ϕ (1)= 0.01142 ϕ (2)= 0.04690	θ (1)= 0.00004 θ (2)= 0.00435
Akaike Criterion	792.9114	798.5411	784.5907	790.9208	794.7327

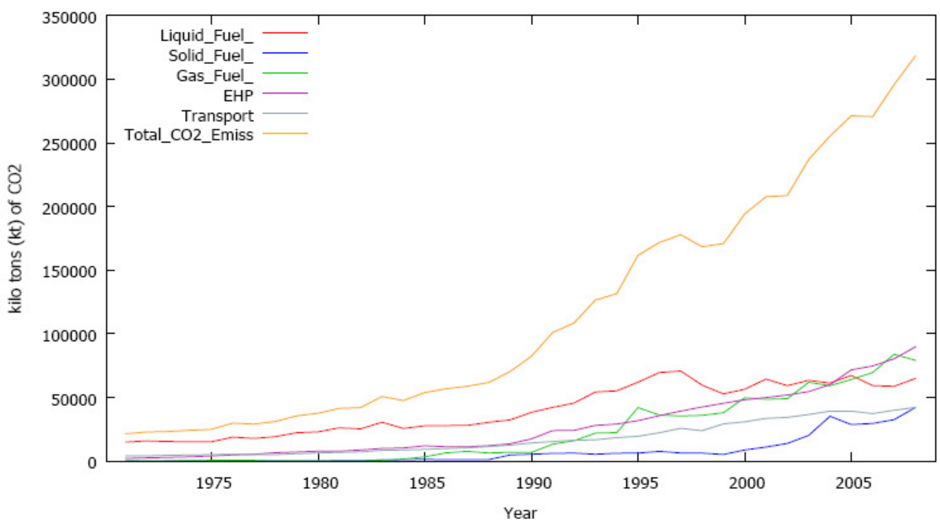

Figure 1: Total CO_2 emissions and its breakdown by different sources. (Source: CDIAC, 2010)

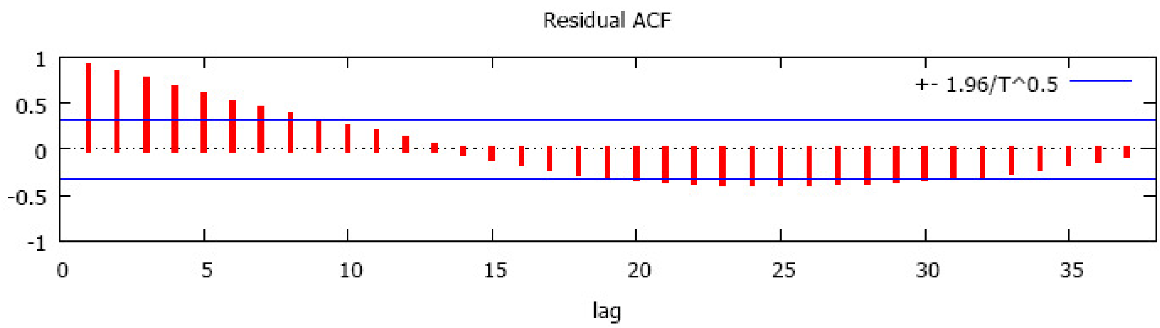

Figure 2: ACF residual with lags

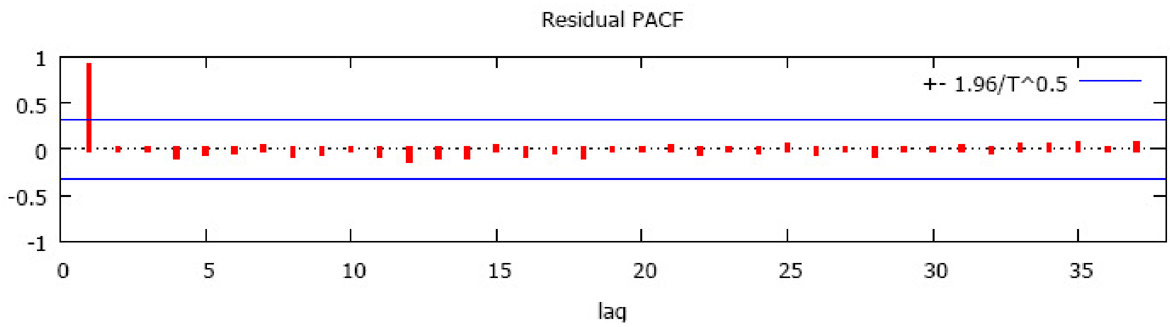

Figure 3: PACF residual with lags

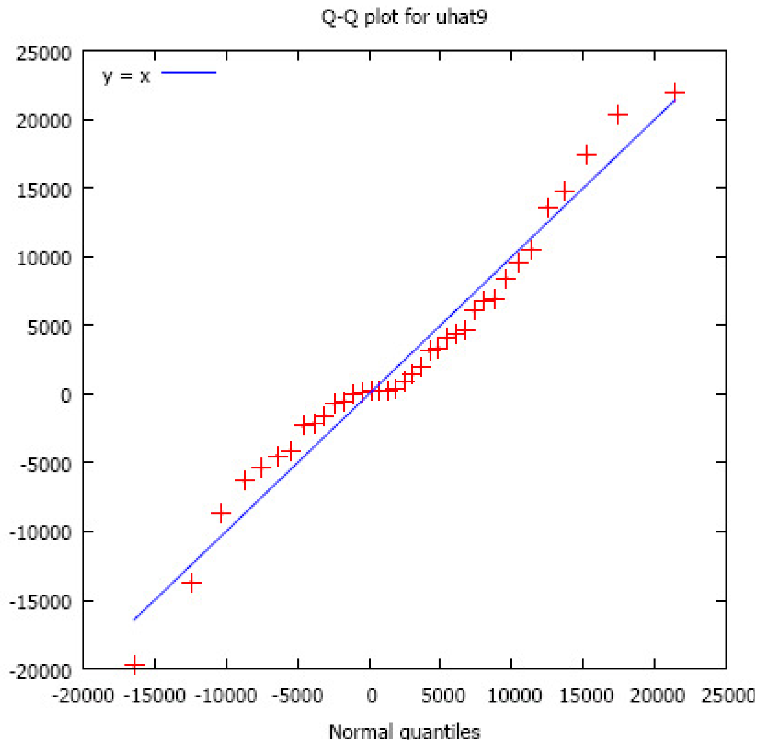

Figure 4: Q-Q plot shows the error term is normally distributed.

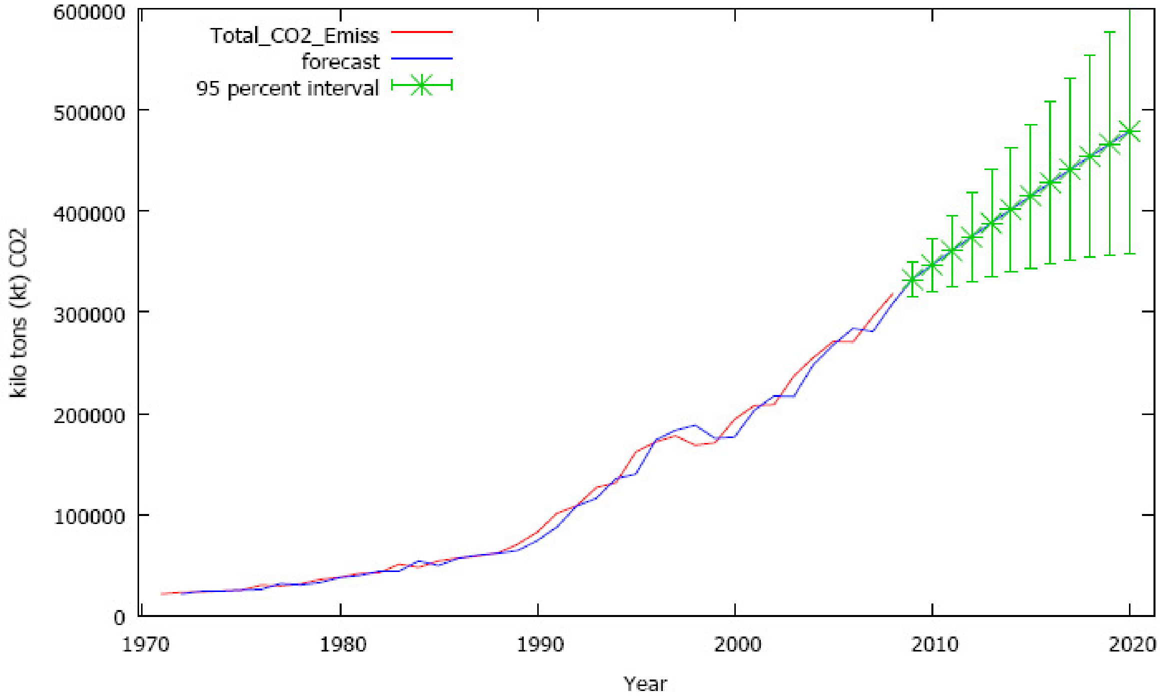

Figure 5: Predicted and actual values of total CO_2 emissions in Malaysia (1971-2020)