# METHANE EMISSION INVENTORY AND FORECASTING IN MALAYSIA

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A thesis submitted in fulfilment of the
requirement for the award of the degree of
Doctor of Philosophy (Environmental Engineering)

Faculty of Chemical Engineering
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SEPTEMBER 2013

## ABSTRACT

The increase in global surface temperature by 0.74 ± 0.18 $^{o}C$ between 1901 and 2000 as a result of global warming has become a serious threat. It is caused by the emission of greenhouse gases into the atmosphere due to human activities. The major greenhouse gases are carbon dioxide, methane and nitrous oxide. Records show that only carbon dioxide received detailed investigation but not methane, hence the motive behind this study. This study examined the emission of methane from six main sources in Malaysia. Data for the inventories of the production of these six sources were taken from 1980 – 2011 and were used to forecast emissions from 2012 – 2020. The data were sourced from Ministries, Departments and International Agencies. Six categories of animals were studied under livestock with their corresponding methane emissions from 1980 – 2011 computed as follows: cattle: 1993Gg (6.13%), buffaloes: 341Gg (10.8%), sheep: 24Gg (0.8%), goats: 55Gg (1.8%), horses: 3Gg (0.1%), poultry: 161Gg (5.1%), and pigs: 579Gg (18.3%). Methane emissions from the other sources from 1980 to 2011 are rice production: 1617Gg (0.02%), crude oil production: 8016636Gg (99.8%), Wastewater (POME): 11362Gg (0.14%), municipal solid waste landfills: 3294Gg (0.04%), coal mining: 14Gg (0.0002%). Forecasting of methane emissions from 2012 to 2020 were carried out using the Box-Jenkins ARIMA method. There were close similarities between the observed and forecast values. In the year 2020 predicted methane emissions will be cattle: 113Gg (72.2%), buffaloes: 8.0Gg (5.1%), sheep: 1.2Gg (0.8%), goats: 4.2 Gg (2.7%), horses: 0.2Gg (0.1%), pigs: 13.2Gg (8.4%), and poultry: 16.8Gg (10.7%) for the livestock sector. For other sectors the forecast will be wastewater: 836Gg for wastewater, 4.7 Gg for coal production, 503,208 Gg for crude oil production, 50.6 Gg for rice production, and 167 Gg from municipal solid waste landfills. Population and GDP will rise to 33.26 million and 329US $ billion by 2020, respectively. Optimisation was carried out after running a linear regression to determine the significant parameters. The equation developed was a nonlinear programming problem and was solved using sequential quadratic programming (SQL) and implemented on MATLAB environment. Sensitivity analysis carried out on the constraints showed the need to maintain the present livestock and rice production levels. The amount of meat protein currently available far exceeds the dietary protein requirement by more than five times. Several mitigation measures aimed towards reducing future methane emissions in Malaysia were also suggested for the various sources. These are in line with the country's commitment to reduce greenhouse gas emissions by 40% over the 2005 level by 2020. The use of renewable energy in the energy mix was suggested in line with the government's five fuel policy and increase in the number of vehicles using gas was also proposed.

# ABSTRAK

Peningkatan suhu pada permukaan global dengan 0.74 ± 0.18$^{o}$C di antara tahun 1901 dan 2000 merupakan akibat pemanasan global telah menjadi satu ancaman yang serius. Ia adalah disebabkan oleh pelepasan gas rumah hijau ke atmosfera akibat daripada aktiviti manusia. Gas rumah hijau yang utama adalah karbon dioksida, metana dan nitrus oksida. Rekod menunjukkan bahawa hanya karbon dioksida sahaja yang menerima siasatan terperinci tetapi tiada siasatan dilakukan atas gas metana. Maka, motif di sebalik kajian ini ialah untuk meneliti pelepasan metana dari enam sumber utama di Malaysia. Data bagi inventori pengeluaran dari enam sumber diambil diantara tahun 1980 - 2011 dan telah digunakan untuk meramal pengeluaran dari tahun 2012-2020. Data diperolehi daripada Kementerian, Jabatan dan Agensi Antarabangsa. Pelepasan gas metana dari enam kategori haiwan ternakan telah dikaji dari tahun 1980 - 2011 telah dikira seperti berikut: lembu: 1993Gg (6.13%), kerbau: 341Gg (10.8%), kambing biri-biri: 24Gg (0.8%), kambing: 55Gg (1.8 %), kuda: 3Gg (0.1%), ayam: 161Gg (5.1%), dan khinzir: 579Gg (18.3%). Pelepasan metana dari sumber-sumber lain dari tahun 1980-2011 adalah pengeluaran beras: 1617Gg (0.02%), pengeluaran minyak mentah: 8016636Gg (99.8%), Air sisa (POME): 11362Gg (0.14%), tapak pelupusan sisa pepejal perbandaran: 3294Gg (0.04%), perlombongan arang batu: 14Gg (0.0002%). Ramalan pelepasan metana 2012-2020 telah dijalankan dengan menggunakan Kaedah Box-Jenkins ARIMA. Terdapat persamaan yang rapat antara nilai-nilai yang telah diperhatikan dan diramalkan. Pada tahun 2020, pelepasan metana yang diramalken bagi seksor ternakan adalah sepasi berikut: 113Gg (72.2%), kerbau: 8.0Gg (5.1%), biri-biri: 1.2Gg (0.8%), kambing: 4.2 Gg (2.7%), kuda: 0.2Gg (0.1 %), khinzir: 13.2Gg (8.4%), dan ayam: 16.8Gg (10.7%). Bagi sektor-sektor lain, ramalan adulah air: 836Gg untuk air sisa, 4.7 Gg untuk pengeluaran arang batu, 503208 Gg bagi pengeluaran minyak mentah, 50.6 Gg untuk pengeluaran beras, dan 167 Gg dari tapak pelupusan sisa pepejal perbandaran. Jumlah penduduk dan KDNK masing-masing akan meningkat kepada 33.26 juta orang dan US $329 bilion pada tahun 2020. Pengoptimuman dilakukan selepas menjalankan regresi linear parameter yang penting. Persamaan dibangunkan adalah pengaturcaraan masalah bukan linear dan telah diselesaikan dengan menggunakan pengaturcaraan kuadratik berjujukan (SQL) dan dilaksanakan pada persekitaran MATLAB. Analisis kepekaan dijalankan ke atas kekangan menunjukkan keperluan untuk mengekalkan tahap terkni penternakan dan pengeluaran beras. Jumlah protein daging sekarang didapati melebihi keperluan protein pemakanan sebanyak lima kali. Beberapa langkah-langkah pengawalan dicadangkan yang bertujuan untuk mengurangkan pelepasan metana dari pelbagai sumber pada masa depan di Malaysia. Ini adalah selaras dengan komitmen negara untuk mengurangkan pelepasan gas rumah hijau sebanyak 40% berbanding tahun 2005 pada tahun 2020. Penggunaan tenaga yang boleh diperbaharui dalam pencampuran tenaga telah dicadangkan selaras dengan polisi kerajaan dalam lima bahan api dan peningkatan bilangan kenderaan yang menggunakan gas juga telah dicadangkan.

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| | | |
|---|---|---|
| *ANN* | - | Artificial Neural Network |
| *ACT* | - | Australian Capital Territory |
| *API* | - | American Petroleum Institute |
| *AR4* | - | Fourth Assessment Report |
| *ARIMA* | - | Auto-Regressive Integrated Moving Average |
| *ATSDR* | - | Agency for Toxic Substances and Disease Registry |
| *BAU* | - | Business as usual |
| *BIC* | - | Bayesian information criterion |
| *BOD* | - | Biochemical oxygen demand |
| $C_2F_6$ | - | Carbon hexaflouride |
| *CDM* | - | Clean development mechanism |
| *CE* | - | Conservation efficiency |
| $CF_4$ | - | Carbon tetraflouride |
| $CH_4$ | - | Methane |
| *CO* | - | Carbon monoxide |
| $CO_2$ | - | Carbon dioxide |
| *COD* | - | Chemical oxygen demand |
| *COP* | - | Conference of Parties (of the UNFCCC) |
| *CFC* | - | Chlorofluorocarbon |
| *CPO* | - | Crude palm oil |
| *DDOC* | - | Decomposable degradable organic carbon |
| *DOC* | - | Degradable organic content |
| *DOS* | - | Department of Statistics |
| *ECER* | - | East Coast Economic Region |
| *EPU* | - | Economic Planning Unit |
| *EF* | - | Enteric fermentation, or Emission factor |

| | | |
|---|---|---|
| *EIA* | - | Energy Information Administration |
| *EIT* | - | Economies in transition |
| *ENSO* | - | El Nino Southern Oscillation |
| *EPER* | - | European Pollutants Emission Register |
| *EPI* | - | Environmental performance index |
| *ETP* | - | Economic transformation programme |
| *FAO* | - | Food and Agriculture Organisation |
| *FELDA* | - | Federal Land Development Agency |
| *FFB* | - | Fresh fruit bunch |
| *FOD* | - | First-order decay |
| *GDP* | - | Gross Domestic Product |
| *GHG* | - | Greenhouse gas |
| *GMI* | - | Global Methane Initiative |
| *GOR* | - | Gas-to-oil ratio |
| *GWP* | - | Global warming potential |
| $H_2O$ | - | Water |
| $H_2S$ | - | Hydrogen sulphide |
| *HFC* | - | Hydroflourocarbon |
| *IAEA* | - | International Atomic Energy Agency |
| *ICU* | - | Implementation and Coordination Unit |
| *INC* | - | Initial National Communication |
| *IPCC* | - | Intergovernmental Panel on Climate Change |
| *IPP* | - | Independent Power Plant |
| *IRRI* | - | International Rice Research Institute |
| *JPSPN* | - | Jabatan Pengurusan Sisa Pepejal Negera |
| *LandGEM* | - | Landfill gas emission model |
| *LFG* | - | Landfill gas |
| *LULUCF* | - | Land use and land use change and forestry |
| *MAPE* | - | Mean absolute percentage error |
| *MaxAPE* | - | Maximum absolute percentage error |
| *MBM* | - | Mass balance method |
| *MCF* | - | Methane correction factor |
| *MDA* | - | Ministries, Departments and Agencies |

| | | |
|---|---|---|
| *MM* | - | Manure management |
| *MPOB* | - | Malaysian Palm Oil Board |
| *MSW* | - | Municipal solid waste |
| $N_2O$ | - | Nitrous oxide |
| *NaCl* | - | Sodium chloride |
| *NaOCl* | - | Sodium hypochlorite (bleach) |
| *NaOH* | - | Sodium hydroxide |
| *NC2* | - | Second National Communication |
| $NCl_3$ | - | Nitrogen trichloride |
| *NMOC* | - | Non-methane organic compounds |
| $NO_2$ | - | Nitrogen dioxide |
| *NSCCC* | - | National Steering Committee on Climate Change |
| *OP-FTIR* | - | Open-path Fourier Transform Infrared Radiation |
| *PASW* | - | Predictive Analysis Software |
| *POME* | - | Palm oil mill effluent |
| *ppb* | - | Parts per billion |
| *ppm* | - | Parts per million |
| *PSO* | - | Particle swarm optimisation |
| *RBW* | - | Rapidly biodegradable waste |
| *RE* | - | Renewable energy |
| *SAR* | - | Second Assessment Report |
| *SBW* | | Slowly biodegradable waste |
| *SEMEN* | - | Semi-automated empirical methane emission model |
| $SF_6$ | - | Sulphur hexafluoride |
| *SOI* | - | Southern Oscillation Index |
| *SPSS* | - | Statistical Processes for the Social Sciences |
| *SREP* | - | Small Renewable Energy Programme |
| *ST* | - | Surahanjaya Tenaga (Energy Commission) |
| *TAR* | - | Third Assessment Report |
| *TNB* | - | Tenaga Nasional Berhad |
| *UNCED* | - | United Nations Conference on Environment and Development |
| *UNFCCC* | - | United Nations Framework Convention on Climate Change |
| *USEPA* | - | United States Environmental Protection Agency |

| | | |
|---|---|---|
| *VFA* | - | Volatile fatty acids |
| *VOC* | - | Volatile organic compounds |
| *WMO* | - | World Meteorological Organisation |

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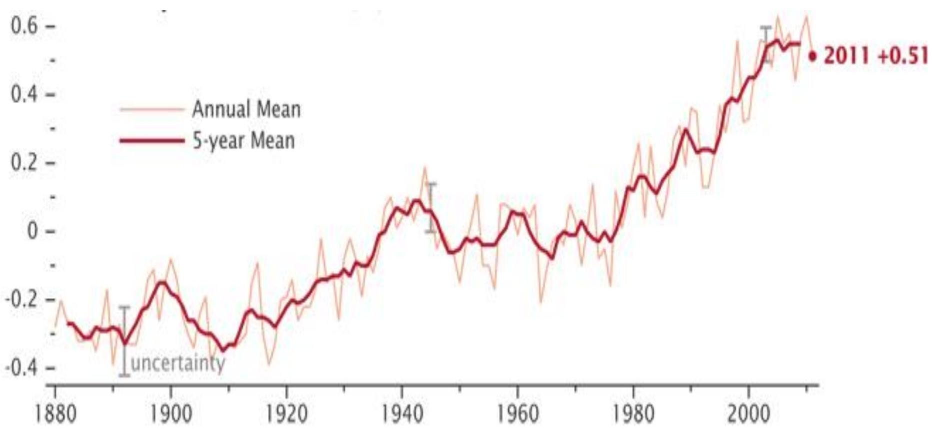
# CHAPTER 1

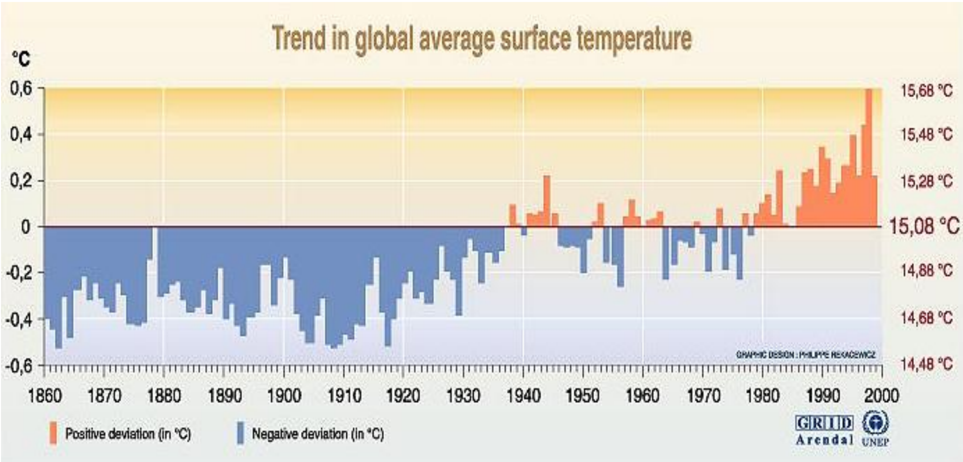
# INTRODUCTION

## 1.1 Introduction

The rising trend in the temperature of the earth has become a global threat. This is as a result of global warming. Global warming is caused by the emission of greenhouse gases into the atmosphere and it has had a significant impact on the world's climate (Boakye-Agyei, 2011; Bulkeley and Newell, 2010; Calabrò, 2009; Doria *et al.*, 2009; Halady and Rao, 2010; Wong *et al.*, 2010). There is increase in global surface temperature by 0.74 ± 0.18 $^{o}$C between the start and the end of the 20th century and is expected to increase by 1.1 to 6.4 $^{o}$C in the 21st century (Karthik, 2011). Another evidence of global warming is the increasing heat content of the oceans and sea level rise (Trenberth, 2010). The planet is said to be heating at a faster rate than at any time in the last 10,000 years. Moreover, eleven of the hottest years on record have occurred since 1983 with the decade of the 1990s being the hottest in the 20th century. The global mean surface temperature in 1998 is the highest on record since 1860 and is followed by 2005 (Hansen *et al.*, 2006; Kaufmann *et al.*, 2006). Figure 1.1(a) shows the global surface temperature change from 1880 to 2010 and Figure 1.1(b) shows the temperature trend from 1880 to 2000 (VijayaVenkataRaman *et al.*, 2012).




(a)




(b)

**Figure 1.1:** Global surface temperature from 1880 to 2010 and trend from 1880 to 2000 (VijayaVenkataRaman *et al.*, 2012)

Naturally greenhouse gases are 1– 2 % of the earth's atmosphere and form a shield that absorbs some of the solar radiation which would otherwise have been radiated into space (Houghton *et al.*, 2001). This helps to keep the planet warm to a comfortable and conducive temperature range of around 14$^{o}$C (57$^{o}$F). Without this natural greenhouse effect, the average temperature on earth would be approximately –18$^{o}$C (–2$^{o}$F).

Climate change is largely a result of human activities, especially the combustion of fossil fuels, which lead to increase in the atmospheric concentrations of greenhouse gases – carbon dioxide ($CO_2$), methane ($CH_4$), nitrous oxide ($N_2O$), and other gases (Figure 1.2) (Boakye-Agyei, 2011; Radojevic *et al.*, 2010;

Ramanathan and Feng, 2009). It is a global concern and its continuation is significantly impacting on people, environment, and economic conditions globally (Al-Amin *et al.*, 2010; Kaijage, 2010; Liu and Sweeney, 2012; Nursey-Bray, 2010).

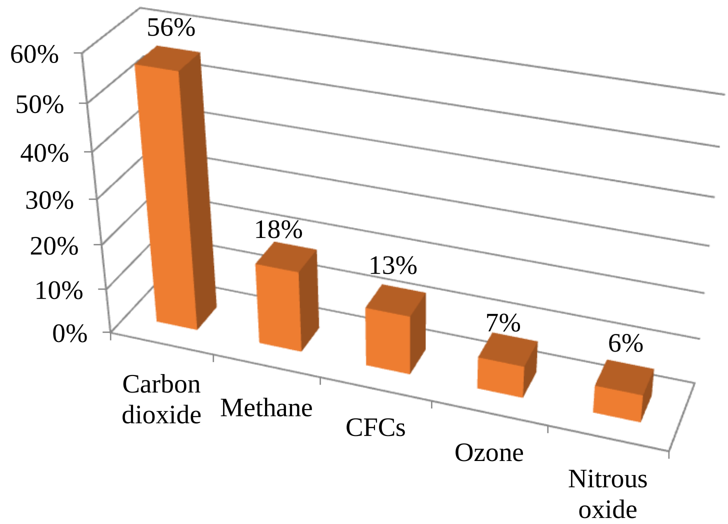



**Figure 1.2:** The major greenhouse gases (Ramanathan and Feng, 2009)

The combustion of fossil fuels and other human activities have increased the atmospheric concentrations of greenhouse gases (GHGs) since the beginning of the industrial revolution, and have increased the heat-trapping capability of the earth's atmosphere. The major greenhouse gases (GHGs) are water vapour (36–70%), carbon dioxide (9–26%), methane (4–9%), and nitrous oxide (3–7%) (Scheutz *et al.*, 2009). Since the pre-industrial era, atmospheric concentrations of $CO_2$ and $CH_4$ have gone up by nearly 30% and more than 100% respectively because of human activities through the burning of fossil fuels (Boakye-Agyei, 2011).

## 1.2 Problem Statement

In managing the world's climate, the primary attention has focused on reducing the emission of carbon dioxide or $CO_2$ (Nusbaum, 2010). Carbon dioxide is a powerful greenhouse gas. It is most often blamed for causing global warming and climate change and has been the main target of emission control. It is a product of combustion of any carbon-based fuel (mainly the fossil fuels), and is produced in large quantities. All measures to reduce global warming due to the greenhouse effect tend to focus on $CO_2$ emissions reduction from combustion of fossil fuels (Nusbaum, 2010). However, it has been reported that the largest cuts in $CO_2$ emission would not be felt in decades, if it is felt at all (Clinkard, 2010). This is because $CO_2$ has a very long atmospheric life of 50 – 200 years and more importantly, it is not the only gas that contributes to global climate change.

Many studies have been carried out on the negative effect of $CO_2$ in Malaysia (Abushammala *et al.*, 2011; Afroz *et al.*, 2003; Awang *et al.*, 2000; Hashim *et al.*, 2005; Mahlia *et al.*, 2001; Safaai *et al.*, 2011). Figure 1.3 shows the emissions of $CO_2$ from the year 2000 and its projected emission till 2025 (Safaai *et al.*, 2011).

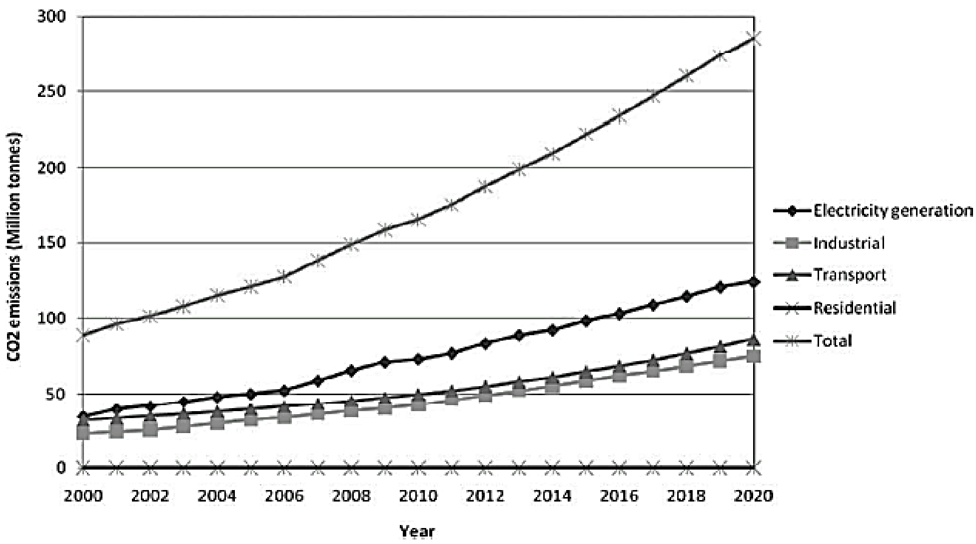



**Figure 1.3:** Past and projected $CO_2$ emissions for four sectors in Malaysia (Safaai *et al.*, 2011)

There is no record to show that such a comprehensive study has been carried out on $CH_4$ inventory, estimation and projection. Compared with studies of $CO_2$ emissions, there is scarcity of literature on $CH_4$ emissions in Malaysia and there is neither a comprehensive nor systematic tool to predict these emissions. The recorded study on methane emissions in Malaysia are from municipal solid waste landfills (Abushammala *et al.*, 2010; Chua *et al.*, 2011; Kathiravale *et al.*, 2003; Kathirvale *et al.*, 2004) and wastewater treatment (El-Fadel and Massoud, 2001; Hassan *et al.*, 2011; Sumathi *et al.*, 2008; Yacob *et al.*, 2005, 2006a). The emissions of methane from the other sources have not been adequately investigated.

Methane ($CH_4$) is another important greenhouse gas and is also a significant contributor to global warming (Xiaoli *et al.*, 2010; Zhang and Chen, 2010). Although annual $CH_4$ emissions around the world are significantly smaller than $CO_2$ emissions, and $CH_4$ concentrations in the atmosphere are about 200 times lower than those of $CO_2$ (Mackie and Cooper, 2009), but $CH_4$ still accounts for about 20% of global warming (Adushkin and Kudryavtsev, 2010; Lelieveld *et al.*, 2009; Szemesova and Gera, 2010). On an equivalent mass basis, $CH_4$ is 21–25 times more powerful greenhouse gas than $CO_2$ (Abichou *et al.*, 2011; Adushkin and Kudryavtsev, 2010). It is even postulated that the Global Warming Potential (GWP) of $CH_4$ could be greater than previously stated (Shindell *et al.*, 2009). Because of its shorter atmospheric life span of 12 – 17 years, reduction in methane emissions will have a much more immediate impact on climate, and its implementation will be cheaper (Clinkard, 2010).

Methane is emitted from various man-made (anthropogenic) and natural sources including municipal solid wastes (MSW) landfills, cattle ranching, rice paddies, coal mining, oil and gas drilling and processing, wetlands, termites, wildfires (Mackie and Cooper, 2009). It is a greenhouse gas ‘second only to carbon dioxide in enhanced climate forcing from the pre–industrial era (1750) to the present’ (Hofmann *et al.*, 2006).

Hence the focus of this research will be to take stock of $CH_4$ emission inventory from 1980 and to project future emissions in Malaysia up to 2020. There is a need to forecast and predict future emission of this gas in order to plan adequately on how to maximally utilise its vast potential as a renewable source of energy. The forecast will provide relevant and reliable information for policy makers for sound planning and to make important decisions. It will also keep all stakeholders alert so as to be able to face the challenges that will arise and to protect the environment. This is more so in view of the drive and plan of the government to make renewable energy the fifth part of the energy mix as enshrined in the Tenth Malaysian Plan. Emission inventories are prepared to determine the contribution from different sources.

The determination of an emission inventory is a useful tool in air quality management. Combined with forecasting, an emission inventory is used to assess the impact of specific human activities and the main sources responsible for such emissions and also to develop and assess the results of specific mitigation strategies (Karl *et al.*, 2009; Winiwarter *et al.*, 2009).

## 1.3 Aims of the research

The focus of this research will be to take stock of methane emission inventory in Malaysia from 1980 – 2011 and to project the emission from 2012 – 2020.

## 1.4 Objectives of the Research

The main objectives of this study are outlined below.

1. To take stock of methane inventory from all the likely sources in Malaysia from 1980 to 2011.

2. To forecast methane emissions from these sources from 2012 to 2020.

3. To develop an optimisation model that will lead to reductions in methane emissions in Malaysia.

4. To propose mitigation measures in line with Malaysian government policies.

## 1.5 Scope of the Research

To achieve the objective of the research, the following will be the scope of study.

The study will be limited to methane emissions from six identified sectors: coal mining, oil and gas production, livestock and poultry activities, rice paddies, wastewater treatment (palm oil mill effluent) and municipal solid waste management in Malaysia.

Palm oil mill effluent (POME) will be used to represent wastewater because it is the highest source of wastewater generation. Other sources like domestic wastewater and other industrial wastewater will be excluded.

Data will be sourced from relevant government Ministries, Departments and similar international organisations. Majority of the data will be from the Economic Planning Unit (EPU) and the Department of Statistics (DOS)

The projection of emissions will be from 2012 - 2020. The time interval was chosen to cover two periods of the national plans (2011-2015 and 2016-2020). Moreover, a longer time horizon reduces accuracy. Box-Jenkins ARIMA model will be used for the forecasting.

Mitigation options will be provided based on sensitivity analysis for some sectors that can be controlled.

The emission factors to be used will be the ones approved by the Intergovernmental Panel on Climate Change, IPCC (IPCC, 2006). These emission factors will be suitable for Tier 1 emissions calculations.

## 1.6 Output/Benefits of the Research

The study will be beneficial in many respects. These include:

The advantage of using methane as a good source of renewable energy from which small-capacity power generating plants of about 5–10 MW could be built will be highlighted.

It will expose the inherent risks (fire hazard) associated with some of the sources of methane emissions and will enhance environmental awareness with respect to the dangers associated with increased anthropogenic activities leading to increased greenhouse gas concentrations.

The economic potentials of some of the emissions sources will be shown. Municipal solid waste landfills are known to be potential sources of renewable energy that are cheaper and cleaner than energy from conventional fossil fuels.

The energy diversification programme of the Malaysian government will be boosted as the quantified potentials will reveal the actual amount of available energy. The heating value of methane which is 55.5 MJ/kg is equivalent to 1.2 kg of diesel or 3.7 kg of wood (Fountoulakis and Manios, 2009).

There will be attainment of sustainable development by relying less on non-renewable fossil fuels that will bring about a reduction in environmental pollution. This will further boost the Clean Development Mechanisms (CDM) being canvassed by the Malaysian government and will be a boost for the five fuel energy mix policy of the government.

Job opportunities will be created through the proliferation of small-capacity generating plants.

It will provide the basis for future policy framework that will address greenhouse gas emissions.

## 1.7 Structure of the Thesis

The thesis is divided into five (5) chapters. The thrust of each chapter is summarised below.

The **first chapter** gives a general introduction to the subject matter which is climate change and its damaging consequences. The chapter also mentions the greenhouse gases (GHG) and their effects including their global warming potentials. The problem statement is mentioned while the aims, objective and scope of the research are highlighted. The expected outputs and benefits of the research are mentioned whiled the chapter ends with an overview of the thesis arrangement

**Chapter two** presents a detailed review of global warming; climate change, greenhouse gases and their effects on the environment are discussed extensively. The major GHGs are introduced and methane gas/emission is given extensive review. The emission of methane in Malaysia is also discussed in this chapter. Detailed discussions of all sources of methane (natural and anthropogenic) are described as well as their estimation methods. The chapter also introduces the ARIMA method and the concept of optimisation.

The research design and the methodology to be employed in carrying out the research are highlighted in **chapter three**. The sources of data used for the inventories and for all computations of methane emissions are mentioned. Methane emission calculation methods, as given by the Intergovernmental Panel on Climate Change (IPCC), are also shown. Forecasting for the years 2012 – 2020 were carried out using the Box-Jenkins Auto-Regressive Integrated Moving Average (ARIMA) from the SPSS-PASW 18 software. The chapter concludes by highlighting the method used in carrying out the optimisation and the development of the model for methane emission reduction.

The results of all the computations are given in **Chapter four**. All inventories taken from 1980 – 2012 and the corresponding amounts of methane that would be emitted from the inventories are also given. Methane emissions forecasts were made for 2012 – 2020 for all the sources. The observed and predicted methane emissions values were compared with each other to determine the accuracy of the model. The comparisons are made in graphical forms. The optimisation aspect of the research was also carried out in this chapter. Optimised and uncontrolled (business-as-usual, BAU) emissions were compared and savings to be made from reduced emissions are shown. The chapter ends with different mitigation methods on how to reduce methane emissions from all the sources.

**Chapter five** presents the conclusions of the study. The research objectives are revisited and the theoretical and practical contributions of the study are mentioned. Recommendations are made in line with the policy direction of the government to make renewable \energy the 5th component of the energy mix.

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