IMPACT OF CLIMATE CHANGE ON OIL PALM PRODUCTION IN MALAYSIA

By

WAN NORANIDA BINTI WAN MOHD NOOR

Thesis Submitted to the School of Graduate Studies, Universiti Putra Malaysia, in Fulfilment of the Requirements for the Degree of Doctor of Philosophy

June 2022

FP 2022 75

COPYRIGHT

Abstract of thesis presented to the Senate of Universiti Putra Malaysia in fulfilment of the requirement for the degree of Doctor of Philosophy

IMPACT OF CLIMATE CHANGE ON OIL PALM PRODUCTION IN MALAYSIA

By

WAN NORANIDA BINTI WAN MOHD NOOR

June 2022

Chairman : Associate Professor Nolila binti Mohd Nawi, PhD
Faculty : Agriculture

Climate change has significantly impacted the economic development and trade of developing countries, particularly those that largely rely on agriculture. Oil palm was the main contributor to the Gross Domestic Product (GDP) of the agriculture sector in Malaysia. Climate change affects the growth and production of oil palm in several ways, including reduction of sex ratio, disruption of the pollination process, abortion of newly formed inflorescences and spread of pests and diseases. Some quantitative research findings, including the Production Function approach, have produced inconsistent results, prompting this study to be conducted by introducing a supply response approach that has not been widely used in the country, particularly in estimating the impact of climate change on commodity crops. Hence, the goal of the study is to quantify the impact of climate change on oil palm production. Specifically, the study was designed to determine the best model for measuring the impact of climate change on oil palm production by using Supply Response and Production Function approaches, to estimate the short-run and long-run impact of the variables associated with climate variables and to predict the future impact of climate change on Malaysian oil palm production. Annual time series data (1980–2019) were collected and analyzed using appropriate time series econometric models: Autoregressive Distributed Lag (ARDL) and Error Correction Model (ECM). Estimated coefficients were constructed in linear and non-linear equations, in logarithmic form and subjected to and passed relevant diagnostic tests. Three simulation scenarios consisting of SN1 (minimum climate variability), SN2 (maximum climate variability) and SN3 (average climate variability) were employed to project the FFB production. The estimated short-run coefficients of Model 3 show price factors respond significantly to increase oil palm production in the second lag period, and the expansion of the oil palm area has a positive relationship with oil palm production in the long-run consideration. The estimated coefficient of rainfall and temperature produces an adverse negative impact on oil palm production in the short run, while rainfall is an important variable for increasing oil palm production in the long run. The estimated short-term coefficients of Model 8 explain that own price and fertilizer use have a positive effect on oil palm

production in the second lag period, and the increase in oil palm area is beneficial for oil palm production in the long run. The rainfall variable has a negative effect in the second lag period, but positively increases oil palm production in the long run. The results of forecasting analysis revealed that SN1, SN2, and SN3 would cause an increase in FFB production by 5%, 1% and 2%, respectively. The production of FFB under SN1 is expected to increase from 90.5 million Mt in 2021 to 122.2 million Mt in 2030, from 87.8 million Mt in 2021 to 9.10 million Mt in 2030 under SN2 and 89.2 million Mt to 105.6 million Mt over the same time period under SN3. The FFB yield under SN1 is predicted to increase from 16.75 tonnes/hectare in 2021 to 16.90 tonnes/hectare in 2030, a decrease in the FFB yield from16.71 tonnes/hectare to 16.57tonnes/hectare under SN2 and anticipated to decrease in FFB yield from 16.71 tonnes/hectare to 16.57 tonnes/hectare under SN3 within the same period. Overall, climate change is likely to reduce FFB yield in the future. These results would serve as empirical guides in helping policymakers, smallholders and agencies involved in oil palm production to make decisions in terms of practical and policy implications to adapt to climate change-related risks and uncertainties. Among the practical implications are investments in technologies, such as developing drought-tolerant and early-maturity crop varieties, controlling emerging pests and diseases, increasing water saving, and reducing evapotranspiration. Production and income insurance policies and disaster assistance could be one way to recover losses, especially for smallholders. In addition, law enforcement for all smallholders to comply with Malaysian Sustainable Palm Oil (MSPO) certificate requirements in operating oil palm plantations is necessary, apart from the introduction of policies such as the National Climate Policy (2009). The findings of this study will prompt a number of studies that require further investigation, such as the application of supply response on other crops and agricultural-related activities, considering other climate indicators such as radiation, light duration, CO_2 concentration, humidity and sea level, and divided regions such as Peninsular Malaysia, Sabah, and Sarawak in order to produce more accurate results regarding climate change scenarios.

Abstrak tesis yang dikemukakan kepada Senat Universiti Putra Malaysia sebagai memenuhi keperluan untuk ijazah Doktor Falsafah

KESAN PERUBAHAN IKLIM TERHADAP PENGELUARAN KELAPA SAWIT DI MALAYSIA

Oleh

WAN NORANIDA BINTI WAN MOHD NOOR

Jun 2022

Pengerusi : Profesor Madya Nolila binti Mohd Nawi, PhD
Fakulti : Pertanian

Perubahan iklim telah mempengaruhi perkembangan ekonomi dan perdagangan negara-negara membangun terutamanya yang bergantung kepada pertanian. Kelapa sawit merupakan penyumbang utama kepada Keluaran Dalam Negara Kasar (KDNK) sektor pertanian di Malaysia. Perubahan iklim mempengaruhi pertumbuhan dan pengeluaran kelapa sawit melalui beberapa cara, termasuk mengurangkan nisbah jantina, menaggangu proses pendebungaan, menyebabkan pengguguran perbungaan yang baru terbentuk dan penyebaran perosak dan penyakit. Beberapa penemuan penyelidikan kuantitatif, termasuk pendekatan Fungsi Pengeluaran, telah menghasilkan keputusan yang tidak konsisten, mendorong kajian ini dijalankan dengan memperkenalkan pendekatan Tindak Balas Bekalan yang belum digunakan secara meluas di negara ini, khususnya dalam menganggar kesan perubahan iklim terhadap tanaman komoditi. Oleh itu, matlamat kajian adalah untuk menilai kesan perubahan iklim terhadap pengeluaran kelapa sawit. Secara khusus, kajian ini dijalankan untuk menentukan model terbaik bagi menilai kesan perubahan iklim terhadap pengeluaran kelapa sawit dengan menggunakan pendekatan Tindak Balas Bekalan dan Fungsi Pengeluaran, untuk menganggarkan kesan jangka pendek dan jangka panjang pembolehubah utama yang dikaitkan dengan pembolehubah iklim dan untuk meramalkan kesan perubahan iklim pada masa hadapan terhadap pengeluaran kelapa sawit di Malaysia. Data siri masa tahunan (1980-2019) dikumpulkan dan dianalisa menggunakan model ekonometrik siri masa: *Autoregressive Distributed Lag (ARDL*) dan *Error Correction Model (ECM*). Anggaran pekali dibina dalam persaman linear dan bukan linear, dalam bentuk logaritma dan tertakluk kepada dan melepasi ujian diagnostik yang relevan. Tiga senario simulasi yang terdiri daripada SN1 (kebolehubahan iklim minimum), SN2 (kebolehubahan iklim maksimum) dan SN3 (kebolehubahan iklim purata) telah digunakan untuk menganggarkan pengeluaran BTS. Anggaran pekali jangka pendek bagi Model 3 menunjukkan faktor harga bertindak balas meningkatkan pengeluaran kelapa sawit dalam tempoh ketinggalan kedua, dan pengembangan kawasan kelapa sawit mempunyai hubungan positif dengan pengeluaran kelapa sawit dalam tempoh jangka masa panjang. Anggaran pekali hujan

dan suhu memberikan kesan negatif yang buruk terhadap pengeluaran kelapa sawit dalam jangka masa pendek, manakala hujan merupakan pembolehubah yang penting untuk meningkatkan pengeluaran kelapa sawit dalam jangka masa panjang. Anggaran pekali jangka pendek untuk Model 8 menjelaskan bahawa harga kelapa sawit dan penggunaan baja memberikan kesan positif terhadap pengeluaran kelapa sawit dalam tempoh ketinggalan kedua, dan peningkatan kawasan kelapa sawit penting untuk pengeluaran kelapa sawit dalam jangka masa panjang. Pembolehubah hujan mempunyai kesan negatif dalam tempoh ketinggalan kedua, tetapi secara positif meningkatkan pengeluaran kelapa sawit dalam jangka masa panjang. Hasil analisis ramalan menunjukkan bahawa SN1, SN2, dan SN3 akan menyebabkan peningkatan pengeluaran BTS masing-masing sebanyak 5%, 1% dan 2%. Pengeluaran BTS di bawah SN1 dijangka meningkat daripada 90.5 juta tan metrik pada 2021 kepada 122.2 juta tan metrik pada 2030, daripada 87.8 juta tan metrik pada 2021 kepada 9.10 juta tan metrik pada 2030 di bawah SN2 dan 89.2 juta tan metrik kepada 105.6 juta tan metrik dalam tempoh masa yang sama di bawah SN3. Hasil BTS di bawah SN1 diramalkan meningkat daripada 16.75 tan/hektar pada 2021 kepada 16.90 tan/hektar pada tahun 2030, penurunan hasil BTS daripada 16.71 tan/hektar kepada 16.57 tan/hektar dibawah SN2 dan penurunan hasil BTS di bawah SN3 daripada 16.71 tan/hektar kepada 16.57 tan/hektar dalam tempoh yang sama. Secara keseluruhannya, perubahan iklim berpotensi mengurangkan hasil BTS pada masa hadapan. Keputusan kajian ini akan menjadi panduan empirikal dalam membantu penggubal dasar, pekebun kecil dan agensi yang terlibat dalam pengeluaran kelapa sawit untuk membuat keputusan dari segi implikasi praktikal dan implikasi dasar untuk penyesuaian kepada risiko dan ketidakpastian berkaitan perubahan iklim. Antara implikasi praktikal ialah pelaburan dalam bidang teknologi seperti membangunkan varieti tanaman yang tahan kepada kemarau dan matang lebih awal, mengawal serangan perosak dan penyakit, meningkatkan penjimatan air, dan mengurangkan sejatan. Polisi insurans pengeluaran dan pendapatan serta bantuan bencana boleh dijadikan salah satu cara untuk mengurangkan kerugian, terutamanya kepada pekebun kecil. Di samping itu, penguatkuasaan undang-undang kepada semua pekebun kecil agar mematuhi keperluan pensijilan Minyak Sawit Mampan Malaysia (MSPO) dalam mengendalikan ladang kelapa sawit adalah perlu, selain daripada pengenalan dasar seperti Dasar Iklim Negara (2009). Penemuan kajian ini boleh mendorong beberapa kajian lain yang memerlukan penyiasatan lanjut, seperti mangaplikasikan tindak balas bekalan pada tanaman lain dan aktiviti berkaitan pertanian, mengambil kira penunjuk iklim yang lain seperti sinaran, tempoh cahaya, kepekatan CO_2 , kelembapan dan paras laut dan membahagikan wilayah seperti Semenanjung Malaysia, Sabah, dan Sarawak untuk menghasilkan keputusan yang lebih tepat berkenaan senario perubahan iklim.

ACKNOWLEDGEMENTS

Foremost, all praises and endless thanks to Allah the Almighty for giving me the opportunity, strength and knowledge to pursue my study and complete it satisfactorily. This research would not have been possible without the guidance and help of several individuals who contributed and extended their valuable assistance in the preparation of this study.

I express my heartfelt thanks and gratitude to my supervisor, Assoc. Prof. Dr. Nolila binti Mohd Nawi, for the continuos support, knowledge and assistance throughout this journey in order to ensure this research was running as planned. I thank my former supervisor, Assoc. Prof. Dr. Mohd Amin bin Mahir, for his patience, knowledge, enthusiasm and encouragement. My sincere thank also go to my supervisory committee, Dr. Kelly Wong Kai Seng and Dr. Mark Buda for providing their suggestions, guidance, and insightful remarks.

I would like to thank my lecturers, Assoc. Prof. Dr. Ismail bin Abdul Latif, Prof. Datuk Dr. Mad Nasir Shamsudin and Prof. Dr Zainal Abidin bin Mohamed, for their invaluable opinion and time. I thank the staffs of the Department of Agribusiness and Bioresource Economics, Universiti Putra Malaysia for their facilities and co-operation. My acknowledgement also goes to the office staffs of Malaysian Meteorological Department (MMD), Malaysian Palm Oil Board (MPOB), Malaysian Rubber Board (MRB) and National Water Research Institute of Malaysia (NAHRIM) for their expertise and providing the information that I needed. Thanks to all my friends and colleagues for their continuous support. I share the credits of this works to all my fellow friends for the priceless discussions and suggestions, legion moral supports and motivations, encouragement and their warm friendship.

I gratefully acknowledge to the Universiti Teknologi Mara Malaysia and Ministry of Higher Education Malaysia. Without the scholarship provided by them, I would not have been study in Universiti Putra Malaysia. The Universiti Putra Malaysia is thanked for giving the Research University Grant Scheme (RUGS) to this research and helping me with providing the data and attending the workshops and seminars.

I am deeply indebted to my husband (Mohd Yusof), my son (Ahmad Fikri), my daughter (Nur Jannah, Nur Husna and Nur Hana), my parents (Wan Mohd Noor and Fatimah), my in laws (Mat Salleh and Halimah) and siblings (Wan Mohd Fauzi, Wan Mohd Ruzifa, Wan Zanariah, Wan Zarina, Wan Norilah, Wan Norihan and Wan Nor Fadilah) for their pray, advice, affections, and concern. I also place on record, my sense of gratitude to everyone, who directly and indirectly has lent his or her hand in this venture.

Thank You,

WAN NORANIDA BINTI WAN MOHD NOOR
UPM, Serdang Malaysia
January 2023

This thesis was submitted to the Senate of the Universiti Putra Malaysia and has been accepted as fulfilment of the requirement for the degree of Doctor of Philosophy. The members of the Supervisory Committee were as follows:

Nolila binti Mohd Nawi, PhD
Associate Professor
Faculty of Agriculture
Universiti Putra Malaysia
(Chairman)

Kelly Wong Kai Seng, PhD
Senior Lecturer
Faculty of Agriculture
Universiti Putra Malaysia
(Member)

Mark bin Buda, PhD
Senior Lecturer
Faculty of Agriculture
Universiti Putra Malaysia
(Member)

____

ZALILAH MOHD SHARIFF, PhD
Professor and Dean
School of Graduate Studies
Universiti Putra Malaysia

Date: 9 February 2023

Declaration by graduate student

I hereby confirm that:

- this thesis is my original work;
- quotations, illustrations and citations have been duly referenced;
- this thesis has not been submitted previously or concurrently for any other degree at any institutions;
- intellectual property from the thesis and copyright of thesis are fully-owned by Universiti Putra Malaysia, as according to the Universiti Putra Malaysia (Research) Rules 2012;
- written permission must be obtained from supervisor and the office of Deputy Vice-Chancellor (Research and innovation) before thesis is published (in the form of written, printed or in electronic form) including books, journals, modules, proceedings, popular writings, seminar papers, manuscripts, posters, reports, lecture notes, learning modules or any other materials as stated in the Universiti Putra Malaysia (Research) Rules 2012;
- there is no plagiarism or data falsification/fabrication in the thesis, and scholarly integrity is upheld as according to the Universiti Putra Malaysia (Graduate Studies) Rules 2003 (Revision 2012-2013) and the Universiti Putra Malaysia (Research) Rules 2012. The thesis has undergone plagiarism detection software

Signature: ________________________ Date: _______________

Name and Matric No: Wan Noranida binti Wan Mohd Noor

Declaration by Members of Supervisory Committee

This is to confirm that:

- the research conducted and the writing of this thesis was under our supervision;
- supervision responsibilities as stated in the Universiti Putra Malaysia (Graduate Studies) Rules 2003 (Revision 2012-2013) are adhered to.

Signature: ______________________

Name of Chairman of Supervisory Committee: Associate Professor Dr. Nolila Mohd Nawi

Signature: ______________________

Name of Member of Supervisory Committee: Dr. Kelly Wong Kai Seng

Signature: ______________________

Name of Member of Supervisory Committee: Dr. Mark Buda

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

LIST OF APPENDICES

LIST OF ABBREVIATIONS

ACF	Auto-correlation function
ADF	Augmented Dickey Fuller
APSIM	Agricultural Production System Stimulator
AFRIMA	autoregressive fractionally integrated moving average
AI	artificial intelligence
AIC	Akaike information criterion
AOGCMs	Atmosphere/Ocean General Circulation Model
ANN	artificial neural network
AR	autoregressive
ARDL	Autoregressive Distributed Lag
BPG	Breusch-Pagan Godfrey
BIC	Bayesian information criterion
BTS	Buah Tandan Segar
CCSM3	Third Generation of the Community Climate System Global Climate Model
CES	Constant Elasticity of Substitution
CFC	chlorofluorocarbon
CMS	Constant Marginal Shares
CO_2	carbon dioxide
CPO	crude palm oil
CUSUM	Cumulative sum of the recursive residual
CUSUMSQ	Cumulative sum of squared recursive residuals
DOSM	Department of Statistic Malaysia

ECHAM5	Fifth Generation of the Coupled Atmospheric-Oceanic Global Climate Model of the European Center-Hamburg
ECM	Error Correction Model
EFB	Empty Fruit Bunch
EM	East Malaysia
ETP	Economic Transformation Programme
FAOSTAT	Food and Agriculture Organization of the United
FELDA	Federal Land Development Authority
FELCRA	Federal Land Consolidation and Rehabilitation Authority
FFB	fresh fruit bunch
FPE	Final Prediction Error
GCM's	Global Circulation Models
GDP	Gross Domestic Product
GHGs	green house gases
GLS	generalized least squares
GNI	Gross National Income
HQC	Hannan-Quinn criterion
HadCM	Hadley Centre Couple Model
IFA	International Fertilizer Industry Association
IPCC	Intergovernmental Panel on Climate Change
JB	Jarque-Bera
KDNK	Keluaran Dalam Negara Kasar
LM	Lagrange Multiplier
LPF	Leontief Production Function
LUCF	land use change and forestry

MA	moving average
MAE	mean absolute error
MAgPA	Malaysian Agricultural Policy
Mha	Million hectares
MAPE	mean absolute percent error
MMD	Malaysia Metrological Department
MPOB	Malaysian Palm Oil Board
MPOC	Malaysian Palm Oil Council
MRI-CGCM2.3.2	Coupled Oceanic-Atmospheric Global Climate Model of the Meterological Research Institute of Japan porosity
MRB	Malaysian Rubber Board
Mt	Metric tonnes
MSPO	Malaysian Sustainable Palm Oil
NAHRIM	National Water Research Institute of Malaysia
NAP	National Agricultural Policy
NEM	New Economic Model
NPK	Nitrogen, Phosphorus, and Potassium
OER	oil extraction rate
OLS	ordinary least square
PA	partial adjustment
PAAE	Partial Adjustment Adaptive Expectation
PACF	Partial autocorrelation
PKO	palm kernel oil (PKO)
PM	Peninsular Malaysia
PP	Phillips-Perron

ppm	part per million
PRECIS	Providing Regional Climates for Impacts Studies
RCPs	Representative Concentration Pathways
RegHCM-PM	Regional Hydroclimate Model of Peninsular Malaysia
RegHCM-SS	Regional Hydroclimate Model of Sabah and Sarawak
RESET	Regression Specification Error Test
RMSE	Root Mean Squared Error
RSPO	Palm Oil Sustainable Roundtable
R&D	Research and Development
SIC	Schwarz Bayesian information criterion
SLR	sea level rise
SOI	South Oscillation Index
sq. km	square kilometer
U	Theil inequality
UECM	Unrestricted Error Correction Model
VAR	Vector Autoregressive
VECM	Vector Error Correction Model
VES	Variable Elasticity of Substitution
WAM	West African Monsoon
Yp	yield potential
Yw	water-limited yield

CHAPTER 1

INTRODUCTION

The first chapter introduces the background of the study, development and factors affecting of oil palm in the country and further describes the field of climate change in Malaysia. The methodologies applied in assessing the impact of climate change also discussed in this section. It includes the statement of the problem, the research question, the objective of the study, the importance of the study, and the scope of the study. The chapter concludes with the organization of the thesis.

1.1 Background of the Study

Agriculture is the foundation of a developing nation's economy. The agricultural sector presents its gross output of RM73.9 billion from 2015 to RM91.2 billion in 2017, an increase of 11.1% per year. Value added for this sector also increased by 15% per year from RM41.47 billion to RM54.87 billion within the same period (Department of Statistics Malaysia (DOSM), 2020). Export of agriculture sector in 2020 amounted to RM118.6 billion compared to RM115.5 billion in 2019, increased by 2.7%. Meanwhile, total import was valued at RM98.0 billion compared to RM93.5 billion in 2019, with an increase of 4.8% (DOSM, 2021). The contribution of agriculture to the GDP (Gross Domestic Product) declined from 28.8% in 1970 to 7.3% in 2010. The contribution was maintained in 2018 before increasing to 7.4% in 2020.

Albeit the diminishing contribution of agriculture to the economy, the agriculture sector remains essential to guarantee the country's food supply remains sufficient and, most importantly, as a wellspring of farmer’s income and agro-based industries. The DOSM (2021) revealed that the oil palm was the main supporter to the value added of agriculture, representing over 37.1%, followed by other agriculture, livestock, fishing, forestry and logging, and rubber, with the percentage contribution of 27.9%, 16.1%, 11.2%, 5.2%, and 2.5%, respectively in 2020. This shows that oil palm has contributed significantly to the national economy and can be considered as the most important crop in the agricultural sector. The demand for palm oil has expanded to more than 140 countries, of which Malaysia is the second largest producer after Indonesia (Malaysian Palm Oil Council (MPOC), 2022), owing to Malaysia’s geographical and climate conditions favorable for oil palm growth. According to Figure 1.1, Malaysia produced 19 million metric tonne (Mt) of the world's palm oil, with 26% share of global palm oil production in 2019. The remaining oil palm plantations have been established in Thailand, Columbia, Nigeria, Guatemala, and Papua New Guinea, with a combined contribution to global oil production of less than 8 Mt and a global share of less than 4% for each nation (United States Department of Agriculture (USDA), 2020).

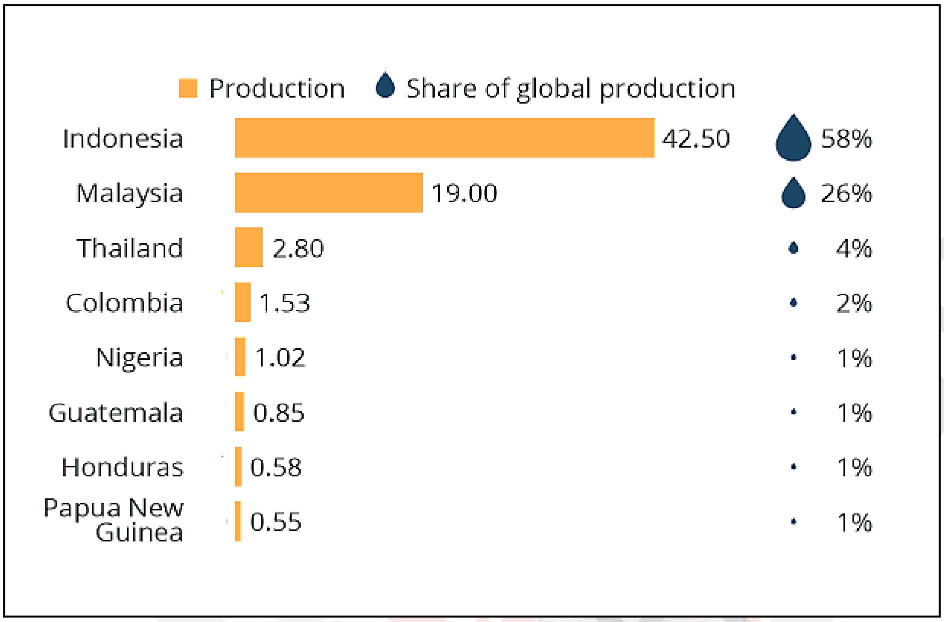

Figure 1.1 : Global Palm Oil Production and Share in 2019
Note: Value of palm oil production and share of global production in million Mt
(Source: USDA, 2020)

1.1.1 Malaysia Oil Palm Development

Palm oil is a profoundly valuable commodity, which is obtained from the flesh of the fruit of the oil palm species *Elaeis guineensis.* The first batch of oil palms was planted in the highlands of the Fouta Djallon district of Guinea, West Africa, which is believed to be a suitable location for oil palm cultivation (Yusof, 2007). However, Africa has restricted climatically suitable regions, with Northern and Eastern Africa experiencing a rapid decline in rainfall and the country's high altitude has caused unsuccessful plantation in the origin country. From that point forward, oil palm was introduced to Malaysia in 1871 after the original oil palm was transported from West Africa to Bogor Botanical Gardens, Indonesia, in 1848 (Sheil et al., 2009). From a mere four seedlings shipped via Amsterdam, the oil palm was initially planted to determine their suitability for decorative and medicinal purposes. The prolific growth of the oil palm in tropical countries has been induced by the fact that oil palm recorded the highest yield among all kinds of oils that are produced in worldwide (Nur Nadia and Syahadatul, 2017).

The first oil palm plantation was established in 1917 at Tenamaran Estate in Kuala Selangor, which concurs with the beginning of the rubber industry in 1896 (Yusof, 2007). The plantation area covered 3,325 hectares by 1925, and subsequently, the sector forged ahead rapidly before World War II, and the area increased to 20,000 hectares by 1938 (Corley et al., 2003). The growth was sluggish until rehabilitation was done, and the sector was fully established in 1947. The pace of the sector's expansion was rapid in the 1960s, even though the country endured terrorist threats during that period. The oil palm planting area covered 60,000 hectares by 1960, and it reached one million hectares (Mha) and 4.85 Mha in 1980 and 2010, respectively (MPOC, 2020b; Yusof, 2007). A growing trend in the total area of oil palm is illustrated in Figure 1.2. Sabah and Sarawak, as represented by East Malaysia (EM), have seen a significant surge for the period 1980-2020, in contrast to the more modest growth of Peninsular Malaysia (PM). In 1980, the oil palm planted areas were 0.1 Mha and 0.9 Mha in EM and PM, respectively. The planted areas of oil palm in EM outgrew the areas in PM in 2013, and by 2020, it increased to 3.1 Mha, or 53.3% of the total oil palm area (Malaysia Palm Oil Board (MPOB), 2021a).

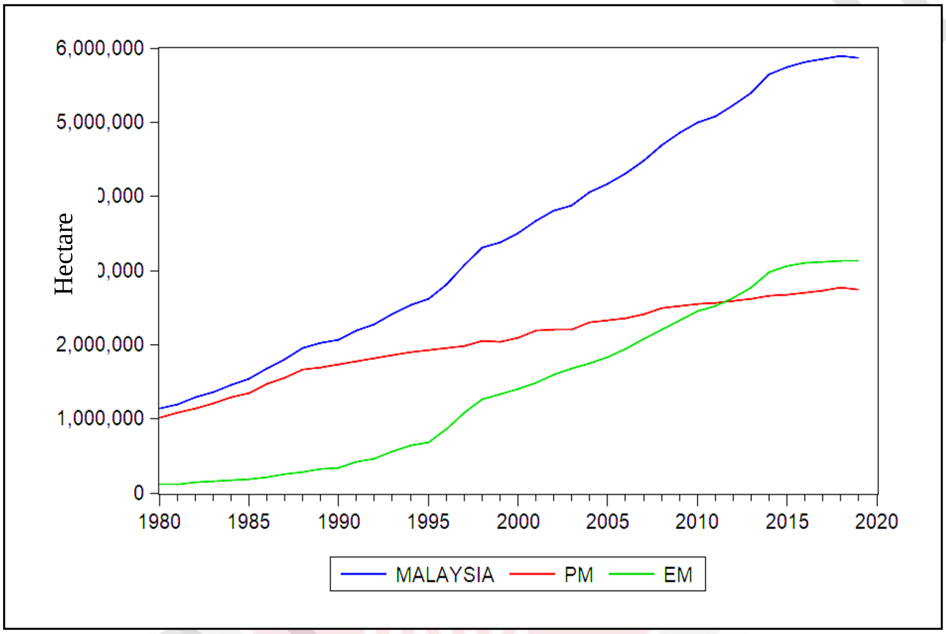

Figure 1.2 : Oil Palm Planted Area, 1980-2020
(Source: MPOB, 2021b)

Table 1.1 shows total oil palm planted areas in 2015 reached 5.64 Mha, an increase of 16.3% as against 4.85 Mha recorded in the previous five years. This was mainly due to the increase in new planted areas, especially in Sarawak, which recorded an increase of 56.5% for the period 2010 to 2015. Sabah remains the state with the most oil palm plantations, with 1.55 Mha or 27% of the total oil palm planted areas, followed by Sarawak with 1.51 Mha or 26% and PM with 2.68 Mha or 47% of the total planted areas in 2015. Sarawak then overtook Sabah as the largest oil palm planted state, with 1.58 Mha or 27% of the total Malaysia oil palm planted areas in 2020, and Pahang leads the largest area of oil palm in the PM with 0.78 Mha or 13.3%, followed by Johore with 0.74 Mha or 12.6%.

Table 1.1 : Oil Palm Planted Area by State

State	2010		2015		2020	
	Total (Ha)	%	Total (Ha)	%	Total (Ha)	%
Johore	717,398	14.8	739,583	15.9	740,828	12.6
Kedah	78,539	1.6	87,244	1.6	89,782	1.5
Kelantan	132,715	2.7	151,973	2.7	167,599	2.9
Malacca	51,350	1.1	54,603	1	56,361	1
Negeri Sembilan	164,362	3.4	177,471	3.1	190,462	3.2
Pahang	688,866	14.2	725,239	12.9	782,247	13.3
Perak	13,595	0.3	17,447	0.3	391,768	6.7
Perlis	382,527	7.9	398,314	7.1	694	0
Pulau Pinang	234	0	294	0	12,829	0.2
Selangor	129,000	2.7	137,336	2.4	126,525	2.2
Terengganu	166,086	3.4	172,587	3.1	178,628	3
Peninsular Malaysia	2,524,672	52.0	2,659,361	47.1	2,737,723	46.7
Sabah	1,409,676	29.0	1,544,223	27.4	1,543,054	26.3
Sarawak	9,19,418	18.9	1,439,359	25.5	1,584,520	27.0
Sabah And Sarawak	2,329,094	48.0	2,983,582	52.9	3,127,574	53.3
Malaysia	4853766	100	5,642,943	100	5,865,297	100

(Source: MPOB, 2021b)

In terms of production, crude palm oil (CPO) increased almost 180 times over a span of 50 years; the records indicate that the yield rose from 94,000 metric tonnes (Mt) in 1960 to 16.99 million Mt in 2010 (MPOB, 2016). In 2016, the CPO production fell to 17.32 million Mt or 13.2% as against 19.96 million Mt produced in 2015. Lower FFB processed and lower oil extraction rate (OER were the causes of the fall in CPO production. Besides that, the El-Nino phenomenon, which started in the second half of 2015 and resulted in prolonged dry weather and below-average rainfall, had an impact on the production of fresh fuit bunch (FFB) in 2016 (MPOB, 2016). However, the CPO production increased again from 19.52 million Mt to 19.86 million Mt in 2019, an increase of 1.8% compared to 2018 (Malaysian Palm Oil Board, 2020b). This is mainly attributed to the increase of FFB being processed, denoted by a rise of 0.5% as a result of a 0.2% increase in FFB production, and higher OER performance, which increased from 19.95% to 20.21% in 2018 and 2019, respectively.

The oil palm plantation was handled by independent smallholders, organized smallholders and private estates, as shown in Table 1.2. The organized smallholders involved are settlers under Federal Land Development Authority (FELDA), Federal Land Consolidation and Rehabilitation Authority (FECLRA), Sarawak Land Consolidation and Rehabilitation Authority (SALCRA), Rubber Industry Smallholders Development Authority (RISDA), Sarawak Land Development Board (SLDB) and Lembaga Kemajuan Kelantan Selatan (KESEDAR), while the plantation category includes private estates, Felda Global Venture Holdings Berhad (FGV), and plantation sector of FELCRA and RISDA. Table 1.2 depicts that the oil palm planted areas under the plantation category have expanded by 10,000 ha from 2019 to 2020. On the contrary, the independent category and the organized smallholder's category had oil palm planted areas declined from 0.68 Mha to 0.67 Mha and 16.7 Mha to 16.3 Mha, respectively.

Table 1.2 : Oil Palm Planted Area by Category (2019-2020)

Category	2019		2020	
	Ha (million)	%	Ha (million)	%
Plantation	4.23	71.7	4.24	72.2
Organized smallholders	0.68	11.6	0.67	11.5
Independent smallholders	0.99	16.7	0.96	16.3

(Source: MPOB, 2021b)

The contribution of oil palm is very significant for the Malaysian economic, with the export revenue produced is RM68,648 million, or 6.7% of nation's total GDP in 2021 (DOSM, 2022). Malaysia has been the second largest producer of palm oil since it produces almost half of all the palm oil consumed in the world. The development of oil palm increases every year, with the interest of this edible oil has had far-reaching effects on the economy, social and the environment. Table 1.3 shows palm oil export volume fell by 8.2% to 23.3 million tonnes in 2016 from 25.37 million tonnes in 2015. Nevertheless, as a result of higher export prices, overall export revenue increased by 7.3% to RM64.59 billion in 2016 from RM60.17 billion in 2015. Overall, palm oil exports rose further, reaching a total of 27.88 million tonnes in 2019 before falling to 26.73 million tonnes in 2020. Palm oil products rose due to higher demands, especially from Saudi Arabia, Iran, Pakistan, and the Philippines. India maintained its position as the largest palm oil export market, followed by China. The increase in trade prices caused the total export revenue to climb by 13.4% to RM73.25 billion from RM64.59 billion in 2016.

Table 1.3 : Total Exports and Total Revenue of the Malaysian Palm Oil

Year	Total Exports (Tonnes)	Total Revenue (RM Million)
2015	25,370,294	60,169.49
2016	23,294,140	64,591.82
2017	23,974,526	77,848.39
2018	24,876,769	67,515.98
2019	27,879,177	67,546.15
2020	26,725,135	73,253.19

(Source: MPOB, 2021a)

1.1.2 Factors behind the Rapid Growth of Malaysian Oil Palm Sector

Malaysia plays a significant part in satisfying the worldwide demand for edible oil as it represents 8.4% of the world's oils and fats production and 19.1% of the export trade of oils and fats in 2020 (MPOB, 2021a). The development of the oil palm sector indirectly brings advanced technology and expansion of mills and refinery factories. Recently, MPOB (2021a) reported that there are 451 palm oil mills, 49 refineries, 19 oleo-chemical plants and 43 palm crushers. This sector additionally provides employment to more than half 750,000 people, excluding around a million smallholders.

The major reasons for this expansion are profitability, population growth, increasing demand for oil and fats, the government supports, downstream activities, biofuel development, suitable climate and soil conditions, and the characteristics of the oil itself (Suhaila, 2012; Kushairi et al., 2019). Firstly, oil palm is referred to as 'Malaysia's Golden Crop' due to its colour and high productivity compared to other crops. Research shows that oil palm yields an average of 3.5 tonnes for each hectare per year, which is four times higher than rapeseed and about seven times more than soybean (Yusof, 2014). In terms of comparative analysis, one tonne of palm oil can be produced from 2.2 hectares of soybean, 1.5 hectares of sunflower, 1.3 hectares of rapeseed, and only 0.3 hectares of oil palm (European Commision Report, 2018). Undoubtedly, oil palm cultivation can minimize the amount of land required to generate the same quantity of vegetable oils, hence the interest of other tropical nations that want to generate profits from it. Profits gained from oil palm are due to reasonably priced land, higher export prices of palm oil and other oil palm products, availability of financing facilities, and support from private and public institutions regarding research and development (R&D) (Sheil et al., 2009; Parveez et al., 2021).

Secondly, the government played a crucial part in facilitating the oil palm expansion by formulating agricultural policies. The First National Agricultural Policy (NAP1) was formed in 1984 to eradicate poverty among rural smallholders' farmers and raise the value of agricultural products for export markets. Among the achievements throughout NAP1 is the development of additional land that has generated employment in rural areas and also increased production of agricultural products and food for domestic consumption.

The NAP1's success has been demonstrated by the growth of 51.9% of the oil palm planted areas, from 1.36 Mha in 1984 to 2.07 Mha in 1991 (Malaysian Palm Oil Board, 2016). The Second National Agricultural Policy (NAP2), adopted in 1992 until 2010, was the extension of the NAP1 and has placed more focus on the productivity, competitiveness, and sustainable production of agro-food policy. Additionally, the government offers subsidies and incentives to smallholders in order to encourage them to open new land areas for industrial crops, such as oil palm and rubber. However, in response to the impacts of the Asian Financial Crisis (AFC) 1997–1998 and the opening of financial markets to the Malaysian economy, the government endorsed the Third National Agricultural Policy (NAP3) in 1998 to address agriculture's challenges, such as changes in the economic structure due to the lack of agricultural land, the lack of labor due to competition with other parties, efficiency and effective use of resources to boost competitiveness. The policy's particular goals are to ensure food security, increase agricultural production and competitiveness, strengthen ties with other industries, and sustainably conserve and use natural resources (Murad et al., 2008).

The NAP3 continues to pursue agricultural growth through moderate land expansion and land use intensification. Production of rubber and cocoa substantially decreased and were replaced by oil palm, fruit, and vegetable farming. Meanwhile, a significant amount of new land has been widened for the production of palm oil in Sabah and Sarawak. As a result, the area planted with oil palm increased dramatically during the plan period, from 3.08 Mha in 1998 to 4.85 Mha in 2010. Additional markers of NAP3 effectiveness were the utilization of high-yielding clones, improvements in agronomic practices among smallholders and plantations, and rising mechanization.

The ongoing challenges in the agricultural sector require a new set of strategic directions. The National Agro-Food Policy (2011-2020) has been enacted to ensure a sustainable and competitive agro-food industry with aspects of food safety and nutrition along the value chain, as well as increasing the income levels of agricultural entrepreneurs. The National Commodity Policy (2011-2020) was also established in the same period with the goals of increasing the economic contribution of industrial plantation commodities to the nation, modernizing and transforming the commodity industry toward a more competitive and sustainable level, encouraging the development of the commodity industry along the value chain, raising the income of operators and smallholders in the commodity industry, and promoting the country as the center of excellence in R&D, technology development and the downstream processing of industrial commodities. This policy placed a greater emphasis on the valuable commodity, i.e., palm oil, in order to guide the Malaysian oil palm sector and forecast the expansion of oil palm planted areas between 2011 and 2020. The government then established the National Agrofood Policy 2.0 (2021-2030), which has three main policy tenets: a paradigm shifts toward a sustainable food system that is climate change-adaptive; the incorporation of food producers' welfare in the sector; and a highly competitive and innovative agro-food sector. All formulated policies are crucial to drive the agricultural economy, especially in the oil palm sector, which has brought success in the expansion of oil palm areas.

Increasing world demand for oil and fats is one of the factors of the expansion of the oil palm sector. The palm oil production has surpassed other vegetable oils since 2004, which was previously overwhelmed by soybean oil (Yusof, 2014). Demand for this edible oil is related to the strength of economy and population growth, particularly in major importers, such as China and European countries. Furthermore, surging prices of crude oil along with growing concerns for global warming have led many countries to seek alternative energy from renewable resources. Among other renewable resources that are being researched, biodiesel has drawn a great deal of interest because of its similarity to conventional diesel (Man et al., 2009; Ganjehkaviri et al., 2016; Parveez et al., 2021). Biodiesel is made from renewable biological resources, such as rapeseed, soybean, and sunflower. The modification of oil palm could likewise be utilized as palm diesel. Ganjehkaviri et al. (2016) highlight the fuel properties of palm diesel as practically identical to those of petroleum diesel and can be used directly in unmodified diesel engines. Approximately 80% of palm oil is consumed for food products and the rest for non-edible use, such as oleochemicals. The oleochemicals are believed to have thousands of uses in personal care products, detergents, lubricants, and agrochemicals (Khoo et al., 2005; Kushairi et al., 2019). The oleochemicals products derived for direct uses include soap, polyols, printing ink and polyurethanes, while the indirect uses include fatty acids, fatty esters, glycerols as well as in numerous industrial applications (Yusof et al., 2009; Teh et al., 2018).

Consumers tend to use palm oil because it has several advantages. For example, it contains oleic acid, which is used to retain the flavor of a food. This versatile oil also found its ways into confectionary, chocolate, chewing gum, and it is widely used as medium for frying food because it has the capability to absorb at a slow rate (Yusof, 2007; Teh et al., 2021). Palm oil has proven to contain powerful antioxidants, such as vitamin E, carotenoids, and vitamin C, which are important for human body's defence and they are also helpful in cancer therapy (Khoo et al., 2005; Kushairi et al., 2019).

Climatic factor is essential in determining suitability and success of palm oil production. Yield productivity increases when temperature range from 24°C to 30°C and rainfall averages 2030 mm per year (Corley, 2003; Sheil et al., 2009; Nur Nadia and Syuhadatul, 2017). The oil palm flourishes under tropical climate, which is ideal to Malaysia's temperature and rainfall pattern. In any case, changes in climate, such as heavy rainfall and high temperature, will give broad scale impacts on the distribution of oil palm. Figure 1.3 illustrates the annual expansion in oil palm planted areas, with a slight decrease in FFB production recorded in certain years. The production of FFB fell most dramatically in 1998 by 7.9% and again in 2016 by 12.2% compared to the prior years. The declining FFB production was due to the strong El Ninos that hit in the second half of 1997 and 2016. When El-Nino occurs in the Pacific Ocean, Peninsular Malaysia experiences less rainfall and higher air temperatures, which places a lot of stress on the groundwater of the oil palm trees. As a result, the annual production of FFB is lower than in a typical year due to water stress during the southwest monsoon, resulting in a considerable impact on annual FFB yields (Harun et al., 2014; Abu Bakar et al., 2021).

Production typically declines as heavy rainfall usually brings floods that could disrupt normal harvesting operations, damage roads, bridges, and palm oil processing equipment in low lying oil palm areas. For instance, in December 2014, oil palm planted areas in Pahang, Terengganu, and Kelantan experienced rainfall exceeding 1,750 mm or 70 inches, which is equivalent to roughly 300–600 percent of the monthly average rainfall, causing significant localized flooding and decreased FFB production. The production of FFB decreased approximately 500,000 tonnes in October 2014 until September 2015 compared to previous year due to the decline in harvested crop yield. The palm oil production in January 2015 is also lower than normal, owing to continuing after-effects of the heavy rainfall and floods (USDA, 2014).

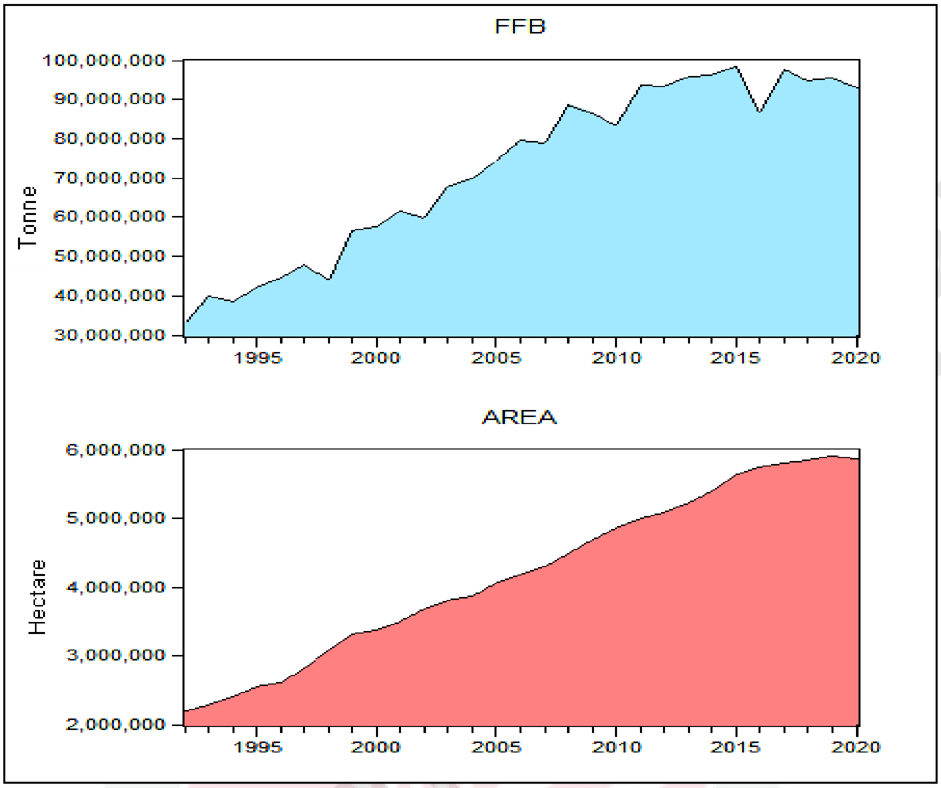

Figure 1.3 : Oil Palm Planted Area and FFB Production
(Source: MPOB, 2020a)

1.2 Climate Change

Climate change refers to any significant changes in the measures of temperature, precipitation, or wind patterns, among other effects, that happen over several decades or longer (Tang, 2019; Molua, 2002; IPCC, 2001). These changes can be caused by natural factors and, more recently, by human activities. There are various natural causes for climate change, such as continental drift, volcanoes, ocean currents, and the earth's tilt. Nonetheless, the primary cause of global warming is human activities, through the mass utilization of fossil fuels, industrial activities, transportation, energy, and agricultural sector.

Agricultural activities, such as land clearing, are responsible for increasing the release of carbon dioxide, i.e., when forest areas are cut down or burned. Besides that, the decomposition of carbon-containing organic material by anaerobic bacteria in moist places, such as rice paddies, sanitary landfills, and the intestinal tracts of cattle and other large animals are the significant wellspring of methane. Industrial activities contribute to global warming through the burning of carbon-containing fossil fuels, such as oil, coils, and natural gases, which represent most human-made carbon dioxide.

Furthermore, not only do the levels of carbon dioxide increase when the gasoline burns in the car's engine, but nitrous oxide also triggers the production of tropospheric ozone. All these activities have contributed to the release and accumulation of greenhouse gases, such as carbon dioxide (CO_2) and certain trace gases, including methane, nitro oxide, chlorofluorocarbons (CFCs), and troposphere ozone (atmosphere) in the atmosphere. Clearly, numerous pieces of evidence show that human activities are the main force behind global warming.

IPCC (1995) stated that higher atmospheric CO_2 levels have led to an increase in global mean temperature and rainfall. For instance, the concentration of atmospheric CO_2 has increased from about 288 parts per million (ppm) roughly 200 years prior (before Industrial Revolution began) to 376 ppm in 2003 (Rahman, 2009). In the Fourth Assessment Report in 2007, the IPCC (2007) states the presence of CO_2 concentrations of 350 ppm in the atmosphere is typically connected with an average rise in global temperature in excess of 2°C. The continued climate change could result in more extreme and regularly more perilous weather phenomena like heat waves, droughts, heavy rains, and intense cyclonic storms.

1.2.1 Climate Change in Malaysia

Malaysian annual climate variability is closely tied to the Southwest and Northwest Monsoons. The Southwest Monsoon features drier weather with less rainfall that happens from April to September, while the Northwest Monsoon happens from October to March and brings more rainfall (Kwan et al., 2013). The National Water Research Institute of Malaysia (NAHRIM), (2006) and the Malaysia Meteorology Department (MMD), (2009) noticed that climate-related hazards in Southeast Asia are tropical hurricanes, floods, landslides, droughts, and sea-level rise. Climate change variables assessed in this study were rainfall and temperature.

1.2.1.1 Rainfall

For decades, Malaysia has experienced rapid climate change, as published by NAHRIM (2006). Among the important climate factors are changes in rainfall amount and patterns, which causes floods. Flooding can occur due to unusually fast water flow due to heavy rainfall and is further exacerbated by water flow obstructions in the drainage system. The states most frequently hit by floods are Johor, Kelantan, Terengganu, and Pahang, while Perlis recorded received lowest annual flood frequency in PM. The MMD (2009) reported that Sabah experienced lesser rainfall than Sarawak. The historical rainfall data showed the rainfall peaked at the end of 2004 and 2009 (MMD, 2009; Tang, 2019). In general, flood-prone areas in Malaysia were estimated at 29,800 square kilometers (sq. km) or 9% of land area and affected 3.9 million people in the country (Al-Amin et al., 2011; Jabatan Pengaliran dan Saliran, 2018).

Higher detailed regional analysis of Providing Regional Climates for Impact Studies (PRECIS) rainfall simulations released by MMD is shown in Table 1.4. A significant period of increased annual rainfall is predicted to occur toward the century's end

(2090-2099), with a higher increase in rainfall for PM compared to EM. During 2050-2059, North-West PM recorded the highest increase in rainfall (6.4%), followed by North-East PM, while Sabah recorded a negative anomaly. The least rainfall increment is simulated in Sabah, with East Sabah recording negative anomalies during 2090-2099 compared to other regions in Malaysia, which recorded positive anomalies during the same period.

Table 1.4 : Projection annual rainfall change (%) for 2020-2099 relative to 1990-1999 period

Region	2020-2029	2050-2059	2090-2099
North-West PM	-11.3	6.4	11.9
North-East PM	-18.7	6.0	4.1
Central PM	-10.2	2.3	14.1
Southern PM	-14.6	-0.2	15.2
East Sabah	-17.5	-12.8	-3.6
West Sabah	-8.9	-1.2	0.3
East Sarawak	-9.1	-1.3	6.2
West Sarawak	-8.8	3.8	14.6

(Source: MMD, 2009)

1.2.1.2 Temperature

The country's second issue associated with climate change is an extreme temperature that will lead to drought conditions. Table 1.5 displays time series data for minimum and maximum temperatures from 1990 to 2017. There were minimum temperatures below 26℃ in 1990-1996 and 2011. The oil palm, primarily a lowland crop of the humid tropics, thrives best in regions with an annual mean temperature between 24℃ and 28℃. Therefore, the minimum temperature recorded by MMD is favorable for the oil palm, while the high temperature, especially on acid sulphate soil, makes it more difficult to maintain water level above the sulphidic layer and hence impedes the growth of palm trees (Goh et al., 2011). Maximum temperatures above 28.5℃ are recorded in 1997, 1998, 2010, 2013, 2014, and 2016 have had a negative impact on the country's palm production (World Bank, 2001; Harun et al., 2014; MMD, 2009).

The prolonged dry weather condition and below average rainfall, which occurred in the second half of 2015 and into the first half of 2016, had lessened FFB yield by 13.9 to 15.91 tonnes per hectare as against 18.48 tonnes per hectare attained in the previous year. Peninsular Malaysia's FFB yield fell by 16.0 to 15.77 tonnes per hectare. Sabah reported a 14.5 decrease from 19.99 tonnes per hectare the year prior to 17.10 tonnes per hectare. Sarawak's FFB yield dropped significantly, falling from 16.21 tonnes per hectare in 2015 to 14.86 tonnes per hectare in 2016, a decline of 8.3% (MPOB, 2016).

Table 1.5 : Historical data for minimum and maximum temperature (°C) for 1990- 2017

Year	Max Temperature	Min Temperature
1990	27.9	25.9
1991	27.7	25.6
1992	27.8	25.7
1993	27.5	25.9
1994	27.4	25.9
1995	27.7	25.7
1996	27.6	25.6
1997	28.9	26.3
1998	28.5	26.1
1999	27.6	26.1
2000	27.9	26.0
2001	27.9	26.3
2002	28.2	26.4
2003	28.3	26.2
2004	28.2	26.1
2005	28.1	26.2
2006	27.7	26.1
2007	27.8	26.0
2008	27.5	26.1
2009	27.9	26.0
2010	28.5	26.0
2011	27.8	25.9
2012	28.1	26.4
2013	28.5	26.2
2014	28.7	26.0
2015	28.4	26.5
2016	29.2	26.7
2017	28.1	26.6

(Source: MMD database)

The MMD (2009) has applied highly detailed regional analysis of PRECIS simulation driven by the Hadley Centre Coupled Model (HadCM), version 3 coupled with atmosphere-ocean general circulation (AOGCM) to generate future climate change for three decades representing the first quarter (2020 – 2029), middle (2050 – 2059) and end of the century (2090 – 2099) relative to 1990-1999 period. The projected annual mean temperature changes for the whole area of the country are shown in Table 1.6.

Table 1.6 : Projection annual average change in temperature (°C) for 2020-2099 relative to 1990- 1999 period

Region	2020-2029	2050-2059	2090-2099
North-West PM	1.3	1.9	3.1
North-East PM	1.1	1.7	2.9
Central PM	1.5	2.0	3.2
Southern PM	1.4	1.9	3.2
East Sabah	1	1.7	2.8
West Sabah	1.2	1.9	3.0
East Sarawak	1.4	2.0	3.8
West Sarawak	1.2	2.0	3.4

(Source: MMD, 2009)

According to Table 1.6, higher temperature increment during the first decade is recorded for Central PM compared with the rest of the regions in the country. Meanwhile, for the middle of the century, the Central PM and Sarawak shared the same increase in temperature change of 2°C. Eastern Sarawak region records the highest temperature increment (3.8ºC) compared to North-Eastern PM, which records the lowest (2.9ºC) at the century's end. Overall, the rate of increase in temperature over a period of 30 years from 2059 to 2090 is generally double the rate of increase simulated for the previous 20 years period from 2029 to 2050.

Based on the projection issued by MMD, there is a sharp increase in the percentage of the annual average change in temperature from the middle (2050-2059) to the end of the century (2090-2099), which involves an increase from 1.89°C to 3.18°C for the entire region in Malaysia. The same situation occurs with rainfall, which shows a significant trend in the percentage of annual rainfall in 2090-2099 compared to 2020-2029 and 2050-2059. This projection clarifies that climate change in Malaysia should not be underestimated because there is indeed an increase in temperature and the percentage of rainfall which will adversely affect crop growth and yield.

1.3 Methodologies Applied in Assessing the Impact of Climate Change on Oil Palm Production

In examining the impact of climate change on agriculture, existing research had either concentrated on the entire sector or a specific set of crops in a country. Prior research produced a wide range of findings depending on the methods employed. This study focuses on two: the Supply Response Approach, a novel way of measuring the impact of climate change on oil palm, and the Production Function, an extensively used approach.

1.3.1 Production Function Approach

The Production Function is a tool of analysis used to describe the technical relationship between inputs and output in physical terms. In its most basic form, it states that the production of a certain commodity is contingent on a set of specific inputs. The history and development of production function began in the late 1700s, which was discovered by Adam Smith (Brauke, 1982). Then, various scholastics addressed a wide range of economic concerns, including a superficial consideration of production and distribution. For example, in 1767, Anne Robert Jacques proposed the concept of diminishing returns in a one-input production function. Von Thunen in the 1840s extended it to a two-input with the concept of diminishing returns. Shortly after, in 1894, Philip Wicksteed formalized the Neo-classical Production Function, which is considered a core of the famous Cobb-Douglas Production Function. Philip Wicksteed further demonstrated that if production experienced constant returns to scale or a linearly homogenous function, then the total product would be absorbed in factor payments without any deficit or surplus, with each input receiving its marginal product (Gordon and Vaughan, 2011).

Although some evidence suggests that Knut Wicksell developed the relationship between output and inputs in the 1920s, it is widely assumed that Paul Douglas and Charles W. Cobb were the first economists to algebraically formulate it (Gordon and Vaughan, 2011). Cobb and Douglas (1928) have assumed an elasticity of scale was equal to unity; hence, the exponents in production function necessarily restricted to one which exhibits constant return to scale. In 1937, David Durand introduced the elasticity of substitution would be more and less than one that exhibits the increasing and decreasing returns to scale, respectively (Gordon and Vaughan, 2011). In 1956, Solow and Swan introduced a neo-classical economic model to predict long-term growth equilibrium at the natural rate. They emphasized capital accumulation, labor or population growth, and productivity increases in an attempt to explain long-term economic growth (Masoud, 2013). From time to time, there have been breakthroughs with flexible forms and tractability for developing production function models, as evidenced by recent scholarly publications on the subject.

The common ways to classify the various types of production functions are based on their forms; fixed or flexible, the elasticity of substitutions, the type of returns to scale, and whether or not it is constant across output levels (Gordon and Vaughan, 2011). This classification covers the criteria of the homogeneity, homotheticity, and the separability function. Economic researchers usually work with homogeneous functions of degree one or linear homogeneity. It indicates that if all of the production inputs increase, the total output must also double. Meanwhile, homothetic production functions indicate that the output elasticities for all inputs would be equal at any given point. Another important feature of a production function is separability because most production processes require more than two inputs. However, not all production functions may be regarded separable since if these discrete production functions can be specified, then the technology is assumed to be separable. As a result, the presence of separability reduces the number of parameters to be examined in cost or production function analysis.

There are some well-known types of production functions, such as the Leontief Production Function (LPF), Constant Elasticity of Substitution (CES), Variable Elasticity of Substitution (VES), and Cobb-Douglas Production Function. The LPF stating that the production factors used must be in a fixed proportion (technologically determined), as there is no substitution among factors (Miller and Blair, 2009). This means that even if a firm increases one input while the other inputs remain constant, then the output will not increase. LFP does not provide much flexibility in the case of output adjustment as it only allows a fixed proportion of both inputs in the production process.

The LFP has been applied by Kahn et al. (2019) to investigate the long-term macroeconomic effects of climate change across 174 countries from 1960 to 2014. The analysis involves the estimation of temperature, precipitation, storms, and other aspects of the weather on economic performance, such as agricultural production, labor productivity, commodity prices, health, and economic growth using a cross sectional approach and standard fixed effect (FE) estimators, assuming that climate variables are strictly exogenous. In fact, recent climate science researches provide compelling evidence that human-caused greenhouse gas emissions are the primary factor contributing to contemporary global warming (Brown et al., 2016). As a result, the climate variables could be considered as weakly exogenous. Thus, modification on this approach is necessary, considering that bias exists when the cross-sectional dimension is larger than the time series dimension in the dynamic panel and one or more regressors are not fully exogenous. Alternatively, Kahn et al. (2019) have employed the half-panel Jackknife FE (HPJ-FE) estimator to address the potential bias and size distortion of the widely used FE estimator given the climatic variables are weakly exogenous.

In the field of econometrics, another popular production function approach is Cobb-Douglas production function. It has several advantages, such as it is flexible to use the number of input variables to explore the effects of production process, the elasticity of substitution is unity, and the scale of economies can be estimated as restricted input coefficients that sum to one to reflect the type economy of scale. The Cobb-Douglas production function was applied in this research to examine the effects of climate change along with other variables on fresh fruit bunch produciton. Among the previous studies of using Cobb-Douglas production function approach in assessing the impact of climate change were Sarkar et al. (2020), Ammani et al. (2012), Chizari et al. (2017a), Chizari et al. (2017b), and Zhai et al. (2017).

However, the production function has long been restricted to the Cobb-Douglas Production Function and LPF where the elasticity of substitution is one and zero, respectively. It was not until the discovery of the CES Production Function by Arrow in 1961 that has a unique characteristic, such as the elasticity of substitution among factors of production is not necessarily equal to unity, but it ranges from zero to infinity (Xiaoshu and Yu, 2013). The CES Production Function also has a wider scope and applicability because it is based on the assumption of substitutability and the complementarity of factors compared to the Cobb-Douglas Production Function, which neglects the assumption of complementarity of factors. The main drawback of the CES production function is that it is restricted to two variables to be estimated at once. Even though it can be extended to more than two inputs, it becomes difficult and complicated mathematically to apply for more than two inputs. Thus, the CES Production Function is not applicable to this study.

1.3.2 Supply Response Approach

In the field of agriculture, empirical studies on estimating the responsiveness of total output to the change in the prices and non-price factors are known as Supply Response. There are two approaches employed by various researchers to conduct supply response either to analyze both speed and level of adjustment of actual acreage toward the desired acreage, known as the direct reduced form approach, and the supply function approach is emanated from the profit-maximizing framework or indirect structural form approach (Tabe-Ojong et al., 2020). The first method involves the direct estimation of the single commodity supply function from time series data. Supply in agriculture is dependent on time lag, which means that supply in any period or season is influenced by previous decisions and expectations (Narayana and Parikh, 1981; Arnade and Copper, 2013). The necessity for dynamic specification of the agricultural supply function stems from the premise that production activities do not respond instantly to market stimuli and new economic conditions. It is caused by psychological resistance to change, particularly when the change involves the adoption of new techniques or the production of goods that differ from traditional methods.

According to Nerlove's theory, the merits of employing the Supply Response approach are in terms of the three different types of output change (Narayana and Parikh., 1981). The first is output changes in response to changes in current prices that do not affect the level of predicted future prices. There are two reasons for this: (i) it is difficult to achieve an immediate change in output based on a sudden change in input-output pricing, and (ii) if the changes (increase or decrease) do occur, they are only temporary and costly. Second, output changes in instantaneous response to a change in predicted future prices. Finally, following a full adjustment, output changes in response to changes in the predicted and actual level of prices. Of these, output change of the first type can be ignored, leaving only the three main tenets of the Nerlovian model: (i) farmers persistently adjust their output toward a desired (or equilibrium) level of output in the long run, which is based on expected future prices; (ii) current prices affect the output only to the extent that farmers change expected future prices; and (iii) short-term adjustments in output do not entirely reach the long-term desired level because of constraints on the speed of acreage adjustment. Short-term constraints in the adjustment process are caused by technical elements of agricultural production, such as fixed capacity in terms of land, and institutional factors like production quotas, farm tenure, and rural credit (source). As a result, production operations will be delayed and spread over several periods, implying that the supply function is dynamic.

The Nerlove model has been adopted, modified, and even extensively revised by numerous scholars in various angle studies of Supply Response. As evidence, Askari and Cumings (1977) have documented the results of well over one hundred studies in the Nerlovian tradition. Nerlove's partial adjustment model had previously been constrained by the assumption that farmers make decisions based on the fixed situation. It is unrealistic since farmers tend to deal with diverse situations when they make decisions. The problem has been resolved by researchers by utilizing error correction modeling (ECM) to analyze the supply response of agricultural products (Aipi et al., 2012). In addition, ECM has the benefit of being able to capture both short-run dynamics and modifications toward long-run equilibrium compared to the conventional Nerlove model. The impact of climate change on crops also can be investigated using the ECM in the Supply Response approach, leading to additional climate change research. The Supply Response approach has been employed in Malaysia with perennial crops, but not in the context of researching the effects of climate change.

1.4 Problem Statement

Being a worldwide phenomenon, there has been increasing interest to look at the climate trends and their effects unfold regionally, as well as in Malaysia. NAHRIM addressed that Malaysia's climate is changing in tandem with global climate change. According to Malaysia Meteorological Department (2009) projections, temperatures will climb by an average of 1.3°C throughout the first quarter of the twenty-first century (2020-2029), 1.9°C in the middle (2050-2059), and 2.9°C at the end (2090-2099). East Malaysia (EM) will experience a higher temperature than Peninsular Malaysia (PM). Rainfall is predicted to increase in a similar trend, with increases ranging from 4.1% to 15.2% at the end of the century compared to the middle and first quarter of the century. These projections illustrate that climate change is one of the biggest threats to the agricultural sector in the long term in the country because agriculture is conditioned by temperature and rainfall.

The agriculture sector contributes 7.4% to the GDP, with oil palm as the major contributor to the value-added agricultural sector at 37.1% in 2020 (Department of Statistics Malaysia, 2021). Oil palm is the country's most valuable crop, with export earnings of RM118.6 billion in 2020, up 2.7% from the previous year (Malaysian Palm Oil Board, 2021). The growth and production of oil palm will be affected when the oil palm trees are subjected to water stress conditions and excess rainfall (Nur Nadia and Syahadatul, 2017). The occurrence of adverse weather conditions does not directly affect the oil palm tree but is reflected in the yield in subsequent months (Harun et al., 2014).

Paterson and Lima (2017) anticipate the countries that are involved in oil palm cultivation to confront uncertainty in production in the future. The mean temperature above 28°C coupled with monthly rainfall less than 100 mm exacerbated the loss of FFB yield. For example, the El Nino event in 1997 caused FFB yield in the following year to drop by 14.6%, 18.7%, and 28.6% over that of the previous year for Peninsular Malaysia, Sabah, and Sarawak, respectively (Harun et al., 2014). Severe moisture deficit causes abortion of newly formed inflorescences, resulting in a lower number of developing fruit bunches (Nur Nadia and Syuhadatul, 2017).

Besides that, the severity of declining FFB yield is also largely determined by total annual rainfall that exceeded 2,030 mm (Ishak et al., 2012). Sarawak was reported to have had exceptionally high rainfall of over 4000 mm per year from 2007 to 2009, while PM and Sabah experienced annual rainfall between 2500 and 3000 mm from 2007 to 2009. Excessive rainfall caused FFB yields in Sarawak to decline by about 25%, and around 20% of FFB yield in PM and Sabah decreased from the previous year's yield of 20 tonnes of FFB per hectare (Harun et al., 2014). Meanwhile, the localized floods were most severe in three states on the East Coast of Peninsular Malaysia, namely Kelantan, Terengganu, and Pahang in 2014, with a combined contribution of about 17% to Malaysia's total production and 35% to Peninsular Malaysia's output (Malaysia Palm Oil Board, 2106). Prolonged water-logging could inhibit the respiration of oil palm roots, disrupt the pollination process, and reduce the mean of fruit bunch weight (Harun et al., 2014; Nur Nadia and Syahadatul, 2017).

Numerous specialized studies have been conducted in an effort to better understand how oil palm is affected by climate change. For instance, Ahmad et al. (2021), Nur Nadia and Syahadatul (2017), Paterson and Lima (2015), Shanmuganathan and Narayanan (2012), and Harun et al. (2010) investigated the impact of climate change in terms of oil palm growth and yield, mitigation and adaptation strategies. Most scholars who studied this issue employed forecasting based on some sort of simulation with a variety of assumptions. However, quantitative studies have also been conducted, such as research by Zainal et al. (2012), who found that climate change has a significant non-linear impact on oil palm net revenue based on the Ricardian approach. Study carried out by Sarkar et al. (2021) using the Production Function approach found that temperature had a negative effect on oil palm yield. Prior to this, with the same approach, Chizari et al. (2017b) found that temperature was insignificant while the rainfall variable has a negative effect on the first lag period of the short-run basis. Despite employing the same methodology, the study's findings are inconsistent. Thus, this study has been improved by performing a stationary test prior to testing on the oil palm model as it was not done by Sarkar et al. (2021) and forecasting of oil palm production for a longer period that was not covered by Chizari et al. (2017b). Additionally, this study also takes into consideration the non-linear relationship between climate variables and oil palm production to close the knowledge gap.

There are small numbers of supply response studies in Malaysia. Among these studies are Mustafa et al. (2016) for rubber, Tey et al. (2010) for rice, and Talib and Darawi (2002) for oil palm. However, all these studies did not evaluate the effect of climate change in the country, ignoring the unit root problem of time series data that poses spurious regression and applying classical regression analysis mainly Nerlove's (1958) that restricted adaptative expectations or partial adjustment models. One of the problems of the Nerlovian adjustment model is that it does not give an adequate distinction between short-run and long-run elasticities (Aipi et al., 2012). The dynamics of supply can be better described by error correction models (ECM) and in recent years' cointegration, the combination of error correction model and Autoregressive Distribution Lag (ARDL) method has been widely used by different economists for supply response estimation elsewhere.

Based on NAP3 policy, there is a transfer of resources from the rubber sector to the oil palm sector, including land and other inputs. As a result, this study also examined the price of rubber, which has not yet been addressed in the context of measuring the impact of climate change in oil palm in the country. Given this shortcoming in the methodologies and research findings, the purpose of this research is to determine the effects of climate change on oil palm production by applying Supply Response and Production Function approaches in order to contribute in literature as different approaches will produce different estimation results and to close the knowledge gap. Additionally, this study emphasized the forecasting of oil palm production for a longer time period in order to provide information to parties involved with oil palm to manage the future uncertainties of climate change.

1.5 Research Questions

The study is aimed at resolving the following research questions:

1) What is the best model for assessing the impact of climate change from the application of the Supply Response and Production Function approach?

2) What are the short-run and long-run impacts emerge from the price and non-price factors related to the climate variables in the oil palm production?

3) What are the future impacts of climate change on oil palm production in Malaysia?

1.6 Research Objectives

The general objective of this study is to estimate the potential impact of climate change on oil palm production in Malaysia. Specifically, the study aimed:

1) To determine the best model of measuring the impact of climate change on oil palm production by using Supply Response and Production Function approaches.

2) To estimate the short-run and long-run impact from the major variables associated with climate variables in the oil palm production.

3) To predict the future impact of climate change on oil palm production in Malaysia.

1.7 Significance of the Study

Oil palm is a highly efficient and versatile crop, which means it produces more oil per hectare than any other oil crop and can grow on a variety of soils in tropical climates. Palm oil is traded in well-established global markets, benefiting the economies of low and middle-income countries in tropical climate zones. The impact of climate change on oil palm has been studied using a range of approaches, though only a handful of research has focused on quantitative analysis, particularly involving the co-integrating of short-run and long-run bases. This study explained the relationship between oil palm production associated with price and non-price factors and climate variables, namely temperature and rainfall. The selected model was applied to measure the possible forecasted future oil palm production under expected scenarios of climate in Malaysia.

The findings of this research exert multidimensional significance in the study area to oil palm stakeholder, government, educational institution and research organization related to oil palm. It provides enormous benefits for the farmers and oil palm stakeholders to adapt with these uncertainties condition of climates. Farmers and oil palm stakeholders can take the initiative by planting the genetically modified improved variety that can increase the tree's resistance to disease and withstand the effects of temperature and rainfall variability. These can be accomplished through intensive research and development conducted by educational institutions and oil palm research organization. Besides that, the application of mulching, cover cropping, intercropping can help in conserving moisture and minimize evapotranspiration in order to reduce the effect of deficit moisture on oil palm. The output of this study can provide information for those involved in the planning and policy making to improve guidelines related to mitigation and adaptation strategies to reduce the impact of climate change and assist in the development of long-run projection of oil palm production. Finally, this work avails information to validate or refute past research findings, which are useful in teaching, and add to a growing body of literature, especially the methodologies applied in Production Function and Supply Response approach to further bridge the study gap.

1.8 Scope of the Study

The scope of the study covers price and non-price factors, especially climate factors that affect oil palm in Malaysia. Malaysia was chosen as an area of concern because oil palm is the main crop that contributes to the country's economy. Malaysia is geographically located in Southeast Asia with two segments: the peninsular Malaysia and East Malaysia or Borneo. The study covered secondary data from production of FFB, the price of FFB, the price of rubber, the price of fertilizer, fertilizer consumption, and planted areas of oil palm in the country for 40 years from 1980 to 2019.

1.9 Organization of the Study

This research report on the impact of climate change on oil palm production in Malaysia and is organized into five chapters. Chapter one focuses on the introduction of studies where relevant introductory issues, such as climate change scenarios in Malaysia and methodologies used in assessing the impact of climate change on the oil palm production. Chapter two reviewed related literature on empirical findings on the impact of climate change on oil palm production from around the world, including Malaysia. This chapter also covers the theoretical review and empirical findings from the study of climate change using the Supply Response and Production Function approaches. Chapter three captured the conceptual and theoretical framework, and functional form of time series econometric models. Others were data analysis approach, and study area description.

Chapter four reports the empirical results of the study. It discussed the data analysis, beginning with unit root tests, co-integration (Bound) test, estimated short-run and long-run equations of Supply Response and Production Function approaches, validation test results and simulation and forecasting results. Finally, chapter five captured on summary of the study, implication of the study, contribution of the study, limitations of the study, recommendations for future study, and conclusions. Reference section and appendices appear after chapter five.

REFERENCES

Abubakar, A., Ishak, M., Uddin, M., Abd Samad, M., Sulaiman, M & Danhassan, S. (2021). Effects of Some Weather Parameters on Oil Palm Production in the Peninsular Malaysia. 10.20944/preprints202106.0456.v1.

Afzal, M., Ahmed, T., & Ahmed, G. (2016). Empirical Assessment of Climate Change on Major Agricultural Crops of Punjab, Pakistan. MPRA Paper No. 70958, Pakistan Institute of Development Economics, Islamabad.

Ahad, M., & Muzammil, M. (2015). Impact of financial development on trade balance: An ARDL cointegration and causality approach for Pakistan. *Munish Personal RePEc Achive*, No. 68545.

Ahmad, K. and Heng, A. C. H. (2012). Determinants of agriculture productivity growth in Pakistan. *International Research Journal of Finance and Economics*, 95: 163-172.

Aipi, B., Irau, T., & Aba, L. A. (2012). *Supply response of palm oil in Papua New Guinea.* Working Paper BPNGWP2012/03. Bank of Papua New Guinea

Albayrak, N. (1997). *Applying time series analysis to supply response and risk*. Phd thesis, Department of Economics, University of Leicester. https://hdl.handle.net/2381/30123.

Ali, R., Ali, R., Mehmood, S. S., Zou, X., Zhang, X, Lv, Y., & Xu, J. (2019). Impact of climate change on crops adaptation and strategies to tackle its Outcome: A Review. Plants, 8 (34): 1-29.

Ammani, A. A., Ja'afaru, A. K., Aliyu, J. A., & Arab, A. I. (2012). Climate change and maize production: Empirical evidence from Kaduna State, Nigeria. *Journal of Agricultural Extension*, 16 (1): 1-8.

Al-Amien, A. Q., Filho, W.L., Kabir, M. A., Azam, M. N., Jaafar, A. H., & Kari, F. (2011). Climate change, impacts: Prioritizing mechanism and needs for future Malaysian agriculture. *International Journal of Physical Sciences*, 6(7): 1742-1748.

Arnade, C., & Cooper, J. (2013*). Price expectations and supply response*. Poster presentation at the agricultural & applied economics association's 2013 AAEA & CAES joint annual meeting, Washington, D.C. August 2013.

Askari, H., & Cummings, J. T. (1977) Estimating agricultural supply response with the Nerlove Model: A survey. *International Economic Review*, 18: 257-92.

Ayinde O. E., Bessler D. A., & Oni, F. E.(2014). *Analysis of supply response and price risk on rice production in Nigeria*. Selected paper prepared for presentation at the Agricultural & Applied Economics Association"s 2014 AAEA Annual meeting, Minneapolis MN, University, Texas USA.

Barford, A., Hagen, M., & Borchsenius, F. (2011). Twentyfive years of progress in understanding pollination mechanism in palms (Areacaceae). *Annals of Botany*, 108: 1503-1516.

Belloumi, M. (2014). Investigating the impact of climate change on agricultural production in Eastern and Southern African countries. African Growth and Development Policy Modeling Consortium (AGRODEP) Working Paper 0003, Washington, D.C: International Food Policy Research Institute.

Bilgili, F. (1998). Stationarity and cointegration tests: comparison of Engle -Granger and Johansen methodologies. Munich Personal RePEc Archive (MPRA) Paper No. 75967: 131-141, Erciyes University, Faculty of Economics and Administrative Sciences.

Birau, F. R. (2012). Econometric approach of heteroscedasticity on financial time series in a general framework. *Economic Series*, 4: 1-4.

Braulke, M. (1982). A note on the Nerlove model of agricultural supply response. *International Economic Review*, 23(1): 241-244.

Brown, R. L., Durbin, J., & Evans, J. M. (1975). Techniques for testing the constancy of regression relationships over time. *Journal of the Royal Statistical Society. Series B (Methodological)*, 37(2): 149-192.

Caporale, G. M., & Pittis, N. (2004). Robustness of the CUSUM and CUSUM of squares tests to serial correlation, endogeneity and lack of structural invariance: Some Monte Carlo Evidence. *Economic Series*, 157: 1-33.

Chizari, A., Mohamed, Z., Shamsudin, M. N., & Seng, K. W. K. (2017a). The effects of climate change phenomena on cocoa production in Malaysia. *International Journal of Environment, Agriculture and Biotechnology (IJEAB*), 2(5): 2599-2604.

Chizari, A., Mohamed, Z., Shamsudin, M. N., & Seng, K. W. K. (2017b). Economic climate model of the oil palm production in Malaysia. *International journal of Horticulture, Agriculture and Food science (IJHAF)*, 1(3): 27-32.

Chaw, C. S. (1992). The effects of season, rainfall and cycle on oil palm yield in Malaysia. *Elaeis*, 4(1): 32-43.

Choo. (2011). Malaysia's economic transformation programme: The role of the oil palm industry. *Proceedings of Global Economics and Marketing Conference*. Nov. 2011.

Cobb, C. W., & Douglas, P. H. (1928). A theory of production. *American Economic Review*, 18(1): 139-165.

Corley, R. H. V., & Tinker, P. B. (2003). *The oil palm*, Wiley-Blackwell Science

Corley, R. H., & Tinker, P. B. (2003). *World Agriculture Series: The Oil Palm*. Blackwell Science, Oxford.

Das, K. R., & Imon, A. H. M. R. (2016). A brief review of tests for normality. *American Journal of Theoretical and Applied Statistics*, 5(1): 5-12.

Department of Statistic Malaysia (DOSM) (2016). Selector agriculture indicators, Malaysia, 2016, Retrieved from https://www.dosm.gov.my/v1/index.php?r=column/cthemeByCat&cat=72&bul_id=T2Z3NkhLSFk2VjZ5dkdUL1JQUGs4dz09&menu_id=Z0VTZGU1UHBUT1VJMFlpaXRRR0xpdz09. Accessed 12-08-2019.

Department of Statistic Malaysia (DOSM) (2020). Selector agriculture indicators, Malaysia, 2020, Retrieved from https://dosm.gov.my/v1/index.php?r=column/cthemeByCat&cat=72&bul_id=RXVKUVJ5TitHM0cwYWxlOHcxU3dKdz09&menu_id=Z0VTZGU1UHBUT1VJMFlpaXRRR0xpdz09. Accessed 18-08-2022.

Department of Statistic Malaysia (DOSM) (2021). Selector agriculture indicators, Malaysia, 2022, Retrieved from https://www.dosm.gov.my/v1/index.php?r=column/ctwoByCat&parent_id=45&menu_id=Z0VTZGU1UHBUT1VJMFlpaXRRR0xpdz09. Accessed 15-08-2022.

Egwuma, H., Shamsudin, M. N., Mohamed, Z., Kamarulzaman, N. H., & Wong, K. K. S. (2016). A model for the palm oil market in Negeria: An econometrics approach. *International Journal of Food and Agricultural Economics*, 4(2): 69-85.

Elbeydi, K. R., Aljdi, A. A., & Yousef, A. A. (2007). Measuring the supply response function of barley in Libya. *African Crop Science Conference Proceedings*, 8: 1277-1280.

Engle, R. F., & Granger, C. W. J. (1987). Co-integration and error-correction: Representation, estimation and testing. *Econometrica*, 55 (2): 251–276.

European Commision Report (2018). Vegetable crops. https://goldenagri.com.sg/wp-content/uploads/2019/01/Oil-palm-is-the-most-productive-vegetable-oil.pdf. Accessed 26 September 2022.

Fair, R. C. (1986). Handbook of econometrics, *Evaluating the predictive accuracy of models* (pp. 1980-1994). Elsevier Science Publishers BV. Amsterdam.

Fairhurst, T. H., & Mutert, E. (1999). Introduction to palm oil production, *Better crops International*, 13: 1-6.

Fatimah, M A., & Ghaffar, R. A. (1986). Crude palm oil price forecasting: Box Jenkins approach. *PERTANIKA*, 9(3): 359 - 367.

Fatimah, M. A., Noh, K. M & Zainalabidin, S. M. (2014). Agricultural policy and institutional reforms in Malaysia: Experiences, impacts and lessons. *Southeast Asian Agriculture and Development Primer Series*: 1-131.

Fatukasi, B., Olorunleke, G. K., Olajide, G. F., & Alimi, R. S. (2015). Bounds testing approaches to the analysis of macroeconomic relationships In Nigeria. *European Journal of Business and Management, 7(8): 26-35.*

Frank, R. H. (2008). *Micro-economic and behavior* (7th ed.). New York: McGraw-Hill Irwin.

Ganjehkaviri, A., Mohamad Nazri, M. J., Hosseini, S. E., & Anas, B. M. (2016). Performance evaluation of palm oil-based biodiesel combustion in an oil burner. *Energies*, 9 (97): 1-10.

Goh, K. J., & Teo, C. B. (2011). Agronomic principles and practices of fertilizer management of oil palm. Agricultural Crop Trust, Kuala Lumpur: 241-388.

Goh, K. J., Teo, C. B., Chew, P. S., & Chiu, S. B. (1999). Fertilizer management in oil palm: Agronomic principles and field practices. In: *Fertilizer management for oil palm plantations,* 20-21, September 1999, ISP North-east Branch, Sandakan, Malaysia: 1-44.

Gordon, D., & Vaughan, R. (2011). The historical role of the production function in economics and business, *American Journal of Business Education (AJBE),* 4(4): 25-29.

Gujarati, D. N., & Portal, D. C. (2009). *Basic Econometrics*. MeGraw-Hill/ Irwin Publisher, New York, USA.

Gulati, A., & Tim, K. (1999). *Trade Liberalization and Indian Agriculture*, Oxford University Press.

Hamuda, M., Sulikova, V., Gazda, V., & Horvath, D. (2013). ARDL investment model of Tunisia. *Theretical and Applied Economics*. 2(579): 57-68.

Harun, M. H., Mohammad, A.T., Noor, M. R., Din, A. K., Latiff, J., Sani, A.R., & Abdullah, R. (2010). Impact of El Nino occurrence on oil palm yield in Malaysia, *The Planter*, 86 (1017): 837-852.

Harun, M. H., Noor, M .R .M., Razak, A. A., Kamarudin, N., & Abdullah, R. (2014). Impact of El Nino on oil palm yield in Malaysia. Paper presented at Forum Iklim Kebangsaan-Monsun Timur Laut 2014/2015. Malaysia Metrological Department, Selangor. October 2014.

Haq, A., & Larsson, R. (2016). The dynamics of stock market returns and macroeconomic indicators: An ARDL approach with cointegration. Unpublished Master of Science thesis, Stockholm, Sweden.

Hazir, M. H. M., Kadir, R. A., & Karim, Y. A. (2017). Projections on future impact and vulnerability of climate change towards rubber areas in Peninsular Malaysia. I*OP Conference Series: Earth and Environmental Science* 169: 1-9.

Hill, R. C., Griffiths, W. E., & Lim, G. C. (2012). *Principles of Econometrics*, John Wiley & Sons.

Hjalmarsson, E., & Osterholm, P. (2007). *Western Hemisphere division testing for co-integration using the Johansen methodology when variables are near integrated*. IMF Working Paper2007/141, Washington.

Howard, J. (2015). Impact of Climate Change on Wheat Production in Kansas. Special studies series no. 1504. Department of Economics,The University of New Haven.

Hubard, R. G., & Obrien, A. P. (2006). *Economics*. Upper Saddle River, N.J: Pearson Prentice Hall.

Insah, K. O. B. (2014). The impact of climate change on cocoa production in West Africa", *International Journal of Climate Change Strategies and Ma*nagement, 6(3): 296 – 314.

Ishak, A., Shahlal, N., Zaidan, N. Z., Ramli, M., Edros, N. H., Jayathissa, N. M., Poh, T. K., & Byungsun, K. (2012). *Determination of oil palm suitability using GIS at district levels in Peninsular Malaysia*. Research Publication, No.7, MMD & MOSTI.

Isik, M., & Devadoss. S. (2006). An analysis of the impact of climate change on crop yields and yield variability. *Applied Eco*nomics, 38: 835–844.

Ismail, A, & Mamat, M. N. (2002). The optimal age of oil palm replanting. *Oil Palm Industry Economic Journal*, 2 (1): 1-18.

Intergovernmental Panel on Climate Change (IPCC), (2001). *Climate change 2001: Impacts, adoption and vulnerability* – Contribution of Working Group II to the Third Assessment Report of IPCC. Cambridge University Press, Cambridge: UK and New York.

Intergovernmental Panel on Climate Change (IPCC). (1995). *The science of climate change*. Contribution of WGI to the Second Assessment Report of the Intergovernmental Panel on Climate Change (pp. 285-358). Cambridge University Press, Cambridge, UK.

Intergovernmental Panel on Climate Change (IPCC). (2007). *Summary for policymakers. In: Climate Change 2007: Impacts, Adaptation and Vulnerability*. Contribution of Working Group II to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change (pp. 7-22). Cambridge University Press, Cambridge, UK.

Jalil, A., Manan, A., & Saleemi, S. (2016). Estimating the growth effects of services sector: A cointegration analysis for Pakistan. *Economic Structures*. 5:6.

Jabatan Pengaliran dan Saliran. (2018). *Laporan banjir tahunan tahun 2016/2017*. Seksyen Ramalan dan Operasi Pusat Ramalan dan Amaran Banjir Negara, Bahagian Pengurusan Sumber Air dan Hidrologi, Jabatan Pengairan dan Saliran, Malaysia.

Karia, A. A., Bujang, I., & Ahmad, I. (2013). Forecasting on crude palm oil prices using artificial intelligence approaches. *American Journal of Operations Research*, 3; 259-267.

Kariuki, G. M., Njaramba, J., & Ombuki, C. O. (2020). Maise output supply response to climate change in Kenya: An econometric analysis. *European Scientific Journal*, 16(3): 63-83.

Kenneth, O. B., & Baba, I. (2014). The impact of climate change on cocoa production in West Africa. International Journal of Climate Change Strategies and Management, 6(3): 296-314.

Khalid, H., & Tarmizi, A. M. (2008). Techniques of soil and water conservation and nutrients recycling on oil palm plantation in inland soil, *Oil Palm Buletin*, 56:1-11.

Khoo, K. M., Belvinder, K. S., Chandran, M. R., Chew, P. S., Chong, G. G., & Hashim, M. Y. (2005). *Malaysian palm oil: A success story*. Perpustakaan Negara Malaysia, Malaysia.

Kremer, J. J. M., Ericsson, N. R., & Dolado, J. J. (1992). The Power of Co-integration Tests. *Oxford Bulletin of Economics and Statistics*, 54: 325-343.

Kuha J. (2004). AIC and BIC: Comparisons of assumptions and performance. *Sociological Methods & Research*, 33(2): 188–229.

Kumar, P., & Sharma, A. (2006). Parennial crop supply response function: The case of Indian rubber, tea and coffee. *Indian Journal of Agricultural Economics*, 61(4): 630-646.

Kumar, M., & Sharma, S. (2016). Forecasting tourist in-flow in South East Asia: A case of Singapore. *Tourism & Management Studies*, 12(1): 107-119

Kurukulasuriya, P., & Mendelson, R. (2008). A Ricardian analysis of the impact of climate change on African cropland. AfJARE 2(1).

Kushairi, A.., Loh, S. K., Azman, I., Hishamuddin, E., Ong-Abdullah, M., Izuddin, Z. B. M. N., & Parveez, G. K. A.(20019). Oil palm economic performance in Malaysia and R&D progress in 2017. *Journal of Oil Palm Resource*, 30, 163–195.

Kwan, M. S., Tangang, F., & Liew, J. (2013). Projected changes of future climate extremes in Malaysia, *Sains Malaysiana*, 42(8): 1051-1059.

Lanfranchi, M., Giannetto, C., & Pascale, A. D. (2014). Economic implications of climate change for agricultural productivity. *WSEAS Transactions on Environment and Developmen*t, 10: 233-241.

Labys, W. C. (2005). Commodity price fluctuation: A centuryof analysis, www.rri.wvu.edu. Accessed 20-10-20.

Liew, V. K. S. (2014) "Which lag length selection criteria should we employ?. *Economics Bulletin*, 3(33): 1−9.

Li, X., & Suzuki, N. (2013). Implications of climate change impacts on regional maize production in the United States: Risk mitigation strategies and food security. *International Journal of Environmental Science and Development*, 4(5): 446-451.

Lopez, R. A., & Munoz, A. O. (1987). Supply response in the Northeastern fresh tomato market. *Northeastern Journal of Agricultural and Resource Economics*, 16(1): 35-43.

MAgPA (2012). *Malaysia Agricultural Policy Analysis Model (MAgPA):* User Guide. Institut Kajian Dasar Pertanian dan Makanan (IKDPM), Universiti Putra Malaysia.

Malaysia Metrological Department. (2009). *Climate change scenarios for Malaysia 2001-2099*. Numerical Weather Prediction Development Section Technical Development Division, Malaysian Meteorological Department, Malaysia.

Malaysian Palm Oil Board (MPOB). (2021a). Overview of the Malaysian Oil Palm Industry 2021. Retrieved from https://bepi.mpob.gov.my/images/overview/Overview2021.pdf. Accessed 10-09-2022

Malaysian Palm Oil Board (MPOB). (2021b). Oil Palm Planted Area. Retrieved from https://bepi.mpob.gov.my/images/area/2020/Area_summary.pdf. Accessed 10-09-2022

Malaysian Palm Oil Board (MPOB). (2020a). Oil palm planted area, Economics and Industry Development Division. Retrieved from http://bepi.mpob.gov.my/index.php/en/?option=com_content&view=category&id=115. Accessed 10-01-2021.

Malaysian Palm Oil Board (MPOB). (2020b). Production, Economics and Industry Development Division. Retrieved from http://bepi.mpob.gov.my/index.php/en/?option=com_content&view=category&id=106. Accessed 10-01-2021.

Malaysian Palm Oil Board (MPOB). (2016). Overview of the Malaysian Oil Palm Industry 2016. Retrieved from https://bepi.mpob.gov.my/images/overview/Overview_of_Industry_2016.pdf. Assessed 10-10-2022.

Malaysian Palm Oil Council. (2022). Malaysian Palm Oil Industy. Retrieved from https://mpoc.org.my/malaysian-palm-oil-industry. Accessed 28.07.22.

Malaysian Palm Oil Council. (2020a). About palm oil. Retrieved from http://mpoc.org.my/about-palm-oil/. Accessed 02.01.21.

Malaysian Palm Oil Council. (2020b). Malaysian Oil Palm Statistics 2019. 39th Edition. MPOB, Bangi.

Mamingi, N. (1997). The impact of prices and macroeconomic policies on agricultural supply: A Synthesis of available results. *Agricultural Economic*, 16: 17–34.

Man, K. L., Kok, T. T., Keat, T. L. and Mohamed, A. R. (2009). 'Malaysian palm oil: Surviving the food versus fuel dispute for a sustainable future', *Renewable and Sustainable Energy Reviews*, 13: 1456-1464.

Mantalos, P. (2011). *Three Different Measures of Sample Skewness and Kurtosis and their Effects on the Jarque-Bera Test for Normality*. JIBS Working Papers No. 2010-9, Jonkoping International Business School.

Martínez, C. I. P., Piña, W.H. A., & Moreno, S. F. (2018). Prevention, mitigation and adaptation to climate change from perspectives of urban population in an emerging economy, *J. Clean. Prod*. 178: 314–324.

Masih, R., & Masih, A. M. M. (2001). Long and short term dynamic causal transmission amongst international stock markets. *Journal of International Money and Finance*. 20: 563–587.

Masoud, N. (2013). Neoclassical economic growth theory: An empirical approach. *Far East Journal of Psychology and Business*, 11(3): 10-31.

McConnell, C. R., & Brue, S. L. (2005)Economics principles, problems and policies (6^{th} ed.). New York: McGraw-Hill Irwin.

Meléndez, M. R., & Ponce, W. P. (2016). Pollination in the oil palms *Elaeis guineensis, E. oleifera* and their hybrids (OxG), in Tropical America, *Pesq. Agropec. Trop., Goiânia*, 46: 102-110.

Mendelsohn, R., & Dinar, A (1999). Climate change, agriculture, and developing countries: does adaptation matter? *World Bank Research Observer*, 4(2): 277-293.

Mendelson, R., Nordhaus, W.D., & Shaw, D. (1993). Measuring the Impact of Global Warming on Agriculture. Cowles Foundation Discussion Paper No. 1045. Yale University, New Haven.

Miller, R. E., & Blair, P. D. (2009). Input-output analysis: Foundations and extensions (Second edition). New York: Cambridge University Press.

Molua, E. L. (2002). Climate variability and effectiveness of farm-level adaptation options: The challenges and implications for food security in Southern Cameroon. *Environmental and Development Economics*, 7: 529-545.

Muchapondwa, E. (2009). Estimation of the aggregate agricultural supply response in Zimbabwe: The ARDL approach to cointegration. *African Journal of Agricultural and Resource Economics*, 3(1): 28-42.

Murad, M. W., Chamhuri, S., & Mustapha, N. H. N. (2008). Review of malaysian agricultural policies with regards to sustainability. *American Journal of Environmental Sciences*, 4(6): 608-614.

Mustafa, G., Latif, I. A., & Egwuma, H. (2016). An empirical analysis of supply response of rubber in Malaysia. *American Journal of Agricultural and Biological Sciences*, 12(4): 148-156.

Nambiappan, B., Ismail, A., Hashim, N., Ismail, N., Shahari, D. N., Idris, N. A. N., Omar, N., Salleh, K. M., Hassan, N. A., & Kushairi, A. 2018. Malaysia: 100 years of resilient palm oil economic performance. *Journal of Oil Palm Research*, 30 (1): 13-25.

Narayan, P. K. (2004). Reformulating critical values for the bounds F-statistics approach to co-integration: An application to the tourism demand model for Fiji. A Discussion Papers. Department of Economics, Monash University, Australia.www.arrow.monash.edu.au:2167. Accessed 15-01-2019.

Narayan, P. K. (2005). The saving and investment Nexus for China: Evidence from cointegration tests. *Applied Economics*, 37:17.

Narayana N. S. S., & Parikh, K. S. (1981). Research Report . *Estimation of farm supply response and acreage allocation: A case study of Indian agriculture*. International Institute for Applied systems Analysis, Laxenburg, Austria.

National Water Research Institute of Malaysia, (2006). *Final Report: Study of the Impact of Climate Change on the hydrologic Regime and Water Resources of Peninsular Malaysia*. National Hydraulic Research Institute of Malaysia (NAHRIM) and California Hydrologic Research Laboratory (CHRL). Ministry of Natural resources and Environment, Kuala Lumpur, Malaysia.

Nerlove, M. (1958). *The dynamics of supply: Estimation of farmer response to price*. John Hopkins Press.

Nkoro, E., & Uko, A. K. (2016). Autoregressive Distributed Lag (ARDL) cointegration technique: Application and interpretation. *Journal of Statistical and Econometric Methods*, 5(4): 63-91.

Nughara, I. S., Alamsyah, A., Aji, M., Ardika, R & Cahyo, A. N. (2022). Optimization of rubber farmer revenue in relation to rainfall fluctuations in South Sumatera. *IOP Conference Series: Earth and Environmental Scienc*e, 995: 1-6.

Nur Nadia, K., & Syuhadatul, F. O. (2017). The impact of El Nino and La Nina on Malaysia palm oil industry. *Oil Palm Buletin*, 74: 1-6.

Oettli, P., Behera, S. K., & Yamagata, T. (2018). Climate based predictability of oil palm tree yield in Malaysia. *Scientific Reports*, 8: 2271.

Oil World. (2016). Where is palm oil grown, https://www.greenpalm.org/about-palm-oil/where-is-palm-oil-grown-2. Accessed 19-6-2020.

Okon, E. B., & Sunday, A. (2014). Supply response of selected agricultural export commodities in Nigeria. *Journal of Economics and Sustainable Development*, 5(5): 47-57.

Omoniyi, L. G., & Olawale, A. N. (2015). An Application of ARDL bounds testing procedure to the estimation of level relationship between exchange rate, crude oil price and inflation rate in Nigeria. *International Journal of Statistics and Applications*. 5(2): 81-90.

Onyango, B., & Bhuyan, S. (2000). *A supply response analysis of the fruits and vegetables sector in New Jersey*. Report by Cooperative Agreement No. RBS-98-27 between Rutgers University and Rural Business-Cooperative Service, United States Department of Agriculture (USDA).

Palecvescu, F. M. (2011). Some aspects of the translog production function estimation, *Romanian Journal of Economics*, 1: 131-150.

Pandey, L. (2016). Modelling supply response and investment in agriculture in developing countries: A view from the Cloister. SSRN: https://ssrn.com/abstract=2890848 or http://dx.doi.org/10.2139/ssrn.2890848.

Parveez, G. K. A., Tarmizi, A. H. A., Sundram, S., Loh, S. K., Ong-Abdullah,. & Palam, K. D. (2021). Oil palm economic performance in Malaysia and R&D progress in 2020. *Journal of Oil Palm Research*, 33 (2): 181-214.

Paterson, R. R. M, & Lima, N. (2017). Climate change affecting oil palm agronomy, and oil palm cultivation increasing climate change, require amelioration. *Ecology and Evolution*, 8(6): 1-10.

Paterson, R. R. M., Kumar, L., Taylor, S., & Lima, N. (2015). Future climate effects on suitability for growth of oil palms in Malaysia and Indonesia. *Scientific Reports*, 5, 14457. https://doi.org/10.1038/srep14457.

Paterson, R. R. M., Sariah, M., & Lima, N. (2013). How will climate change affect oil palm fungal diseases? *Crop Protection*, 46: 113-120.

Pesaran, M. H., Smith, R. J. & Shin, Y. (2001). Bounds testing approaches to the analysis of level relationships, *Journal of Applied Econometrics*, 16: 289-326.

Pesaran, M. H., & Shin, Y. (1999). *An Autoregressive Distributed Lag Modeling approach to cointegration analysis*, In: Strom, S., Holly, A., Diamond, P. (Eds.), Centennial Volume of Rangar Frisch, Cambridge University Press, Cambridge, (1999).

Phillips, P. C. B., & Perron, P. (1988). Testing for a unit root in time series regression. *Biometrika*. 75(2): 335-346.

Ping-Yu, C., Chia-Lin, C., Chi-Chung, C., & Mc Aleer, M. (2012). Modeling the effects of global prices on global fertilizer prices and volatility. *Journal of Risk and Financial*, 5: 78-114.

Piskin, S. (2014). *Short run and long run dynamics of trade balance: Testing for the validity of Marshall Lerner condition and J-Curve hypothesis in Turkey*. Unpublished master thesis, School of economics and Managament, Lund University.

Puah, P. W., & Sidek, M. J (2011). Impacts of rainfall, temperature and recent El Niños on fisheries and agricultural products in the West Coast of Sabah (2000-2010). *Borneo Science* 28(3): 73-85.

Radin, F., Ismail, A. L., Borkotoky, P. (2012). The impact of climate change towards Malaysian paddy farmers. Journal of Development and Agricultural Economics, 5(2): 57-66.

Rahman, A. K. A., Abdullah, R., Balu, N., & Shariff, F. M. (2013). The impact of La Nina and El Nino events on crude palm oil prices: An Econometric analysis. *Oil Palm Industry Economic Journal*, 13(2): 38-51.

Rahman, H. A. (2009). Global climate change and its effect on human habitat and environment in Malaysia. *Malaysian Journal of Environmental Management*, 10(2): 17-32.

Rao, J. M. (1989). Agricultural Supply Response: A Survey. *Agricultural Economics*, 3:1-22.

Rhebergen, T., Hoffmann, M., Zingorea, S., Oberthur, T., Acheampong, K., Dwumfoure, G., Zutah, F., Adu-Frimpong, C., Ohipeni, F., & Fairhursth, T. (2014). The effects of climate, soil and oil palm management practices on yield in Ghana. *International Oil Palm Conference*: 1-17.

Santoso, H. and Yusof, M. A. (2016). Climate change on oil palm: It's impacts and adaptation strategies. Retrieved from: https://www.researchgate.net/publication. Accessed 15th June 2019.

Sarkar, M. S. K., Begum, R. A., & Pereira, J. J. (2020). Impacts of climate change on oil palm production in Malaysia. *Environmental Science and Pollution Research*, 27: 9760-9770.

Seng, K. W. K., Shamsudin, M. N., Zainalabidin, M., & Juwaidah, S. (2014). Effect of export duty structure on the performance of the Malaysia palm oil industry. *Journal of Food Products Marketing*, 20(1): 1-31.

Shamsudin, M. N. (2008). Econometric modelling for agricultural policy analysis and forecasting: Between theory and reality. *Journal of Quantitative Methods*, 4(2): 1–18.

Shanmuganathan, S., & Narayanan, A. (2012). Modelling the climate change effects on Malaysia's oil palm yield. *Commodity Intelligent Repo*rt. Accessed from https://doi.org/10.1109/IS3e.2012.6414948.

Sheil, D., Casson, A., Meijaard, E., Nordwijk, V. M., Gaskell, J., Sunderland-Groves, J., Wertz, K., & Kanninen, M. (2009). The impacts and opportunities of oil palm in Southeast Asia: What do we know and what do we need to know? Occasional paper no. 51. CIFOR, Bogor, Indonesia.

Shrestha, M. B., & Batta, G. R. (2018). Selecting appropriate methodological framework for time series data analysis. *The Journal of Finance and Data Science*, 4:71-89.

Shri, D., Arshad, F. M., Shamsudin, M. D., & Hameed, A. A. (2011). An econometric analysis of the link between biodiesel demand and Malaysian palm oil market. *International Journal of Business and Managemen*t, 6(2): 36-45.

Shoko, R. R. (2009). Estimating the supply response of maize in South Africa. Master Thesis, University of Limpopo, South Africa.

Simeh, M, A. (2010). Impact of increase in fertilizer prices on long-term economic viability of palm oil production. *Oil Palm Buletin*, 60: 1-16.

Siwar, C., Ahmed, F., & Begum, R. A. (2013). Climate change, agriculture and food security issues: Malaysian perspective. *J. Food*, *Agric*. *Environment*, 11: 1118–1123.

Sober, E. (1981). The principle of parsimony. *The British Journal for the Philosophy of Science*, 32: 145-156.

Solow, R. M. (1956). A contribution to the theory of economic growth. *QuarterlyJournal of Economics,* 70: 65– 94.

Spanos, A. (2011). *Foundational issues in statistical modeling: Statistical model specification and validation*. Paper presented at the conference on Statistical Science & Philosophy of Science, London School of Economics, June 21–22, 2010 2: 146-178.

Steve Z. Y., Foong, A., Carmen K. M., Goh, B., Christina, V., Supramaniam, C., Denny K. S. Ng. (2019). Input–output optimisation model for sustainable oil palm plantation development. *Sustainable Production and Consumption Journal*, 17: 31-46.

Suhaila, A. M. (2012). The palm oil industry from the perspective of sustainable development: A case study of Malaysian palm oil industry. (Master's thesis, Ritsumeikan Asia Pacific University Japan). Retrieved from https://core.ac.uk/download/pdf/60541187.pdf.

Sutarta, E. S., Santoso, H., & Yusof, M. S. (2015). Climate change on oil palm: It's impacts and adaptation strategies. https://www.researchgate.net/publication/265201096.

Tabe-Ojong, M. P. J., Molua, E. L., Nziec, J. R. M., & Fuhd, G. L. (2020). Production and supply of tomato in Cameroon: Examination of the comparative effect of price and non-price factors. *Scientific African*, 10: 1-13.

Talib, B. A., & Darawi, A. (2002). An economic analysis of the Malaysia palm oil market. *Oil Palm Industry Economic Journal*, 2(1): 19-27.

Talib, B. A. (1988). Supply Response Analysis of Palm Oil in Malaysia 1961-1985. *Journal Economy Malaysia*, 18: 43-55.

Tang, K. H. D. (2019). Climate change in Malaysia: Trends, contributors, impacts, mitigation and adaptations. *Science of the Total Environment*, 650: 1858-1871.

Teh. C. B. H., & Siang, C. H. (2018). Modelling crop growth and yield in palm oil cultivation. *Burleigh Dodds Series In Agricultural Science*, 1: 1-48.

Teh, S., Mah, S. H., Lau, H. L., Teng, K. T., & Loganathan, R. (2021). Antioxidant potential of red palm-pressed mesocarp olein. *Journal of Oleo Science*, 70, (12): 1719-1729.

Tey, Y. S., Suryani, D., Aswani, F. M. N., & Nurjihan, I. (2010). Acreage response of paddy in Malaysia. *Agric. Econ*, 56(3): 135–140.

Thiele, R. (2000). Estimating the aggregate agricultural supply response: A survey of techniques and results for developing countries. Working Paper 1016, Kiel Institute for World Economics, Kiel, Germany.

Thompson, O. A., Akande, S. O., Onukwube, K., Boateng, N. A., & Ewulom, B. S. (2021). Climate change vulnerability assessment of oil palm yield in Akwa Ibom, Nigeria. *Journal of Global Ecology and Environment*, 12(3): 14-23.

Thong, K. C., Goh, K. J., Leong, C. W., Nawi, C. Y.. & Yew, C. C. (1990). Yield trends of cocoa on inland soils of Peninsular Malaysia. *Proceedings of the MCGC - Malaysia Cocoa Board workshop in cocoa agricultural research*, Kuala Lumpur.

Thursby, J. G. (1987). OLS or GLS in the presence of specification errors? *Journal of Econometric*, 35: 359-374.

Tocco, B., Bailey, A., & Davidova, S. (2013). The Theoretical Framework and Methodology to Estimate the Farm Labour and Other Factor-Derived Demand and Output Supply Systems. Factor Markets Working Paper no. 44. CEPS, Brussels, Belgium.

Tripathi, A., & Prasad, A. R. (2009). Estimation of agricultural supply response by co-integration approach. *The India Economic Journal*, 57(1): 106-131.

Turner, P. M. (2010). Power properties of the CUSUM and CUSUMSQ tests for parameter instability. *Applied Economics Letters*, 17(11): 1049-1053.

Ukoro, S. U., Schickhoff, B, J., Schneider, U. A., & Huth, N. I. (2017). Climate impacts on palm oil yields in the Nigeria Niger Delta. *European Journal of Agronomy*, 85: 38-50.

Unjan, R., & Nissapa, A. (2017). Climate considerations which support the choice between natural rubber and oil palm in Nakhon Si Thammarat, Southern Thailand. *Kasetsart Journal of Social Sciences*, 38: 273-281.

United State Department of Agriculture (USDA). (2015). Malaysia: 2014/15 Palm oil production affected by flooding. Retrieved from https://ipad.fas.usda.gov/highlights/2015/03/Malaysia/Index.htm. Acessed 16th July 2018.

United State Department of Agriculture (USDA). (2020). Malaysia: 2014/15 Palm oil production affected by flooding. Retrieved from https://www.statista.com/chart/23097/amount-of-palm-oil-produced-in-selected-countries/.Acessed 16th July 2022.

Verheye, W. (2010). Growth and production of oil palm. In: Verheye, W. (ed.), *Land Use, Land Cover and Soil Sciences* (pp.1-25). Encyclopedia of Life Support Systems (EOLSS), UNESCO-EOLSS Publishers, Oxford.

Verma, K. (2007). Saving, investment and growth in India: An application of the ARDL bounds testing approach. *South Asia Economic Journal*. 8(1): 89-98.

Waziri, S. I., Nor, N. M., Muktar, B. G. (2017). Export of agricultural raw materials, exchange rate and economic growth in Nigeria: An ARDL approach to co-integration. *Journal of Economics and Sustainable Development.* 8(22): 76-86.

Woittiez, L. S., Turhina, S., Deccy, S., Slingerland, M., & Giller, K. (2019). Fertiliser application practices and nutrient deficiencies in smallholder oil palm plantations in Indonesia. *Experimental Agriculture*, 55(4); 543-559

Woittiez, L. S.,Wijk, M. T. V., Slingerlanda, M., Noordwijka, M. V., & Giller, K. E. (2017). Review article yield gaps in oil palm: A quantitative review of contributing Factors. *Europ. J. Agronomy,* 83: 57-77.

Wooldridge's. (2013) *Introductory Econometrics: A Modern Approach*, Fifth Edition, Cenage Learning, South-Western, USA.

World Bank. (2001). Climate Change Knowledge Portal. https://climateknowledgeportal.worldbank.org/download-data.

Xiaoshu, W., & Yu, F. (2013). Some characterizations of the Cobb-Douglas and CES production functions in microeconomics. *Abstract and Applied Analysis*. 2013: 1-6 https://doi.org/10.1155/2013/761832.

Xu, Y., Yu, L., Li, W., Ciais, P., Cheng, Y., & Gong, P. (2020). Annual oil palm plantation maps in Malaysia and Indonesia from 2001 to 2016, *Earth System Science D*ata, 12: 847–867.

Yusuf, A., & Francisco, H. (2009), Climate change vulnerability mapping for Southeast Asia. Retrieved from: https://www.idrc.ca/sites/default/files/sp/Documents%20EN/climate-change-vulnerability-mapping-sa.pdf. Accessed 10th June 2020.

Yusof, B. (2014). Malaysian palm oil- Moving forward and addressing challenges in a changing global scenario. Paper presented at the Palm Oil Trade Fair and Seminar, Kuala Lumpur. Malaysia. October 2014.

Yusof, B. (2007). Palm oil production through sustainability plantations. *European Journal Lipid Science Technology*, 109: 289-295.

Yusof, B., & Chan, K. W. (2004). The oil palm and its sustainability, *Journal of Oil Palm Research*, 16(1): 1-10.

Zainal. Z., Shamsudin, M. N., Mohamed, Z. A., & Adam, S. U. (2012). Economic impact of climate change on the Malaysian palm oil production. *Trends in Applied Sciences Research,* 7: 872–880.

Zhai, S., Song, G., Qin, Y., Ye, X., & Le, J. (2017) Modeling the impacts of climate change and technical progress on the wheat yield in inland China: An autoregressive distributed lag approach. *PLoS ONE,* 12(9): 1-20.