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A Status Quo Review of Approach, Method, and Empirical Studies on Assessing the Impacts of Climate Change Variability on Agriculture

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Abstract

It is no longer contentious that climate change has a serious impact on agriculture for the past decades with varying consequences across the globe. These consequences are beneficial to some areas while others the story is disastrous. Therefore, estimating the impact of climate change variability has been the onus of many academic and professional researchers using various methods and approaches such as the partial equilibrium models or the economy- wide models. This review paper therefore, highlights on the various methods and approaches use to estimate the impact of climate change variability on crop production and further reviewed past empirical studies with a view to, (a) understanding the merits and demerits of each method and approach; (b) understanding the regional spread of the past research directions and current knowledge across the globe including Malaysia. The paper concluded by drawing attention to the need in paradigm shift. Refocusing future research efforts toward integrated vulnerability assessment as it offers fuller appreciation of the roles of adaptation in facilitation, supporting, and invariably sustaining the communities affected by the climate change vulnerability as suggested by many scientific bodies including the Intergovernmental Panel on Climate Change (IPCC).

Keywords: Climate Change, Variability; Impacts; agriculture, Crop production, Approach

1. Introduction

Climate changes in terms of increasing temperature, precipitation and extreme events are predicted by models with increasing Green House Gas (GHG) emissions (IPCC, 2007). This has been one of the issues of primary concern all over the world for the past two decades. The variability and changes in climate condition affects the environment physically, socially, and economically world over. The overriding influence of Climate on agriculture set limits to food production (Fazal & Abdul Wahab, 2013), and the negative consequences of this have direct bearing on the farmers in terms of their food security and livelihood across the world, especially in the developing countries (FAO, 2008; Fazal & Abdul Wahab, 2013; IPCC, 2007; Khee, Mee, & Keong, 2011).

The impacts of Climate change variability on agricultural crop production resulting from rising temperatures, variation in the magnitude, frequency and distribution of rainfall and incidences of extreme events like flooding, droughts, cyclones and the rise in sea levels has been negative in recent times (IPCC, 2007, 2012; Kotir, 2011).

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This made many scientific and policy analysts to doubt whether farmers will have the capacity to adapt to these changes which is making agriculture more vulnerable (Mertz, Halsnaes, Olesen, & Rasmussen, 2009; Reid, Smit, Caldwell, & Belliveau, 2007). Therefore, estimating the impact of climate change variability has been the onus of many academic researches focusing primarily on the biophysical climate change with a view to understanding the best options for adaptation. This paper highlights the interface between climate change and agriculture and various approaches and methods use in assessing the impact of climate change on agriculture with a view to identify the strength and weakness of each of the approaches, it also review some of the empirical researches so far conducted using the various approaches and methods from various regions across the globe. The paper is aimed at identifying and pointing at research gap in literature.

2. The relationship between Climate change and agricultural crop production

Climate change and agriculture are interconnected and related to two processes taking place at a global dimension (IPCC, 2007). The changes in global climate have significant and direct impact on agriculture and food systems (Brown & Funk, 2008). The impact on agriculture may have different consequences depending on the climate change scenario and geographic location(IPCC, 2007), investigation have shown that food production in the temperate zones will have beneficial impact of climate change while areas of the mid- and higher latitude the impact of climate change on food production will be negative (Gregory, Ingram, & Brklacich, 2005; IPCC, 2007; Parry, Rosenzweig, Iglesias, Fischer, & Livermore, 1999; Reilly & Schimmelpfennig, 1999; Rosenzweig & Parry, 1994). Globally, extreme events (drought, floods, and cyclones) will significantly reduce food production. This will invariably affect the global distribution of food production due to the influence of climate change, as such all dimensions of food security in terms of availability, access, stability and utilization will equally be affected (Gregory et al., 2005).

3. Methodologies of estimating the Impacts of climate Change on crop production

The various approaches are categorized into two main groups; the partial economic models and the economy -wide models. Partial equilibrium model is a quantitative method of assessing the impact of an economic or policy shock as it affects two or more interrelated specific sectors of the economy with the assumption that the rest of the sectors of the economy remain fixed. While the economy - wide or computable general equilibrium model is use to evaluate policy shocks that has a very complex impacts which can be transmittable through various channels, and affects various components (Sadoulet & De Janvry, 1995). Cumulative general equilibrium (CGE) is the commonest economy -wide model while partial equilibrium models comprises of the eco-physiological or "crop" or "agronomic" model, Ricardian or cross sectional model, and agro - ecological zone (AEZ) model (Deressa & Hassan 2009).

3.1 Computable general equilibrium model

The computable general equilibrium model uses linear and non- linear equations to simulate equilibrium (Deressa & Hassan 2009), and the model can adequately be used to assess the impact of climate change on the various sector of the economy directly or indirectly (Winters, Murgai, Sadoulet, De Janvry, & Frisvold, 1996). The advantage of this model is that it takes into consideration more than one variable or the whole economy with the assumption that all the different sectors are mutually interdependent and changes in one has effects on all other components. The limitation of this model is that it is difficulty to make model selection, functional forms, data parameterization and data calibration. It also lack specific statistical tests for model specification, the model is also difficult to handle due to its complexity (Partridge & Rickman, 1998), the model requires higher level of skills to develop and make use of (Burfisher, 2011).

3.2 Partial equilibrium models

3.2.1 Eco-physiological model

Eco-physiological model is also referred to as "crop model" or simulation models (Lobell & Burke, 2010). This model aggregate all available physiologic, agronomic, pedological as well as agro-meteorological information for the purpose of forecasting how particular plant will grow base on particular environmental settings (Lobell & Burke, 2010). The models are "eco-physiological" as it describes statistically the physiological, biochemical and environmental dynamics to replicate plant growth and development (Adams, Fleming, Chang, McCarl, & Rosenzweig, 1995; Lobell & Burke, 2010; Rosenzweig & Parry, 1994).

The models generates initial environmental conditions to determine crop yields and variations of output in a laboratory- like settings (Guiteras, 2009), the variations are then inputted into the economic model to determine the overall impact of crop yields and prices under different conditions (Adams, 1989; Rosenzweig & Parry, 1994). Several crop simulation models were developed and used in many researches across the world. They includes CERES developed in Hawaii, CROPSYST in Washington, the Food and Agricultural Organization (FAO) developed CROPWAT and CROP Yield Forecasting model, ASPIM model developed in Australia and SBW model developed in Pretoria (South Africa) (Iglesias, Rosenzweig, & Pereira, 2000; Rosenzweig & Parry, 1994; Tubiello & Rosenzweig, 2008). While these models have the advantage of carefully controlling and randomizing conditions of the environment its outcome might not capture the farmers' adaptation capacity. Although some level of adaptation is modelled but this did not indicate how well this relate with the real farmers' behaviour. This lead to negative bias in estimation even where farmers exhibit high adaptive practices; besides, the estimate could also be more hopeful where the supposed adaptation did not consider the adjustment processes (Guiteras, 2009). Agronomic models used in developing countries functions poorly in incorporating adaptation, besides, the model often ignored incorporation of new technologies (Mendelsohn & Tiwari 2000).

3.2.2 Ricardian / cross -sectional approach

The cross-sectional approach assesses performance of farms under climatic regions. This approach is also called the hedonic or Ricardian (Lobell & Burke, 2010) approach owing to the theoretical framework of the English classical economist David Ricardo (1773-1823) (Kurukulasuriya & Mendelsohn, 2008). According to Ricardian rent theory, he postulated firstly, that rent is a prize paid for the land services as its supply remained constant. Secondly, the prize evolves as a result of the original qualities of the land which are indestructible". These initial abiding properties of the land comprises of natural soil, fertility, mineral deposits, climatic conditions etc. The theory "states that land values or net revenue from land uses reflect land productivity at a particular site under conditions of perfect competition"(Sarker & Rashid, 2012).

This approach examines under different climatic conditions a cross-section of farmers and considers the correlation between the net revenue and agro -climatic conditions (Kabubo-Mariara & Karanja, 2007; Mendelsohn , Nordhaus, & Shaw, 1994). In other words land value or rent is considered as function of climatic, demographic, economic and physical conditions, hence, the minimal or marginal role of each element as an input to farm income is determine by regressing the net revenue on a set of environment input variables (Mendelsohn et al., 1994). It appears that this method has the main advantage of considering efficient adaptation in its prediction (Mendelsohn & Dinar, 2003). This method has been employed with a degree of success in many countries around the world. For instance, in USA (R. Mendelsohn & Dinar, 2003; R. Mendelsohn et al., 1994), in U.S. and Canada (R. Mendelsohn & Reinsborough, 2007); in England and Wales (Maddison, 2000; Seo, Mendelsohn, & Munasinghe, 2005), in Srilanka (Seo et al., 2005); in Kenya (Kabubo-Mariara & Karanja, 2007); in Taiwan (Chang, 2002), in South Africa (Gbetibouo & Hassan, 2005), in Cameroun (Molua, 2008, 2009) and in India and Brazil (Sanghi & Mendelsohn, 2008).

The shortcoming of this approach has been identified thus; firstly, It is premised on the assumption that there is constant price (Kabubo-Mariara & Karanja, 2007; Mendelsohn, Nordhaus, & Shaw, 1994), for this according to Cline (1996) will result to bias in computation of welfare; secondly, the approach however, does not assess the effects of climate on the individual crop yields (Kaufmann, 1998); thirdly, the model cannot encapsulate the influence of climate change on the variability of yields as widely reported in the literature (Barnwal & Kotani, 2010); fourthly, it require data from various agro - ecological areas or meteorological stations which often proves difficult to an individual researcher due to financial and time constraints; fifthly, the method can be influenced by the occurrences of omitted variables as it does not consider time independent or location specific variables like farmers skills, or soil quality (Barnwal & Kotani, 2010; Di Falco, 2014). The shortcomings of this model compel economists to look for other alternative techniques of estimation, such as the panel data technique (Guiteras, 2009).

3.2.3 Panel data approach

The use of the panel data technique is a reaction to resolves the bias arising from the problems of omitted variables in the use of cross - sectional method in measuring the effects of climatic variability on the agricultural crop productivity and net revenue (Deschenes & Greenstone, 2007; Schlenker & Roberts, 2006).

Panel data approach assesses the influence of climate change on both the average yield of crop and its variability (Barnwal & Kotani, 2010). There are two types of panel data approaches found in the literature. These are fixed effect method and random effect method (Baltagi, 2008).

The Fixed Effect Model (FE) allows for the determination of effects at a district specific level, time – invariant, and correlation or association between un- measured effects of variables that has been omitted such as the effects of the condition of the soil, the labour input and availability of fertilizer, farm infrastructure, market accessibility and skills of the farmers(Barnwal & Kotani, 2010). This model however, enables assessment of specific district effects by correlating the features of the time invariant and the intervening variables.

On the other hand the Random Effect model is premised on the assumption that there is no correlation between unobserved time – invariant features and the independent variables, for this reason therefore, Fixed Effect gives a better estimate (Barnwal & Kotani, 2010). In essence if the assumption stated above is violated then Fixed Effect will offer an unbiased assessment whereas Random Effect will not.

3.2.4 Agro – ecological zone approach

The agro-ecological zone (AEZ) approach is called crop suitability approach. This model was developed by the Food and Agricultural Organization of the United Nations (FAOUN) in 1992. The model assesses land suitability and other biophysical factors for better crop production (Deressa & Hassan 2009). The model like the agronomic model relies on the interactions between natural environments, but it is built on very careful eco-physiological modelling procedures that make use of crop yield simulation instead of measuring crop yields (Mendelsohn, 2000). The model considers many characteristics of crop, including length of the growing circle, yield formation period, leaf area index and harvest index, the available technology, edaphic and climatic factors are considered as the factors determining crop production (FAO, 2006). Based on the combination of these factor that suitable cropping land is identified and also the distribution of potential land areas for crop production. The model consists of climate as a determining factor hence can therefore, be used to assess the impacts of climate variables such as rainfall and temperature on potential agricultural productivity and cropping systems(du Toit & Prinsloo, 2001; Mendelsohn & Tiwari 2000). The model is also used to identify suitable options for adaptation to the climate change impact by creating fixed scenarios and modifying the technological options. The disadvantage of this model is that it is impossible to make prediction finally unless all the associated variables are modelled (Mendelsohn & Tiwari 2000).

4. Some empirical studies on the impacts of climate change on crop production

4.1 Climate change impacts on the global agriculture

A number of literature provides some explanations on the impact of climate change on global agriculture production, amongst those studies include the following; Kane, Reilly, and Tobey (1992) conducted an empirical study of the economic effects of climate change on world agriculture where they estimated the economic effects of doubling amount of co_2 in the atmosphere on world agriculture using two different crop response scenarios. Their findings indicated that the effects include changing prices of agricultural goods due to changes in domestic agricultural productivity, as well as economic welfare changes emanating from the changes in the global consumption and production pattern of the global agricultural products. Under the two different crop-response arrangement, except in few instances the effects on national welfare income is moderate. But under worst scenario the price of agricultural goods are expected to rise significantly. The rising price causes reduction in consumer surplus and reduce the climate change benefits which some countries will likely benefit from.

Rosenzweig and Parry (1994) Using crop growth model study the potential impact of climate change on world food supply. Findings from this research revealed that due to the doubling amount of co_2 concentration in the atmosphere this will result in slight reduction of world agricultural food production, and that the impact of climate change between the developed and developing countries will be different. Much of the impact will be felt in the developing countries located in the tropical areas. The model simulated various adaptation options considered by the farmers and it was shown that the adaptation options are not adequate to ameliorate the difference between the developed and developing areas.

The study of Parry et al. (1999) titled Climate change and world food security: a new assessment. This study used the global climate change model scenario (Hardly Centre Coupled Model, (HadCM2)) and considered the likely impacts of climate change on crop production, world food supply and possible risk of hunger. The study shows that climate change impact on crop yields has positive consequential benefit to the developed countries of the middle and higher latitudes, whereas low latitude developing countries especially in Africa with the exception of China will suffer a damaging effects with increasing risk of hunger, thus, this pattern will continue to expand as time goes on.

Parry , Rosenzweig, Iglesias, Livermore, and Fischer (2004) analyses and estimated the resultant consequences of the world crop yields, production and the likely risk of hunger associated with socio –economic and climate change scenarios developed from HadCM3 global climate model of the IPCC (SRES). Generally, the outcome from this study showed that crop yield drastically reduced both at regional and global scale due largely to wide range of global rising temperatures. This study further demonstrated how climate change may not likely affect crop production negatively of the whole world. As the impact of climate change on crop production will benefit developed countries, in developing countries the consequences are deleterious.

Fischer, Shah, Tubiello, and Van Velhuizen (2005) studied the socio- economic and climate change impacts on agriculture using agro – ecological model. Their study assessed comprehensively the impacts of climate changes over agro –ecosystems. The results from this study reveal that serious impact abnormalities largely from the combined effects of climatic and socio-economic settings may widen the existing gaps in production and consumptions between the advanced and the developing countries world over. The study therefore, considered adaptation of various agricultural skills as the only panacea to the potential harmful effects of the climate change.

Lobell and Field (2007) studied how the recent global warming relates with crop yields using the global scale climate. They were able to estimate the resultant effects of warming since 1981 that gave rise to the annual loss of 40 Mt ($5 billion) of the three crops under study as at 2002. This study has demonstrated how recent climate variability impacted negatively on crop yields globally.

Lobell et al. (2008) assessed how climate change influenced twelve food insecure regions of the world by the year 2030, the study was meant to essentially identify the best adaptation options, and thus, the study pointed out how south Asia and South Africa will suffer adversely from the future climate change in the absence of insufficient adaptation strategies.

While Cline (2008), predicted the impact of climate change on the productivity of agriculture up to 2080. This study predicted the warming level of global temperature to rise by 3.3^{0}c assuming that no action is to mitigate the emissions of greenhouse gases resulting from human activities. As such the study concluded that agriculture will be negatively affected most especially in the developing countries.

Lobell, Schlenker, and Costa-Roberts (2011) studied the past global climatic trends and crop production up to 1980 so as to understand how the impacts of this changes will affect future food production. The important finding from this study shows that the trend of temperature variability since 1980 up to 2008 went beyond one standard deviation annually in virtually all countries with exception of USA. Out of the four major crops under their study, the model they used to link crop yields and weather variability showed that production of maize and wheat globally was reduced 3.8% and 5.5% correspondingly. While in the case of soya beans and rice there was balanced out between losers and gainers. The study however, pointed to the fact that variability trend in many countries was so huge to counterbalance in increase in average yields as a result of innovation, co_2 fertilization and so forth.

4.2 Empirical studies from the developed Countries

A number of impact studies conducted in the past on agricultural production largely came from the developed countries, more especially the USA. Some of the studies used the production function approach in predicting the impact of climate change on the yield of crops with the aid of simulation models (Adams, Glyer, & McCarl, 1989; Adams et al., 1995; Rosenzweig, 1989). The outcome of the studies indicated that climate change has considerable impact on the US agriculture, other studies in recent times (Lobell, Cahill, & Field, 2007) demonstrated that the recent climate changes in California has a little impact on the crop yields.

Another component of researches from the USA (Lippert, Krimly, & Aurbacher, 2009; R. Mendelsohn et al., 1994; Reinsborough, 2003; Schlenker, Hanemann, & Fisher, 2005; Weber & Hauer, 2003) used Ricardian approach with aid of cross – sectional data their studies assessed how climate change impacted on agriculture.

Mendelsohn et al. (1994) pointed to the fact that climate change in the United State will have potential advantage. They estimated an increase in the GDP by 1% within carbon dioxide doubling scenario. The study of Weber and Hauer (2003) found out the same circumstance under Canada's agriculture, while in his study Reinsborough (2003) reported that agriculture in Canada will be less affected from the impact of climate change within the next thirty years. The study conducted by Schlenker et al. (2005) using accounting for irrigation in the hedonic approach attempted to investigate as to whether US agriculture will really be at advantage under current global warming. Their findings projected negatively impact on the United States agricultural income to the tune of $5.3 billion yearly. In Germany, Lippert et al. (2009) used farm level data and projected how climate change will benefit German's agriculture, but with disadvantages in the long run when rainfall and temperature variability became more erratic. The general agreement on impact of climate change of developed countries agriculture is that it is unlikely to be more severe (IPCC, 2007).

4.3 Empirical studies from the developing Countries

Developing countries are said to be the most vulnerable to the climate change impacts due to their poor resources base – in terms of social, technological and financial capacity to adapt(Antle, 1995; IPCC, 2007; Mendelsohn & Dinar, 2009). A number of research from the developing countries used Ricardian approach (Benhin, 2008; Deressa & Hassan 2009; Gbetibouo & Hassan, 2005; Guiteras, 2009; Kabubo-Mariara & Karanja, 2007; Kurukulasuriya & Ajwad 2007; Kurukulasuriya & Mendelsohn, 2008; Molua, 2009; Sanghi & Mendelsohn, 2008; Seo et al., 2005; Wang et al., 2009). Other studies used the production function approach (Chang, 2002; Haim, Shechter, & Berliner, 2008; Jones & Thornton, 2003; Lansigan, De Los Santos, & Coladilla, 2000).

In Philippines, Lansigan et al. (2000) reviewed the agronomic impacts of climate change on rice production. They revealed that both short term and persistent variability in the climate affects rice production by influencing crop sowing date, duration, yields and management practices. The extent of crop vulnerability rests on the crop's developmental stage at the period of weather abnormality. In Taiwan, Chang (2002) reported how both warming climate variability have considerable and wide range of impacts on crop yields. This study further shows that not all farmers in Taiwan will be adversely affected by the warming effect, but excessive rainfall could be disastrous to all farmers. Jones and Thornton (2003) used process – based model to predict the impact of climate change on maize production across Africa and Latin America by the turn of 2055. The result from their research revealed a general reduction in maize production by about 10% by 2055 which is equivalent to $2 billion annually. Although the cumulative result from the study did not revealed wide variability, yet places where productivity may have considerable change can be identified. This study therefore, stressed the need for household level assessment so as to adequately target the poor and vulnerable people within research and development endeavours to alleviate their poverty.

Haim et al. (2008) using production –function approach further reveals that sustainable agriculture in Israel will be greatly influenced by the climate changes resulting from the accretion of greenhouse gases. Their findings under different climate scenarios generated using global climate change model (HadCM3) shows that revenue from, wheat a major crop grown in the southern region, will be negatively affected under extreme climate change scenario and there is likelihood of revenue increase under mild changes, however, rainfall distribution was found to be major determining factor of crop yield. Cotton a second major crop was also found to be grossly affected under all different scenarios. Gbetibouo and Hassan (2005) employed the of Ricardian approach to determine the current and future impact of climate change on field crops in South Africa. Their findings reveal that crop production was more responsive to slight changes in temperature than in rainfall. In the same vein, Benhin (2008) assessed the economic loss arising from perceived negative changes of the climate on crop production in South Africa using Ricardian model. His findings shows that 1% rise in temperature will result in the increase of almost US$ 80.00 net crop revenue, while decrease in 1mm of rainfall resulted in US$ 2.00 net crop revenue, but with seasonal and spatial variation in the impact. The study also projected a decrease in the net revenue of about 90% by 2100, where the small- holders were mostly affected.

Seo et al. (2005) used Ricardian model to study the impact of climate change on agriculture in Sri Lanka, they used four major crops in the country to assess the net revenue per hectare.

Their study reveals that increase in the amount of rainfall will benefit the entire country under different scenarios, whereas, increasing temperature is found to be deleterious. The impact of climate change on agriculture in the country varies spatially and also with the climate scenario.

Kurukulasuriya and Ajwad (2007) study the impact of climate change on small holder agriculture in Sri Lanka using Ricardian approach to assess how climate change affected the profitability of farmers at farm level. This study revealed that climate change has a remarkable impact on small – holder farm profitability with a varying degree of the negative impact on net revenue between the dry zone of the North Central and dry regions of South Eastern Sri Lanka, while the wet areas are said to benefit positively. The study of Kabubo-Mariara and Karanja (2007) assessed the long term impact of climate change on the production of cereal crops in Kenya using cross – sectional and Ricardian model. The result from this study shows the detrimental effect of global warming on agricultural productivity; hence, they revealed how a change in temperature will have more significant impact than changes in rainfall.

Kurukulasuriya and Mendelsohn (2008), used farm data from 11 country and surveyed over 9500 farmers by employing Ricardian cross – sectional method to assess the impact of climate change on African cropland. Their findings shows that current climate have impact on the farmers' net income all over Africa and used the results to predict the future climates shows that irrigated lands are more sensitive to climate. They further reveals how the changing climate will impact negatively on the existing dry areas up to the beginning of 2020. Their projection under mild future warming with high precipitation could raise net revenue from dry land crop by 51%, while under high temperature and dry future climate change the net revenue will decline by 43%.

In his study Benhin (2008) employed the revised Ricardian model to examine the projected unfavourable climate changes and its economic impact on South African crop farming. His findings shows that a rise in 1% temperature will give rise to increasing net crop revenue to about US$ 80.00 whereas 1mm per month decrease in rainfall will lead to a loss of US$ 2.00. Under extreme seasonal variability the net revenue will significantly decline to up to 90% by 2100 and small –scale farmers will be worst affected. Sanghi and Mendelsohn (2008) used cross-sectional analysis to examine sensitivity of agriculture to climate change in the two countries. Their findings indicated that climate change will probably cause enormous destruction by 2100 in Brazil & India, though the effects may be reduced through carbon fertilization in the future.

Guiteras (2009) examines how climate change impacted on the agriculture in India. His projection of the climate changes over the period 2010-2039 affected majority of crop yields between 4.5 and 9%, while projection over long period from 2070 to 2099 shows greater effect of 25% and above reduction in yields. This study proves how significant Indian climate will impact on the economy if farmers did not adapt to the changing temperature. Deressa and Hassan (2009), employed Ricardian technique to capture farmers' adaptation to different environmental factors and indicated that climatic variability will affect crop production significantly in Ethiopia. They further predicted decline in revenue per hectare using three different climate scenarios for the year 2050 and 2100. The changes in revenue per hectare is shown to increase up to 2100 indicating negative trend but not uniformly distributed across the various Ethiopian ecological zones.

In Cameroun, (Molua, 2009) evaluated the impact of climate change on small holder agriculture using Ricardian approach. The result shows that 7% reduction in rainfall will reduce net income from crops by US$2.86 billion, and reduction in rainfall by 14% will cause decrease in crop net income by US$3.48 billion. Conversely, increasing rainfall affects net income positively, but a rising temperature, of 2.50c will cause net income to decline by US$0.79 billion and 50c rise will reduce the net revenue by US$1.94 billion. The study shows how net income is more sensitive to rainfall than temperature while high temperature was more deleterious to agricultural production. Ajetomobi, Abidun, and Hassan (2010), applied the Ricardian model to assess the influence of climate elements (temperature and rainfall) on net revenue from Agricultural land under irrigation and dry land cultivation in Nigeria. Their finding shows that rising temperature will lower the net revenue from the dry rice cultivated land, but in the land put under irrigation they estimated increase in revenue with rising temperature. The same applies to the impact of precipitation on net revenue of the rice.

Wang et al. (2009), this study examined the linear consequences of temperature and rainfall on the income derivable from both rain- fed and irrigation farms in China. Their investigation shows how climate change is beneficial to irrigation farming while it is destructive to rain- fed agriculture. Moreover, rising temperature averagely have negative effects on farm income, while, the average impact of higher rainfall was said to be positive. The impact generally varies spatially across the country.

The work of Derbile and Kasei (2012) in Ghana assessed the vulnerability of cereal crops (millet & Guinea corn) to the high amount of rainfall from 1987- 2007 by contrasting the Standard Precipitation Index (SPI) and the yields of the two crops. The result indicates that high amount of rainfall causes declining productivity of the crops. They corroborated their finding with farmers' opinion through interview and Focus group discussion. One major drawback of this study is that it does not apply any econometrics in their analysis.

4.4 Empirical studies in Malaysia

In spite of the looming threat from climate change vulnerability to Malaysia's agricultural and other sectors (Abul Quasem Al-Amin, Jaafar, Azam, Kari, & Agil, 2013), yet, climate change vulnerability assessment on agriculture are limited. Many of the previous studies can be grouped into two components, the simulation or model type, and descriptive studies which is not intrnded to be covered here.

One of the earliest simulation study by Singh, Amartalingam, Wan Harun, and Islam (1996), used crop simulation model ORYZA1 to examine the impacts of climate change on the production of rice using MR-84 rice variety of the three main areas of rice production within two seasons of the year. Their finding shows that $1^{0}c$ increase in temperature within the current level of atmospheric co_2 reduces yields to about 4.6 to 6.1 % and continuous increase in the temperature with more co_2 will result in more decrease in yield. The study showed that doubling atmospheric co_2 from 340 ppm to 680 ppm will cushion the destructive effect of rising temperature at $4^{0}c$.

Some few years later, Lin, Ariff, Serin, and Ghani (2010) used DSSAT model and Economic regression Model and assess the impact of rising temperature on rice productivity in Muda Agricultural Development Authority (MADA), Malaysia. Their finding shows that climate factors i.e. temperature, rainfall & Relative humidity have significant relationship with crop production. Specifically, temperature influence rice yield in that as temperature increases, production of rice decline with negative impact on farmers' income and Self-sufficiency Level (SSL).

Using system Dynamic model (SD) to determine how subsidies in form of fertilizer, cash and land conversion as well as soil fertility, Arshad (2010), analysed their effects on self-sufficiency level (SSL) of Malaysian rice production. They simulated the causal and feedback relationship of the variables within paddy rice framework under six varying scenarios. Their findings doubted Malaysia's achievement of SSL in the absence of adequate Research and Development to offset production threats like climate change and low harvest. In another simulation study Vaghefi, Shamsudin, Makmom, and Bagheri (2011)determine the impact of changing temperature and atmospheric carbon dioxides (co_2) on the production of rice in the eight granaries of the west coast Malaysia using ORYZA2000 simulation model. Their findings predicted decline in rice yield of about 0.36 t/ ha with an increase in $2^{0}c$ of temperature at the present co_2 concentration of 383 ppm, the decline increases as the co_2 level increases to 578 from 383 ppm. This study estimated economic loss due to climate change per annum in the rice industry.

Using data from GCM model, Abul Quasem Al-Amin, Leal, de la Trinxeria, Jaafar, and Ghani (2011), assess the impact and vulnerability of climate change to rice farming in Malaysia using GCM and DSSAT models. The study simulated the effect of climate variability outcome on the income from rice farming for the next 40, from 2020 up to 2060. Their estimation indicated serious doubt on the rice production in the future due the climate changes. They therefore, proffered future pathway for planning approaches to future investment decision making to avert future vulnerability of agriculture in Malaysia. Also Abul Quasem, Filho, Kabir, Azam, and Abdul Hamid (2011), used Empirical downscaling model (EDM) and crop modelling (DSSAT) to investigate the possible impacts of climate change on agricultural activities in Malaysia with observed data of rainfall inter- annual variation and projected rising temperature up to the year 2080. Their investigation revealed a possible reduction in rice production by 6.1% due to $1^{0}c$ temperature increase and doubling concentration level of co_2 from 400-800 ppm based on the current climate changes. This will reduce income from rice production annually. The study suggested 10% improvements in adaption options to adequately prevent the possible downward reduction in rice yield up to 2080.

The study conducted by Ramli, Shamsudin, Mohamed, and Radam (2012), employed system dynamic SD model to examined the impact of any change in the government fertilizer intervention policy on paddy and rice industry in Malaysia. They discovered that fertilizer subsidy has significant impact on the paddy and rice industry. Thus, its removal can cause decline in paddy production and invariable cause a downward decline in SSL.

Another study by Vaghefi (2013), studied the economic impact of Malaysia's rice industry. The study estimated the future impact of rainfall and temperature changes on rice yield in the eight granary areas using DSSAT – CERES model up to the year 2030 using forecasted weather data. The result of the crop simulation shows varying degree of reduction in yield at different seasons. The simulation of the System Dynamic model indicated that yield reduction affects self- sufficiency level, income to the farmers and nation's food security negatively; hence the study suggested increased subsidy and incentive policies to the farmers as a panacea to improving rice production.

Other strand of studies using modified Ricardian approach Zainal, Shamsudin, and Mohamed (2013), examined how climate change impacted economically on the production of paddy in Malaysia. The study focused on the impact of variation in temperature and rainfall on paddy rice productivity within the last 31 years from 1980 to 2010 using time- series regression and PRECIS (RCM) models. Their findings indicated that both rainfall and temperature have negative significant impacts on rice production and farmers' net revenue. The study suggested the need for alternative mitigation and adaptation mechanisms to upset the deleterious effects of climate change on rice production.

Radin Firdaus, Abdul Latiff, and Borkotoky (2013), analyzed the potential changes of climate extreme events in Malaysia using emission scenario A1B developed by IPCC SRES. They made projections on the changes of future extremes from 17 stations through bias correction of the UKMO PRECIS downscaling simulation output. The result predicted rainfall extreme to occur in the Malaysia west coast peninsular with high level probability within the monsoon autumnal transition period.

To further determine the impact of climate change on rice production, Radin Firdaus et al. (2013), assessed the impact of climate changes on paddy rice production in the eight granary areas. The study predicted changes in net revenue due to the impact of climate change at granary levels using Ricardian model. The results from their study indicated that paddy rice productivity is highly determined by climatic factors. This study underscores the future vulnerability of paddy farmers to the vagaries of climate changes. The study therefore, suggested for urgent adaptation approaches to arrest the impending consequences.

Much recently however, Rahman, Al-Amin, Kari, and Leal Filho (2014), used Ricardian model to assess the future impact of climate change variability of temperature, rainfall and precipitation on rice production during the two seasons in Muda Agricultural Development Authority of Kedah, Malaysia. The findings from this study reveals that factors of temperature, rainfall, size of the farm, labour, farmers' education and knowledge have significant impact rice productivity per unit hectare of land.

5. Conclusion

This review has drawn our understanding of the intricate inter-connectivity between climate change impacts, agricultural crop production, and food systems are manifested to be significant and direct throughout the world. Therefore, estimating the varying impacts of climate change on agricultural sector is approached from two main categories by the experts and scientific communities; by either the partial economic models, and/or the computable general equilibrium models. The economy- wide models or computable general equilibrium models consists of the eco- physiological or "crop" or agronomic models, the Ricardian or cross- sectional model and the agro- ecological models. Each of these models has been identified with their relative merits and demerits.

The various empirical studies conducted in the developed and developing countries using the various methods and approaches have generally concurred that the impact of climate change on crop production will be negatively affected across the globe with varying degrees between developed and developing countries. That the impacts of global climate change will affect commodity prices, economic welfare with worst consequences in the developing countries that stand the risk of excruciating hunger. That the pattern of the impact of climate change across the globe will widen consumption and production gap between the developed and developing countries.

Howbeit, one fundamental thing to note is that the past studies show overwhelming concentration of researches in the developed countries even though they are said to be least affected. Also of the few studies conducted recently in the developing countries many comes from Africa probably due to the continent's high levels of exposure and its low adaptive capacity. The various studies further indicated that embracing agricultural adaptation options will be the only panacea to the harmful effects of climate change across the globe. Yet, a number of these studies have not taken into account the existing adaptation capacities rather purely focused on the possible repercussion of the climate perturbations on the agriculture. The fact that developing countries are more vulnerable to the impacts of climate change due largely to their poor resource base in terms of social, technological and financial capacity to embrace adaptation.

Similarly, strand of past studies in Malaysia as discussed above followed the same approach of the developed and developing countries. They fall into either simulation/modelling studies employing process- based modelling or econometrics, and others were mere descriptive in nature. The outcome of the previous individual studies described the future or outcome vulnerability of the Malaysian Agriculture. The studies only estimated future impact of climate change on agriculture such as rice productivity and the concomitant welfare loss. The studies do not take into account the current vulnerability vis-à-vis, the role of the existing adaptive capacities in addressing the issues of vulnerability to climate change.

From the foregone discussion, this has underscores the existing gap in climate change vulnerability study more specifically in Malaysia. It is pertinent to have a paradigm shift in the domain of subsequent climate change studies and research endeavours to give more credence to integrated vulnerability assessment. This will provide a scrutiny of the agricultural system through the lenses of three vulnerability layers of exposure, sensitivity and adaptive capacity as advocated by many scientific bodies including the IPCC. Thus; this will inarguably cause to appreciate the role of adaptation in facilitation, supporting, and invariably sustaining the communities affected by the climate change risks.

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