Climate change effects on agricultural productivity and its implication for food security

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Abstract. This paper demonstrates the climate change consequences on agricultural sector in the scope of agricultural market and socioeconomic. Agricultural output and food prices would change as the climate change may negatively affect the agricultural input. The implication of climate change on the food security pillars is discussed. It is proposed to apply farming integration system by cultivating local crops that do not harm the environment, which could be developed by local people. Good infrastructure and implementation of research and innovation would be beneficial to deal with the impacts of climate change to promote sustainable economic growth, social development and environment.

1. Introduction

Climate change is known as one of the considerable environmental failures as a result of human activities. This occurs since the growth concentration of Greenhouse Gases (GHGs) emission has raised the earth’s temperature. Climate change could be categorised as a market failure in the perspective of economics. The existence of climate change impacts causes inefficient market in a free market condition. This market failure generates an externality, which means a benefit received or cost bear by people as the impact of economy activities. This is classified as a ‘classical global stock externality’ since the greenhouse gas (GHG) emissions have been accumulated in the atmosphere for hundreds of years that induces risks to people [1]. The GHGs mainly generated by human activities such as industry, agriculture, forestry, transportation and infrastructure. In the report of Intergovernmental Panel on Climate Change – IPCC [2], it states that climate change may increase temperature that affects agriculture, forestry, human health, raising sea levels, flood, losses of coastal areas, coral, and mangroves.

There are many studies have been conducted to measure the impact of climate change on agriculture. Hanjra and Qureshi [3] discuss several mitigation actions that must be taken to reduce the threat of less water and land resources for enhancing food security. In addition, Parry, ML et al. (2004) highlight the consequences of climate change to agricultural outputs such as decreased in crop yields, risk of hunger and socioeconomic development in developing countries. A report by FAO, I (2011) and a study by Valenzuela and Anderson [4] demonstrate that food price fluctuation will trap smallholder farmers and poor consumers to poverty because food consumption is the largest portion of expenditure for farmers’ income and poor consumers. Unexpected food prices would diminish
farmers’ attraction to invest in agriculture that leads to decreasing labour demand in the agricultural sector.

It could be argued that climate change and agriculture have causal and effect relationship. This is because the agricultural sector depends on climate condition, but at the same time the sector also contributes to the global emission. Agriculture including livestock production contributes about 1/5 of global emission [5]. This leads to a trade-off between an attempt to increase productivity to feed the growing global population and to reduce global emission caused by agriculture.

World Bank [6] estimates that there must be an increase production by at least 50% to feed 9 billion people in 2050. However, the need of increasing agricultural output should also consider protecting the environment. According to Parry, ML et al. [7], climate change impacts on agriculture could be divided into two aspects: biophysical and socioeconomics. Biophysical changes could be in terms of rising temperature and precipitation that would influence agricultural production. Socioeconomics changes are related to shift in inflation, labor and poverty. Inflation may occur as the instability food prices due to production interruption. This influences demand for labour as the shift of production activities. Inflation and demand for labour are associated with poverty, particularly in developing countries since agriculture tends to be labour intensive that may affect the economic growth.

2. Methods

2.1. Climate change impacts on agricultural output and prices

Nelson et al. [8] have estimated that four main crops (rice, wheat, maize and soybeans) prices will increase by 2050 by using Commonwealth Scientific and Industrial Research Organisation (CSIRO) and The US National Centre for Atmospheric Research (NCAR) scenario without counting the effect of carbon fertilization (see Figure 1). All scenarios expect a higher temperature, evaporation and rainfall in 2050. However, the NCR scenario represents wetter climate that increase precipitation by 10% and for CSIRO goes up by 2% only. Nevertheless, all the scenarios show that global prices of main crops will increase relative to year 2000. Even without the effect of climate change, the prices may increase since the growing of world population that results to a higher food demand.

![Figure 1. World Prices, major grains](image)

Several considerations about how the climate change impacts on agricultural production and prices that limited to agricultural inputs quality and quantity are as follows:
2.1.1. Water availability. Climate change increases global temperature that causes extreme event such as drought, which reduces water availability and affect directly to the agricultural production. The IPCC report Solomon et al. [2] shows that as the temperature increases, water availability will decrease particularly at the low latitudes countries and increase at the high latitude countries. The report also projects that agriculture and forestry production are expected to decrease in Southern part of Australia and Europe, Eastern part of Australia and New Zealand by 2030 because of drought and fire risks. The drought in Australia has impacted on increased market price for fruit and vegetables by 43% and 33% respectively within two years from September 2005 to September 2007 [9]. Hanjra and Qureshi [3] add that increasing water demand for urban and industrial use exacerbates water resource for agriculture. Quantity supplied would drop that leads to a higher market prices.

2.1.2. Land fertility and availability. Land is an important input factor in the agricultural sector. The amount and fertility of land determine the level of agricultural output. Drought caused by climate change reduces the amount of arable land to increased food production [3]. Heavy rainstorms that results flood risk is also the major impact of climate change (NDRC n.d.). Flood may cause run off and erosion on the land that loses the fertility of the land. On the other hand, land availability is decreasing due to increased population that requires more places to live by converting agricultural land to housing. Hanjra and Qureshi [3] report that one million hectares of agricultural land in Indonesia have been converted to industrial and infrastructure sector within five years. Less amount of land would increase the market price of land for agricultural that raises required capital investment for agriculture. Unfertile land would also push farmers to use more fertilizer to stimulate their crops which would increase the production cost and produce GHG emission as well. Consequently, these would increase the prices of agriculture output.

2.1.3. Labour productivity. Labour productivity may be affected by the increased of temperature. This effect may be much felt by people in developing countries that rely on labour intensive industry particularly in the agricultural sector. Kjellstrom et al. [10] point out that climate change negatively affect labor productivity without any adaptation. They argue that the industry may require more workers to maintain similar level of output. Crop and labor productivity in Australia, the US, Western Europe and China would decrease by 1.20, 0.90, 3.70, and 46.7 (2004 US$ billion) respectively in 2030 [11]. Extreme events such as flood, heavy rainfall and typhoon could disperse diseases and result to community disruption and broken environment would decrease labor productivity (NDRC n.d.). Warmer climates would stimulate the growth of agricultural pests that increases the use of pesticides or chemical fertilisers which could harm humans’ health. As a result, labours require more capital for their health to keep them working and to maintain their productivity. Employers should increase labour wages that leads to increase the production costs and food prices.

2.1.4. Capital and insurance. Capital plays an important role in escalating the agricultural production. More capital may be required as the risk of running business becomes higher. In this case, as the weather condition is unstable, this will increase uncertainty of agricultural profit. Farmers have to spend more money on maintaining their production that will increase production cost. For example, farmers may purchase weather index insurance to shift or transfer the risks of weather uncertainty. The insurance grants the farmers to defend themselves from disaster risks by paying out when an observable trigger occurred that measured by local weather stations [12]. This actually would raise commodity prices because insurance cost is imposed to consumers.

2.1.5. Crop diverting. As the use of fossil fuels contributes to a higher GHG emission, bio-fuel comes as an alternative energy source to reduce emission caused by fossil fuel. Bio-fuel creates new potential market to substitute fossil fuel and to tackle energy crisis problem. The production of bio-fuel requires abundant of land to grow bio-fuel that produced from conventional foods such as corn, sugarcane and oil palm [13]. Abundant of land will be required to produce bio-fuels which would be more than 50%
of total global crop land (1540Mha) that equivalent to all crop land in developing countries (904Mha) [14]. To minimize the cost of opening new land, bio-fuel production utilizes current cropland by converting food cropland to bio-fuel crops land. As a result, supply of feed crops would be less since less amount of land to grow feed crops. This raises commodity prices that also may impact on food insecurity.

3. Results and discussion

3.1. Climate change impacts on different economies

The impact of climate change may vary across countries as each country has different climate condition which determined by its distance to the equator. Crop yields are expected to increase at temperate, higher and mid-latitudes countries because of longer growing period [7,15]. Negative impact is mostly suffered by countries located near to equator with lower latitude, particularly developing countries. Climate change increases evaporation, lowers soil humidity, raises land aridity and stimulates agricultural pest which is not suitable for crops [15]. Countries in Africa and South Asia which categorized as arid and sub humid tropical countries would be severely affected because they have low capacity for adaptation, risk of hunger and food insecurity threats [3].

Table 1 reveals the summary projection of yield changes for three main crops in developing and developed countries in 2050. Irrigated wheat yields would decline by almost 30% in developing countries, but by the effect of carbon fertilization the yield only decreases by 1.4%. Developing countries are much negatively affected by climate change with higher decrease or lower increase of yield change than developed countries. Different management of crop system would also have different changes. Irrigated crops would be harmed by the effect of less water supply and rainfed crops would be benefit as the increase of rainfall due to climate change.

Table 1. Yield changes from 2000 to 2050 (%)

| Region            | Maize | Rice | Wheat |
|-------------------|-------|------|-------|
|                   | Irrigated | Rainfed | Irrigated | Rainfed | Irrigated | Rainfed |
|                   | without CO2 Fertilisation | | | | | |
| Developing Countries | -2.0    | 0.2  | -14.4 | -1.3  | -28.3 | -1.4 |
| Developed Countries | -1.2    | 0.6  | -3.5  | 17.3  | -5.7  | 3.1 |
|                   | CO2 Fertilisation | | | | | |
| Developing Countries | -1.4    | 2.6  | 2.4   | 6.5   | -1.4  | 9.3 |
| Developed Countries | -1.2    | 9.5  | 10.5  | 23.4  | 3.1   | 9.7 |
| Source: [8]       |       |      |       |       |       |       |

Increasing food production by using chemical input production factors would be harmful for people living in tropical or developing countries which most of them depend on agriculture. Estimated increased prices due to supply shock drops their purchasing power because food consumption is one of the biggest expenditure for rural people. Fischer et al. [16] argue that climate change may deepen the gap of current production and consumption between developed and developing countries. Several impacts on macroeconomics indicators in developing countries are as follows:

3.2. Inflation

Projected increased prices of food in developing countries would cause domestic inflation that may result in decreasing real value of money. People in developing countries whose biggest expenditure is
on food would be disadvantaged. This will lead to depressing purchasing power, declining investment, and decreasing net export as a result of increasing in import value. These things would drop economic growth off that will delay national economic development in developing countries. A report by ADB [17] estimates that higher inflation due to global food prices would hit net food importers in Asian countries in 2011 (see Figure 2). Singapore that highly rely on global food market would be vulnerable that may decrease its GDP by around 0.6 percentage points in 2011. Contrarily, the GDP Thailand as a food-exporting country would slightly increase. In 2012, India and Indonesia would experience larger decrease in GDP than in 2011. However, Republic of Korea, Singapore, and Taipei, China would improve their GDP in 2012 as the assumed of decline in global food price

![Figure 2. Changes in GDP growth due to increase 30% global food prices in 2011 (percentage point) (ADB 2011)](image)

3.3. Labour

It could be argued that agriculture in developing countries tends to be labour intensive sector. It is accounted that more than 2/3 people in developing countries work in agriculture sector while in developing countries decreases to less than 5% because of technology used [18]. As the impact of climate change, labour productivity would be lower since human diseases could be easily disperse in warmer climate and more extreme weather events. Anderson [11] has estimated that crop and labour productivity would decrease by 164.2 billion (2004 USD) in 2030 due to climate change. Lower productivity means that production could not meet demand which may enforce government to increase import. This would undermine the terms of trade (ToT) that affect to country’s GDP.

3.4. Poverty

Climate change impacts would impede the poverty reduction efforts in most of developing countries. Based on the $1.25-a-day poverty line, 10% rise in domestic food prices in Asian countries would increase number of poor people by 29.0% or 968 million people [17]. Household would spend more money on food since food crops prices becomes higher. They would reduce their budget allocation for investing in business or saving. Inflation reduces the value of crops generated by farmers while other input production prices such seeds, fertilizer, land and water increase. This condition would harm farmers and confine them in a poverty trap. Furthermore, government may push food import to maintain access of poor people to food. This would depress government budget for production factors and other investments that result in increasing unemployment rate due to declining demand for labour. As agriculture in developing countries is a labour intensive sector, this would eliminate jobs for rural people that would generate higher poverty rate.
### Table 2. Impact of Domestic Food Price Increase on Poverty for Developing Asia

| Change of number of poor people (%) | Poverty before food price increases | Poverty after food price increase |
|-------------------------------------|-------------------------------------|----------------------------------|
| 10%                                 | 27.1                                | 29.0                             |
| 20%                                 | 30.9                                | 32.9                             |
| 30%                                 | 32.9                                |                                  |

| Number of poor (Million)            | 903                                 | 968                              | 1,032 | 1,097 |
|-------------------------------------|-------------------------------------|----------------------------------|-------|-------|

Source: [17]

3.5. Implication on food security

Food and Agricultural Organisation (FAO) [19] defines food security as "a situation that exists when all people, at all times, have physical, social and economic access to sufficient, safe and nutritious food that meets their dietary needs and food preferences for an active and healthy life". Food security is one the priority goals in the Sustainable Development Goals (SDGs) to reduce global poverty and hunger. A country is perceived to be food secure if the country is able to achieve four food security pillars including food availability, accessibility, utilisation and stability. Availability refers to the ability of people to purchase food, accessibility refers to national food supply sufficiency, utilisation refers to nutritional quality and safety of food while stability refers to the stability of the other three pillar [19].

The previous section highlight that climate change would affect the agricultural productivity. By looking at the four food security pillars, below is short explanations how climate change effects threat the food security pillars.

3.6. Food availability

Food availability refers to sufficient supply of food with appropriate quality which can be sourced locally or through imports [19]. Climate change influences food supply as the agricultural productivity depends on the climate. A report by USDA Brown et al. [20] highlight that climate change affects the productivity in every agricultural sector especially in crop and livestock sector. Climate change stimulate the growing of crop pests and pathogens as the cause of changing in temperature and precipitation which may negatively affect the crop productivity. The effect of climate change in livestock production is related to heat stress that reduce the feed intake and physical activity of the animals causing lower productivity. Additionally, frequent extreme events such as flood, drought and storm as the effects of climate change may influence land fertility that ultimately declining agricultural production.

3.7. Food access

Food accessibility is whether individual have access to adequate resources to acquire nutritious food; from own production and consumption, purchases from the market, in-kind transfer or loan from relatives or community, government and foreign aid that is determined by the ownership of asset, social, economy, policy, physical and natural environments. Food accessibility is highly related to the food prices that may influence income for purchasing food [20]. The previous section of this paper demonstrates the climate change effects on food prices that mainly because of increasing agricultural production costs. Brown et al. (2015) also highlight that climate change can increase logistic costs in distributing food from farm to consumers due to extreme climate related events such as heavy rainfall, drought and storm damaging the road infrastructure.

3.8. Food utilisation

Food utilisation refers to adequate diet, good sanitation, clean water, and health care to meet physiological needs [19]. Food utilisation has a socioeconomic dimension including decisions of what
of kind of food is consumed and allocation of food in the household, in which the decisions may be influenced by the social condition and biological dimensions [21]. This relates to the individual’s ability to consume nutritional food and transform it to energy for daily activities which also relates to food storage, food safety and good management practices of food to maintain the quality and nutritional content of food [21,22]. The effects of raising temperature would stimulate the growing of food bacteria due to lack proper food storage in the supply chain that ultimately would negatively affect the food quality [20]. Cold chain is still a challenge in most of developing countries due to high capital investment causing the threats of food bacteria may harm the food safety. Most of the agricultural commodities are perishable products that require a proper handling in the distribution until reaching consumers’ tables to main the quality of the products.

3.9. Food stability
The last food security pillar is related to the stability of the other three pillars which means a population, household or individual must have access to adequate and nutritious food at all times. The effects of climate change may influence the status of food supply, people’s access and the quality of food. Food system would be interrupted especially in countries where the agricultural producers are mainly smallholder farmers who have limited capital, skills and access to advanced technology to undertake adaptation actions to climate change.

4. Conclusions
The trade-off between an attempt to increase food production and to reduce GHG emission will generate inefficient market. The effects of climate change on agricultural production leads to an imbalance condition between food supply and demand which ultimately influence the pillars of food security. Multi stakeholder collaborations may be needed to tackle the effects of climate change with an aim of increasing agricultural productivity with an approach that promotes sustainable economic growth, social development and environment. Several approaches that can be taken are through livestock and crop integration, local food and infrastructure development and investment in research and innovations.

4.1. Farming integration system
This integrates crop and livestock production that aims to reduce the waste of their production. Waste from crops could be used to feed the livestock and waste from livestock could be utilised to produce biogas that can be used to generate power and organic fertilizer. This could reduce emission of methane (CH4) because the gas is not released to the air. Furthermore, farmers may apply renewable sources such as wind, water and solar to reduce the use of fossil fuel. This would promote environmental sustainability that may prevent environmental damages.

4.2. Local product development
Every region may specialize in its local crops which are known to be more resistance to the local climate. Changes in climate may not significantly affect the productivity by encouraging mitigation and adaptation activities. This mechanism could be implemented in a small-scale business that may bring positive multiplier effect to the local community such as improving value added for local crops, providing employment, generating income for local people that would break the poverty cycle. In addition, encouraging local crops would make efforts to meet local demand and to reduce food import. This would also not be costly in terms of production and distribution since the products are developed locally that may maintain local prices stability.

4.3. Infrastructure development
Boosting infrastructure development would be important, particularly in developing countries. An appropriate and adequate infrastructure could support local production in every level of value chain from production and distribution. Sufficient infrastructure would improve food access for people that
may maintain prices. This also could assist the local products development program. As a result, carbon footprint could be reduced by encouraging all the activities locally and efficiently.

4.4. Research and innovation
Promoting research and innovation is also important to explore the best way to deal with climate change impacts. This could be through interdisciplinary collaboration to facilitate knowledge, experience and technology exchange. This may explore more about low emission varieties, irrigation technology, and renewable sources that could be accessed by poor people. Green technology innovation in agriculture would be crucial to generate green energy (renewable sources) and to produce product that do not harm the environmental.

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