sustainability

MDPI

Article

Assessing the Impacts of Climate Variations on the Potato Production in Bangladesh: A Supply and Demand Model Approach

Arifa Jannat [1,2], Yuki Ishikawa-Ishiwata [3] and Jun Furuya [4,*]

[1] Graduate School of Life and Environmental Sciences, University of Tsukuba, 1-1-1 Tennodai, Tsukuba, Ibaraki 305-8572, Japan; s1936023@s.tsukuba.ac.jp
[2] Institute of Agribusiness and Development Studies, Bangladesh Agricultural University, Mymensingh 2202, Bangladesh
[3] Global and Local Environment Co-Creation Institute (GLEC), Ibaraki University, 2-1-1 Bunkyo, Mito-city, Ibaraki 310-8512, Japan; yuki.ishikawa.ga@vc.ibaraki.ac.jp
[4] Social Sciences Division, Japan International Research Center for Agricultural Sciences, 1-1 Owashi, Tsukuba, Ibaraki 305-8686, Japan
* Correspondence: furuya@affrc.go.jp; Tel.: +81-29-838-6304

Abstract: From the perspective of nutritional security, we investigated the influence of climate change on potato production in Bangladesh using a supply and demand model by considering the potato as an important non-cereal food crop. To provide an outlook on the variation in potato supplies and market prices under changing climatic factors (temperature, rainfall, and solar-radiation), the yield, area, import, and demand functions were assessed using district-level time-series data of Bangladesh (1988–2013), disaggregated into seven climatic zones. Results suggest that temperatures above or below the optimal range (18–22 °C) lowered yields. Little rainfall and low solar radiation hinder potato cultivation areas during the potato maturity stage. During the simulated period, the annual production was projected to rise from 88 to 111 million metric tons (MT), with an equilibrium farm price of 155 to 215 US dollars MT^{-1}. Between 2014 and 2030, the nation's per-capita potato intake is expected to increase from 49 to 55 kg $year^{-1}$ because of changing dietary patterns. According to the estimated equilibrator, scenario simulations that incorporated various dimensions of Intergovernmental Panel on Climate Change (IPCC) scenarios indicate that potato production and consumption can increase in the future.

Keywords: climate change; econometric model; outlook; potato market

check for updates

Citation: Jannat, A.; Ishikawa-Ishiwata, Y.; Furuya, J. Assessing the Impacts of Climate Variations on the Potato Production in Bangladesh: A Supply and Demand Model Approach. *Sustainability* **2021**, *13*, 5011. https://doi.org/10.3390/su13095011

Academic Editor: Hossein Azadi

Received: 9 March 2021
Accepted: 26 April 2021
Published: 29 April 2021

1. Introduction

Climate change will make hunger eradication more challenging, with reduced agricultural production, increased food prices, and reduced food availability, with consequent adverse health effects [1–3]. To ensure a supply sufficient to satisfy global food demand in 2050, agricultural production must be boosted by 60% [4]. However, the yields of major staple crops are projected to decline considerably because of changing climate. Research results indicate that climate change is expected to reduce yields of maize (20–45%), wheat (5–50%), rice (20–30%), and soybeans (30–60%) [4] by 2100. Agriculture must transition to more productive, resilient, and sustainable processes to cope with changing climate [4]. Most economically developing and low-income countries rely on cereal crops for their nutritional security. Research findings have demonstrated that 1.9–2.3 billion people obtain 60–70% of their iron and zinc from the major staple crops: rice, wheat, and maize [5].

Few researchers have reported attempts to assess the effects of dietary diversity on nutritional deficiency, but their findings have shown that protein, iron, and zinc deficiencies are more concentrated in the Global South than in other regions [6–9]. Therefore, reliance on these cereal crops alone will not be sufficient to close the gap separating food supply and demand. Primary crops such as rice, wheat, and maize are sufficiently calorific to prevent hunger, but they fail to provide all necessary nutrients for a balanced diet. Under these circumstances, research assessing major non-cereal supply and demand scenarios under climate change variations must be conducted immediately. Currently, the United Nations (UN) Food and Agriculture Organization (FAO) is promoting tubers as economical and nutritious food crops that can improve food and nutritional security in many economically developing countries [10]. Therefore, through substituting staples such as wheat, rice, and maize partly with potatoes, the production and consumption of this crop are expected to increase.

Due to its position between the Himalayas and the Bay of Bengal, Bangladesh, an economically developing nation, is regarded as among the world's most climate-sensitive countries. Natural hazards such as high salinity, hurricanes, irregular rains, drought, high temperatures, and flash flooding have increased in severity and frequency because of atmospheric warming [11]. These increasing occurrences resulting from global warming adversely affect crop production both directly and indirectly. Bangladesh is endowed with highly fertile soil and moderate rainfall and temperature conditions that can produce various crops year-round. Compared with other economically developing countries, Bangladesh has certain advantages including rich genetic and ecosystem diversity and enormous dedicated human resources that are willing to participate in diverse agricultural activities [12,13]. In this respect, crop intensification and diversification are excellent strategies for combining the production and consumption of main cereal crops with non-cereal crops. Therefore, Bangladesh, with its scarce agricultural land, is perhaps the best-suited environment to meet growing needs for food by increasing potato production on small patches of agricultural land.

Potatoes constitute the world's main non-cereal food crop, ranking fourth behind rice, wheat, and maize. [14]. Furthermore, because of their climate-resilient characteristics, they are useful to replace cereal crops [14]. This high-yielding crop has rich nutrient contents [15,16]. Suitable potato cultivation is possible under different and changing climatic environments. Moreover, because of the temperate climates in Bangladesh, they are a particularly suitable crop [17–19]. To investigate future scenarios of potato supply and demand, Bangladesh was chosen as a temperate region and the seventh-largest potato producing country in the world as well as the third-largest potato producing country in Asia after China and India [20]. The annual production of potatoes in Bangladesh is estimated at 11 million metric tons (MT) [21]. Bangladesh has already attained food security status, although nutritional security remains questionable [22]. According to estimates, more than 20 million people in Bangladesh are adversely affected by chronic vitamin A, iron, and zinc deficiencies, which more strongly affect pregnant women and infants [23]. However, the changing climate has had an adverse effect on food and nutritional security in Bangladesh [24]. It has been predicted that major crop production in Bangladesh might decline by 30% because of negative consequences of climate change [25]. Therefore, considering both population growth and climate change, and knowing that rice is the major staple food in Bangladesh, an urgent need exists for specific examination of alternative crops that can stabilize the country's economy and change its dietary patterns. Potatoes constitute the second largest crop in terms of cultivated area (after rice), corresponding to 3% of Bangladesh's total area and providing as many as 6.0% of the daily per-capita calories and protein consumed in rural areas because of the abundant supply. It is regarded as a partial substitute in many households [21,26].

Reports of studies using supply and demand modeling of major cereals conducted under changing climatic conditions are scarce in the literature [27,28]. Salam et al. examined the rice production and price volatility in Bangladesh in light of climate change, reporting that the yield of modern and local varieties of rice fluctuated during the pre-monsoon (December–January) and dry (March–May) seasons [29]. Similarly, the yield variation was higher under Representative Concentration Pathways (RCP) 6.0 (2.0–3.7 °C) than under RCP 8.5 (3.2–5.4 °C) where each scenario is more suitable for the South Asian region, including Bangladesh [29]. Another study revealed that climate change harmed the rice yield in India; more specifically, higher temperatures lowered rice yields in most states, except for those states at high altitudes [30]. Researchers have also emphasized the supply and demand elasticities of major agricultural commodities in the U.S.A. [31]. Studies have proven that supply and demand models are effective and fruitful approaches for elucidating the consequences of climate change on the production and market price dynamics of different enterprises [29,30,32].

With rising global population and changing climate patterns, an urgent need exists to adopt appropriate policy recommendations to ensure a consistent supply of agricultural products with fair market prices [29]. In this regard, the current study specifically examines the evaluation and forecasting of climate change effects on potato supply and demand, a model that incorporates the climate and socioeconomic scenarios of the Fifth Assessment Report (AR5) of the Intergovernmental Panel on Climate Change. The model outputs are also known collectively as the "Coupled Model Intercomparison Project Phase 5 (CMIP5) multi-model dataset" [33].

Most modeling studies are conducted for the major cereals such as rice, wheat, and maize: tubers have generally been ignored. In Bangladesh, several studies have been conducted by considering agronomic, economic and physiological aspects of potato cultivation [34–36], but incorporating supply and demand in the context of climate change is quite uncommon. Consequently, the present study was undertaken to estimate a supply and demand model to assess climate change effects on Bangladesh's potato production using a supply and demand model approach. In light of climate change, the findings of the present research are expected to help policymakers in determining pricing strategies and improving market information and tracking mechanisms to minimize supply uncertainty. The following question was considered: What are the effects of climate change on potato production for different climatic zones in Bangladesh?

2. Materials and Methods

2.1. Study Area

This study used district-level time series data and grouped them into seven climate zones of Bangladesh following a method explained by Rashid [37,38]. The study area map with classification of the seven climatic zones was created in the ArcGIS environment. Basic layers were projected in the WGS84 using ArcGIS 10.4.1® software (Figure 1).

2.2. Data Sources

2.2.1. Historical Data

According to data availability, the assessment was conducted for 1988–2013. Yield and area data of potato for seven climate zones are available for 1986–2014 [39]. Climate variable information such as rainfall data is available for 1970–2013. However, temperature and solar radiation data before 1980 are limited for the respective districts [40]. Similarly, consumer price index data are available from 1986 from the World Bank database [41]. Considering uniformity of analysis, this research was conducted using data available for 1988–2013.

However, the analysis was extended up to 2030 for the econometric assessment. The demographic and climatic characteristics of Bangladesh are presented in Appendix A. Before analyzing the supply and demand model of potato, it is important to assess the growing stages of potato production in Bangladesh. In this regard, the potato crop calendar is presented in Appendix B.

Time-series data for the historical yield and cropped area of potato were collected from the Bangladesh Bureau of Statistics (BBS) [39]. The following data were obtained from [42] Food and Agricultural Organization's statistical database, FAO-STAT (2019): The market price of potatoes in Bangladesh was assumed as the farm price (FP), world price (WP) (Netherlands's price), imports (IMP), exports (EXP), food demand, seed, loss, and other uses. Data related to the consumer price index (CPI), exchange rate (EXR), real gross domestic product (GDP), GDP deflator (GDPD), and population (POP) were collected from the World Bank [41]. The monthly mean data of climate variables, i.e., temperature, rainfall, and solar radiation, were gathered from the Bangladesh Meteorological Department (BMD) [40] and the Bangladesh Agricultural Research Council (BARC) [43] for the estimated period. The annual average temperature, rainfall and solar radiation for the historical period are presented in Appendix E.

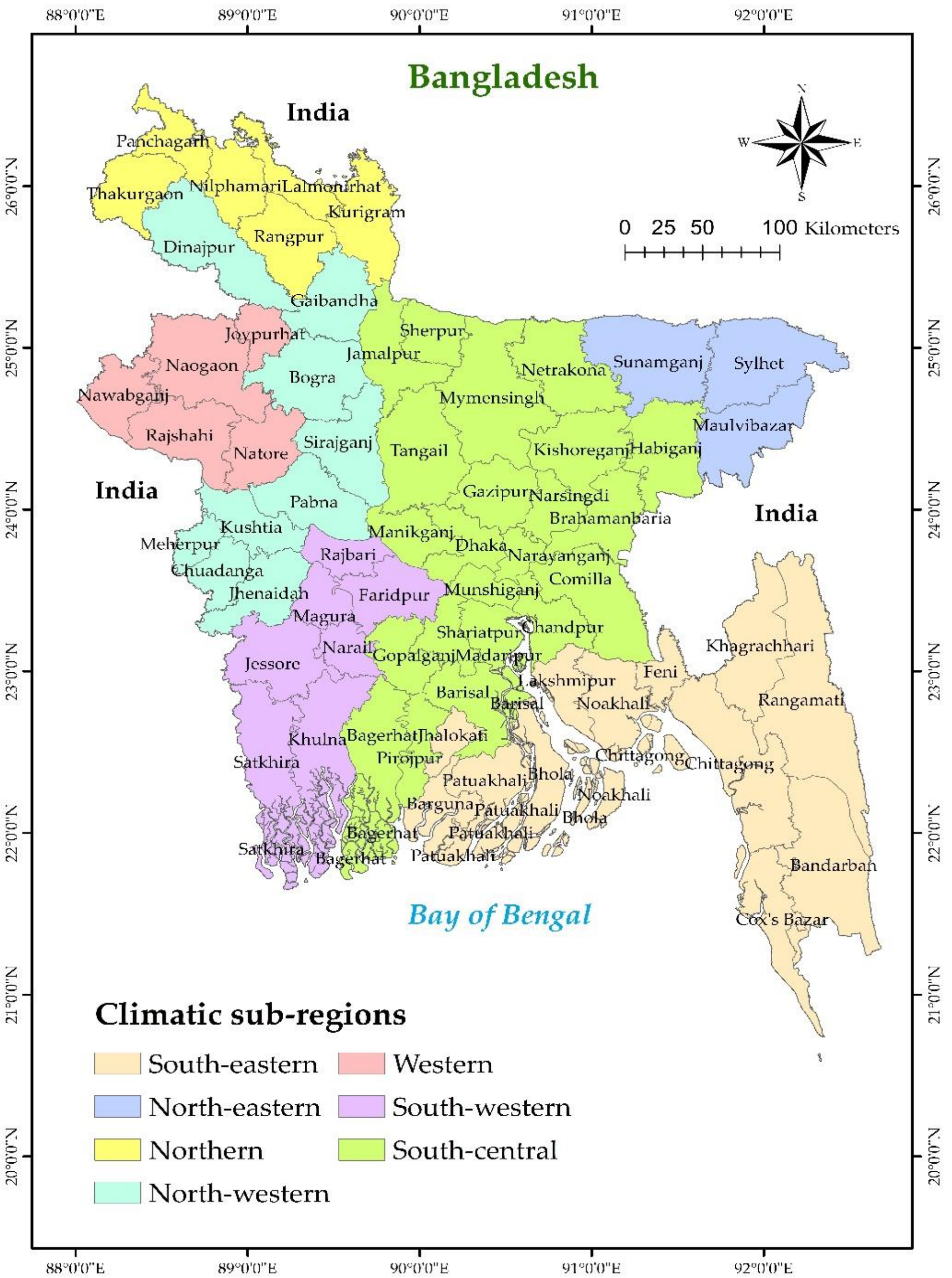


Figure 1. Climate zone map of Bangladesh. Source: Author's own creation using ArcGIS 10.4.1® software.

2.2.2. Forecast Data

The simulated period was from 1988 until 2060 for the supply and demand of potato. The Model for Interdisciplinary Research on Climate (MIROC5) General Circulation Model (GCM) of the University of Tokyo, National Institute for Environmental Studies (NIES) and the Japan Agency for Marine-Earth Science and Technology (JAMSTEC) were used as the sources of future climate data in the simulations. The IPCC AR5 developed four

RCP scenarios (RCP 2.6, RCP 4.5, RCP 6.0, and RCP 8.5). They can be delineated based on radiative forcing and the direction of change [44,45]. A set of five Shared Socioeconomic Pathways (SSPs) (SSP1–SSP5) that explains the microscale conditions of human and natural resources was considered based on O'Neill et al. [46]. In all, 20 possible scenarios (four RCPs × five SSPs) exist in the RCP–SSP combination. However, all scenarios are not applicable to a specific country because of variation of the GDP growth rate, population pressure, and climate change adaptation and mitigation challenges. Among the representative scenarios, two contrasting scenarios were selected for this study: RCP 6.0 (medium emission) and RCP 8.5 (high emission).

The SSP scenarios, three SSPs (SSP2, SSP3, and SSP4) were chosen among five combinations of the International Institute for Applied Systems Analysis (IIASA). All the criteria of these three SSPs are highly observed and practiced in the Bangladesh context (an economically developing nation in South Asia) [29]. The forecast GDP and population under SSPs of the AR5 of the IPCC were incorporated into climate scenarios to predict the food situation and price instability in the future under climate change.

2.3. Supply and Demand Model of Potato

The potato yield, area, imports, and demand functions were estimated based on work reported by Hung et al. and Furuya et al. to develop an outlook with regard to the variation in the supply and market price of potatoes as a result of climate change [30,47]. Their model's basic mathematical expressions were followed and improved for this study by adding climatic variables to generate the potato supply and demand model. The supply and demand model for potatoes in Bangladesh is the following:

Yield functions

$$Y_{i,t} = \alpha_{iY} + \beta_{iY,1} T_t + \beta_{iY,2}\, TMP_{i,t} + \beta_{iY,3} RAF_{i,t} + \beta_{iY,4}\, SLR_{i,t} + \varepsilon_{iY,t} \quad (1)$$

In that equation, $Y_{i,t}$ represents the potato yield (MT ha^{-1}), T stands for the time trend, and $TMP_{i,t}$, $RAF_{i,t}$, and $SLR_{i,t}$, respectively, denote the monthly average temperature (°C), solar radiation (W m^{-2} day^{-1}), and total rainfall (mm) in the given period. Additionally, α_i, $\beta_{i,1}$, $\beta_{i,2}$, $\beta_{i,3,}$ and $\beta_{i,4}$ are the parameters, and $\varepsilon_{iY,t}$ is the error term. Subscripts i and t, respectively, denote the regions and year.

Area functions

$$A_{i,t} = \alpha_{iA} + \beta_{iA,1}\, A_{i,t-1} + \beta_{iA,2}\, FP_{t-1}/CPI_{t-1}/100) + \beta_{iA,3}\, TMP_{i,t-1} + \beta_{iA,4} RAF_{i,t-1} + \beta_{iA,5}\, SLR_{i,t-1} + \varepsilon_{iA,t} \quad (2)$$

In the equation presented above, $A_{i,t}$ is the harvested area for the time t, and $A_{i,t-1}$ is the lagged area. FP_{t-1} (USD MT^{-1}) is the lagged farm price of potato deflated by the lagged consumption price index $CPI_{t-1}/100$. CPI is the consumer price index (2010 = 100) of Bangladesh. $TMP_{i,t-1}$, $RAF_{i,t-1}$, and $SLR_{i,t-1}$, respectively, represent the lagged seasonal temperature, rainfall, and solar radiation on a monthly basis. Additionally, α_i, $\beta_{i,1}$, $\beta_{i,2}$, $\beta_{i,3}$, $\beta_{i,4}$, and $\beta_{i,5}$ are the estimated parameters.

The total production identity is the following:

$$IMP_t = \alpha_{IMP} + \beta_{1IMP}\, TQ_{i,t} + \beta_{2IMP}\, WPR_t + \varepsilon_{IMP} \quad (3)$$

In the equation above, IMP_t stands for the quantity of imports (MT), $TQ_{i,t} = \sum_i Y_{i,t} A_{i,t}$ denotes the total domestic production (MT) of seven climate regions, and $WPR_t = (WP_t * EXR_t/(CPI_t/100))$ is defined as the world price (US dollars) where EXR_t is the exchange rate (local currency/USD). Additionally, α, β_1, and β_2, respectively, represent the estimated parameters.

The net supply identity is shown below.

$$NS_t = TQ_{i,t} + IMP_t - EXP_t - LOSS_t - SEED_t - OTHER_t \quad (4)$$

Therein, NS_t stands for the net supply (MT). EXP_t, $LOSS_t$, $SEED_t$ and $OTHER_t$, respectively, express the export, loss, seed, and other usages (MT).

Per-capita consumption is calculated as

$$QD_t = NS_t / POP_t, \tag{5}$$

where QD_t signifies the per-capita consumption of potato (kg year^{-1} person^{-1}), and POP_t represents the populaton of Bangladesh (thousand persons).

The demand function is

$$DD_t = \alpha_{DD} + \beta_{1DD} FP_t / CPI_t / 100) + \beta_{2DD} rGDPPC_t + \varepsilon_{DD} \tag{6}$$

where DD_t denotes the per-capita consumption of potato, FP_t is the farm price (USD MT^{-1}), and $rGDPPC_t$ ($rGDP_t/POP_t$) is derived from the real GDP, which is divided by population (POP_t). Here, the real $rGDP_t$ is the GDP that is transformed into constant international dollars (base 2010) followed by purchasing power parity (PPP) rates.

Figure 2 displays the structure of the supply and demand model analysis for potatoes in Bangladesh. Total potato production is the aggregate output of all seven climate zones.

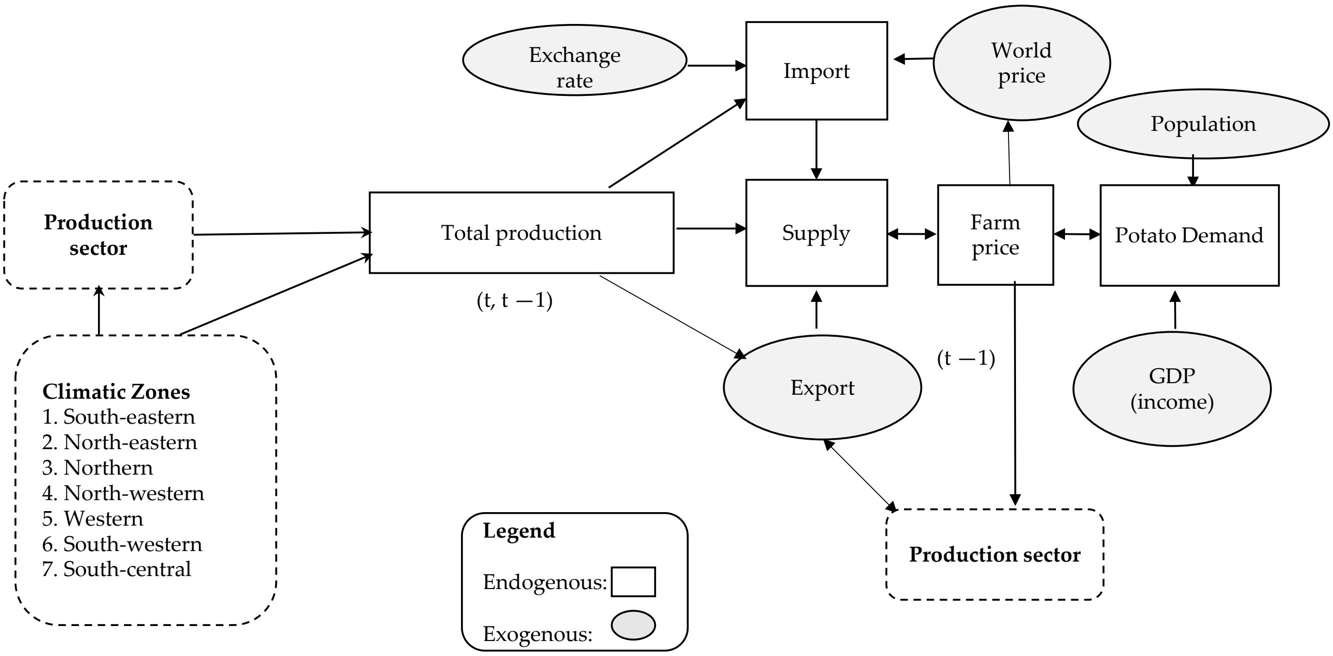


Figure 2. Schematic diagram for the supply and demand of the potato econometric model for Bangladesh.

The yield and area functions were used to measure the potato supply. After estimating the import function, the value of imports was added to the total production. To measure the net domestic supply, the value of exogenous variables such as export, loss, seed, and other usages was subtracted from the overall output. By incorporating GDP and domestic farm prices, the demand function was estimated. In the final step, the procedures were also executed by an equilibrator to find the expected point of convergence which indicates the domestic market price in a spreadsheet [48].

The convergence mechanism for equilibrium condition is described as

$$SS_t - DD_t \times POP_t = 0, \tag{7}$$

where SS_t represents the net supply in the market, DD_t is the per-capita domestic demand, and POP_t denotes the population.

Shifts in market prices of potatoes are influenced by supply and demand interaction. The iteration of price adjustments can be conducted repetitively in the following procedures.

$$\text{Adjusted value } (ADV_t) = (SS_t - DD_t) \times (-DF), \quad (8)$$

In that equation, DF is the damping factor, which can be measured as a constant number:
$SSt > DD_t$ when ADV_t became negative and FP_t decreased;
$SSt < DD_t$ when ADV_t became positive and FP_t went up;
The iteration process was terminated when $ADV_t \approx 0$.

To apply the above econometric model of supply and demand for potatoes, the following statistical analyses were made. After the descriptive statistics, the correlation coefficient was measured to identify the relation between the dependent (yield, area) and independent (temperature, rainfall and solar radiation) variables for the seven climatic zones. An Augmented Dickey–Fuller (ADF) test was used to assess all variables' stationarity. Results indicated that most variables had unit roots (Appendices C and D) and almost all climate variables were stationary (Appendix D). If the variables had unit-roots, then Johansen Cointegration tests were used in the next step. Cointegration relations were absent from these functions. As most variables were nonstationary, the first-order difference technique was used to make all variables stationary to ensure uniform estimation methods for each region [28,49]. The estimation method was ordinary least squares (OLS) method. When serial correlation was found in the error term, an autoregressive (AR1) model was applied. The goodness of fit of the model was identified with the information criteria, i.e., Akaike Information Criterion (AIC), whereby the lower the values of those criteria, the better the model specification. F-stat was regarded as identifying the model accuracy. However, the Durbin Watson Stat (DW Stat) shows the autocorrelation in residuals. If the DW stat value is nearly two, then the model can be regarded as 'autocorrelation free'. We regard this as the lag of the dependent variable in the regression equation.

3. Results

3.1. Estimation of Functions of the Supply and Demand Model

Table 1 presents the relation between the potato yield with temperature, rainfall, and solar radiation. The estimated parameters of the study revealed that temperatures higher or lower than the optimal temperature (18–22 °C [50]) hindered potato yield growth because potatoes are cultivated in all zones of Bangladesh during winter [43]. Specifically, northern, north-western, south-western and south-central regions are affected mostly by variations of temperature. However, higher altitude (south-eastern and north-eastern regions) and cold weather with less precipitation (northern region) and high solar radiation (south-eastern region) during the potato production cycle also adversely affect the potato yield. The findings revealed that temperature, rainfall, and solar radiation (beyond 120–210 W m^{-2} day^{-1} [51]) negatively affect potato production in almost all regions. These results are consistent with those reported by Adavi et al. [52] and Rana et al. [53]. Most of the applied variables in the yield and area functions were found to be statistically significant (Tables 1 and 2).

In general, climate variables negatively affected the tuberization and growth stage in most areas. Along with results shown in Table 2, higher farm prices encouraged farmers to expand their cultivated areas of potatoes. The area function findings showed that the previous year's cultivation area positively influenced the current year's potato cultivation area. This study also found that, in every crop year, potato cultivated areas increased in Bangladesh [42,54]. Similar findings were also observed by Li and Zhang, who found that climatic factors variously affect different potato producing provinces in China [55]. The elasticity of the lagged year's farm price was 0.04–0.12, indicating that potato prices played a significant role in deciding the allocation of lands and that they had a positive and statistically associated effect on potato producer behavior. The lagged temperature, rainfall (<300 mm [33]), and solar radiation had a negative consequence on the potato cultivation area, which might affect the yield ultimately. Potato plants are less resistant to drought than many plants. They need optimum rainfall or equivalent irrigation throughout the season. Minimum temperatures, little solar radiation, and minimal or no rainfall during cold weather (November through March) diminish the potato cultivation area (Table 2).

Most agricultural areas are dominated by rice production, whereas other regions, such as the south-eastern, north-eastern, and south-western regions, are suitable for more diverse cultivation (aquaculture, tea cultivation, floriculture, and so on) because of the weather patterns, salinity, and competition with other enterprises [56]. However, during the simulation phase, potato production is projected to increase from 85 to 212 million MT year^{-1}.

The baseline outlook for the main producing regions, i.e., northern, north-western, western, and south-central is presented in Figure 3.

Table 1. Estimation of potato yield function according to temperature, rainfall, and solar radiation.

Climate Zones	**Climate Variable**					**AdjR^2 DW**
	Nov.	**Dec.**	**Jan.**	**Feb.**	**Mar.**	
SE		−0.336TMP ** (−2.40)		−0.005RAF ** (−1.80) −0.052SLR *** (−6.17)		0.75 2.65
NE	−0.246TMP ** (−2.38)		−0.023RAF *** (−3.58) −0.023SLR * (−1.69)			0.55 2.16
N	−0.022RAF ** (−2.35)		−0.771TMP *** (−3.20)		−0.032SLR * (−1.69)	0.56 2.36
NW				−0.170TMP * (−1.68) −0.028RAF *** (−3.6)	−0.048SLR ** (−3.17)	0.67 2.12
W				−0.233TEMP * (−1.70)	−0.012RAF ** (−2.3) −0.031SLR * (−1.68)	0.60 1.89
SW	−0.042SLR (−1.83)	−0.027RAF * (−1.67)	−0.567TMP ** (−2.57)			0.47 2.40
SC			−0.014RAF ** (−1.92)	−0.514TMP *** (−5.20)		0.55 2.22

Note: ***, **, and *, respectively, denote the levels of significance at 1, 5, and 10%. Values in parenthesis represent *t*-values. AdjR^2 is adjusted R^2 and DW stands for Durbin–Watson values. Note: Temperature (TMP), rainfall (RAF), solar radiation (SLR): south-eastern (SE), north-eastern (NE), northern (N), north-western (NW), western (W), south-western (SW), south-central (SC); November (Nov.), December (Dec.), January (Jan.), February (Feb.), and March (Mar.).

The findings of the import function showed an inverse relation between imports, total quantity, and world price, which revealed that increased potato production and the world price of potatoes were able to reduce the extent of imports. The findings showed that one thousand MTs of total production increase led to decreased imports of 4 MT. Similarly, a US dollar increase in the world price of potato reduced imports by 0.107 MT. The per-capita consumption of potato is projected to increase from 49 to 55 kg year^{-1} between 2014 and 2030. The equilibrium farm price is estimated to increase from 155 to 215 USD MT^{-1} between 2014 and 2030. In Bangladesh, the potato price is directed by the upstream transmission. Consequently, the direction of the potato farm prices is influenced by the retail price. As a developing nation, Bangladesh's government cannot import potatoes from potato-exporting countries with high prices (Table 3).

Table 2. Estimation of planted area functions of potato with climate variables.

Climate Zones	*A* (*t* − 1)	*FP* (*t* − 1)	Climate Variable					AdjR^2
			Nov. (*t* − 1)	Dec. (*t* − 1)	Jan. (*t* − 1)	Feb. (*t* − 1)	Mar. (*t* − 1)	
SE	0.43 *** (3.38) [0.55]	0.13 * (1.61) [0.11]			−688.71TMP ** (−2.65) [−1.67]	−16.77RAF ** (−2.40) [−0.04] −70.01SLR *** (−3.54) [−1.45]		0.71
NE	0.32 *** (3.52) [0.31]	0.06 * (1.84) [0.09]				−266.63TMP *** (−3.41) [−0.92]	−12.387SLR ** (−2.31) [−0.39]	0.86
N	0.36 * (1.74) [0.32]	0.53 * (1.66) [0.10]				−1181.40TMP ** (−2.75) [−0.59] −132.28SLR * (−2.41) [−0.52]		0.69
NW	0.30 ** (1.78) [0.26]	0.51 ** (1.51) [0.07]	−133.96SLR * (−1.66) [−0.28]		−1593.89TMP *** (−2.35) [−0.37] −133.57RAF ** (−1.79) [−0.01]			0.65
W	0.16 ** (1.59) [0.14]	0.40 ** (2.02) [0.10]			−1696.66TMP *** (−4.55) [−1.01] −75.68RAF *** (−2.03) [−0.019]	−81.95SLR (−1.90) [−0.47]		0.76
SW	0.47 ** (3.67) [0.41]	0.12 ** (1.52) [0.12]		−53.59RAF *** (−3.15) [−0.02]	−515.31TMP * (−1.86) [−0.87] −46.28SLR * (−1.99) [−0.63]	−24.65RAF ** (−2.70) [−0.06]		0.78
SC	0.36 ** (2.39) [0.35]	0.35 * (1.74) [0.04]				−38.83RAF * (−1.93) [−0.01] −107.63SLR ** (−2.49) [−0.20]	−891.12TMP ** (−2.52) [−0.28]	0.65

Note: ***, **, and *, respectively denote the levels of significance at 1, 5, and 10%. A and FP, respectively represent cropped area and farm price. Values in () and [[], respectively denote t-values and elasticity. AdjR2 is adjusted R2. Temperature (TMP), rainfall (RAF), and solar radiation (SLR).

Table 3. Estimation of imports and food demand functions.

Equations	Variable Estimate		AdjR^2 DW
Import	−0.0040TQ *** (−4.64)	−0.107WPR$_t$ * (−1.71)	0.81 2.20
Food demand (per capita)	−0.00065FP *** (−6.78) [−0.298]	−0.5371rGDPPC ** (−2.55) [−1.193]	0.79 1.97

Note: ***, **, and *, respectively represent levels of significance at 1, 5, and 10%. Values in () and [], respectively denote t-values and elasticity, respectively. AdjR2 is adjusted R2 and DW stands for the Durbin-Watson values.

Most producers earn low profits because they sell their product as soon as it is harvested. This practice is attributable to the limited number of storage facilities as well as the chances of diseases, weather instability, cash necessary to repay loans, and limited information about market prices [57,58]. These unexpected and quick sales occur during the harvesting season in March–April. Market intermediaries take advantage of hoarding (creating an artificial market crisis) and then selling between October–December when the prices are higher because of reduced potato supply [59]. Recently, the GDP growth rate in Bangladesh has been increasing quickly. The rising trend of per-capita income (USD) is expected to motivate households to make optimal use of their consumption expenditures because they will have the opportunity to choose diverse food items.

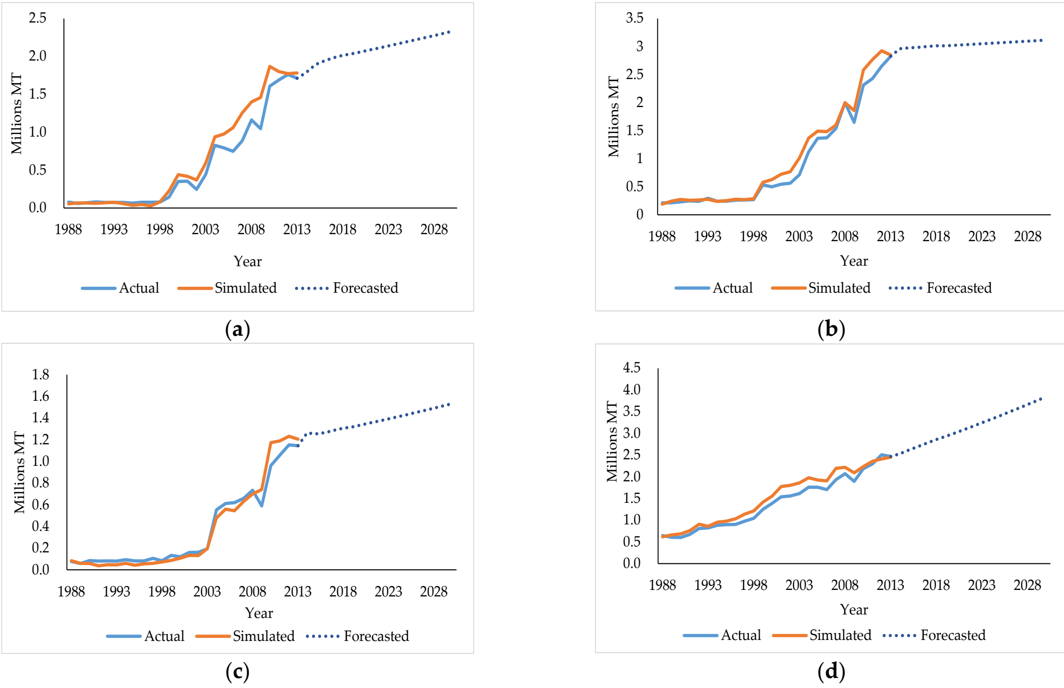


Figure 3. Baseline outlook of main potato producing regions in Bangladesh. (**a**) northern, (**b**) north-western, (**c**) western, and (**d**) south-central.

3.2. Simulation Analysis

Potato Production Scenario under RCP 6.0 and RCP 8.5

The simulation results obtained for potato production for different regions were derived through equilibrators of the model. Under RCP 6.0 and RCP 8.5, three SSP (SSP2, SSP3, and SSP4) scenarios were investigated (Appendix E). The equilibrator is a method for finding equilibrium quantities and prices of a supply and demand model in a Microsoft Excel© spreadsheet. This method was developed by the Food and Agricultural Policy Research Institute, University of Missouri (FAPRI-MU) [60]. The following simulation assumptions were made: (i) the estimated parameters were fixed because of the inverse U-shaped pattern of agricultural products in the long run. Therefore, the parameters of temperature, rainfall and solar radiation were negative and already past the optimum point. We assumed that the yield change is slight because of the change of slope followed by many crop models; (ii) the linear trend continues in the yield functions; (iii) the average trend is applied for area functions; (iv) the average growth of the GDP deflator and exchange rate during the forecasted period are assumed between 2011 and 2013 because of the changes of GDP deflator and exchange rate in the forecasted period having very slight influence on the determination of import and demand for potatoes; (v) each climate scenario has individualistic trends that might be affected separately by determination of the supply and market price scenario. However, we also demonstrated the overall simulation analysis for potato production (Million MT), farm price of potatoes (USD MT^{-1}), and per-capita consumption (kg year^{-1} person^{-1}) under RCP 6.0 and RCP 8.5 with corresponding SSPs.

Bangladesh is progressing as a sustainable potato-producing country and, surprisingly, appeared as a potato exporting country during the simulation period. In addition, the per-capita food demand (kg person^{-1}) was negatively related to the farm price of potatoes and GDP per capita. A 1% increase in the potato farm price would likely reduce potato consumption by 0.298%. The income elasticity of demand was −1.193 under the potato supply and demand model. These results indicate that potatoes are an inferior good in Bangladesh. The farm price of potatoes was estimated as a market-clearing price using the convergence mechanism of the supply and demand for the simulation period. Per-capita potato consumption under RCP 6.0 had a slow and steady trend. However, under RCP 8.5, it showed a fluctuating and constant trend in different SSP scenarios. According to Figure 4, the average per-capita consumption of potatoes under RCP 6.0 with SSP2, SSP3, and SSP4 scenarios were, respectively, 70.22, 67.26, and 63.80 kg, and 69.43, 66.51, and 63.08 kg under RCP 8.5. The farm price fluctuated significantly under both RCP 6.0 and RCP 8.5, but had an increasing trend over the forecasted period considering the constant price of 2010 in USD (exchange rate, 2010 [61]). This finding also predicted that the potato price would be higher under RCP 6.0 and RCP 8.5 with SSP2 than with SSP3 and SSP4. Rising national income and poorer people's per-capita income and food diversification would bring potato consumption to a static situation. The potato supply and demand model's simulation results indicated that the effects of climate change influenced the potato market price variations (Figure 4).

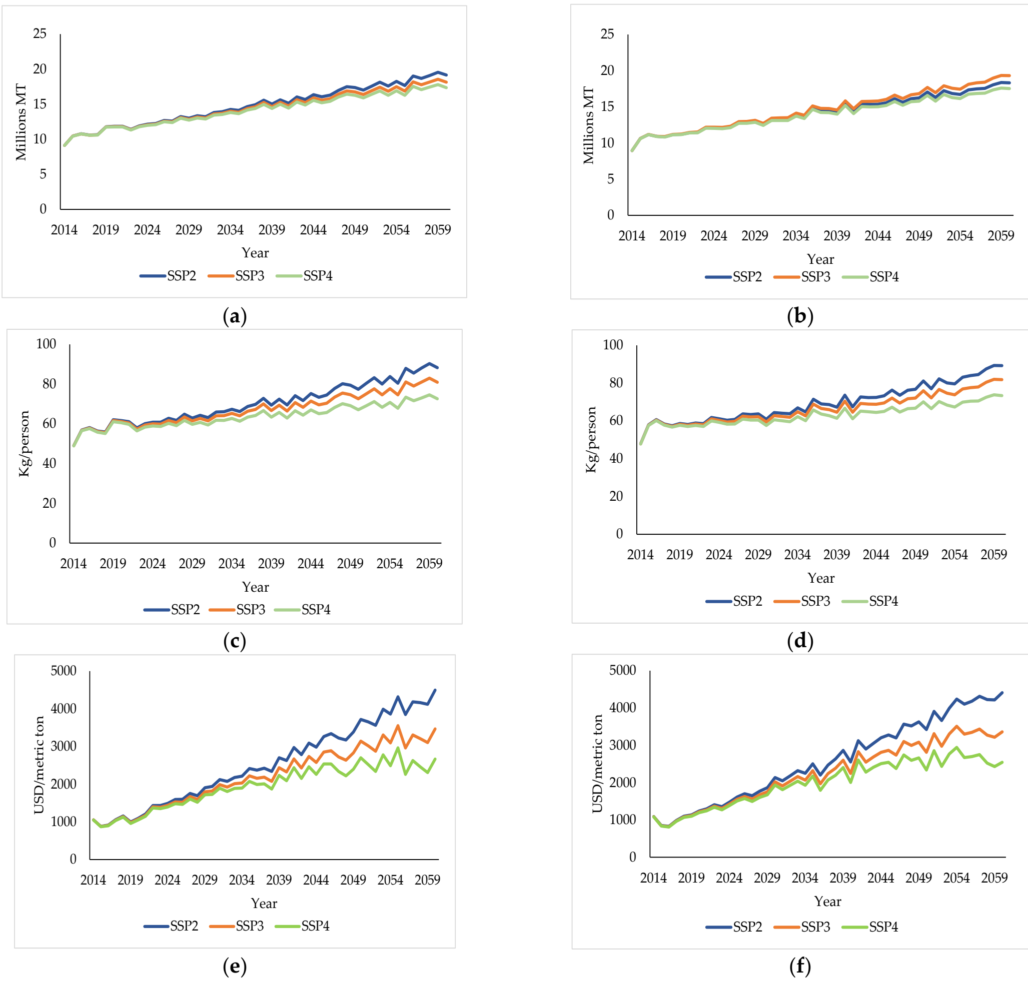


Figure 4. Differences in (**a**) production under Representative Concentration Pathways (RCP) 6.0, (**b**) production under RCP 8.5, (**c**) consumption under RCP 6.0, (**d**) consumption under RCP 8.5, (**e**) farm price under RCP 6.0, and (**f**) farm price under RCP 8.5 in Bangladesh with Shared Socioeconomic Pathways (SSPs).

4. Discussion

Climate change is a consequence of anthropogenic greenhouse gas (GHG) emissions related to resource consumption and production processes, which simultaneously influence the productive basis of the economy and human living conditions. Rising temperatures, shifting rainfall patterns, rising sea levels, and the frequency and severity of extreme weather events are wreaking havoc on ecosystems, agriculture, food security, infrastructure, water supplies, and human health [62]. However, there is much controversy about how severe the detrimental consequences of climate change will be in various parts of the world. Economists are concerned that agriculture in many economically developing countries will be more vulnerable to climate change than agriculture in economically developed countries [63] because economically developing countries are more reliant on agriculture (a vulnerable sector). Moreover, many are located in hot and dry climates; poor farmers are less adaptable to climate change. Climate change, which affects crop productivity and efficiency and which engenders marked changes in agricultural outcomes, causes changes in temperature, rainfall, soil moisture, and fertility, changes in growing season lengths, and increased probability of extreme climatic conditions. As a result of changes in agricultural productivity, global agricultural commodity prices are expected to adjust to these changes in global supply and demand. Due to their linkages to the agricultural sector, these productivity and price effects will have broader economic effects, ultimately jeopardizing food availability and security in vulnerable regions such as India, Bangladesh, Nepal, and Africa [64]. To adapt to these variations, farmers' responses to climate change have been and will continue to be shifting land allocation between crops and other uses, as well as the spatial distribution of crops by adopting improved cultivars as well as more resilient varieties.

Bangladesh, as an economically developing country, was regarded as a good target area for this study because it is known to be exceedingly vulnerable to climate change because of its geographical location, low lying and delta exposed topography, high population density, and agricultural reliant economy. Due to reductions in crop productivity and resiliency, adverse effects of different climate events on agriculture have important implications for food security, human diet, and nutrition. Bangladesh has already attained self-sufficiency status, although the status of its nutritional security remains questionable. The diet composition of cereal (85% calories and 60% protein) cannot satisfy all nutritional requirements, although the major non-cereal food crop, potato, regarded as a substitute of cereals, contains abundant carbohydrate, protein, minerals, vitamin B, vitamin C, and dietary fiber [15]. Considering the previously described circumstances, this study was conducted to evaluate the effects of climate variation on potato production in different climate zones of Bangladesh and the probable market scenario for coping with upcoming food and nutritional security and safety challenges. For this study, we have considered only in-natura (raw) potatoes rather than processed potatoes. The production of potatoes in different regions of Bangladesh is affected differently by climatic factors. To distinguish those effects, an urgent need exists to assess the effects of climate variables (temperature, rainfall, and solar radiation) on potatoes in Bangladesh using district-level time series data grouped into seven climate zones.

The results of yield functions were derived by considering the climatic variables (temperature, rainfall, and solar radiation) [65,66] which were treated as main determinants for potato yield variation. Other factors such as improved cultivars, all types of machinery, and fertilizers were regarded as dummy variables for additional technological progress of the model. The minimal variation in productivity that influences farmers' decisions was slightly higher than the overall variation attributable to climate factors. Our study findings showed that lower temperatures (18–22 °C) and rainfall negatively affect tuberization in the south-eastern, north-eastern, northern, south-western, and south-central regions of Bangladesh. However, less than optimum rainfall (<300 mm) and solar radiation (120–210 W m^{-2} day^{-1}) adversely affected the harvesting stages in the remainder of the country because of the cold weather. Similar findings for climate change effects on potatoes in Iran were observed by Adavi et al. [52] who found that early planting can accelerate harmful effects of climate change on potato yield and that the medium and early maturing varieties showed a better tuber yield under climate change conditions than common (delayed maturing) varieties. The area (harvested area) functions of the seven climate regions were identified as a linear model depending on the adaptive expectation model (AEM) [29,67].

The elasticity of farm prices, which is regarded as an important economic variable, and the derived value of the area functions indicate that potato prices play an important role in the allocation of land and in producers' actions related to potato production, which was also supported by Fei et al. [68]. However, the fluctuation of potato prices in the world market is a worldwide problem [69]. Potatoes are products that exhibit severe seasonal price fluctuations both in Bangladesh and among developing countries. In addition to other periods, the price declines significantly during harvesting season (February and March). During March, most potatoes are harvested. The price declines drastically. Farmers are unable to earn a fair price because of improper marketing channels and low levels of education among producers [50]. Potato producers usually must accept established prices because the farm price of potato for a given year is not determined by the costs incurred during that year, but by the total supply and demand for the product during the year. In addition, because the supply of agricultural commodities (i.e., potato) cannot be altered in the short term, demand is more determinative of price [70].

According to international potato market data, China (50.19 million MT), India (91.82 million MT), and Russia (22.07 million MT) are the top potato-producing countries in the world, whereas Bangladesh is ranked seventh. However, the export values in 2020 for the top three countries were USD 317.26 million for Germany, USD 309.63 million for France and USD 254.54 million for Canada. For importing potatoes, Spain, the U.S.A., and Germany are the top ranked countries. Their accumulated amounts were, respectively, around USD 269.04 million, USD 253.04 million, and USD 216.77 million [71].

Bangladesh faces trade difficulties because of poor infrastructure, poor transportation facilities, climate constraints and inadequate financial aid for agricultural commodities, including potatoes. Although Bangladesh produces around 11.0 million MT (2.61% of the world's share) of potatoes annually, only a negligible amount is exported [72]. Due to the unstable domestic prices, farmers are de-motivated to produce more potatoes, although potatoes are proven to be economically profitable crops [35,73]. If production is insufficient to meet domestic food demand, then the government of Bangladesh must decide to import potatoes from other potato-producing countries such as China, the Netherlands, India, Russia, and Ukraine [72]. Even with strong and rising overseas demand, potato farmers in Bangladesh often struggle to distribute their products because of a lack of quality cold storage services, high transportation costs because of moisture contents, and restricted access to overseas buyers [74].

With annual average demand of around 7 million MT, Bangladesh currently has a surplus of about 4 million MT, most of which is wasted [75]. Potatoes are mostly consumed as a vegetable (non-cereal) by middle and lower-class consumers, which places potato consumption third after the main cereals of rice and wheat [50]. To meet rising food demand and to ensure long-term sustainable potato production in Bangladesh, farmers should adopt climate-resistant potato varieties for the region. This argument is consistent with the findings of Rana et al. [50]. As the government of Bangladesh wants to encourage eating potatoes rather than rice to reduce the constant pressure on rice [50,76], an urgent need exists to introduce and implement a potato pricing policy for the sustenance of potato producers as well as ensuring the food supply to the consumer. The continuing effects of climate change on potato production are assumed to become more complicated and uncertain. Due to data availability, this study did not assess fertilizer effects, CO_2 concentrations, and severe climatic events that negatively affect potato yields [55,77,78]. Further detailed and comprehensive assessments are needed for future studies along with assessment of the development of crop cultivars and producers' behavior.

5. Conclusions

Climate variation is constantly affecting agriculture, threatening humanity's food and nutritional safety. That threat has been identified as a difficulty in the SDG overall development plan. As a result, this study investigated how climate changes affect potato production in specific climatic zones in Bangladesh. The findings indicated that higher temperatures lowered potato yields in most climatic zones: less precipitation hindered the yields and growth of potato cultivation areas during the growing period. If the domestic production and world price of potato (raw) were to increase, it would likely reduce imports. Alternatively, estimation showed that per-capita potato consumption is negatively related to farm prices and real GDP per capita. If the income increases 1%, then consumption can be expected to decrease 1.193% because potatoes are inferior goods. With the pace of other crop items, the respective stakeholders should revise their import and export strategies to accommodate a continuous supply of potatoes. Therefore, to increase potato production extensively, the government must adopt new guidelines related to the fair price of potatoes, storage facilities, and approval of improved cultivars (high-temperature tolerant) that might lead the country to better socioeconomic pathways (SSP2). With the adaptation of heat-tolerant cultivars and shifting the planting and harvest times of potato, it will be possible to move toward existing production zones and into zones where potato production is currently low or limited. This supply and demand model will help to produce informed decisions related to production possibilities by growers in a cost-effective manner that will benefit consumers. Moreover, the findings will contribute to implementing measures to promote a stable food and balanced nutrition supply by encouraging potato growers. Furthermore, this study can help policy makers produce pricing policies and improve market information and monitoring systems to reduce price volatility even in a context of climate change.

Author Contributions: Conceptualization by A.J. and J.F.; software by A.J., Y.I.-I. and J.F.; formal analysis by A.J.; writing—original draft preparation by A.J.; writing—review and editing by A.J., Y.I.-I. and J.F.; and supervision by J.F. All authors have read and agreed to the published version of the manuscript.

Funding: This research received no external funding.

Institutional Review Board Statement: Not applicable.

Informed Consent Statement: Not applicable.

Data Availability Statement: Not applicable.

Acknowledgments: We are grateful to the BBS, BMD, BARC, FAO, WB, IMF, IPCC, JAMSTEC, and IIASA for access to data. We also express our gratitude to the More Jobs Better Lives (MJBL) Foundation, Japan, for providing scholarships to pursue this research in Japan. We acknowledge the cordial support of Motoki Nishimori, Principal Researcher, Institute for Agro-Environmental Sciences, NARO, Japan, for providing historical and forecasted climate data of RCPs and SSPs.

Conflicts of Interest: The authors declare that they have no conflict of interest.

Appendix A

Table A1. Seven climate zones of Bangladesh and their characteristics.

Climate Region	Districts	Climate Characteristics
South-eastern (SE)	Bhola, Barguna, Patuakhali, Noakhali, Lakshmipur, Feni, Khagrachari, Rangamati, Chittagong, Bandarban, Cox's Bazar, and Jhalakati	Heavy rainfall and a small mean temperature range
North-eastern (NE)	Sunamganj, Sylhet, and Moulvibazar	Mild summer temperatures, heavy rainfall, and cloudy, cold winters
Northern (N)	Panchagarh, Thakurgaon, Nilphamari, Rangpur, Kurigram, and Lalmonirhat	Heavy rainfall, hot summer temperatures, and cold winters
North-western (NW)	Dinajpur, Gaibandha, Bogra, Sirajganj, Pabna, Kushtia, Meherpur, Chuadanga, and Jhenaidah	Hot summer temperatures and moderate rainfall
Western (W)	Jaipurhat, Chapai Nawabganj, Naogaon, Natore, and Rajshahi	Very hot summer temperatures and low rainfall
South-western (SW)	Jessore, Khulna, Satkhira, Magura, Narail, Faridpur, and Rajbari	Hot summer temperatures and heavy rainfall
South-central (SC)	Barisal, Brahmanbaria, Chandpur, Comilla, Dhaka, Gazipur, Gopalganj, Habiganj, Jamalpur, Kishoreganj, Madaripur, Manikganj, Munshiganj, Mymensingh, Narayanganj, Narsingdi, Netrakona, Pirojpur, Shariatpur, Sherpur, Tangail, and Bagerhat	Mild summers and heavy rainfall

Appendix B

Table A2. Potato crop calendar for Bangladesh.

Production Activities	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec

Source: Adopted from GIEWS, FAO 2008 and modified by the authors [79].

Appendix C

Table A3. ADF test for checking the stationarity of the yield and area.

Climate Zone	Yield			Area		
	t Statistics	*p* Value	Decision	*t* Statistics	*p* Value	Decision
SE	−2.905	0.008	I (1)	−1.288	0.213	I (1)
NE	−3.086	0.005	I (1)	−1.307	0.203	I (1)
N	−2.533	0.018	I (1)	−1.794	0.085	I (1)
NW	−1.809	0.083	I (1)	−1.487	0.15	I (1)
W	−1.822	0.081	I (1)	−2.232	0.035	I (1)
SW	−3.613	0.000	I (0)	−1.417	0.169	I (1)
SC	−3.381	0.002	I (1)	−2.373	0.026	I (1)

Note: All the unit root tests include both a constant and a linear trend. Decision based on *p*-value at 5% level of significance.

Appendix D

Table A4. ADF test for checking the stationarity of the data series.

Variables	*t* Statistic	*p*-Value	Decision
GDP	4.20	0.000	I (0)
FOOD	−2.11	0.045	I (1)
FP	−3.29	0.003	I (1)
WP	−3.38	0.002	I (1)
IMP	−2.69	0.013	I (1)
EXP	1.42	0.169	I (1)
CPI	−3.92	0.001	I (0)
LOSS	−1.95	0.062	I (1)
SEED	−2.71	0.012	I (1)

Note: All unit root tests include both a constant and a linear trend. Decision based on *p* value at 5% level of significance.

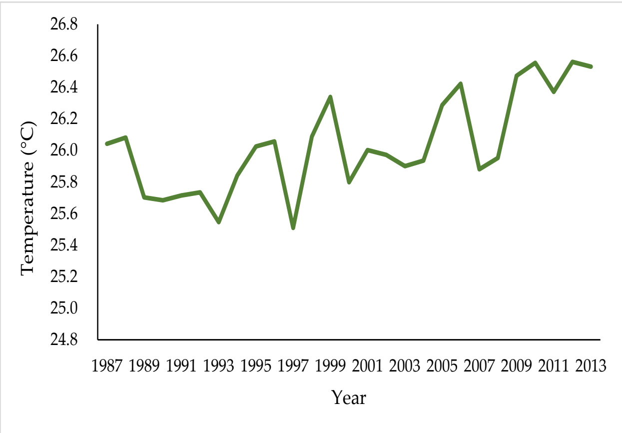
Appendix D

Table A5. ADF test for checking the stationarity of climate variables in different regions.

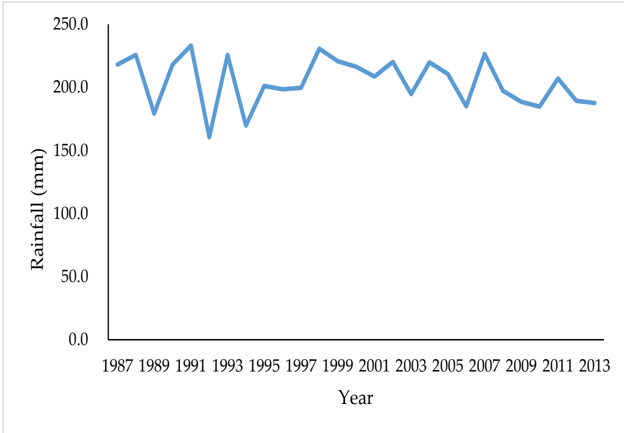
Climate Zone	January		February		March		November		December	
	t Statistic	Decision	*t* Statistic	Decision	*t* Statistic	Decision	*t* Statistic	Decision	*t* Statistic	Decision
Temperature										
SE	−7.10	I (0)	−5.02	I (0)	−6.73	I (0)	−4.83	I (0)	−4.43	I (0)
NE	−7.68	I (0)	−5.55	I (0)	−7.27	I (0)	−5.02	I (0)	−5.08	I (0)
N	−6.31	I (0)	−3.58	I (1)	−7.25	I (0)	−3.55	I (1)	−4.75	I (0)
NW	−6.66	I (0)	−5.65	I (0)	−7.28	I (0)	−3.44	I (1)	−4.88	I (0)
W	−6.47	I (0)	−5.23	I (0)	−6.57	I (0)	−3.68	I (1)	−4.09	I (0)
SW	−6.49	I (0)	−5.03	I (0)	−7.08	I (0)	−3.59	I (1)	−4.73	I (0)
SC	−6.62	I (0)	−5.41	I (0)	−6.83	I (0)	−4.33	I (0)	−4.73	I (0)
Rainfall										
SE	−6.79	I (0)	−4.05	I (0)	−5.02	I (0)	−6.02	I (0)	−6.44	I (0)
NE	−5.74	I (0)	−4.82	I (0)	−8.60	I (0)	−6.42	I (0)	−5.74	I (0)
N	−4.82	I (0)	−6.55	I (0)	−5.20	I (0)	−5.94	I (0)	−5.74	I (0)
NW	−5.21	I (0)	−6.35	I (0)	−6.94	I (0)	−6.35	I (0)	−5.98	I (0)
W	−6.08	I (0)	−7.08	I (0)	−6.14	I (0)	−5.44	I (0)	−5.65	I (0)
SW	−6.29	I (0)	−4.61	I (0)	−6.80	I (0)	−7.47	I (0)	−5.66	I (0)
SC	−6.68	I (0)	−4.76	I (0)	−6.59	I (0)	−7.46	I (0)	−5.32	I (0)
Solar radiation										
SE	−4.49	I (0)	−5.17	I (0)	−4.91	I (0)	−4.67	I (0)	−4.28	I (0)
NE	−4.94	I (0)	−5.94	I (0)	−5.74	I (0)	−4.48	I (0)	−3.00	I (1)
N	−4.92	I (0)	−3.93	I (0)	−3.48	I (1)	−6.11	I (0)	−3.41	I (1)
NW	−5.06	I (0)	−4.99	I (0)	−4.83	I (0)	−5.11	I (0)	−3.09	I (1)
W	−5.58	I (0)	−6.08	I (0)	−4.16	I (0)	−4.53	I (0)	−3.07	I (1)
SW	−4.67	I (0)	−5.54	I (0)	−3.89	I (1)	−4.31	I (0)	−4.13	I (0)
SC	−4.83	I (0)	−3.91	I (0)	−4.82	I (0)	−5.00	I (0)	−3.80	I (1)

Note: All unit root tests include both a constant and a linear trend. Decision based on *p*-value at 5% level of significance.

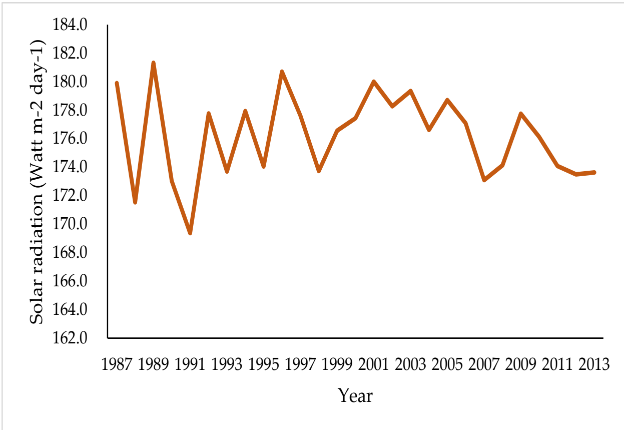
Appendix E



(**a**)

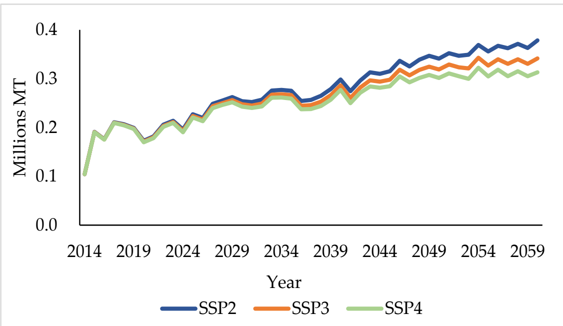


(**b**)

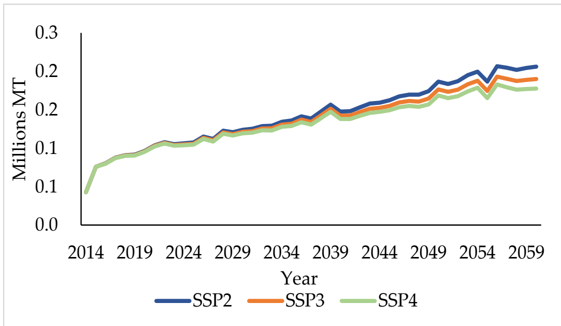


(**c**)

Figure A1. Historical outlook of annual average (**a**) temperature, (**b**) rainfall, and (**c**) solar radiation of Bangladesh.

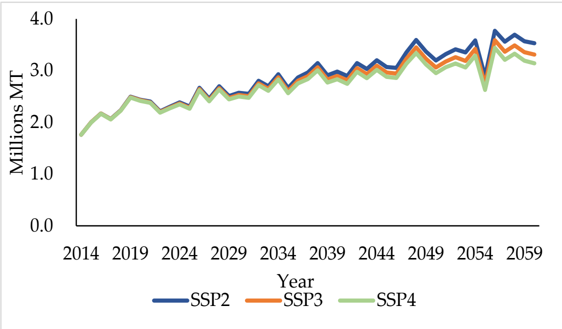


(**a**)

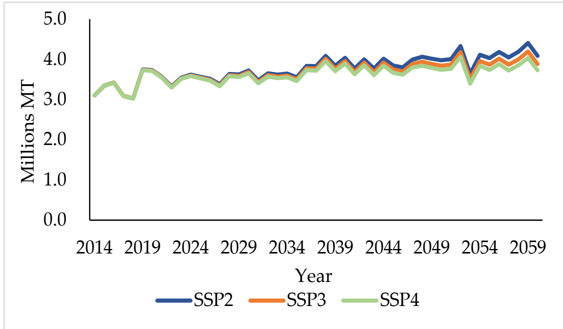


(**b**)

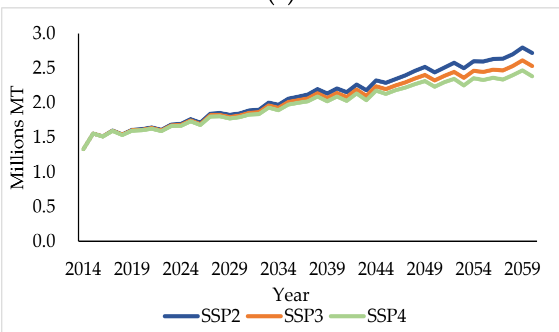
Figure A2. *Cont.*



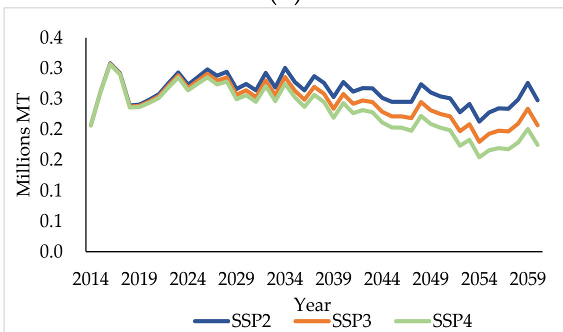
(**c**)



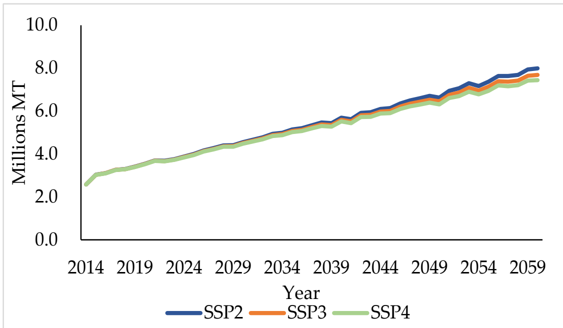
(**d**)



(**e**)

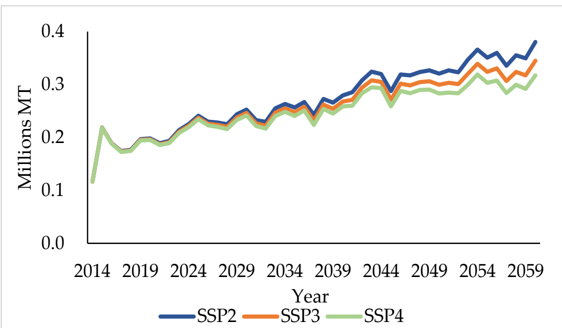


(**f**)

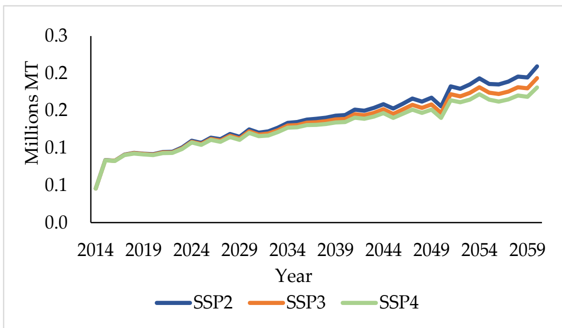


(**g**)

Figure A2. Production in (**a**) south-eastern, (**b**) north-eastern, (**c**) northern, (**d**) north-western, (**e**) western, (**f**) south-western, and (**g**) south-central regions under RCP 6.0 with SSPs.

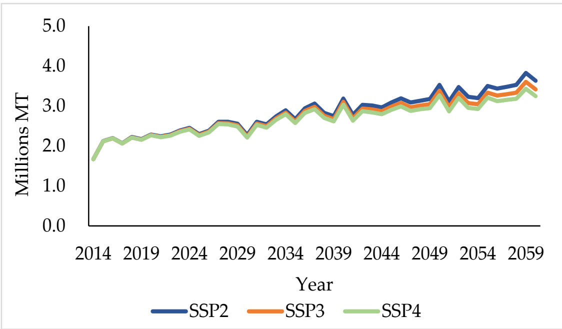


(**a**)

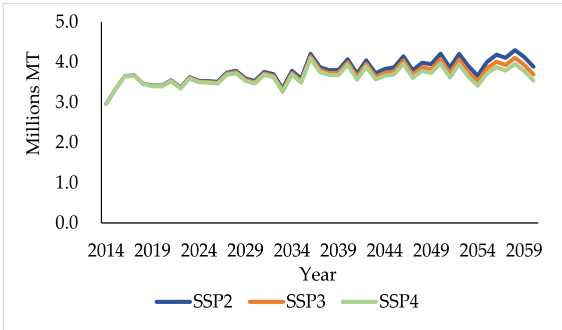


(**b**)

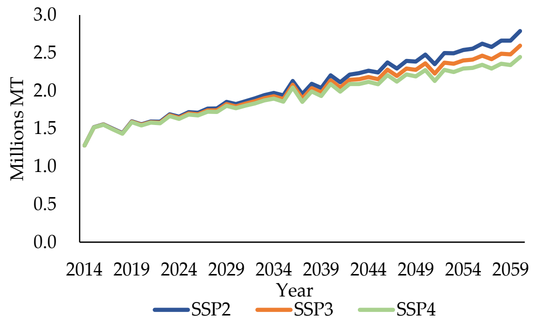
Figure A3. *Cont*.



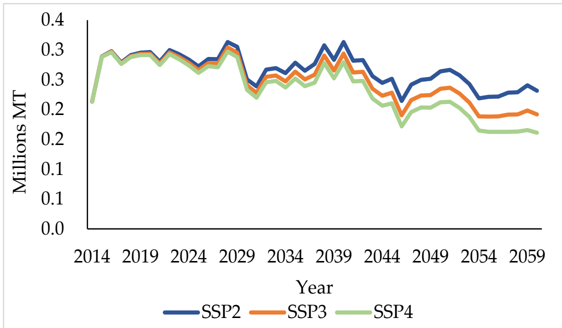
(c)



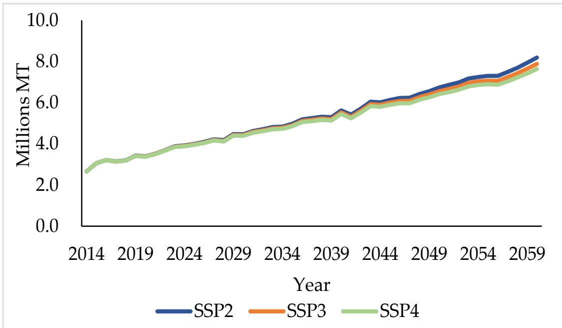
(d)



(e)



(f)



(g)

Figure A3. Production in (**a**) south-eastern, (**b**) north-eastern, (**c**) northern, (**d**) north-western, (**e**) western, (**f**) south-western, and (**g**) south-central regions under RCP 8.5 with SSPs.

References

1. Springmann, M.; Mason-D'Croz, D.; Robinson, S.; Garnett, T.; Godfray, H.C.J.; Gollin, D.; Scarborough, P. Global and regional health effects of future food production under climate change. *Lancet* **2016**, *387*, 1937–1946. [CrossRef]
2. Badiane, O.; Makombe, T. *Beyond a Middle-Income Africa: Transforming African Economies for Sustained Growth with Rising Employment and Incomes, ReSAKSS Annual Trends and Outlook Report 2014*; International Food Policy Research Institute (IFPRI): Washington, DC, USA, 2015. [CrossRef]
3. Mason-D'Croz, D.; Sulser, T.B.; Wiebe, K.; Rosegrant, M.W.; Lowder, S.K.; Nin-Pratt, A.; Willenbockel, D.; Robinson, S.; Zhu, T.; Cenacchi, N.; et al. Agricultural investments and hunger in Africa modeling potential contributions to SDG2—Zero Hunger. *World Dev.* **2019**, *116*, 38–53. [CrossRef] [PubMed]
4. FAO (Food and Agriculture Organization). Climate is Changing. Food and Agriculture Must Too. World Food Day. 2016. Available online: http://www.fao.org/zhc/detail-events/en/c/413181 (accessed on 3 April 2020).
5. Myers, S.S.; Zanobetti, A.; Kloog, I.; Huybers, P.; Leakey, A.D.; Bloom, A.J.; Carlisle, E.; Dietterich, L.H.; Fitzgerald, G.; Hasegawa, T.; et al. Increasing CO_2 threatens human nutrition. *Nature* **2014**, *510*, 139–142. [CrossRef]
6. Medek, D.E.; Schwartz, J.; Myers, S.S. Estimated effects of future atmospheric concentrations on protein intake and the risk of protein deficiency by country and region. *Environ. Health Perspect.* **2017**, *125*, 087002. [CrossRef] [PubMed]
7. Myers, S.S.; Wessells, K.R.; Kloog, I.; Zanobetti, A.; Schwartz, J. Effect of increased concentrations of atmospheric carbon dioxide on the global threat of zinc deficiency: A modeling study. *Lancet Glob. Health.* **2015**, *3*, 639–645. [CrossRef]

8. Smith, M.R.; Myers, S.S. Impact of anthropogenic CO_2 emissions on global human nutrition. *Nat. Clim. Chang.* **2018**, *8*, 834–839. [CrossRef]
9. Myers, S.S.; Smith, M.R.; Guth, S.; Golden, C.D.; Vaitla, B.; Mueller, N.D.; Dangour, A.D.; Huybers, P. Climate change and global food systems: Potential impacts on food security and undernutrition. *Annu. Rev. Public Health* **2017**, *38*, 259–277. [CrossRef] [PubMed]
10. Lutaladio, N.B.; Ortiz, O.; Haverkort, A.; Caldiz, D. *Sustainable Potato Production, Guidelines for Developing Countries*; International Year of the Potato 2008; FAO, UN: Rome, Italy, 2009.
11. Banholzer, S.; Kossin, J.; Donner, S. The impact of climate change on natural disasters. In *Reducing Disaster: Early Warning Systems for Climate Change*; Banholzer, S., Kossin, J., Donner, S., Eds.; Springer: Dordrecht, The Netherlands, 2014; pp. 21–49. [CrossRef]
12. Faroque, M.; Asaduzamman, M.; Hossain, M. Sustainable agricultural development under climate change in Bangladesh. *J. Sci. Found.* **2013**, *11*, 17–28. [CrossRef]
13. Roy, A.; Haider, M.Z. Stern review on the economics of climate change: Implications for Bangladesh. *Int. J. Clim. Chang Str.* **2019**, *11*, 100–117. [CrossRef]
14. Hong, Z.; Fen, X.; Yu, W.; Hong-hai, H.; Xiao-feng, D. Progress of potato staple food research and industry development in China. *J. Integr. Agric.* **2017**, *16*, 2924–2932. [CrossRef]
15. Chung, I.M.; Kim, J.K.; Jin, Y.I.; Oh, Y.T.; Prabakaran, M.; Youn, K.J.; Kim, S.H. Discriminative study of a potato (*Solanum tuberosum* L.) cultivation region by measuring the stable isotope ratios of bio-elements. *Food Chem.* **2016**, *212*, 48–57. [CrossRef]
16. Arun, K.B.; Chandran, J.; Dhanya, R.; Krishna, P.; Jayamurthy, P.; Nisha, P. A comparative evaluation of antioxidant and antidiabetic potential of peel from young and matured potato. *Food Biosci.* **2015**, *9*, 36–46. [CrossRef]
17. Haverkort, A.J.; van de Waart, M.; Bodlaender, K.B.A. The effect of early drought stress on numbers of tubers and stolons of potato in controlled and field conditions. *Potato Res.* **1990**, *33*, 89–96. [CrossRef]
18. Stol, W.; de Koning, G.H.J.; Kooman, P.L.; Haverkort, A.J.; van Keulen, H.; Penning de Vries, F.W.T. *Agroecological Characterization for Potato Production CABO Report, 155*; CABO: Wageningen, The Netherlands, 1991; Volume 53.
19. Reynolds, M.P.; Ewing, E.E. Effects of high air and soil temperature stress on growth and tuberization in *Solanum tuberosum*. *Ann. Bot.* **1989**, *64*, 241–247. [CrossRef]
20. FAOSTAT. *FAO Statistical Database*; Food and Agricultural Organization of the United Nations (FAO): Rome, Italy, 2019; Available online: www.fao.org/faostat/en (accessed on 14 April 2020).
21. BBS. Bangladesh Bureau of Statistics. Yearbook of Agricultural Statistics of Bangladesh. Statistics Division, Ministry of Planning, Government of the People's Republic of Bangladesh. 2017. Available online: www.bbs.gov.bd (accessed on 19 November 2019).
22. Talukder, R.K. Food security, self-sufficiency and nutrition gap in bangladesh, bangladesh development studies. *BIDS* **2005**, *31*, 35–62. Available online: https://ideas.repec.org/a/ris/badest/0470.html (accessed on 22 June 2020).
23. FAO (Food and Agriculture Organization of the United Nations). The State of Food and Agriculture, Rome. 2015. Available online: http://bit.ly/KAn84P (accessed on 16 May 2020).
24. Household Income and Expenditure Survey. *Preliminary Report on Household Income and Expenditure Survey*; Bureau of Statistics Division, Ministry of Planning, Government of the People's Republic of Bangladesh: Dhaka, Bangladesh, 2010.
25. FAO/WHO (Food and Agriculture Organization of the United Nations/World Health Organization). Bangladesh Country Nutrition Paper. In Proceedings of the International Conference on Nutrition 21 Years Later, Geneva, Switzerland, 19–21 November 2014.
26. Hossain, M.M.; Abdulla, F. Forecasting potato production in Bangladesh by ARIMA model. *J. Adv. Stat.* **2016**, *1*, 191–198. [CrossRef]
27. Kobayashi, S.; Furuya, J. Comparison of climate change impacts on food security of Bangladesh. *Stud. Reg. Sci.* **2011**, 41. [CrossRef]
28. Soora, N.K.; Aggarwal, P.K.; Saxena, R.; Rani, S.; Jain, S.; Chauhan, N. An assessment of the regional vulnerability of rice to climate change in India. *Clim. Chang.* **2013**, *118*, 683–699. [CrossRef]
29. Salam, M.A.; Furuya, J.; Kobayashi, S. Climate effect on supply and market price stability of rice in Bangladesh: Assessment of climate and socioeconomic scenarios. *Jpn. J. Agric. Econ.* **2017**, *19*, 60–65. [CrossRef]
30. Hung, C.; Zhou, L.; Furuya, J. Climate change effects on supply and demand of rice in India. *Jpn. Agric. Res. Q.* **2018**, *52*, 255–272. [CrossRef]
31. Roberts, M.J.; Schlenker, W. Identifying supply and demand elasticities of agricultural commodities: Implications for the US ethanol mandate. *Am. Econ. Rev.* **2013**, *103*, 2265–2295. Available online: http://www.jstor.com/stable/42920650 (accessed on 27 December 2020). [CrossRef]
32. Furuya, J.; Kobayashi, S.; Yamauchi, K. Impacts of climate change on rice market and production capacity in the Lower Mekong Basin. *Paddy Water Env.* **2014**, *12*, 255–274. [CrossRef]
33. Stocker, T.F.; Qin, D.; Plattner, G.K.; Tignor, M.; Allen, S.K.; Boschung, J.; Nauels, A.; Xia, Y.; Bex, V.; Midgley, P.M. *Climate Change 2013: The Physical Science Basis. Working Group I Contribution to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change—Abstract for Decision-Makers: Groupe d'Experts Intergouvernemental Sur l'Evolution du Climat/Intergovernmental Panel on Climate Change-IPCC, C/O World Meteorological Organization*; 7bis Avenue de la Paix, CP 2300 CH-1211 Geneva 2 (Switzerland); Cambridge University Press: Cambridge, UK, 2013.

34. Alam, M.K.; Zaman, M.M.; Nazrul, M.I.; Alam, M.S.; Hossain, M.M. Performance of some exotic potato varieties under Bangladesh conditions. *Asian J. Plant Sci.* **2003**, *2*, 108–112. [CrossRef]
35. Begum, M.M.; Saha, J.K.; Rahman, M.A.; Ahmed, M.R. An economic study of potato production in selected areas of Sylhet district. *J. Sylhet Agric. Univ.* **2017**, *4*, 129–136.
36. Begum, F.; Kundu, B.; Hossain, M. Physiological analysis of growth and yield of potato in relation to planting date. *J. Bangladesh Acad. Sci.* **2015**, *39*, 45–51. [CrossRef]
37. Sarker, M.; Alam, K.; Gow, J. Performance of rain-fed Aman rice yield in Bangladesh in the presence of climate change. *Renew. Agric. Food Syst.* **2019**, *34*, 304–312. [CrossRef]
38. Rashid, H.E. *Geography of Bangladesh*; University Press: Dhaka, Bangladesh, 1991.
39. Bangladesh Bureau of Statistics. *Statistical Year Book of Bangladesh*; Ministry of Planning, Government of the People's Republic of Bangladesh: Dhaka, Bangladesh, 2014.
40. BMD. Bangladesh Meteorological Department. Climate Data Library. Available online: http://iridl.ldeo.columbia.edu (accessed on 21 January 2020).
41. WB. World Bank. World Development Indicators. Available online: https://datacatalog.worldbank.org/dataset/world-development-indicators (accessed on 19 December 2019).
42. FAO-STAT. FAO Statistical Database. Available online: http://www.fao.org/faostat/en/#data (accessed on 19 December 2019).
43. BARC. Bangladesh Agricultural Research Council. Climate Database: Climate Information Management System. Available online: http://climate.barcapps.gov.bd/dashboard (accessed on 26 November 2019).
44. Moss, R.H.; Edmonds, J.A.; Hibbard, K.A.; Manning, M.R.; Rose, S.K.; Van Vuuren, D.P.; Meehl, G.A. The next generation of scenarios for climate change research and assessment. *Nature* **2010**, *463*, 747–756. [CrossRef]
45. Van Vuuren, D.P.; Carter, T. Climate and socioeconomic scenarios for climate change research and assessment: Reconciling the new with the old. *Clim. Chang.* **2014**, *122*, 415–429. [CrossRef]
46. O'Neill, B.C.; Kriegler, E.; Riahi, K.; Ebi, K.L.; Hallegatte, S.; Carter, T.R.; van Vuuren, D.P. A new scenario framework for climate change research: The concept of shared socioeconomic pathways. *Clim. Chang.* **2014**, *122*, 387–400. [CrossRef]
47. Furuya, J.; Meyer, S.; Kageyama, M.; Jin, S. Development of supply and demand models of rice in lower mekong river basin countries: REMEW-Mekong. *JIRCAS Work. Rep.* **2010**, *68*, 91–117.
48. Meyer, G.; Westhoff, P.; Binfield, J.; Kirsten, J.F. Model Closure and Price Formation under Switching Grain Market Regimes in South Africa. In Proceedings of the International Association of Agricultural Economist (lAAE) Conference, Gold Coast, QLD, Australia, 12–18 August 2006.
49. Min, B.S.; Guna, R.B. Selecting appropriate methodological framework for time series data analysis. *J. Financ. Data Sci.* **2018**, *4*, 71–89. [CrossRef]
50. Singha, U.; Maezawa, S. Production, marketing system, storage and future aspect of potato in Bangladesh. *Rev. Agric. Sci.* **2019**, *7*, 29–40. [CrossRef]
51. Samanta, S.; Banerjee, S.; Mukherjee, A.; Patra, P.K.; Chakraborty, P.K. Determining the radiation use efficiency of potato using sunshine hour data: A simple and costless approach. *SJAR* **2020**, *18*, 2171–9292. [CrossRef]
52. Adavi, Z.; Moradi, R.; Saeidnejad, A.H.; Tadayon, M.R.; Mansouri, H. Assessment of potato response to climate change and adaptation strategies. *Sci. Hortic.* **2018**, *228*, 91–102. [CrossRef]
53. Rana, A.; Dua, V.K.; Chauhan, S.; Sharma, J. Climate change and potato productivity in Punjab—Impacts and adaptation. *Potato Res.* **2020**, *63*, 597–613. [CrossRef]
54. Bangladesh Bureau of Statistics. *Statistical Yearbook of Bangladesh*; Ministry of Planning, Government of the People's Republic of Bangladesh: Dhaka, Bangladesh, 2016.
55. Li, Q.; Zhang, S. Impacts of recent climate change on potato yields at a provincial scale in northwest China. *Agronomy* **2020**, *10*, 426. [CrossRef]
56. Shelley, I.; Takahashi-Nosaka, M.; Kano-Nakata, M.; Haque, M.S.; Inukai, Y. Rice cultivation in Bangladesh: Present scenario, problems, and prospects. *J. Int. Coop. Agric. Dev.* **2016**, *14*, 20–29. [CrossRef]
57. Hajong, P.; Moniruzzaman, M.; Mia, M.I.A.; Rahman, M.M. Storage system of potato in Bangladesh. *Uni. J. Agrl. Res.* **2014**, *2*, 11–17. [CrossRef]
58. Hall, C.; Brooker, J.; Eastwood, D.; Epperson, J.; Estes, E.; Woods, T. A marketing systems approach to removing distribution barriers confronting small-volume fruit and vegetable growers. *Choices* **2006**, *21*, 259–264.
59. BIDA. Bangladesh Investment Development Authority. Potato processing. Publications on Agribusiness, potato: 1–7, Government of People's Republic of Bangladesh. 2016. Available online: www.bida.gov.bd (accessed on 13 January 2021).
60. Scott, B.; Ho, S.H.; Daniel, M.; Hwan, K.M.; Oh, K.B.; Su, C.Y.; Seob, L.D.; Hoon, K.T.; Duk, H.; Phil, K.K.; et al. *Korean Agricultural Simulation Model and Livestock Quarterly Model*; Food and Agricultural Policy Research Institute, University of Missouri (FAPRI-MU): Columbia, MO, USA, 2008; Available online: http://repository.krei.re.kr/handle/2018.oak/15373 (accessed on 17 February 2021).
61. Exchange Rate, 2010. US Dollar to Bangladesh Taka Spot Exchange Rates for 2010. Available online: https://www.exchangerates.org.uk/USD-BDT-spot-exchange-rates-history-2010.html (accessed on 12 December 2010).

62. Hoegh-Guldberg, O.; Jacob, D.; Taylor, M.; Bindi, M.; Brown, S.; Camilloni, I.; Diedhiou, A.; Djalante, R.; Ebi, K.L.; Engelbrecht, F.; et al. Impacts of 1.5 °C global warming on natural and human systems. In *Global Warming of 1.5°C. An IPCC Special Report on the Impacts of Global Warming of 1.5°C Above Pre-Industrial Levels and Related Global Greenhouse Gas Emission Pathways, in the Context of Strengthening the Global Response to the Threat of Climate Change, Sustainable Development, and Efforts to Eradicate Poverty*; Masson-Delmotte, V., Zhai, P., Pörtner, H.-O., Roberts, D., Skea, J., Shukla, P.R., Pirani, A., Moufouma-Okia, W., Péan, C., Pidcock, R., et al., Eds.; Korea Rural Economic Institute: Seoul, Korea, 2018; In Press.
63. Mendelsohn, R. The impact of climate change on agriculture in developing countries. *J. Nat. Resour. Policy Res.* **2008**, *1*, 5–19. [CrossRef]
64. Arora, N.K. Impact of climate change on agriculture production and its sustainable solutions. *Environ. Sustain.* **2019**, *2*, 95–96. [CrossRef]
65. Haverkort, A.J.; Verhagen, A.; Grashoff, A.C.; Uithol, P.W.J. Potato-zoning: A decision support system on expanding the potato industry through agro-ecological zoning using the LINTUL simulation approach. In *Decision Support Systems in Potato Production: Bringing Models to Practice*; MacKerron, D.K.L., Haverkort, A.J., Eds.; Wageningen Academic: Wageningen, The Netherlands, 2004; pp. 29–44.
66. Haverkort, A.J.; Verhagen, A. Climate change and its repercussions for the potato supply chain. *Potato Res.* **2008**, *51*, 223. [CrossRef]
67. Colasante, A.; Palestrini, A.; Russo, A.; Gallegati, M. Adaptive expectations versus rational expectations: Evidence from the lab. *Int. J. Forecast.* **2017**, *33*, 988–1006. [CrossRef]
68. Fei, C.J.; McCarl, B.A.; Thayer, A.W. Estimating the impacts of climate change and potential adaptation strategies on cereal grains in the United States. *Front. Ecol. Evol.* **2017**, 5. [CrossRef]
69. Arısoy, H.; Bayramoğlu, Z. Determination of the effect of price fluctuations on producer income—The case of potatoes. *Turk. J. Agric. Food Sci. Technol.* **2017**, *5*, 1342–1349. [CrossRef]
70. Bor, O.; Ismihan, M.; Bayaner, A. Asymmetry in farm-retail price transmission in the Turkish fluid milk market. *New Medit.* **2014**, *13*, 2–8. Available online: http://www.iamb.it/share/img_new_medit_articoli/975_02bor.pdf (accessed on 19 November 2020).
71. Tridge. Top Producing Countries of Potato. 2021. Available online: https://www.tridge.com/intelligences/potato/production (accessed on 1 April 2021).
72. The Financial Express. Drive to Increase Potato Exports Reaches Landmark. 2020. Available online: https://www.thefinancialexpress.com.bd/trade/drive-to-increase-potato-exports-reaches-landmark-1584275314 (accessed on 30 November 2020).
73. Sujan, H.; Islam, F.; Kazal, M.; Mondal, R. Profitability and resource use efficiency of potato cultivation in Munshiganj district of Bangladesh. *SAARC J. Agric.* **2018**, *15*, 193–206. [CrossRef]
74. The Daily Star. Potato Glut Badly Hurts Growers. 2019. Available online: https://www.thedailystar.net/backpage/potato-production-in-bangladesh-glut-badly-hurts-growers-1748572 (accessed on 30 November 2020).
75. Raymundo, R.; Asseng, S.; Robertson, R.; Petsakos, A.; Hoogenboom, G.; Quiroz, R.; Hareau, G.; Wolf, J. Climate change impact on global potato production. *Eur. J. Agron.* **2018**, *100*, 87–98. [CrossRef]
76. Deena, C.M.; Hayath, C.A. Problems and prospects of potato cultivation in Bangladesh. *Asian Bus. Consort.* **2015**, *5*, 28–32. [CrossRef]
77. Körner, C. Plant CO_2 responses: An issue of definition, time and resource supply. *New Phytol.* **2006**, *172*, 393–411. [CrossRef]
78. Kaminski, K.P.; Kørup, K.; Nielsen, K.L.; Liu, F.; Topbjerg, H.B.; Kirk, H.G.; Andersen, M.N. Gas-exchange, water use efficiency, and yield responses of elite potato (*Solanum tuberosum* L.) cultivars to changes in atmospheric carbon dioxide concentration, temperature, and relative humidity. *Agric Meteorol.* **2014**, *187*, 36–45. [CrossRef]
79. FAO. *GIEWS—Global Information and Early Warning System*; Country Brief: Dhaka, Bangladesh, 2008.