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File name:	IOP.pdf
File size:	761.55K
Page count:	11
Word count:	5,148
Character count:	27,565
Submission date:	23-Jan-2023 03:43PM (UTC+0700)
Submission ID:	1997608180

A review of climate change studies on paddy agriculture in Indonesia

M F Ikhwali [1]*, S Nur[1], D Darmansyah[2], A M Hamdan[3], N S Ersa[3], N Aida[1], A Yusra[4], A Satria[4]

[1]Department of Environmental Engineering, UIN Ar-Raniry Banda Aceh, Banda Aceh, Indonesia 23111
[2]Department of Agribusiness, Faculty of Agriculture, Universitas Teuku Umar, Indonesia 23615
[3]Department of Civil Engineering, Universitas Malikussaleh, Lhokseumawe, Indonesia 24352
[4]Department of Civil Engineering, Universitas Teuku Umar, Aceh Barat, Indonesia 23615

*Email: faisi.ikhwali@ar-raniry.ac.id

Abstract. Indonesia is often referred to as an agricultural country as most of its population is working in agricultural sectors. Rice is one of the staple foods of the Indonesian people. The issues concerning the global climate change impose a potential threat on Indonesia's food security as the rice crop is extremely sensitive to climate change. The IPCC has released climate change scenarios as highlighted in Fifth Assessment Report (AR5) that could contribute positively to projecting the possible condition of future rice farming in Indonesia. Therefore, the goal of this research is to examine how far the Representative Concentration Pathway (RCP) scenarios have been implemented in relevant studies relating the rice farming. By 2021, the RCP scenarios in Indonesia at least have been studied and used in 13 relevant publications. The type of scenario used is mostly dominated by RCP8.5 scenario which is accounted used by 11 publications. Basically, the RCP8.5 is a scenario that projects the climate change with minimal efforts in reducing the emissions and expose the failures to tackle the global warming by 2100. Based on the findings of those research, it is possible to assume that the rice farming in Indonesia is going to face enormous challenges, particularly the potential decline in rice productivity. The emergence of those studies that interrelate the rice farming and climate change definitely will provide the initial footsteps to figure out on how to deal with future weather conditions.

1. Introduction

Indonesia is an agricultural country with large agricultural lands. Most of Indonesian population is very dependent on the agricultural sector, especially rice commodities because rice is the country's main staple diet. However, with the increasing population, the demand for rice will increase and will

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1. Introduction

Indonesia is an agricultural country with large agricultural lands. Most of Indonesian population is very dependent on the agricultural sector, especially rice commodities because rice is the country's main staple diet. However, with the increasing population, the demand for rice will increase and will

not be able to meet the demand for rice domestic [1]. One of the government's policies to meet rice needs is to boost domestic rice production. Moreover, the Indonesian government must also ensure that farmers can produce high quality rice through various production policies related to paddy agriculture. By maintaining the quality of domestic rice, the orientation of consumers who always want to buy imported rice can be reduced, so that consumer orientation change to domestic rice consumption [2].

According to BPS data in 2021, Indonesia has 10,4 million hectares of rice fields with an annual production of 54,4 million tons. Rice farming are highly dependent on water resource availability because of the process of cultivating rice requires large quantities of resource water compared to the cultivation of other agricultural commodities. Rice is classified as a water sensitive agriculture that requires intensive irrigation. Therefore, the availability of water supply infrastructure and the level of soil fertility have a considerable impact on rice output in paddy fields. The impact can be clearly seen if we look at the differences of rice production that cultivated on rainfed lands, which is less than the production of rice cultivated on the lands with appropriate irrigation system.

Climate change is one of major issues that endangering the sustainability of food production and therefore considerable the relevant efforts have been made to prevent potential food shortages in the future. This food shortages condition is the result of climate change which will change the condition of the availability or quantity of water resources (such as streamflow, groundwater, and rainfall) that exist in an area or watershed [3]. Climate change is a challenge that cannot be avoided entirely by government. Yet, government can anticipate and adapt to sustainability of rice productivity toward the impact of global warming. The policy of developing water resources infrastructures and effective management of water resources must be carefully examined in order to fulfill the water demands of rice plants in situations of extremely restricted water availability [4]. Other efforts that may be made include using high producing types that are resistant to drought, soaking, and salt. In anticipation of a dry environment, the Ministry of Agriculture has produced numerous types of drought-tolerant rice plants [5].

In Indonesia, where most of population relies on rice, most of rice is still cultivated on rain-fed lands that resulting on highly dependent on the climate conditions including rainfall and temperature. Climate change, on the other hand, has been recognized as a variable that has a good or negative impact on rice growing. In the perspective of the crop pattern criteria, particularly for rice farming, the criteria commonly used to determine the start of the rice farming in Indonesia is at the start of the rainy season, i.e. when the quantities of the rainfall is available more than 50 mm in three consecutive bases [6]. The dependency on these cropping criteria can influence the rice production in Indonesia in the long term.

According to the International Food Policy Research Institute (IFPRI), climate change may have an impact on rice yield across Asia and the Pacific. The effects might endanger many countries throughout Asia and lead to food insecurity [7,8]. Therefore, this paper aims to review the studies that concern at the interrelation of climate change and rice farming, particularly on how far the implementation of climate change scenarios as outlined by Intergovernmental Panel on Climate Change (IPCC) in the AR5. The IPCC is the United Nations institution in charge of solving global warming issues. The AR5 IPCC has accommodated new evidence of climate change as the results of various independent scientific investigations such as climate system measurements, paleoclimatic archives, theoretical studies of climate processes, and climate model simulations.

2. Climate conditions in Indonesia

The climate is impacted by its latitude, slope, height, distance from the sea, and the status of the ocean currents. In the world, for example, the area near the Earth's equator (low latitude or zero) is known as a tropical climate. Meanwhile, climates in the intermediate and high latitudes are referred to as subtropical and polar climates, respectively. Climatology is the study of global climatic trends and their features [9].

The climate in Indonesia belongs to a unique climate category. This is influenced by many factors, among others due to its geographical siting in the tropical climate zone as well as its distinctive archipelagic features. Its location in between of two oceans (Pacific and Indian) make it possible for Indonesia to have three different climate patterns namely monsoon, equatorial, and local climates [9]. Indonesia's rainfall pattern can be classified into three zone with a transitional area as shown in Figure 1.

The monsoon region (zone A) is the primary climatic pattern in Indonesia, covering nearly the whole country. The rainy northwest monsoon influences the rainfall in this area between November and March. Furthermore, the zone has a period from May to September affected by the dry southeast monsoon. As a result, there is a distinction between the dry season (monthly rainfall less than 150 mm) and the rainy season (monthly rainfall above 150 mm). Furthermore, fluctuations in sea surface temperature (SST) are significantly associated with area A. The equatorial region (zone B) has two peaks in October to November and March to May. The average monthly rainfall is fairly high, at more than 150 mm. Shifts to the north and south of the Sun's equinox have an impact on this pattern (culmination). When the Sun is above a region known as the Inter-Tropical Convergence Zone (ITCZ), the rain normally begins to fall. Meanwhile, the local climate area (zone C) has one peak in June to July which is the opposite of Zone A. When the rainy season hits the monsoon type area (zone A), the dry season hits the local type area (zone C). Zone A experiences a dry season if zone C experiences a rainy season. Furthermore, due to geographical constraints, certain local type regions have fairly little rainfall throughout the year, with a monthly average of less than 150 mm [10].

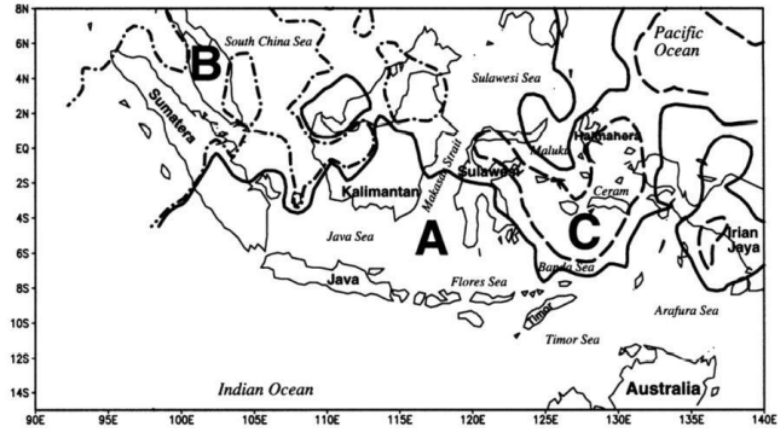

Figure 1. Indonesia has three regions with different rainfall patterns. Zone A has a monsoon climate, B is equatorial, and C is a local climate [9]

Based on data obtained from 89 BMKG observation stations, the average normal air temperature in Indonesia for the period of 1981-2010 is 26.6 ºC in comparison of average air temperature in 2021 of 27.0 ºC. It is found that 2016 was the hottest year with an anomaly value of 0.8 °C throughout the observations during period of 1981 to 2020 [11]. Climate change in Indonesia has caused an increase in temperature in all regions and a decrease in rainfall in the southern region of Indonesia, while an increase in rainfall in the northern region. Changes in rain patterns alter the start and length of the rainy season [12]. If shorter-lived cultivars are not accessible and irrigated systems are not developed, improving the cropping index in the southern part of Indonesia will be challenging. On the other hand, in the northern part of Indonesia, increased rainfall during the rainy season will increase the chance of planting index, but land conditions are not as good as in Java. This changing tendency is undoubtedly linked to the agriculture industry.

3. Rice farming conditions in Indonesia

Climate change can increase disaster risk and impose adverse impacts on agricultural areas and crop productions. In the long term, this condition can threaten food security in Indonesia as most of rice cultivation system in Indonesia is highly sensitive and vulnerable to climate change. This condition threatens not only the food security, but also at macro level can threaten the Indonesian economy. At macro level, the Indonesian economy has already contracted by the imports including rice import. Therefore, it is crucial for Indonesia to maintain the national rice production to reduce its dependency on the import products. In this context, it has been said that the Indonesian government's goal for many years to achieve self-sufficiency.

Based on BPS data, The rice production in Indonesia is 54,5 million tons per year in 2021 as shown in Figure 2 [13]. There is a little decline in productivity compared to the production of 2019 and 2020. This condition can be worrying if become a trend in the long run as suggested by Yusman Syaukat who predicted the deficit of 90 million tons of husk rice by 2050 [14]. The decline in rice production will jeopardize the food security in Indonesia and will be worsened by the risk imposed by the global climate change, especially for irrigated areas that use high levels of agrochemical products [15].

Figure 2. Total rice production in Indonesia (2019-2021)

Additionally, Indonesian agricultural land of rice farming is decreasing every year due to the conversion of land function into other land uses. The land use changes from paddy's agricultural to the other plantation commodities, such as palm oils is basically triggered by the farmers perceptions that palm oil is less susceptible to climate influences, therefore it will guarantee the income as well as the long-term welfare. Furthermore, in the absence regulation for agricultural land protections coupled with inadequate of irrigation infrastructures and increasing in housing as well as other infrastructure needs can be huge challenges in the future for paddy's cultivations beside the climate changes that threaten the national food security. Nevertheless, the government's intervention through the stipulation of intact policies to preserve agricultural land will be crucial.

The conversion of paddy fields in Indonesia not only reduces the existing rice production capacity. However, further than that, the conversion of paddy fields also affects the government's purchase price policy (grain/rice). Conversion of paddy fields demands an increase in the amount of imported rice as a consequence of the reduced availability of domestic rice. The increase in the amount of imported rice has an impact on the real retail price of rice in the country [16].

4. Climate change scenario

Climate change and its effects on rice production have been studied in several places around Indonesia, using climate change scenarios from the IPCC AR5. The AR5 presents an assessment of

the state of knowledge in climate change sciences, focusing on new findings since the Fourth Assessment Report (AR4) was published in 2007.

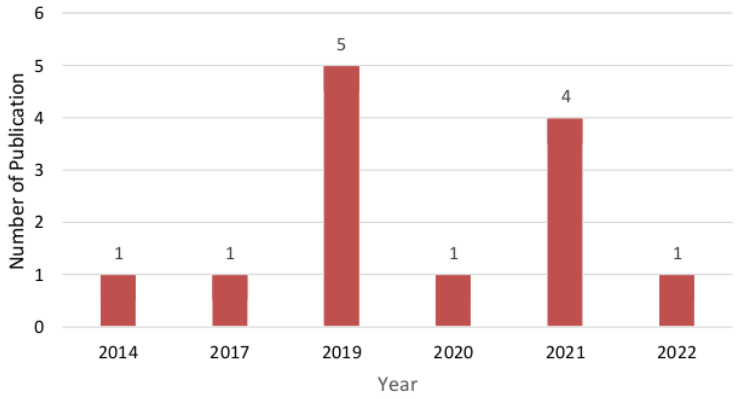

Figure 3. Publication Reports using IPCC AR5 scenarios

Since the IPCC AR5 climate change scenarios were launched in 2014, the researchers in Indonesia have used the scenarios for various purposes. As it is well-known that rice farming is regarded as the most important agricultural activities for the Indonesian, therefore the researchers are highly interested in analyzing potential problems related to the rice farming. We found the first study that applies AR5 climate change scenarios on rice farming was conducted in 2014 with Ujungjaya, Sumedang District, West Java as the locations [17]. The study examines the effects of climate change on rice production and assesses the effectiveness of present adaptation techniques to handle the varied implications under different climatic scenarios. In this study, seventeen General Circulation Models (GCM) have been modeled under the Representative Concentration Pathways (RCP) climate change scenarios of RCP8.5 and RCP4.5 in conjunction with the CROPWAT model for particular projection periods of 2011 to 2040 and 2041 to 2070.

As depicted in Figure 3 it can be seen that after 2014, the study of climate change with regard the rice agriculture continues to increase. Between 2019 and 2021, there are a huge number for 10 studies published in those years pertaining different objectives and locations. However, in 2020, there was only one publication carried out in the Terantang irrigation unit as study targeted area by Maya Amalia Achyadi, *et.al* [18]. The most notably is in 2019 that outlining the research undertaken in Barito Kuala Regency, South Kalimantan [19,20], Lembang Sumani Watershed, West Sumatra [21], and West Java [22,23]. Of the five studies conducted in 2019, the researchers are focusing on the need of water irrigation for rice farming.

Meanwhile, in 2021, similar research was conducted to examine the rice farming in Aceh, West Sumatra, South Sulawesi and Central Sulawesi by Misnawati, Apriyana and F Ramadhani [24]. In the same year, Erni Susanti *et. all* [25] evaluated the projections of rice productivity in mainland Java with two other studies were conducted in the Keduang Subwatershed, Central Java [26] and West Nusa Tenggara [27]. By 2022, at the time of this review is authored, the only research on land suitability analysis for rice farming that uses RCP4.5 scenario is conducted in Sukabumi District to assess the effect of climate changes projected between 2020 [28].

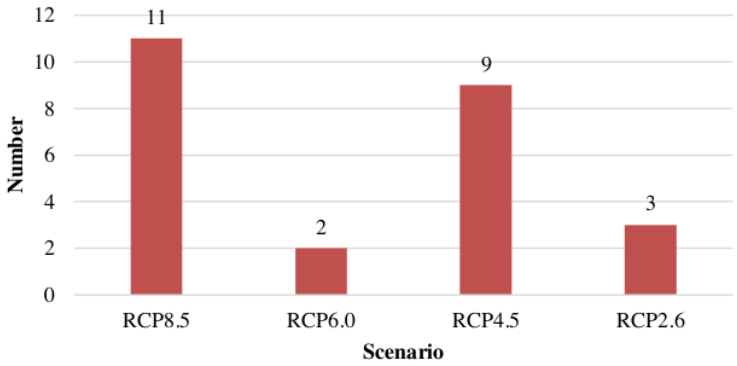

Figure 4. Number of RCPs Scenario Usage

In conducting this research, regional climate model (RCM) and processing of the model data are used to produce a projection of future climate change on a regional scale. The output of this modeling resulting data consists of an ensemble of the results of the global climate projection model (GCM) downscaling process in the RCP2.6, RCP4.5, RCP6.0, or RCP8.5 scenarios.

RCP scenarios are critical in performing climate research and establishing the groundwork and evaluation, such as emission mitigation and effect assessments [29]. This scenario is based on radiative forcing which is defined as the difference in energy received by the earth and reflected. The higher radiative forcing value, the more energy enters the earths and increased heat in the earth. The connection among both CO2 concentration and radiative forcing is logarithmic, small concentration changes can increase radiative forcing [30]. The IPCC develops a mitigation option with extremely low forcing (RCP2.6), two intermediate stabilization scenarios (RCP4.5 and RCP6), and the other one with high baseline emission projection (RCP8.5) [31].

Figure 4 shows the distribution of the uses of RCPs scenarios in Indonesia from 2014 to the present. In the climate change studies regarding the rice agriculture sector, the use of RCP 8.5 was the most widely used scenario with 11 publications, followed by RCP4.5 in the second place with 9 publications. Meanwhile, the RCP2.6 and RCP6.0 have rarely been used with 3 and 2 publications respectively. The selection of RCP scenarios depends on the interests and considerations of each published report. The RCP4.5 scenario is predicted to occur, as stated by W Siska et al [28] in the usage of the RCP4.5 scenario. RCP4.5 assumes that all nations participate in GHG reduction initiatives concurrently and successfully [32]. Meanwhile, Maya Amalia Achyadi, *et all* opted to use RCP8.5 because this scenario is considering the highest emission scenario [19].

In Table 1, the publications that have used the IPCC AR5 scenario are listed with the purposes to analyze or to estimate the condition of rice farming. Every study that uses climate change scenarios is associated with the different types of Global Climate Model (GCM). Climate scenario projections in Indonesia use the Regional Climate Model (RCM) which is a derivative of the Global Climate Model (GCM). Regional climate models are complementary to global climate models [33]. The use of GCM in Indonesia in this case is highly variative, for instance a study conducted by A. Candradijaya, et. all [17] and Andrianto Ansari, et.all [26] have used up to 17 GCM. The 17 GCM used by A. Chandradijaya, et. al adopted the climate change scenarios of RCP8.5 and RCP4.5 in combination with the CROPWAT model applied for short period (2011-2040) and long period (2041-2070) projections. Meanwhile. Andrianto Ansari, et.all used 17 models to simulate climate change scenarios for period of 2021 to 2050 under all RCPs.

The most frequent extracted climate parameters were temperature and rainfall. This is because in the context of rice farming the productivity of rice is highly influenced by the temperature and rainfall.

The increase in temperature will shorten the life of rice and certainly will reduce the rice yields. In addition, low rainfall during the agricultural season also contributes on the decline of rice productivity.

Table 1 Reference to rice farming studies using RCP scenarios

Ref.	Lokasi	GCM/Tool	RCPs	Parameter
[17]	Sumedang District, West Java	17 GCM Model: • CESMI-CAM5, • CSIRO-Mk3-6-0, • FIO-ESM, • NOAA GFDLCM3, • NOAA GFDL ESM2G/2M, • NOAA GFDL ESM2M, • GISS-E2-R1, • GISS-E2-R2, • GISS-E2-R3, • HadGEM2-ES, • MIROC-ESM-CHEM, • BCC-CSM1, • MIROC-ESM, • MIROC5, • IPSL-CM5A-LR, • CCSM4, and • MRI-CGCM3	RCP8.5, RCP4.5	Temperature and Precipitation
[19]	Barito Kuala Regency, South Kalimantan	CMIP5 tool and 4 GCMs: • ACCESS 1.0, • CESM1 (BGC), • CNRM-CM5 and • CanESM2	RCP8.5	Temperature and Precipitation
[34]	Indramayu, West Java	Not Mentioned	RCP8.5, RCP.6	Temperature and Precipitation
[21]	Lembang Sumani Watershed, West Sumatera	5 GCMs: • MPI-ESM-MR, • MPI- ESM-LR, • MRI- CGCM3, • MIROC-ESM, and • MIROC-ESM-CHEM	RCP8.5, RCP.5	Temperature (max and min) and Precipitation
[24]	Aceh, West Sumatera, South Sulawesi and Central Sulawesi	CMIP5 tool and GCM (ACCESS1-0)	RCP8.5, RCP4.5	Temperature and Precipitation
[26]	Keduang Subwatershed, Central Java	MarkSim and 17 GCM: • MIROC-ESM-CHEM, • MIROCS, • NorESM1-M, • BCC-CSM1-1, • BCC-CSM1-1-M,	RCP8.5, RCP6.0, RCP4.5, RCP2.6	Temperature (max and min), Precipitation, Solar Radiation

		• CSIRO-Mk3-6-0, • FIO-ESM, • GFDL-CM3, • GFDL-CM3, • GFDL-ESM2G, • GFDL-ESM2M, • GISS-E2-H, • GISS-E2-R, • HadGEM2-ES, • IPSL- CMSA-LR, • IPSL-CMSA-MR, • MIROC-ESM, and • MRI-CGCM3		
[20]	Barito Kuala, South Kalimantan	CMIP5 tool and 4 GCM: • ACCESS1.0, • CNRM- CM5, • GFDL-CM3, and • MRI-CGCM3	RCP8.5	Precipitation, temperature, humidity, solar radiation and wind velocity
[28]	Sukabumi, West Java	MIROC 5	RCP4.5	Temperature and Precipitation
[18]	Barito Kuala Regency, South Kalimantan	CMIP5 tool and GCM: (MRI-CGCM3 and CNRM-CM5)	RCP8.5, RCP4.5	Temperature and Precipitation
[25]	Java Island	GCM (CSIROMK3.6 and HadGEM2)	RCP8.5, RCP4.5	Precipitation
[22]	West Java	CMIP5 in SEACLID/CORDEX SEA	RCP4.5	Temperature and Precipitation
[23]	West Java	• CNRM v2 RegCM, • CSIRO MK3,6, • EC EARTH, • GFDL ESM, • IPSL, • CNRM RCA, and • CNRM CM5	RCP8.5	Precipitation
[27]	West Nusa Tenggara	GFDL-CM3 and IPSL-CM5A-LR	RCP8.5, RCP6.0, RCP4.5, RCP2.6	Temperature and Precipitation

5. Challenges in the rice agriculture sector due to climate change

The agricultural industry is the most vulnerable, suffering, and sensitive to climate change due to three key factors: biophysical, genetic, and managerial. Extreme weather patterns also have a role in [35]: (a) decreased productivity as a result of failure to grow and harvest; (b) damage to cropland; (c)

increased frequency and intensity of drought; (d) increased humidity; and (e) increased intensity of disturbance by plant-disturbing organisms.

In Indonesia, several studies concerning climate change and its implications for agriculture have been carried out to provide an overview of the current conditions and challenges that will be faced in the future. Addressing these challenges can ensure and maintain the sustainability or even increased the rice production. The studies typically overview climate change's effects on rice production. For example, a study conducted in West Nusa Tenggara shows that despite climate change's harmful influence on rice production, West Nusa Tenggara still can meet its local rice demand. However, West Nusa Tenggara cannot supply enough rice to adjacent provinces like Bali and East Nusa Tenggara [27]. Meanwhile, according to the findings in Java Island, rice agricultural production is now decreasing in 41 of the 191 regencies. Using the RCP8.5 scenario, it is predicted that rice productivity would drop more in the future [25].

According to study conducted in Sukabumi, West Java, the Sukabumi Regency's climate adaptability class for rice cultivation would remain unchanged between 2020 and 2032. Yet, due to the large drop in rainfall, avoiding and adapting to changes in climate is crucial in order to reduce the danger of future rice production loss [28]. In addition, a study was also conducted on the Keduang sub-basic scale in Central Java and the projection by using RCP 8.5 scenario reveals that the impact of climate change on rice harvests in the second dry season might cut output by 11.77 percent in the 2050s [26].

The impact is not only on the productivity of rice farming but also on the schedule of the planting. In West Java it has been examined that climate change has changed the planting schedule to be earlier in pursuing of wet season therefore the availability of groundwater increases. In September, the planting pattern in East and West Java is increasing longer for the year of 2021-2030, compared to 2006-2015 and 2031-2040 [22]. Similarly, the typical results also found in the study conducted in Sumedang District, West Java. Rice production decline is very sensitive to planting timing and irrigation schedule. Based on these results, it can be concluded that the current autonomous adaptation responses of local farmers are effective in reducing the rate of yield decline caused by climate change [17].

In addition, the focus of this review is also on the water availability for rice farming as the irrigation is one of important factor in the rice cultivations. These research have been carried out in numerous Indonesian provinces, including West Java, Barito Kuala Regency - South Kalimantan, Aceh, West Sumatra, South Sulawesi, and Central Sulawesi. Water security for agriculture in West Java may be jeopardized in the future if major efforts are not taken to compensate for the unpredictability of water supply from rainfall and the decline of river flows. Except for the Cilaki-Ciwulan watershed, six watersheds in West Java are susceptible to climate change consequences [23]. Terantang irrigation unit in Barito Kuala Regency, South Kalimantan Indonesia is also affected by climate change, indicated by the increase in irrigation water requirements in two scenarios compared to current conditions [18]. The study, which was conducted in the same location and by the same researchers using a different approach, found that Climate change might increase irrigation water demand for local rice production by 56% and 25%, respectively, compared to existing circumstances in July and September-October [20].

Although the government has been making attempts to improve domestic rice production through the Ministry of Agriculture since the early 1950s [36]. However, given the possible effects of climate change, growing domestic rice production remains a problem. Government adaptation activities are carried out through the General Guidelines for practical measures in climatic change plans.

4. Conclusions

After completing the comprehensive reviews of the studies related the rice farming and climate change by using the RCP scenario as presented in the IPCC AR5, it can be concluded that since the release of the RCPs scenario, the researchers in Indonesia have implemented RCPs at least in 13 peer-reviewed

publications. Most of these publications were carried out in 2019 for five publications and 2021 for 4 publications. The most frequent scenario used in the studies is the RCP8.5. The RCP8.5 is constructed on pessimistic scenario. This indicates the pessimistic intention of researchers in developing countries particularly in Indonesia in their efforts to reduce emissions by 2100. According to the findings of the study, rice cultivation in Indonesia would face significant problems as a result of the effects of climate change. The biggest impact on agriculture is a decline in rice crop productivity.

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