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The Vulnerability of Climate Change in Indonesia to Renewable Energy

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Abstract. The need for electrical energy is growing along with economic and population growth. The position of Indonesia is located on the equator line and is a tropical country that has the potential to get maximum solar energy throughout the year. Solar energy is a potential source of energy for Renewable Energy (RE) which is an alternative energy of low-carbon and clean power plants to solve energy problems. Based on the 14-km CCAM model, we have calculated solar radiation indicators at current baseline conditions (1981 – 2010) and 100 years future projections in order to analyze vulnerability and adaptation of the renewable energy sector to climate change in Indonesia. Although the climate change leads to a projected significant increase in mean air temperature 1,72 K across the whole of Indonesia that affect solar radiation indicator value, especially in Kalimantan with an average decrease of 6,5 W/m^2, but the results of the analysis indicate that the solar radiation indicator value of Indonesia region has excellent area and strength for the use of solar energy both now and in the next 100 years.

Keywords: The New and Renewable Energy, CCAM model, solar energy indicators

1. Introduction

The need for energy especially electricity is growing because it is a daily necessity of society along with economic and population growth. Electrical energy demands in Indonesia for industrial, household, public and commercial facilities, predicted by Djojonegoro [1] can reach 8.2 percent on average per year, in 2000 amounting to 122,603 GWh and in 2010 amounting to 258,747 GWh, while forecast of electricity supply from energy sources of coal, gas, oil, diesel, geothermal, water, biomass, solar and wind in 2000 was 37,860 MW and in 2010 was 68,760 MW [1], with the population is around 237.64 million [2], and the geographical condition of Indonesia consists of thousands of islands, the spread and uneven distribution of electricity centers, low levels of electricity demand in several regions, resulting in high marginal costs of supply system development electrical energy.

The position of Indonesia which is located in the equator line and a tropical country obtaining maximum solar energy throughout the year has good solar energy potential, with an average daily radiation approaching 4 kWh/m^2 [3]. The International Energy Agency (IEA) [4] estimates electricity production of 5.3 GW in 2002 and increases to 46 GW by 2030.

Solar energy is a potential energy source for Renewable Energy (RE) which is an alternative to low-carbon power plants. Solar energy is one of the most promising clean and renewable energy sources and has the greatest potential than other resources to solve the world's energy problems [5], At present, solar energy has become more popular as an energy supply in the world [6] . Renewable energy has the role of reducing greenhouse gases, carbon dioxide and methane, in terms of synergy and efficiency in the use of energy associated with climate change [7].

For solar energy, although climate change is expected to affect the distribution and variability of cloud cover, the impact of these changes on the overall technical potential is expected to be small [8]. The Ministry of Energy and Mineral Resources (KESDM) reported that in 2013 and 2014 fossil energy consumption used for energy supply was dominated by coal (69%) followed by natural gas (20%) and petroleum (11%) [9], while Indonesia is rich with the potential of solar and wind powers. Solar and wind powers have been used as a source of energy for Solar Power Plants (SPP) and Bayu Power Plants (BPP). The potential of solar power in Indonesia varies depending on the radiation level of each region, but in general the average solar radiation potential of Indonesia is 4.8 kWh/m^2/day. Wind power potential in Indonesia also varies by region depending on wind speed and surface conditions. In 2013, the potential capacity of BPP that could be built reached 3 - 6 m/s. During the period 2010 - 2014, solar power production experienced a significant increase from 26.4 thousand Barrel of Oil Equivalent (BOE) in 2013 to 32.9 BOE in 2014. This production was calculated by considering solar power electricity production with efficiency of 12.5%. The use of solar power and wind power will increase as the RE mix target is set at a minimum of 23% by 2025 as stipulated in Government Regulation 79/2014 on National Energy Policy [9]. Based on this regulation, RE continues to be developed with a 23% portion in 2025 and greater than 31% in 2050.

In order to anticipate electricity demands, State Electricity Company (PLN) has planned 140 MW of solar photovoltaic (PV) in 2015 and 620 MW in 2020 [10] and according to National Energy Council (DEN) [11] in 2015 electricity consumption in the final sector is 200 tWh and projection resulted on three conditions. First condition is Bussines as Usual (BaU), a basic of energy forecast scenario which is a continuation of historical development without any intervention of government policy that can change historical behavior with the basic assumption of moderate population growth of Gross Domestic Product (GDP) of 5.6% per year. Second condition is alternative condition 1 (Alt 1), the basis of moderate GDP growth of 5.6% and the adoption of renewable energy technology and energy-saving technologies. The third condition is alternative conditions 2 (Alt 2), assuming 7.1% high GDP growth and the application of RE technology and energy-saving technology.

The final energy demand projection in 2025 is 238.8 Mega Ton Oil Equivalent (MTOE) in BaU conditions, 201.5 MTOE in Alt 1 and 244MTOE in Alt 2, while the projection of final energy needs in 2050 is 682.3 MTOE (BaU), 430.3 MTOE (Alt 1) and 621 MTOE (Alt 2). RE final energy demands alone in 2025 amounted to 18 million TOE (BaU), 23 million TOE (Alt 1) and 60 million TOE (Alt 2) while in the year 2050 is 48 million TOE (BaU), 60 million TOE (Alt 1) and 86 million TOE (Alt 2) [11]. The national renewable energy market is projected to grow strongly in the coming decades and beyond, as indicated by current policies and targets, and based on expert projections.

This study aims to determine the indicators of solar radiation on solar radiation events in the Indonesian region to identify potential vulnerabilities of renewable energy to climate change in Indonesia, based on data from the scenario of numerical CCAM models with a focus on solar energy.

2. Data and Methodology

Determination of the value of the radiation indicator on the analysis of climate change vulnerability to renewable energy uses data from the execution of the atmospheric numerical model Conformal-Cubic Atmospheric Model (CCAM), with the climate model Geophysical Fluid Dynamics Laboratory version 3 (GFDL-CM3), in the emission scenario of Representative Concentration Pathways (RCP) 4.5, with 14 km spatial resolution [12], of which CCAM is an atmospheric numerical model developed by the Commonwealth Scientific and Industrial Research Organization (CSIRO) [13], and the GFDL Climate model version 3 (CM3) is a coupled climate model developed by NOAA formulated with the same oceanic and sea ice components as CM2.1 but with extensive development carried out on the atmospheric and land model components. CM2.1 and CM3 show a stable average climate index, such

as large-scale circulation and sea surface temperature (SSTs). There are several important improvements in CM3 climate simulation relative to CM2.1, including a modified SST bias pattern and a reduced bias in Atlantic sea ice cover, while RCP describes the radiative forcing that will be received by the earth, which is the emission scenario used by IPCC on AR5.

Data processing is carried out by grouping, which is based on a period of 30 years, which is the first 30 years, namely data from 1981 to 2010 and is considered as baseline data which is used as a reference for the next 30 years. Grouping the period of the second 30 years is data from 2011 to 2040, then the data period of the third 30 years is data from 2041 to 2070 and the period of the fourth 30 years is data from 2071 to 2099.

The calculation of the radiation indicator assumes that the use of solar energy depends on the incidence of solar radiation in a particular area, an efficient method of analysis to see the views of this source supply is the radiation balance in a particular region, which can be determined by calculating this radiation and radiation balance is the energy available in Earth's atmospheric system and is defined as the radiation balance of all radiation fluxes leading to and from the surface. The solar radiation indicator (RI) can be determined based on the formulation [14] below:

$$RI = SRI + SER - \alpha\ SRI - SES \tag{1}$$

Which SRI is short wave radiation incident to the surface (W/m^2); α is albedo; SER is a short wave of emerging radiation at the top of the atmosphere (W/m^2) and SES is a short wave of radiation emerging to the surface (W/m^2). Unit of solar radiation indicator is W/m^2.

3. Results and Discussion

3.1. Temperature

Solar energy equipment can be affected by variations in ambient temperature, therefore it is necessary to analyze the projected increase or decrease in temperature in the future throughout the data processing period.

Based on data in the period of 1981 to 2010 for the first 30 years and considered as a baseline, the land temperature ranged from 286.45 K to 302.86 K, which were the lowest and the highest temperatures occurred on the mainland of Papua, respectively (figure 1a).

The temperature in the next 30 years, which is in the period of 2011 to 2040, has the lowest temperature of 287.76 K and the highest temperature of 303.99 K, meaning that there has been an increase in temperature for the lowest and highest values (figure 1b), which increases the temperature generally in Kalimantan and Sumatera compared to baseline conditions. The temperature in the third 30 years period, which is in the period of 2041 to 2070 (figure 1c) has also increased in temperature, with the lowest and highest temperatures were 288.82 K and 304.62 K, respectively. The temperature in the fourth year period in the span of 2071 to 2099 (figure 1d) has the lowest and highest temperatures of 289.61 K and 305.14 °K, respectively with the temperature increase was all compared to baseline data.

The average temperature rise that occur from the 2nd, 3rd and 4th periods to the 1st period (baseline) for the Kalimantan region, the smallest is 1.72 K, and the largest is 2.28 K
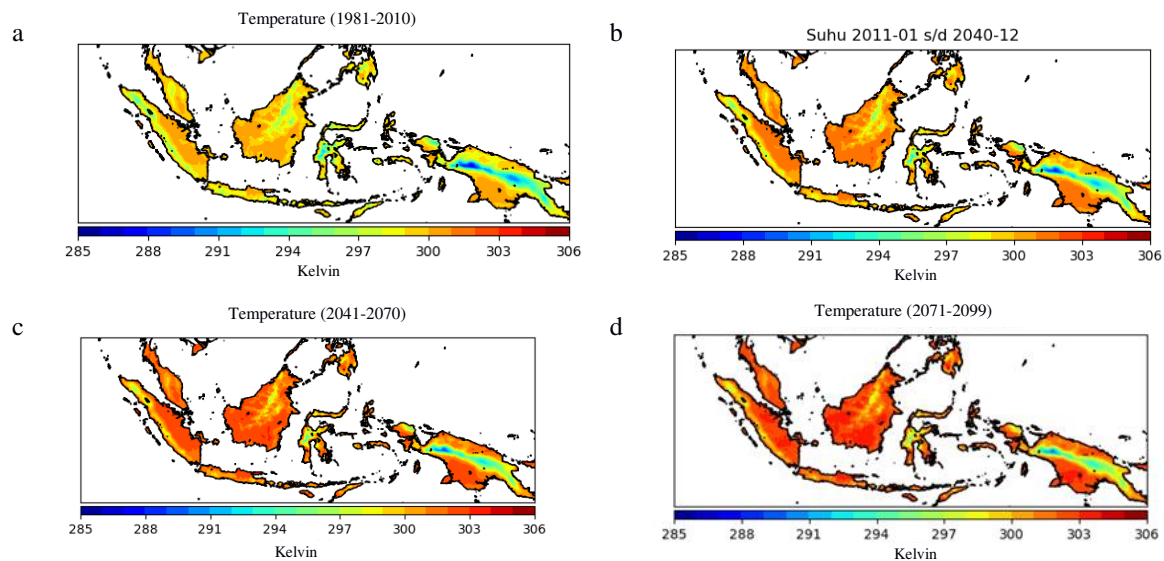
Figure 1. Temperature conditions of the CCAM numerical model output, using the GFDL_CM3 model with a spatial resolution of 14 km, a) period 1981-2010 as baseline, b) period 2011-2040, c) period 2041-2070 and d) period 2071-2099 in unit of Kelvin
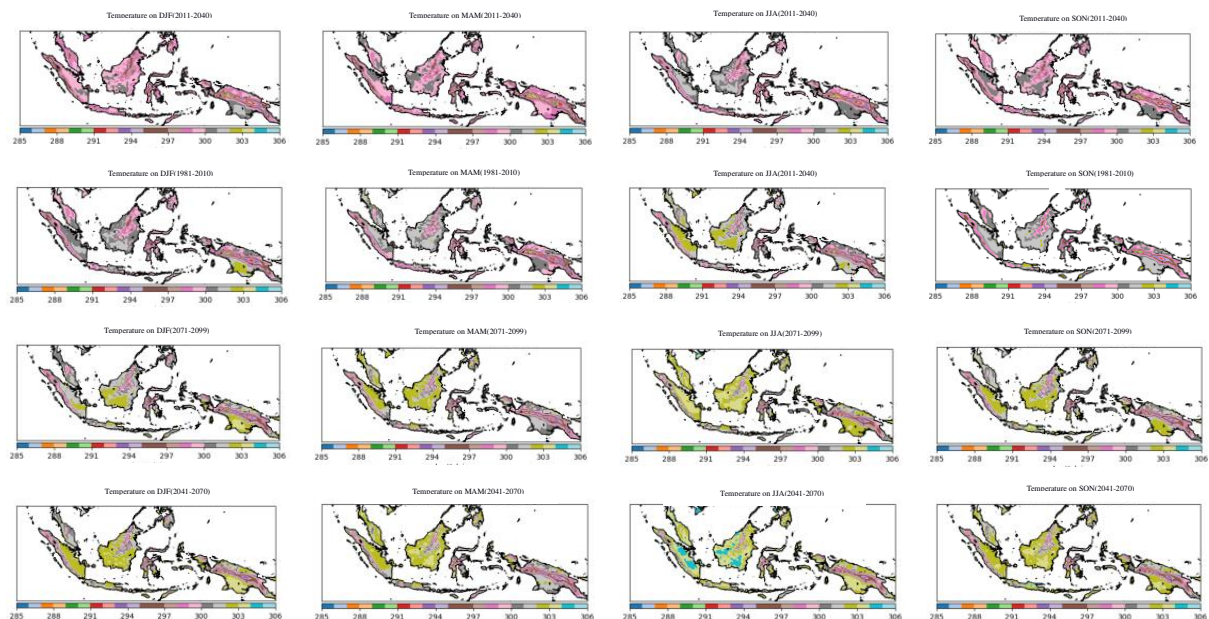
Figure 2. Condition of seasonal temperature released by CCAM numerical models, using the GFDL_CM3 model with a spatial resolution of 14 km, period 1981-2010 as baseline (row 1), period 2011-2040 (row 2), period 2041-2070 (row 3) and period 2071- 2099 (row 4) in units of Kelvin, and the column display shows the condition of the season temperature (DJA, MAM, JJA and SON)

To find out more complete temperature conditions, seasonal temperature analysis will be carried out in each period and figure 2 shows seasonal temperature conditions for December- January - February (DJF), March – April - May (MAM), June - July - August (JJA), September- October - November (SON).

The row display shows the condition of the season temperature, while the column shows the period of temperature. Seasonal temperature conditions based on the same season showed an increase, especially in Kalimantan and Sumatra. A striking increase occurred in the third period, namely the span of 2041 to 2017, both in the same season or in different periods. In the 3rd period, the maximum temperature that occurred was around 302.76 K, except SON season is 301.72 K, while the lowest temperature for all seasons is 299.95 K

3.2. Solar Energy

Results of the calculation of the radiation indicator value for the territory of Indonesia in the 1st period, determined as the baseline, got the smallest and highest radiation indicator values of 401.87 W/m^2 and 600.35 W/m^2, respectively (figure 3.a). The radiation indicator value in the 2nd period has the lowest and highest value of 394.15 W/m^2 (a decrease of 7.72 W/m^2) and 593.32 W/m^2 (a decrease of 7.03 W/m^2), respectively (figure 3.b). The decline generally occurs in all lands, especially in North, East and West Kalimantan, South Sumatra and also in Papua.

The declines still occur in the 3rd period (figure 3.c) and they have the smallest and the highest values of 395.82 W/m^2 (an decrease of 6.50 W/m^2) and 589.86 W/m^2 (a decrease of 10,49 W/m^2). The decline in the second period also generally occurs on all lands, especially in North, East and West Kalimantan, which are increasingly widespread to South Sumatra, East and West Java and also in Papua. While in the 4th period (figure 3.d) has the smallest and the largest values of 396.15 W/m^2 (a decrease of 5,72 W/m^2) and 583.92 W/m^2 (a decrease of 16,43 W/m^2), respectively. The decline in the fourth period still occurs on all lands, especially in North, East and West Kalimantan, South Sumatra, East and West Java and also in Papua. The decrease in the solar radiation indicator is all compared to baseline data. The average reduction in solar radiation indicators that occur from the 2nd, 3rd and 4th periods to the 1st period (baseline) for the Kalimantan region, the smallest is 6.5 W/m2, and the largest is 11.32 W/m^2.
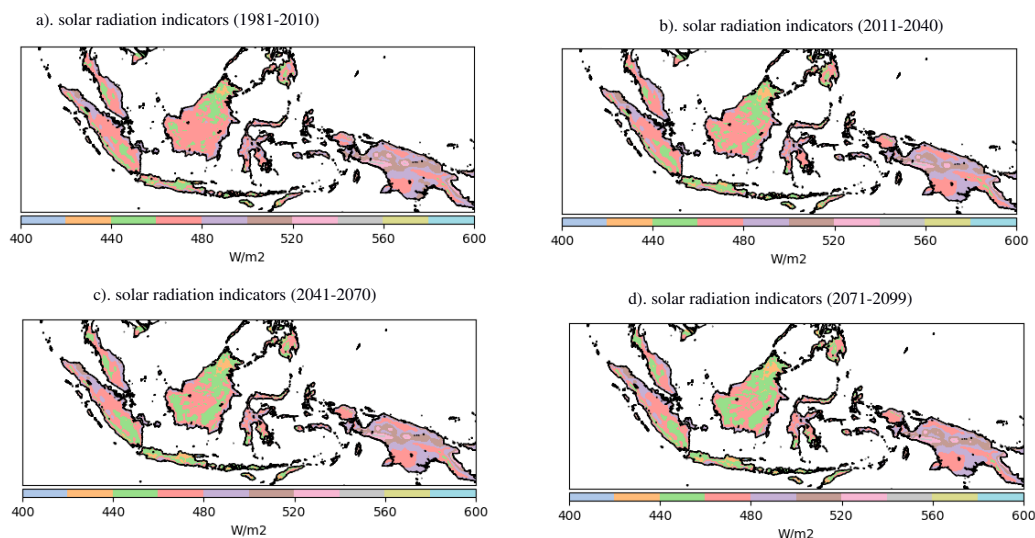
Figure 3 Condition of solar radiation indicator output by CCAM numerical model, using GFDL_CM3 model with 14 km spatial resolution, in a) period 1981-2010 as baseline, b) period 2011-2040, c) period 2041-2070 and d) period 2071-2099 in units of W/m^2

Analysis of the seasonal radiation indicator was carried out for each period to complete information on solar radiation conditions at a location. Figure 4 shows the DJF seasonal radiation indicator shown in the 1st column, MAM in the 2nd column, JJA in the 3rd column, and SON in the 4th column, while the row shows the 1st (as a baseline), the 2nd, the 3rd and the 4th periods.

The baseline period in figure 4 first row shows the highest indicator of seasonal solar radiation occurs in the JJA season, ranged from 451.55 W/m^2 to 567.69 W/m^2. The lowest seasonal solar radiation indicator occurs in the MAM season, ranged from 396.88 W/m^2 to 531.36 W/m^2.

Seasonal solar radiation indicators in the second period across all regions of Indonesia showed decline to the baseline. The highest seasonal solar radiation indicator value of 540.29 W/m^2 (a decrease of 13.27 W/m^2 compared to baseline) occurred in SON season, and the lowest of 1.77 W/m^2 was found in the MAM season.

Likewise, the decline of solar radiation indicator is also observed in the third period, either towards the baseline or the second period. In this 3rd period the highest solar radiation indicator value occurred in the DJF season of 532.13 W/m^2 and the smallest value occurred in the MAM seasons of 396.43 W/m^2.

The 4th period of seasonal solar radiation indicator still shows a decrease compare to the baseline. The biggest value of 536.10 W/m^2 (a decrease of 6.29 W/m^2) occurred in the DJF season, and the smallest value of 397.88 W/m^2 occurred in the MAM season. Comparative results show a decrease in the solar radiation indicator received by a region from a period to period.
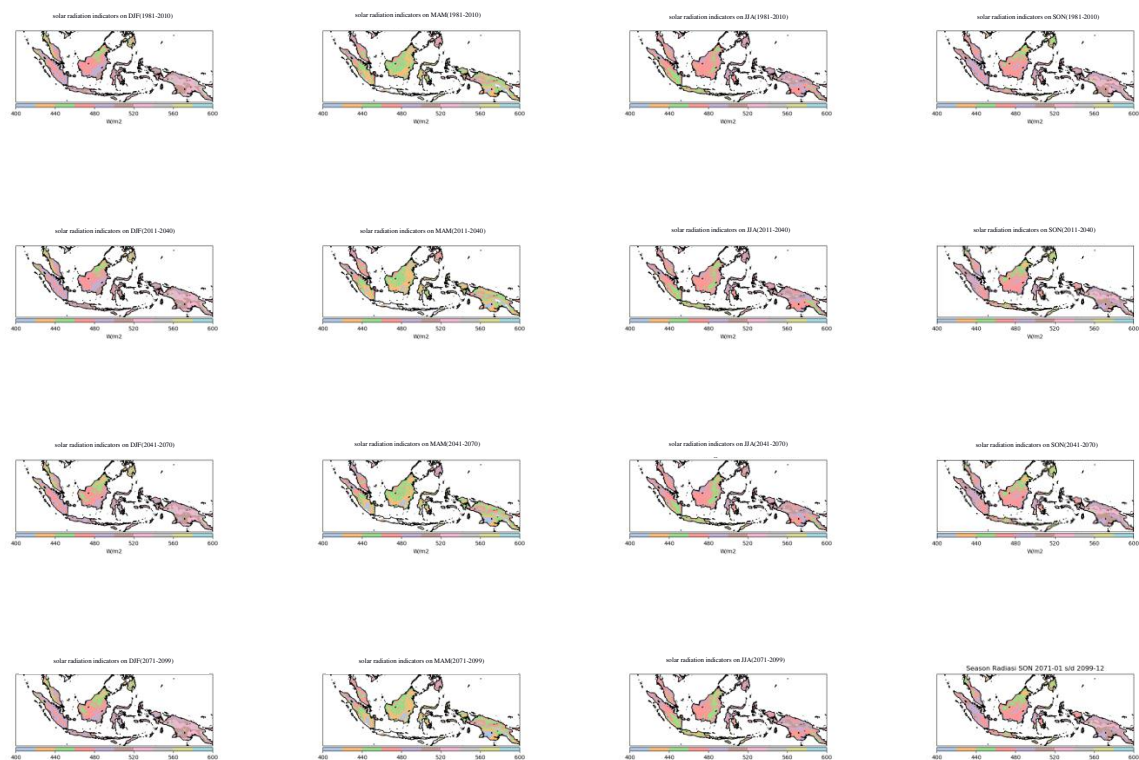
Figure 4. Condition of seasonal solar radiation indicator released by CCAM numerical models, using the GFDL_CM3 model with a spatial resolution of 14 km, period 1981-2010 as baseline (row 1), period 2011-2040 (row 2), period 2041-2070 (row 3) and period 2071-2099 (row 4) in units of W/m^2, and The column display shows the condition of the season DJA, MAM, JJA and SON

Figure 5 showed the percentage reduction of solar radiation indicator. The highest and the lowest differences in the 2nd solar radiation decrease was 2.43% and -2.68%, respectively (figure 5.b). The biggest and the lowest differences for the 3rd period are 2.46 % and -3.98 %, respectively (figure 5.c). The 4th period has the highest and the lowest differences of 2.27% and -4.39%, respectively. These differences are all compared to the baseline (figure 5.a)
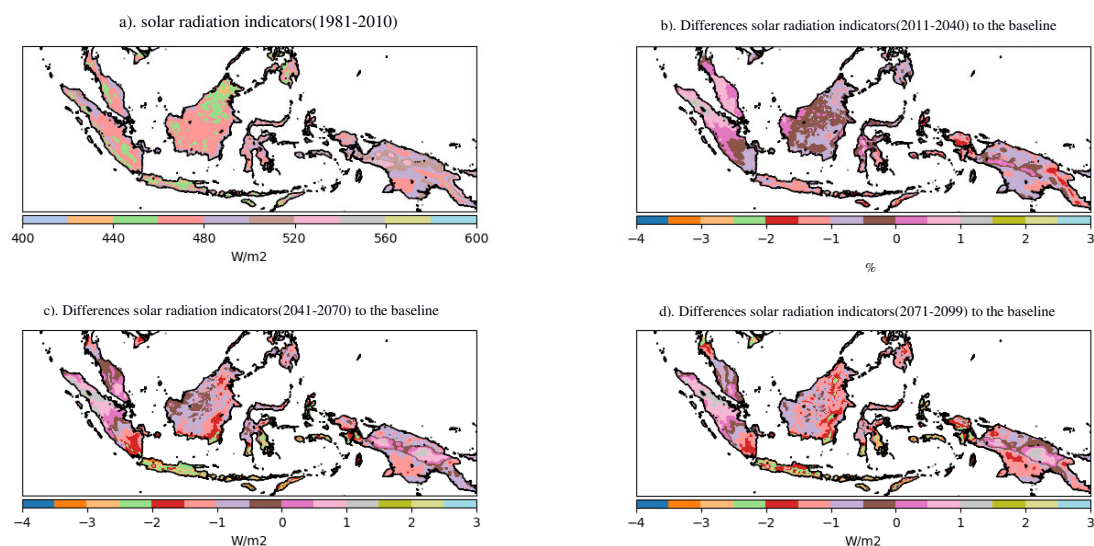
Figure 5. Differences in solar radiation indicators released by CCAM numerical models, using the GFDL_CM3 model with a spatial resolution of 14 km, a) period 1981-2010 as baseline in units of W/ m², b) period 20 11-2040 in % , c). period 2041-2070 in % and d.) period 2071-2099 in %

The occurrence of a decrease in solar radiation indicators is not only based on a review of the 30-year period data analysis, but also based on the results of seasonal analysis and the decline generally occurs on all mainland, especially in North, East and West Kalimantan, South Sumatra and also in Papua. Because the regions of North, East and West Kalimantan, South Sumatra and also in Papua has a continuous solar radiation indicator decline, therefore these regions are areas that are vulnerable to climate change. The decrease in the 30-year period solar radiation indicator that occurs in an area is inversely proportional to the increase in surface temperature.

For our future work, when the data of short-wave radiation incident to the surface; albedo; a short wave of emerging radiation at the top of the atmosphere and a short wave of radiation emerging to the surface are available, then we will validate our model input data against the observations.

4. Conclusion
Climate change has increased land surface temperatures and reduced solar radiation received in a particular area. The results of the climate model projections analyzed using a 30-year data period, indicate that the temperature conditions are increasing, while there are declines in the conditions of solar radiation in particular areas of Kalimantan and Sumatera that indicate these regions vulnerability to climate change.

5. Acknowledgments

6. References

[1] Djojonegoro,W., 1992, Pengembangan dan penerapan energi baru dan terbarukan, Lokakarya "Bio Mature Unit" (BMU) untuk pengembangan masyarakat pedesaan, BPPT, Jakarta.

[2] Badan Pusat Statistik[BPS] . 2010. Sensus Penduduk 2010. BPS, Jakarta.

[3] Indonesia energy outlook & statistic 2006. Depok, Indonesia: Energy Reviewer, University of Indonesia; 2006

[4] IEA, "World Energy Outlook 2004", International Energy Agency, Paris, IEA/OECD, 2004

[5] Kadir MZAA, Rafeeu YA. Review on factors for maximizing solar friction under wet climate environment in Malaysia. Renewable & Sustainable Energy Reviews 2011, doi:10.1016/ j.rser.2010.04.009

[6] Solangi KH, Islam MR, Saidur R, Rahim NA, Fayaz H. A review on global solar energy policy. Renewable and Sustainable Energy Reviews 2011;15:2149–63.

[7] Intergovernmental Panel on Climate Change (IPCC) (2007). Climate Change 2007: Mitigation. Contribution of Working Group III to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change. Cambridge, United Kingdom and New York, NY, USA, IPCC.

[8] IPCC 2011, Special Report on Renewable Energy Sources and Climate Change Mitigation

[9] KESDM, 2015, Perkembangan Penyediaan dan Pemanfaatan Migas Batubara Energi Baru Terbarukan dan Listrik, ISBN : 978-602-0836-15-7, Desember 2015

[10] ADB, Summary of Indonesia's energy sector assesment, No 09, ADB papers on Indonesia, 2015

[11] Dewan Energi Nasional(DEN), Outlook energi Indonesia 2016, ISSN 2527-300, Jakarta November 2016

[12] SRIRAMA,2017, http://srirama.sains.lapan.go.id/srirama

[13] Mc GREGOR JL and DIX MR (2008) An updated description of the Conformal-Cubic Atmospheric Model. In: Hamilton K and Ohfuchi W(eds.) High Resolution Simulation of the Atmosphere and Ocean. Springer Verlag. 51-76.

[14] Oscar, A. Silva,W. Ruffato, V. (2015) Evaluation of Renewable Energy Vulnerability to Climate Change in Brazil: A Case Study of Biofuels and Solar EnergySmart Grid and Renewable Energy, 2015, 6, 221-232 Published   Online   August   2015   in   SciRes.   http://www.scirp.org/journal/sgre http://dx.doi.org/10.4236/sgre.2015.68019