Jagannath University Journal of Life and Earth Sciences, **4**(2): 154 – 163, 2018 ISSN 2414-1402

A PROJECTION HOW TO REDUCE GLOBAL WARMING TO 1.5 °C BY 2100

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Abstract

Presently, global warming has become a topical issue among all stakeholders. Consequently, efforts are being made at the global level to keep global temperature increase well below 2 °C and to pursue an effort to limit it to 1.5 °C. I tried to find out the best possible mitigation measures to reduce CO_2 emission and concentration by 2100. My proposed model suggested a reduction of 49% CO_2 emission in comparison to that of A1B scenario by the first half of 21st century by using renewable energy technology. For the second half of the 21st century, Geoengineering technology (option two) has been considered to remove about 41% CO_2 from the atmosphere in comparison to the A1B scenario. This option can also reduce the radiative forcing by stabilizing temperature changes to 1.5 °C from pre-industrial level. It would help policy makers to take effective steps considering different conditions of technological maturity in different periods.

Key words: Global warming, mitigation, renewable, geoengineering, radiative forcing

Introduction

Burning of fossil fuels emits CO_2, which is the dominant greenhouse gas (GHG) for global warming (IPCC, 2007). In contrast to fossil fuel, renewable energy (RE) is the panacea for solving the climate impact (Shafiullah, *et al*., 2012). Renewable energy includes solar power, hydropower, wind power, biomass, ocean power, geothermal, nuclear power, etc. (Destouni & Frank, 2010). Study found that it is possible to supply 100 percent world's energy from the wind, water, and solar power by 2030 (Jacobson & Delucchi, 2009). Moreover, RE ensures social, economic, and environmental benefits worldwide, although it is more expensive than traditional fossil fuel (Akella *et al*., 2009). However, according to International Renewable Energy Agency (IRENA, 2013), the cost of RE continue to drop. Therefore, for the sustainable future, clean energy technologies become the best possible ways to tackle climate change (IEA, 2015).

Although clean technologies can reduce CO_2 emission, there is still need to reduce the concentration of CO_2 from the atmosphere (Pires, *et al*., 2011). This is because, CO_2 ratio will continue to grow until the corresponding equilibrium is reached even after the emission will be stopped (Sonnemann & Grygalashvyly, 2013; Allen, *et al*., 2009). Besides, CO_2 stays longer in the atmosphere with a lifetime of about 200 years (IPCC, 2007). Carbon cycle feedbacks also continue to increase the emission of CO_2 naturally, thereby contributing to the rising radiative forcing (RF) (Cox, *et al*., 2000). Geoengineering is the best way to stabilize CO_2 concentration in the atmosphere (Wigley, 2006). There are two options in using geoengineering (Wigley, 2006;

Lenton & Vaughan, 2009; Vaughan & Lenton, 2011; Buck, 2012). They are: shortwave options to limit solar radiation and long wave options to modify carbon cycle (Moore, *et al*., 2010). Shortwave options rectify future radiative imbalance by reducing the amount of solar radiation absorbed by the Earth called solar radiation management (SRM) (Vaughan & Lenton, 2012). But most SRM options, such as injecting sulphuric aerosol into the atmosphere, are considered more risky and have to be continually replenished because if deployment is suddenly stopped, it could result to extreme rapid warming (Kosugi, 2013). On the other hand, long wave options can decrease RF mainly by removing CO_2 from the atmosphere called carbon dioxide removal (CDR) (Vaughan & Lenton, 2012). CDR measures are time-dependent to take effect and safer than SRM (Buck, 2012). CDR includes many measures such as carbon capture and storage (CCS), afforestation and reforestation, phosphorus addition to the ocean, wave upwelling, biochar, enhanced weathering of carbonate and silicate rock etc., in other words, the enhancement or creation of land and ocean carbon sinks (Lenton & Vaughan, 2009).

This study proposes a projected model limiting the global warming to 1.5 °C by the end of 21st century with the following assumptions; (a) CO_2 emission would peak by 2030 but the increasing rate would be decreasing over the years (b) from 2015 to 2030, a notable deployment of renewable energy technology would occur, (c) CO_2 emission would be reduced by 35% from the year 2030 to 2055 using renewable energy, and then the emission rate would be stable up to 2100, (d) geoengineering technology deployment would take place and its acceptability would be increased by 2050, (e) there would be rapid economic growth in all regions, (f) world population would rise up to 9 billion in 2050 then decline afterwards, (g) after the year 2050, geoengineering long wave options would contribute in reducing CO_2 concentration by 41% and RF by 63% in comparison to the A1B scenario, (h) emphasis would be given to RE technology, CCS, afforestation, and reforestation, with other effective possible green options, (i) no particular measure would be able to rectify global warming, rather a hybrid of many possible options can help out.

The new model places emphasis on renewable energy (specially on solar, wind and hydropower) for the first half of the 21st century to reduce the emission and then on the geoengineering option two (specially on CCS and afforestation and reforestation) as CDR is less risky than SRM (Vaughan & Lenton, 2011), for the second half of the century to reduce the CO_2 concentration and RF value. Thus, both emission and concentration of CO_2 are considered for this model. This paper also examines three scenarios (A1B, A1FI, and B1) out of forty SRES scenarios to compare different economy, energy source, and technologies with the proposed one.

This research would be helpful to calculate the actual amount of global CO_2 emission that has to be reduced per year. It also shows the guideline how to achieve the target emission of 6.6 PgC (Petagrams of Carbon) per year by 2100. In addition, it shows how we can limit temperature change to 1.5°C from pre-industrial period reducing about 2.8 Wm^{-2} radiative forcing relative to A1B scenario. All these would contribute to global policies on the mitigation of global warming.

Material and Methods

A simple climate model has been used in this study to make global temperature projection based on the GHG emission, concentration and forcing effect by 2100. Three SRES scenarios (out of forty) have been observed to understand the relationship and timing between CO_2 emission, concentration, and their forcing effect for future projections. Besides, other forcing effects and different feedback parameters have been examined to understand the uncertainty of the projection. Scenario A1B, A1FI, and B1 have been chosen because the first two varies based on energy sources and the third one mainly emphasizes on clean and resource efficient technologies. Assuming the feedback parameter Y = 1.3 $Wm^{-2}K^{-1}$, because of inherent uncertainty, it is seen that all these three scenarios show the future temperature beyond the limit agreed by Paris Agreement which is well below 2°C and to pursue efforts to limit it to 1.5°C. For this reason, a new model was developed to limit the temperature to 1.5°C by 2100. This model places emphasis on reducing CO_2 emission, atmospheric CO_2 concentration, and the radiative forcing by using clean technology and geoengineering, while letting the other forcing "on".

Results and Discussion

The new model calculates peak emission up to 2030 and then reduction of CO_2 emission by 2050 (Figure 1a). After 2050 the CO_2 emission would be kept stable (Figure 1a) and the CO_2 concentration would be reduced gradually by removing CO_2 from the atmosphere until 2100 (Figure 1b). RF factor is considered as crucial matter in regulating temperature change, would be kept near to 1.6 Wm^{-2} by 2100 (Figure 1c). Table 1 shows the comparison between three observed scenarios to examine how the model changes with the timescale. Due to the uncertainty of climate feedbacks (shown in Figure 3), the Y value is kept 1.3 $Wm^{-2}K^{-1}$ for the new model. Both anthropogenic and natural forcing kept "on" while developing new proposed model, which is shown in Figure 2b as total RF. A new temperature plot has been made (Figure 2a) considering all above driving forces for temperature change. Therefore, this section has been divided into four parts: (a) CO_2 emission reduction; (b) atmospheric CO_2 removal (c) radiative forcing (d) temperature change.

CO_2 Emission Reduction

Kyoto protocol budgeted cumulative CO_2 emission at 1500 Gt CO_2 equiv.(408.72 PgC) by 2050 (Meinshausen, *et al*., 2009). Rationally, the proposed model limits the cumulative CO_2 emission about 943.02 PgC by 2050 considering gradual reduction instead of rapid reduction of emission, which becomes infeasible (Vuuren, *et al*., 2013). In this model, CO_2 emission would be increased at a rate of 0.116 PgC per year between 2015 and 2020. This rate is 25% less than the A1B emission scenario (Figure 1a). After 2020, the emission would increase until 2030 at the rate of 0.077 PgC per year, which is 50% less than the A1B. At the end of 2030, the emission would be 12.05 PgC per year which is 49.62% less compared to A1B. After 2030 the emission rate would be decreased at 0.218 PgC per year up to the next 25 years which is 35% less from the peak emission, and the emission reaching 6.6 PgC per year in 2055. For the next 45 years, the emission would be stable at 6.6 PgC per year (Figure 1a) up to 2100. It is mentionable that the CO_2 concentration in the atmosphere would be increasing even if emission were reduced (Table 1) and stable at a certain point. The emission reduction would be possible by the deployment of renewable energy technology in a rapid growing economy reducing the dependency on fossil fuel. In comparison to the other scenarios, the model emission would be stable at the second half of the 21st century and continue to emit at a minimal level because negative emission is very uncertain (Vuuren, *et al*., 2013). From the analysis of the emission trend, it is hardly possible to continue reduction to zero emission which is seemed for A1B and B1 scenarios in Figure 1a. Fig1a shows that CO_2 emission line is declining fastest in the case of B1 scenarios because of the use of clean and efficient technology. A1B also declines but not as fast as B1 because of it uses balanced energy source. On the other hand, A1FI is heavily dependent on the use of fossil fuel, thereby, the emission does not decrease but has been slower the rate of emission after the middle of the 21st century because of demographic change, social and economic development, and new efficient technology (IPCC, 2000). It is also noticed that the emission value for A1B and B1 reaches the peak in the middle of the 21st century because of rising population though the values differ from each other. A1B emission value is greater than that of B1 value because A1B emphasis on balanced energy source while B1 rely on only clean technologies. After 2050, both A1B and B1 begin to decrease as a result of declining population. The B1 emission value goes lower than A1B because of increase in forest area and changes in agricultural land-use as demographic and dietary characteristics alter (IPCC, 2000). On the contrary, the A1FI emission value remains highest at the end of the 21st century because of continuing use of fossil fuel for energy.

Table 1. The peak values of CO_2 emission, concentration and forcing, their relationship and timing.

SRES scenarios	**Peak CO_2 emission* (PgC)**	**Year**	**Peak CO_2 concentration* (ppm)**	**Year**	**Peak forcing* $W.m^{-2}$**	**Year**
A1B	16.10	2050	651.38	2100	4.494	2100
A1FI	30.30	2100	807.59	2100	5.644	2100
B1	11.70	2050	567.78	2100	3.759	2100
Proposed Model	12.05	2030	432.49	2049	2.303	2049

*Values are showing for the projected A1B, A1FI, B1 and proposed model scenarios in Figure 1a, Figure 1b, and Figure 1c respectively

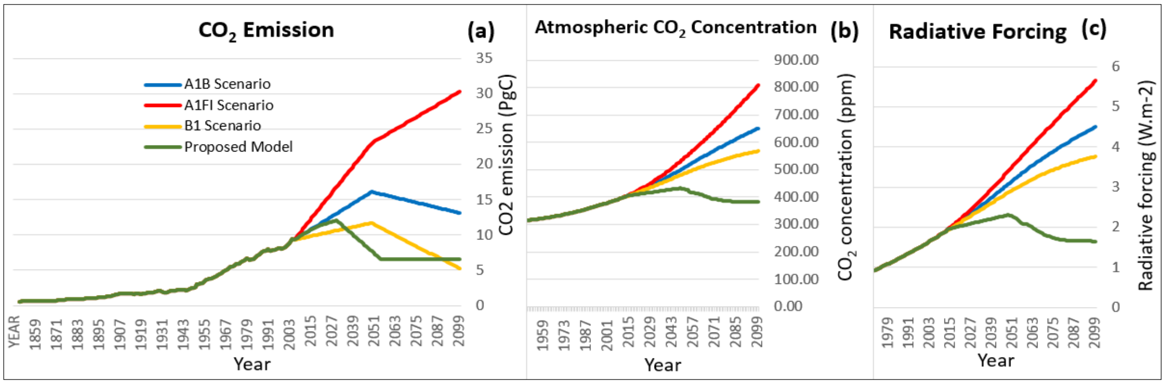

Figure 1. The CO_2 emission in PgC (Figure 1a); CO_2 concentration in ppm (Figure 1b); radiative forcing (RF) in $W\text{-}m^{-2}$ (Figure 1c), per year projected for A1B, A1FI, and B1 scenarios in SRES and a proposed model from 1850 to 2100. "Red" line indicates A1FI scenario; "blue" line indicates A1B scenario; "Yellow" line indicates B1 scenario; and "Green" line indicates a proposed model.

Atmospheric CO_2 Removal

The model shows that the CO_2 concentration would be rising up to the year 2049 at 432.49 ppm (Figure 1b), although the peak emission point would have been limited in 2030. Therefore, steps would be taken to remove CO_2 from the atmosphere by carbon capture, transfer, and storage in geology and increasing capacity of carbon sinks like forest, ocean, or land. By the end of the 21st century, the CO_2 concentration would be reduced to 11.5% than the 2049's concentration. This model assumes that after 2049, a deployment of geoengineering technology can tackle the climate change challenge by controlling the atmospheric concentration of CO_2. This work emphasizes on long wave geoengineering such as CCS and increasing natural carbon sink (forest) for removal of 41% CO_2 from that of the A1B scenario. Thus, it would be possible to reduce CO_2 from the atmosphere without changing the emission rate from 2050 to 2100 (Figure 1a). On the other hand, the CO_2 concentration and radiative forcing (RF) will continue to rise (Figure 1b & 1c) for all three scenarios till the end of 21stcentury, although the emission decreases in the A1B and B1 in the second half of the 21st century. The reason behind the continuation of rising atmospheric concentration of CO_2 is active carboncycle feedback loop and the lifetime of CO_2. The CO_2 concentration also increases the RF as well as the temperature.

Radiative Forcing

Figure 1c shows only CO_2 radiative forcing and Figure 2b shows the total of all forcing for the three scenarios and the proposed one. RF values would be reduced for the proposed model only by balancing CO_2 in the atmosphere because CO_2 is considered as the most important driving force of temperature changing. The RF would be increased or decreased by about 0.0133 Wm^{-2} along with addition or removal of 1ppm CO_2 respectively.

The RF also depends on other anthropogenic and natural sources. But in this paper, only CO_2 forcing is manipulated leaving the other forcing "on" as it is. It is clear that the RF line (green line in Figure 2b) and the model temperature change (red line in Figure 2a) show the resembling pattern and trend, which means that temperature anomaly completely, depends on RF. That is why, geoengineering technologies are being used to control forcing either by shortwave option or by long wave options. The new model assumes long wave options because these are not as risky as shortwave options (Moore *et al*., 2010).

Different RF line Figure 2b represents different economic scenarios. A1FI scenario derived from A1 family shows the highest RF, which is 7.75 Wm^{-2} at the end of the 21st century. In this scenario, the world depends more on fossil fuel for the source of energy. Another subgroup of A1 family is A1B where the source of energy does not rely only on fossil fuel but rather on a balanced use of all types of energy sources. Note that A1B and A1FI both show the same socio-economic condition. Therefore, the RF of A1B is 2.23 Wm^{-2} lower than that of A1FI. The B1 scenario is a bit different from the above two scenarios. B1 is more ecologically friendly and using clean and resource efficient technologies. This world also changes the land-use pattern by increasing forest area and changing agricultural practices because of changing food demand and dietary habit (IPCC, 2000). Consequently, the RF value stands at 4.35 Wm^{-2}, which is lower than the previously stated scenarios. So, it is clear from the different scenarios that the sources of energy play a very important role in increasing and decreasing RF values. And the world can reduce the forcing by (28.77-43.87) percent than the scenario A1FI by shifting energy consumption from fossil fuel to sustainable RE.

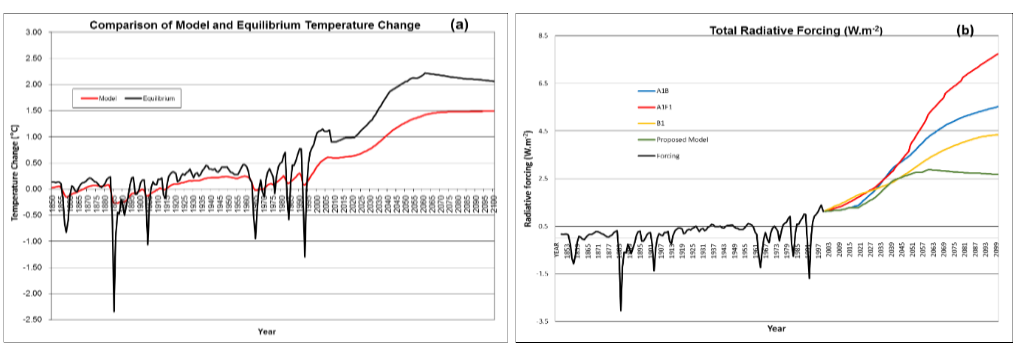

Figure 2. Proposed model projection of temperature change by 2100 shown in Figure 2a. The "red" line in Figure 2a represents the proposed temperature change model and the "black" line represents equilibrium temperature change. Figure 2b shows different RF for different scenarios.

Temperature Change

Based on the target, taken in COP21 climate summit, a new model has been proposed (Figure 2a) to limit temperature change to 1.5 °C by 2100 considering CO_2 and its radiative forcing as the main driving force in a rapid growing economy. As the world is experiencing the temperature around 1°C more than that of the reference (from 1850 to 1900) period (Met Office, 2015), it would not be allowed to increase the temperature more than 0.5 °C over the rest of the century. The temperature can be regulated only if total RF is to be confined around 2.7 Wm^{-2} by the year 2100. Therefore, the green and clean technology would be given priority with renewable and geoengineering options giving less priority on the burning of fossil fuels. As it is known that climate feedback parameter *Y* alter the temperature projections, the uncertainty varies between scenarios showing in Figure 3. The new model projection is made by fixing *Y* value at 1.3 $Wm^{-2}K^{-1}$ since the uncertainty of new model ranges in between 0.7 °C and 1.9 °C (Figure 3d) at the end of the 21st century. It is mentionable that during 20th century, the uncertainty was very unlikely below 1.5 °C and above 4.5 °C (Houghton, 1996; IPCC, 2013).

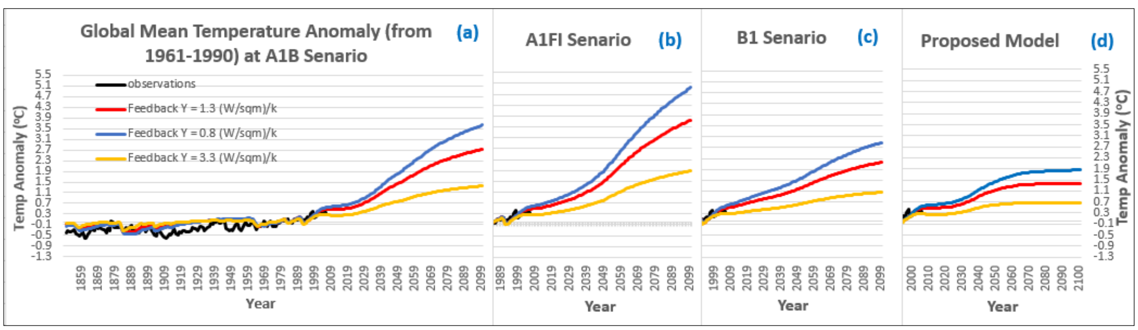

Figure 3. Indicates global mean temperature anomaly with respect to the 1961-1990 average in three different scenarios (A1B, A1FI, & B1) and a proposed model in terms of three different values of climate feedback parameter (*Y*). Figure 3a represents A1B scenario; Figure 3b represents A1FI scenario, and Figure 3c represents B1 scenario and Figure 3d represents a proposed model. "Blue" line is generated for *Y*= 0.8 $Wm^{-2}K^{-1}$; "red" line for *Y*= 1.3 $Wm^{-2}K^{-1}$; and "yellow" for *Y*= 3.3 $Wm^{-2}K^{-1}$.

Compared to the other scenarios, A1FI scenario shows the highest temperature anomaly (Figure 3b) in response to the climate feedback. Therefore, the uncertainty in the projection of A1FI is higher than A1B and B1 because of significantly high range and faster rate of temperature anomaly and RF compared to the previous history (Stott & Kettleborough, 2002). Although A1B, A1FI, and B1 scenarios show an upward trend of rising temperature from the beginning of the 21st century compared to the previous 20th century, proposed model also shows upward tendency for the first half of the 21st century then it tries to stabilize at a certain temperature in the later second half of the century. Thus, proposed model shows less uncertainty relative to other scenarios because of low radiative forcing. As climate feedback (*Y*) increases, the sensitivity decreases. Low sensitivity keeps the temperature anomaly lower. Figure 3 shows different pictures of temperature anomaly in different scenarios despite of having same feedback parameters. The reason behind these variations is having different radiative forcing.

Conclusion

The mechanism to combat the challenge of global warming requires controlling the key driving forces of temperature change. GHGs, certainly, CO_2 emission and concentration in the atmosphere, are the focus to mitigate climate change. It becomes a debate of current literatures that to what mitigation measures can be made CO_2 concentration less than a doubling of preindustrial concentration (Pacala & Socolow, 2004). In recent time, technological development and researches show the best potentiality in reducing CO_2 emission and concentration to tackle climate change. The proposed model tries to limit peak emission as early between the year 2015 and 2030. By this time, the development of RE technologies can be able to limit CO_2 emission at 6.6 PgC/year by 2055. This minimal level of emission can continue to the second half of the century assuming that the geoengineering options (mainly CDR) will have a greater development and deployment within the next 35-40 years. And then the emission will no longer be the concerning issue because CDR can control the ratio of CO_2 in the atmosphere. The controlled concentration of CO_2 will lower the forcing effect and uncertainty. Thus, the mechanisms proposed in this paper will keep the global temperature change not more than 1.5 °C from the reference period. This paper considered the different technological advancement in different periods of the century, may help the policy maker to take the necessary steps implementing locally, regionally, and globally where to suite.

Acknowledgement

The author acknowledges professor Piers Forster for his support to be able to develop the model successfully. Especial thanks to Caroline Prescott for all his assistance.

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