Global Warming: Review on Driving Forces and Mitigation

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Global warming is one of the major consequences of the human activities where the overuse of fossil fuels as energy resources caused the increase in the concentration of the greenhouse gases (GHGs), such as CO_2, CH_4, N_2O, and water vapor, in the atmosphere causing the increase in the average surface temperature of the earth. This article reviews the driving forces of global warming and highlights the major contributors to this phenomenon and presents some of the mitigation techniques. Water vapor is responsible for two-third of the global warming; however, CO_2 is considered as the controlling factor of the global warming. In other words, if the concentration of CO_2 did not increase, global warming would not have happened. Scientists claim that doubling or halving the CO_2 in the atmosphere causes the change in the average surface temperature of the earth by +3.8 °C or −3.6 °C, respectively. However, this amount of change depends on the change in the humidity of the air which in return depends on the air's temperature. Conversely, even though the other GHGs such as CH_4 and N_2O have stronger ability to absorb the radiation, their contribution in the global warming is insignificant because of their low concentration in the atmosphere compared with CO_2. The adoption of the mitigation and adaptation strategies at the same time is the most effective economic and technical solution for the global warming issue. © 2018 American Institute of Chemical Engineers Environ Prog, 2018

Keywords: global warming, greenhouse gases, water vapor, CO_2

INTRODUCTION

Global Warming and Greenhouse Gases

Global warming is defined as "the increase in the surface average temperature of the earth" because of the increase in the concentration of greenhouse gases (GHGs) such as water vapor, methane, ozone, carbon dioxide, chlorofluorocarbons (CFCs), and nitrous oxide [1]. Greenhouse effect is the main cause of being earth a suitable place to live on, without GHGs, the earth surface temperature would be too law and so no life will be on earth. However, the increase in the amount of GHGs in the atmosphere led to this catastrophic phenomenon, that is, the global warming [2].

The atmosphere of the earth consists of nitrogen, oxygen, and argon mainly and other gases in small quantities including GHGs and some pollutants as represented in Table 1. The percentage of the permanent gases (nitrogen, oxygen, and argon) does not change while the percentage of the trace gases (carbon dioxide, methane, nitrous oxides and ozone) changes daily, seasonally, and annually [3,4]. GHGs have the ability to absorb and reradiate infrared radiation because of the internal vibrational modes that their atoms have, unlike the other main components of the atmosphere [5].

Heat Retention Mechanism

The solar radiation spectrum consists of three wavelength ranges; ultraviolet range, visible range and infrared range and each range possess a portion of the solar energy. Figure 1 shows the components of the extraterrestrial solar radiation spectrum and the fraction of the solar energy in each range. Infrared waves carry almost half of the solar energy in the spectrum, most of these infrared waves are with high wavelength due to the sun surface temperature (5777 K) [5,6].

As the sun radiation goes through the atmosphere, minor portions of it get absorbed by the GHGs and reflected toward the space due to clouds and aerosols. Carbon dioxide and methane absorb the waves in the infrared region, while ozone absorbs the waves in ultraviolet region. Moreover, the absorption effect of water vapor is distributed throughout all the wave lengths [7]. The major portion of solar radiation hits the earth's surface and the terrestrial objects causing a rise in the temperature of these objects. As the earth's surface and terrestrial objects get warmer they radiate short-wave infrared radiation (due to their low temperature (277 K) compared with the sun) toward the atmosphere, which will be absorbed by GHGs [4]. Figure 2 shows the extraterrestrial and terrestrial wavelength spectrum and the characteristics of water vapor and carbon dioxide to absorb radiant energy at short-wave infrared region.

THE DRIVING FORCES OF GLOBAL WARMING

Natural Events

The climate of the earth has changed many times in the past with causes related to nature like the variation in the solar radiation emitted by the sun, the volcanic eruptions, and the variation in the incident solar radiation on earth due to Milankovitch cycle [8,9]. Milankovitch cycle is defined as a long-term cycle that occurs every 10,000 years, this cycle launches natural global cooling and warming by three causes: the eccentricity, the obliquity, and the precession. The eccentricity is defined as the change in the elliptical shape of the earth's orbit while the obliquity is defined as the change in the declination angle of the earth and the precession is defined as the wobble of earth's axis [10].

Table 1. The gas content of the earth's atmosphere [3,4].

Gas name	Percentage (%)
Nitrogen	78
Oxygen	21
Argon	0.9
Carbon dioxide	0.0935
Neon	0.004675
Helium	0.001299
Methane	0.000442
Nitrous oxide	0.000078
Ozone	0.00001

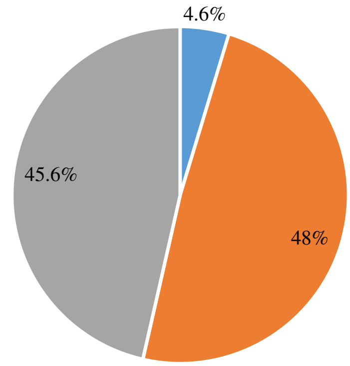

Figure 1. The fraction of the extraterrestrial solar radiation in each range of solar spectrum. [Color figure can be viewed at wileyonlinelibrary.com]

NASA satellites have been measuring the sun irradiation since 1978, the readings show a very slight drop in irradiance (the rate of energy emitted by the sun) over this period of time [11]. Long-term estimations were made to determine the effect of the variation of solar radiation; the results show that the change in the solar radiation could be responsible for not more than 10% of the 20th century warming. Moreover, if the warming is caused by the increase in solar activity the whole layers of atmosphere should be warmed, instead scientist observed a cooling pattern in the upper layers of the atmosphere and a warming pattern in the lower layers of the atmosphere [12].

Volcanic eruptions have a significant effect on the temperature of the earth; the eruptions carry gases and ash into the upper atmosphere; these gases, especially sulfuric gases, help in the formation of clouds causing the reduction of the global temperature for 3 years. In addition, volcanoes emit large amounts of carbon dioxide and water vapor, which contributes in the global warming; however, the amount of carbon dioxide and water vapor emitted by the volcanos is very small compared to human emissions [13,14]. Volcanos emit an annual average between 130 and 230 million tons of carbon dioxide while mankind causes annual emissions of 26 billion tons of carbon dioxide (100 times more than volcanos) [15,16].

Natural events are still acting but with too small and slow influence on the climate compared with human activity influence. Scientist developed climate models based on data from satellites and from ground stations to recreate temperature models over the past 150 years to proof that human activities are the main influence on the climate. The simulations of the model were able to fit the global temperature observations by considering only the solar natural variability and the volcanic emissions for the period between 1750 and 1950, but after 1950, the global temperature trends cannot be explained without considering the GHGs added by mankind [15,16]. Figure 3 shows the ensembles between the global observed temperature anomalies and the simulated ones by considering only the natural causes and by considering both natural and anthropogenic causes.

Anthropogenic Emissions

Water Vapor

Water vapor is considered as the most abundant gas in the atmosphere and it is considered as an important element that gives feedback about the climate and so about global warming. Water vapor is responsible for two-third of the global warming; the amount of additional warming in the atmosphere is determined by the amount of water vaper that enters the atmosphere. The atmosphere currently maintains a constant equilibrium between temperature and water vapor concentration due to the short lifecycle of water vapor. However, as the temperature continue to increase the balances will be lost and will increase the global warming where water vapor has the ability to double the warming caused by carbon dioxide [9,16].

Water vapor can also affect the global warming in an indirect way; when the climate gets warmer the percentage of water vapor increases in the atmosphere, which increases the possibility of forming clouds [11]. Clouds play an important role in cooling or even warming the planet, brighter clouds reflects the solar radiation to space and by that they help in cooling the planet. Conversely, clouds have the ability to absorb and emit energy in the infrared region where low clouds have approximately the same temperature of earth surface and so they emit almost the same amount of infrared energy. While high cold clouds absorb the energy coming from the lower atmosphere and due to their low temperature, the amount of energy emitted will be low which means that high clouds will reduce the ability of earth to cool and so cause the increase in the earth's temperature [9,16].

Carbon Dioxide

Carbon dioxide concentration has increased in the atmosphere by 30% since 1950, which is a significant increase. This increase was caused most likely by human's activities. Figure 4 shows the global change in the concentration of carbon dioxide through the history until 2013. Humankind depends mainly on fossil fuel to produce energy where burning these fuels produces different amount of carbon dioxide, water vapor, and nitrous oxides depending on the fossil fuel type. Coal, natural gas, and oil are the most common types of fossil fuel that are used by humankind where in 2015, it was reported that 45% of CO_2 emissions came from coal burning, 35% from oil burning, and 20% from natural gas burning [17].

Humankind not only increased the amount of carbon dioxide but also disrupted the carbon dioxide cycle in the nature by overcutting the forests. The deforestation will cease the absorption of carbon by trees and so carbon dioxide concentration will increase in the atmosphere where 25–30% of the yearly emitted GHGs is because of deforestation. In addition, 50% of the trees is carbon and burning these trees will release the carbon stored in the trees as CO_2 which will exacerbate the consequences of the deforestations [18].

Carbon dioxide needs hundreds of years (5–200 year) [16] to adjust and achieve the balance and as the percentage of carbon dioxide increases, the balance will happen at higher temperature and at higher water vapor levels. Therefore, scientists believe that carbon dioxide behave as controlling factor rather than reacting factor, as it controls the amount of water vapor carried by the atmosphere [2]. Doubling or halving the carbon dioxide in the atmosphere causes the change in the earth's

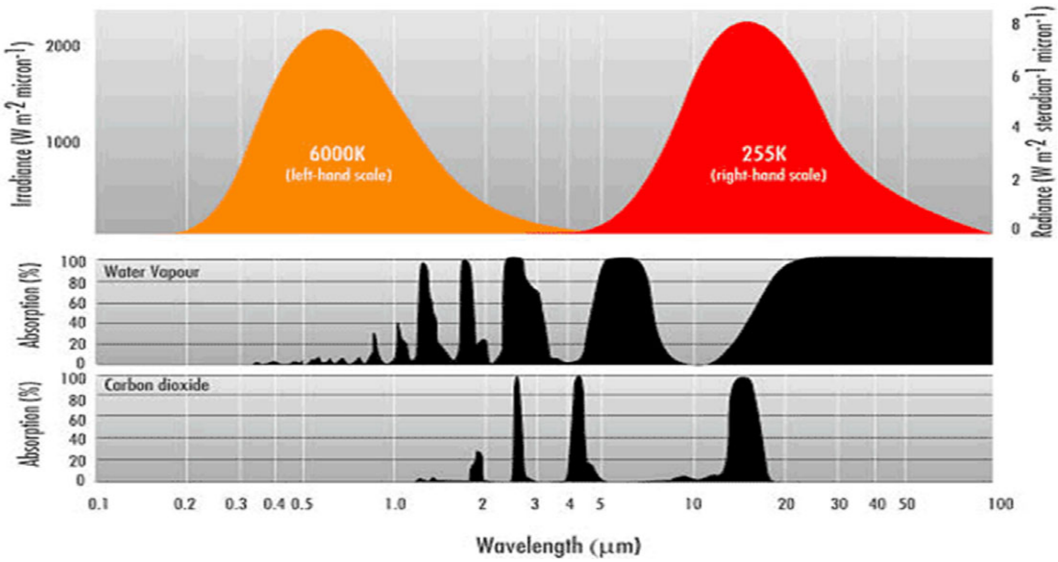

Figure 2. Water vapor and carbon dioxide absorption characteristics of the radiation. Reproduced by permission of Bureau of Meteorology, © 2018 Commonwealth of Australia. [Color figure can be viewed at **wileyonlinelibrary.com**]

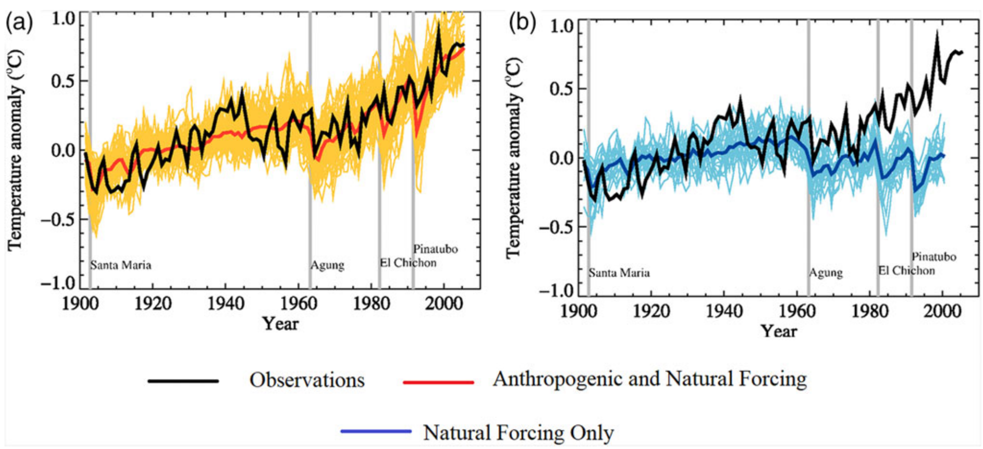

Figure 3. The ensembles between the global observed temperature anomalies and the simulated ones by considering only the natural causes and by considering both natural and anthropogenic causes. Reproduced from: Solomon, S., Qin, D., Manning, M., Marquis, M., Averyt, K., Tignor MMB., et al (2007). Climate Change 2007: The Physical Science Basis. Contribution of Working Group I to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change. [Color figure can be viewed at **wileyonlinelibrary.com**]

temperature by +3.8 °C or −3.6 °C respectively. However, the amount of the change in the earth's temperature—caused by the change in the carbon dioxide concentration—depends on the change in air humidity which in return depends on the air temperature [19,20].

Methane

The second largest anthropogenic contributor to global warming is methane emissions, the amount of methane emissions have increased by more than the double over the last 150 years [21] where it is reported that almost 60% of methane emissions comes from human activities. Anthropogenic methane can be released into the atmosphere during the extraction, production, transportation, refining, and the distribution of natural gas (methane is a primary component). Moreover, significant amounts of methane come from livestock, agriculture, human waste, and from landfills [22]. Table 2 shows the percentage of methane produced globally by different human activities between 2003 and 2012.

Methane molecule has the ability to absorb and reradiate the energy 10 times more effective than the carbon dioxide molecule. However, scientist usually focus on the total levels of the emissions instead of the intensity in their analyses where the concentration of carbon dioxide is approximately 200 times more than methane and also the lifetime of carbon dioxide is much bigger than the atmospheric methane [24,25] (methane life time is 12 years) [16].

Nitrous Oxide

Human Activities such as fossil fuel combustion, agriculture, industrial processes, and wastewater management are responsible for about 40% of the total N_2O emissions [25], Figure 5 shows the global N_2O emissions by sector in 2010. If the trends of N_2O increase continue, the N_2O emissions are

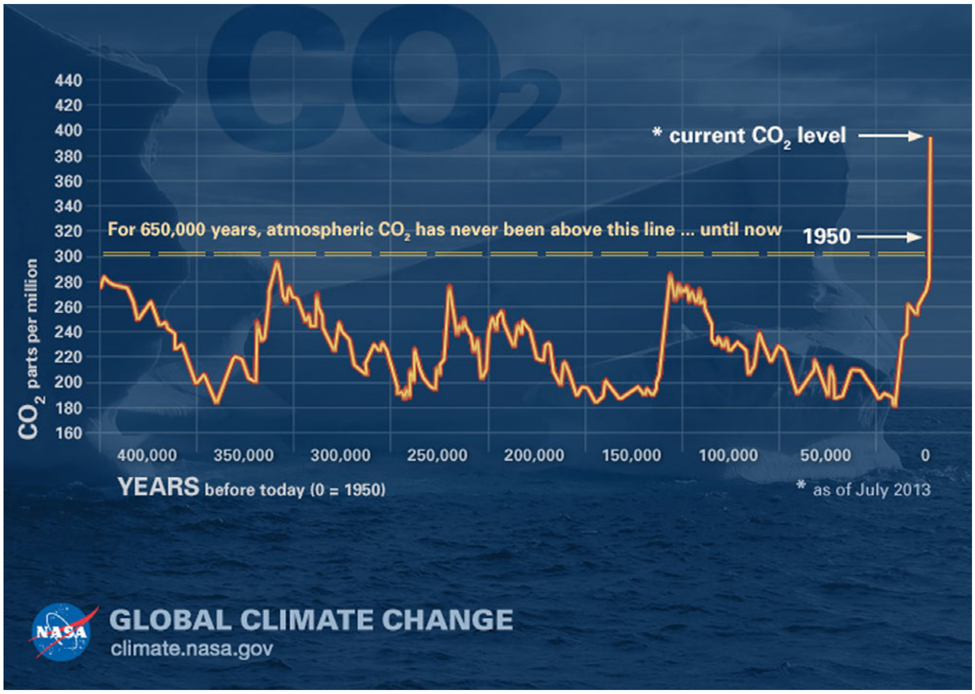

Figure 4. The concentration of carbon dioxide in the atmosphere. Reproduced from: *Climate change: How do we know?* NASA Global Climate Change Center, **https://climate.nasa.gov/evidence/**. [Color figure can be viewed at **wileyonlinelibrary.com**]

Table 2. Global methane emissions by human activities between 2003 and 2012 [23].

Sources	Percentage (%)
Agriculture and waste	37.08
Wetlands	34.83
Oil and natural gas	16.61
Coal	7.87
Biomass burning	5.62

predicted to be 25.7 Tg N_2O/year by 2100 which will cause an increase in the surface average temperature by 0.37 °C [27]. N_2O stays approximately 114 years in the atmosphere and it is removed as a part of the nitrogen cycle by certain bacteria or destroyed by chemical reaction or by ultraviolet radiation. N_2O has the ability to warm the atmosphere almost 300 times more than CO_2 (1 to 1 base); however, the concentration of N_2O is much smaller than CO_2 [25].

THE CONSEQUENCES OF THE INCREASE IN THE CONCENTRATION OF GHGS

Temperature Rise

After the industrial revolution the temperature of the earth's surface began to increase; scientists at Goddard Institute for Space Studies (GISS) say that since 1880, the earth's surface average temperature has increased by about 0.8 °C. NASA, NOAA, the Japan Meteorological Agency and the Met Office Hadley Centre in United Kingdom recorded the annual temperature anomalies from 1880 to 2014, all the records show the same trend (peaks and valleys) with different values [28], as shown in Figure 6.

Earth's average surface temperature will continue to rise as humankind continues his environmentally harmful activities specially burning fossil fuel. Based on three CO_2 emissions scenarios, scientists predict that the average surface temperature will increase by 2–6°C by the end of 21st century [9], as shown in Figure 7. Plants, crops, and animals need specific conditions to survive and grow including the suitable ambient temperature and enough amount of water where the increase in the global temperature will disturb the growth and the breed of these creatures. Moreover, the increase in the global temperature will lead to increase the intensity and the spread of extreme weather events such as droughts, hurricanes, heat waves, and floods [29], which will increase the number of human and material casualties. In addition, as the climate get warmer the snow and the ice melts down causing not just the sea level to increase but also the transformation of sunlight reflecting surfaces (snow surfaces) to sunlight absorbing surfaces which will causes more energy to be trapped in the earth atmosphere [9].

Oceans and Marine Life

Half of the anthropogenic CO_2 has been absorbed with the time by oceans which reduces the warming of the climate; however, this causes a serious change in the chemistry of the water. When carbon dioxide dissolves in water, carbonic acidic is formed which will cause a drop in the surface water's pH. Over the past 300 million years, oceans' water tends to be slightly basic with approximately pH of 8.2, but today it is around 8.1, this drop represents 25% increase in the acidity over the past two centuries and this change in the water's pH will affect the life cycle of many marine creatures [30].

Moreover, almost 80% of the heat trapped because of greenhouse gases is absorbed by oceans causing the rise in the water's temperature and so the expansion of water. Scientists say that about half of the rise in water level in the past century is due to the thermal expansion. Sea level has been rising at a rate of 0.14 in. per year since 1990 where this increase is mainly caused by thermal expansion of water. Furthermore, as the climate get warmer, the snow and the ice will melt down causing sea level to increase [9,31]. Scientists expect that by 2100 sea level will rise between 0.8 and 2 m which mean thousands of coastal cities and islands will be demolished and storm surges will be more powerful [32].

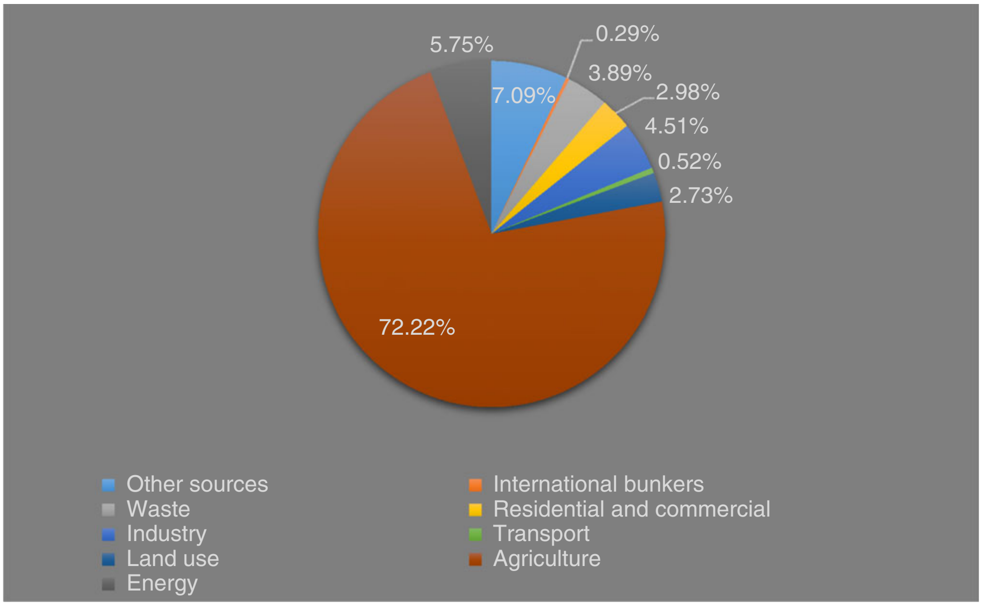

Figure 5. Nitrous oxide global emission by sector in 2010 [26]. [Color figure can be viewed at **wileyonlinelibrary.com**]

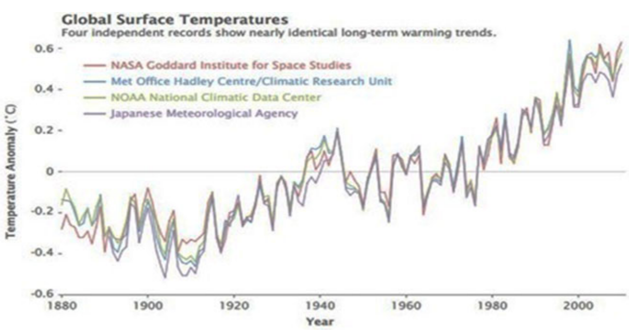

Figure 6. The annual anomalies in average surface earth temperature between 1880 and 2014 from four independent records. Reproduced from: *World of Change: Global Temperatures,* Simmon, *R.,* NASA Earth Observatory Center, **https://earthobservatory.nasa.gov/WorldOfChange/decadaltemp.php**. [Color figure can be viewed at **wileyonlinelibrary.com**]

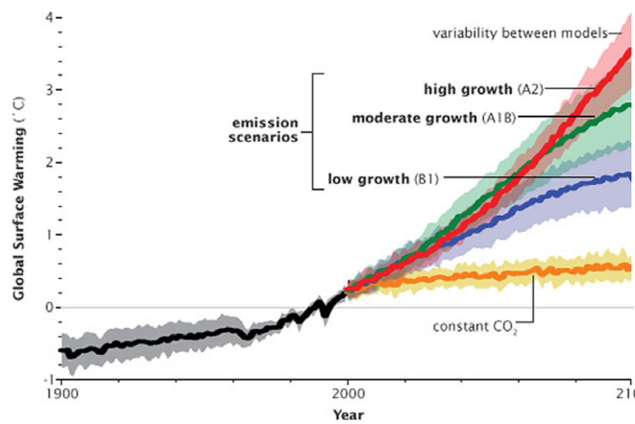

Figure 7. IPCC estimation for the average surface temperature rise based on the rate of CO_2 emissions. Reproduced from Solomon, S., Qin, D., Manning, M., Marquis, M., Averyt, K., Tignor MMB., et al (2007). Climate Change 2007: The Physical Science Basis. Contribution of Working Group I to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change. [Color figure can be viewed at **wileyonlinelibrary.com**]

The increase in water's temperature will not affect only the thermal expansion of the water but also will affect the marine life where as the oceans become warmer the percentage of dissolved oxygen will be reduced which will cause the death of many species. Coral bleach is one of the most dramatic effects of global warming, the increase in the water temperature will cause the death of the algae that lives inside the coral; these algae provides the coral with the food and the death of them means the death of the coral [33,34].

Extreme Weather Events

Storms and Hurricanes

The temperature difference between the equator and the poles fuels the formation of mid-latitude storms and the decrease in this temperature difference by the global warming could affect the formation of the storms. As the temperature of the atmosphere increases, the ability of it to carry water vapor will increase causing humidity to increase where at the poles the humidity and the temperature are low and any increase in water vapor and heat could raise the temperature in a great way. On the other hand, in the equator, the temperature and the humidity are already high and the change in them will not be high; thus decreasing the temperature difference which will decrease the number of storms; however, the increase in the moisture captured in the atmosphere will increase the intensity of these storms [15,35].

Global warming could also affect the formation of tropical storms and hurricanes where the formation of tropical storms is driven by the sea surface's temperature and the air's humidity. Global warming increased the ability of atmosphere to hold moisture and also increased the temperature of the seawater surface, which will increase the intensity of these storms and the possibility of forming hurricanes by increasing the wind speed of these storms. The temperature of the surface seawater was increased by 0.3 °C since 1980 [34], also air humidity has increased about 4% since 1970 [19] which could

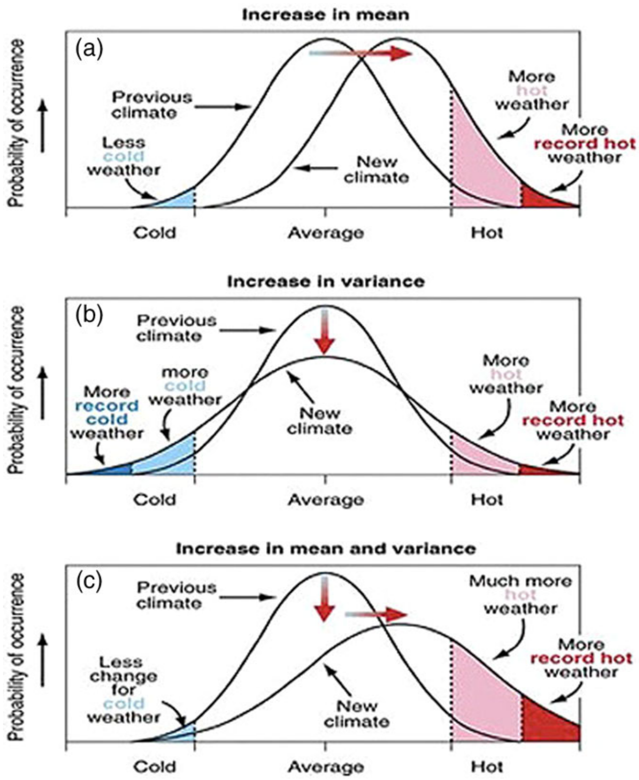

Figure 8. The effect of the average global temperature on the occurrence probability of extreme weather. Reproduced from: Houghton, JT., Ding, Y., Griggs, DJ., Noguer, M., Linden, PJ van der, Dai, X., et al. (2001). Climate Change 2001: The Scientific Basis. Contribution of Working Group I to the Third Assessment Report of the Intergovernmental Panel on Climate Change. [Color figure can be viewed at **wileyonlinelibrary.com**]

increase the hurricanes wind speed by 1 knot according to hurricane intensity models. However, this cannot be verified at the present because the intensity of hurricanes is measured with an accuracy of ∓5 knot and so the difference will not be noticed [34].

Precipitations, Droughts, and Floods

The intensity and the geographic pattern of precipitation have significantly changed in the past 40 years where dry regions have become drier and wet regions have become wetter; however, the total precipitation of the world has slightly changed. Global warming is responsible for these changes where the increase in the atmospheric temperature increased the ability of the atmosphere to hold moisture. As the moisture content in the atmosphere increases, the potential of producing heavier precipitation will increase; however, these precipitations events become shorter and less frequent because it need more time to refill the atmosphere with moisture [35–38].

During the 20th century, the frequency of great floods has increased substantially, the heavy precipitations over a short period of time contributes to the increase in the floods around the world. The ability of soil to soak up the water in the case of heavy precipitation will be low, which will increase the amount of runoff water causing floods also regions near water bodies will witness floods due to the rise in the water's level [38–40].

Since the 1950s, drying trends have been observed in the southern and northern hemispheres and since 1970s, the extent of very dry areas across the world have doubled. Climate models cannot explain these trends and extensions without the effect of global warming where global warming is affecting the factors that cause the increase in droughts, such as the shift in the precipitations trends from moderate and light rains to short and heavy precipitations as well as the early snow melt and the increase in the evaporation rate from vegetation and soil [41–43].

Heat Waves

Heat waves are defined as prolong periods of hot weather where such events have significant effects on human health where the exposure to high temperature for a long period causes serious health issues such as fainting, heatstroke, and clams [35,37,44]. Heat waves used to be extremely unique where in the period between 1951 and 1980 extremely hot temperatures affected only 0.1% of the world but after 1980 the extreme heat events have become more prevalent. Heat waves currently affect approximately 10% of the world and it could affect 17% of the world after one decade if the warming continues [38,45]. As the average global temperature increases, the climate will shift toward warmer climate causing more record of extreme weather as shown in Figure 8 [16] where the mean in the graph is the average temperature and the variance is the spread of the temperature around the mean.

GLOBAL WARMING MITIGATION AND ADAPTATION

There are three strategies to deal with the climate change; the first one is to do nothing and continue to increase the amount of greenhouse gases in the atmospheric, which will lead to the extinction of life on earth. The second strategy is the mitigation of climate change by reducing the amount of anthropogenic greenhouse gases and the third strategy is the adaptation to climate change by developing techniques and ways that will reduce the impact of climate change [39]. Figure 9 shows a schematic diagram for the cost of mitigation, adaptation, impacts, and the inter-relationship between the three strategies.

As shown in Figure 9, the adoption of one strategy has the highest cost where no action strategy has a high cost because of the unpreparedness to face the increasing impacts of the climate change while mitigation strategy means cleaning up the extra greenhouse gases from the atmosphere which is very expensive and unlikely to happened. Conversely, the adaptation strategy means the continuous development of protective techniques to face the increasing impacts of climate change. However, the combination of the adaptation and mitigations strategies will have an optimal cost; reducing the greenhouse emissions to certain limit will make the adaptation strategy less costly because the impacts of climate change will be reduced [39,46].

Intergovernmental Panel on Climate Change (IPCC) defines the adaptation as "the adjustment in nature or human systems in response to actual or expected climatic stimuli or their effects, with moderates harm or exploits beneficial opportunities" [21]. The adaptation of humankind to climate change can happen in different ways like the adaptation driven by the change in government policies and the adaptation driven by the technological advance. However, the adaptation is limited by financial, technological, and social factors; in addition, humankind may have the ability for the climate change adaptation in a short-term using different techniques while many other species may not have the short-term adaptation. The resilience of species to the climate change requires long time so that they can adapt to these changes, which makes the adaptation alone not an effective solution. Building dams at rivers and coasts to prevent the floods and protect the coastal cities from the rise of sea water level is an example of one of the adaptation techniques [39,46,47].

While mitigation is defined by IPCC as "an anthropogenic intervention to reduce the source or enhance the sinks of greenhouse gases" [21]. This can be done by two ways; the

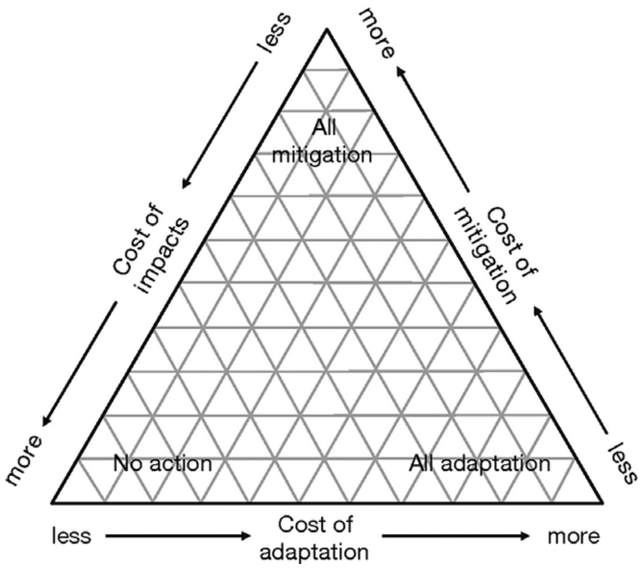

Figure 9. Schematic diagram for the interrelationship between the cost of the three climate change strategies; adaptation, mitigation, and no action. Reproduced from: Solomon, S., Qin, D., Manning, M., Marquis, M., Averyt, K., Tignor MMB., et al (2007). Climate Change 2007: The Physical Science Basis. Contribution of Working Group I to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change.

first one by stop emitting these gases from its sources, Table 3 shows different mitigation techniques to reduce or even stop the greenhouse emissions from different sectors. The second way is to develop techniques to absorb the greenhouse emissions from the atmosphere, for example, trees can absorb CO_2 from the atmosphere where planting trees will be a technique to reduce the amount of CO_2 in the atmosphere. The combination between the two ways is required, nowadays, as the transition to an alternative clean energy source or the prevention of greenhouse emissions is a long-term strategy [39].

As the carbon dioxide is considered as the controlling factor of the global warming, the efforts should be placed toward cutting the CO_2 emission and by the sequestration of these emissions. The sequestration of CO_2 emissions can significantly contribute in limiting the consequences of global warming; however such technologies are still unfeasible from economic point of view [48]. Cutting the CO_2 emissions seems to be the most attractive option accordingly to scholars as this technique is feasible and can be implemented all around the world [49]. Energy generation sector possesses significant potential in cutting the CO_2 emissions as this sector is responsible for almost 37.5% of CO_2 emissions [50,51]. Renewable energy resources such as solar and wind energy are abundant, suitable alternative for fossil fuels and can be utilized in affordable and feasible ways [48]. It was reported in Ref. [52] that renewable energy resources can play a vital role in cutting the CO_2 emissions where if the share of renewable energy in the electricity generation mixture increased by 2050 to 39%, it can reduce the CO_2 emissions by 50%. Moreover, the use of new technologies in the conventional power generation systems with higher efficiencies can contribute significantly in reducing the CO_2 emissions. For instance, the use of integrated gasification combine cycle in coal-fired power plant increases the thermal efficiency to almost 45% while the use of combined cycle gas turbine with natural gas increases the efficiency to about 60%. The use of such technologies can reduce the CO_2 emissions by up to 50% for each power generation unit [51].

Table 3. Different mitigations techniques to reduce the greenhouse emissions from different sources. Adapted from: Solomon, S., Qin, D., Manning, M., Marquis, M., Averyt, K., Tignor MMB., et al (2007). Climate Change 2007: The Physical Science Basis. Contribution of Working Group I to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change.

GHGs source	Mitigation technique
Energy generation	Increasing the efficiency of energy generation from the conventional energy resources; the transition to renewable energy resources instead of fossil fuels; and the use of early carbon capture technologies.
Transportation	Increasing the efficiency of vehicles in utilizing fuels; encouraging the use of hybrid cars; and providing a sufficient public transportation.
Buildings	The shift from regular building to the green building with more energy monitoring and the use of solar energy in cooling and heating the building in addition to heating the water.
Industry	Improving the use of heat and power recovery; encouraging the recycle of the materials and substitutions; and gas emissions control.
Agriculture	Improving the application techniques of nitrogen fertilizer to reduce N_2O emissions and improving livestock and manure management to reduce methane emissions.
Waste management	Increasing the recovery of CH_4 from landfills; controlling incineration of the waste with heat recovery; and recycling and minimizing the wastes.

GHGs, greenhouse gases.

Furthermore, the use of hybrid, electric and the bio-fuel powered vehicles plays a vital role in the reduction of the CO_2 emissions as the transportation sector is responsible for about 22% of the global CO_2 emissions. The use of such vehicles has a potential to decrease the CO_2 emissions by 300–700 Mt-C in 2020 [51,53]. Furthermore, improving the energy efficiency in buildings can contribute in cutting the CO_2 emissions by 950 Mt-C in 2020 as the building sector is responsible for almost 31% of the total CO_2 emissions. This amount of CO_2 emissions reduction can be achieved by enhancing the energy efficiency of the lighting, equipment, and appliances [51]. Heating, ventilation and air conditioning systems (HVAC) account for the majority of the energy consumption in the buildings [54] where the insulation of the building's envelope plays a vital role in this amount [51]. The use of variable refrigerant flow (VRF) HVAC systems can save significant amount of energy where in Ref. [55] they reported almost 82% reduction in the energy consumption in their case study by the use of VRF system instead of conventional ones.

Moreover, by improving the efficiency of the industrial process and the efficiency of the material used in the industry, it is possible to reduce the CO_2 emissions by 1300–1500 Mt-C in 2020 where the industrial sector is responsible for almost 43% of the global CO_2 emissions [51]. The improvement of the industrial process efficiency can be performed by the use of advanced technologies such as the waste heat recovery systems, which would significantly decrease the energy losses while the improvement of the materials' efficiency can be achieved by efficient product design and the adaption of reuse and recycling strategies [51].

CONCLUSION

This article reviews the driving forces of global warming and suggests the most probable cause of global warming based on the literature. Moreover, this article presents some of the techniques that can be adopted to mitigate the global warming phenomenon. Humankind activities are the main contributor to the increase in the GHGs in the atmosphere and so the major contributor to global warming. Natural events such as Milankovitch cycle and volcanic eruptions have too small and slow influence on the climate compared with the human activities influence.

Water vapor is responsible for two-third of the global warming; however, if the concentration of water vapor is only increased, the global warming will not happen. Water can evaporate and condense easily to maintain the equilibrium; however, as the concentration of other greenhouse gases increases specially CO_2, the atmospheric temperature increases which increases the ability of the atmosphere to hold more moisture causing the equilibrium to happen at higher temperature.

The possible actions toward the global warming are summed by three strategies: the no action, the mitigation, and the adaptation strategy. The no action strategy means the continuation of emitting GHGs and so it will have the largest cost which is the extension of life on earth. While the adaptation is the development of new techniques that reduces the impact of global warming and the mitigation is the reduction or even the prevention of GHGs emissions. The adoption of one strategy alone will have high cost while the adoption of both mitigation and adaptation at the same time will have the optimal cost and will be an effective solution for the global warming.

LITERATURE CITED

1. Venkataramanan, S. (2011). Causes and effects of global warming, Indian Journal of Science and Technology, 4, 226–229. **https://doi.org/10.17485/ijst/2011/v4i3/29971**.
2. Anderson, T.R., Hawkins, E., & Jones, P.D. (2016). CO2, the greenhouse effect and global warming: from the pioneering work of Arrhenius and Callendar to today's Earth System Models, Endeavour, 40, 178–187. **https://doi.org/10.1016/j.endeavour.2016.07.002**.
3. Composition of the Atmosphere | North Carolina Climate Office n.d. **https://climate.ncsu.edu/edu/Composition** (accessed May 19, 2018).
4. Khandekar, M.L., Murty, T.S., & Chittibabu, P. (2005). The global warming debate: A review of the state of science, Pure and Applied Geophysics, 162, 1557–1586. **https://doi.org/10.1007/s00024-005-2683-x**.
5. Oktyabrskiy, V.P. (2016). A new opinion of the greenhouse effect, St. Petersburg Polytechnic University Journal: Physics and Mathematics, 2, 124–126. **https://doi.org/10.1016/j.spjpm.2016.05.008**.
6. Duffie, J., & Beckman, W. (2006). Solar engineering of thermal processes. (3rd Edition), Hoboken, N.J: Wiley.
7. Pokorný, J., Kv⊠t, J., Rejšková, A., & Brom, J. (2010). Wetlands as energy-dissipating systems, Journal of Industrial Microbiology & Biotechnology, 37, 1299–1305. **https://doi.org/10.1007/s10295-010-0873-8**.
8. Roe, G. (2006). In defense of Milankovitch, Geophysical Research Letters, 33, 1–5. **https://doi.org/10.1029/2006GL027817**.
9. Riebeek, H. Global Warming : Feature Articles 2010. **https://earthobservatory.nasa.gov/Features/GlobalWarming/** (accessed May 19, 2018).
10. Campisano, C.J. (2012). Milankovitch cycles, paleoclimatic change, and hominin evolution, Nature Education Knowledge, 3, 5.
11. NASA. Global Climate Change: Vital Signs of the Planet n.d. **https://climate.nasa.gov/causes/** (accessed May 19, 2018).
12. Lockwood, M. (2009). Solar change and climate: an update in the light of the current exceptional solar minimum, Proceedings of the Royal Society of London. Series A, 466, 303–329. **https://doi.org/10.1098/rspa.2009.0519**.
13. Man, W., Zhou, T., & Jungclaus, J.H. (2014). Effects of large volcanic eruptions on global summer climate and east asian monsoon changes during the last millennium: Analysis of MPI-ESM simulations, Journal of Climate, 27, 7394–7409. **https://doi.org/10.1175/JCLI-D-13-00739.1**.
14. The Effect of Volcanoes on the Earth's Temperature n.d. **http://www.climatedata.info/forcing/volcanoes/** (accessed May 19, 2018).
15. Reibeek, H. The Rising Cost of Natural Hazards : Feature Articles 2005. **https://earthobservatory.nasa.gov/Features/RisingCost/rising_cost5.php** (accessed May 19, 2018).
16. Houghton, JT., Ding, Y., Griggs, DJ., Noguer, M., Linden, PJ van der, Xiaosu, D., Maskell, K.. & Johnson, CA. (2001). Climate Change 2001: The Scientific Basis. Contribution of Working Group I to the Third Assessment Report of the Intergovernmental Panel on Climate Change. Cambridge University Press: Cambridge, UK.
17. IEA IEA. CO2 Emissions from Fuel Combustion 2017 - Highlights. International Energy Agency 2017;1:1–162. doi: **https://doi.org/10.1787/co2_fuel-2017-en**.
18. Martin, A.R., & Thomas, S.C. (2011). A reassessment of carbon content in tropical trees, PLoS One, 6, e23533. **https://doi.org/10.1371/journal.pone.0023533**.
19. Manabe, S., & Wetherald, R. (1975). The effects of doubling the CO2 concentration on the climate of a general circulation model, Journal of the Atmospheric Sciences, 32, pp 3–15.
20. Held, I.M., & Soden, B.J. (2000). Water vapor feedback and global warming, Annual Review of Energy and the Environment, 25, 441–475.
21. Solomon, S., Qin, D., Manning, M., Marquis, M., Averyt, K., Tignor, MMB., & Miller, HL (2007). Climate Change 2007: The Physical Science Basis. Contribution of Working Group I to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change. Cambridge University Press: Cambridge, UK. doi:**https://doi.org/10.1017/CBO9781107415324.004**.
22. Environmental Protection Agency (EPA). Overview of Greenhouse Gases n.d. **https://www.epa.gov/ghgemissions/overview-greenhouse-gases#methane** (accessed May 19, 2018).
23. Fevre, C Le. (2017). Methane Emissions: From blind spot to spotlight, Oxford Institute for Energy Studies, Oxford.
24. Shaheen, S.A., & Lipman, T.E. (2007). Reducing greenhouse emissions and fuel consumption, IATSS Resarch, 31, 6–20. **https://doi.org/10.1016/S0386-1112(14)60179-5**.
25. Environmental Protection Agency (EPA) (2010). Methane and nitrous oxide emissions from natural sources, Environmental Protection Agency, Washington, DC.
26. Ritchie, H., & Roser, M. CO and other Greenhouse Gas Emissions 2018. **https://ourworldindata.org/co2-and-other-greenhouse-gas-emissions** (accessed May 19, 2018).
27. Kroeze, C. (1994). Nitrous oxide and global warming, Science of the Total Environment, 143, 193–209. **https://doi.org/10.1016/0048-9697(94)90457-X**.
28. Hansen, J., Ruedy, R., Sato, M., & Lo, K. (2010). Global surface temperature change, Reviews of Geophysics, 48, RG4004. **https://doi.org/10.1029/2010RG000345**.
29. Dosio, A., Mentaschi, L., Fischer, E.M., & Wyser, K. (2018). Extreme heat waves under 1.5°C and 2°C global warming, Environmental Research Letters, 13 (5), 54006.
30. Logan, C.A. (2010). A Review of ocean acidification and America's response, BioScience, 60, 819–828. **https://doi.org/10.1525/bio.2010.60.10.8**.

31. Vijayavenkataraman, S., Iniyanm, S., & Goic, R. (2012). A review of climate change, mitigation and adaptation, Renewable and Sustainable Energy Reviews, 16, 878–897. https://doi.org/10.1016/j.rser.2011.09.009.
32. Rohling, E.J., Haigh, I.D., Foster, G.L., Roberts, A.P., & Grant, K.M. (2013). A geological perspective on potential future sea-level rise, Scientific Reports, 3, 3461. https://doi.org/10.1038/srep03461.
33. Hughes, T.P., Kerry, J.T., Álvarez-Noriega, M., Álvarez-Romero, J.G., Anderson, K.D., Baird, A.H., et al. (2017). Global warming and recurrent mass bleaching of corals, Nature, 543, 373–377. https://doi.org/10.1038/nature21707.
34. Great Barrier Marine Park Authority. Coral bleaching 2014. http://www.gbrmpa.gov.au/managing-the-reef/threats-to-the-reef/climate-change/what-does-this-mean-for-species/corals/what-is-coral-bleaching (accessed May 19, 2018).
35. Easterling, D.R., Meehl, G.A., Parmesan, C., Changnon, S. A., Karl, T.R., & Mearns, L.O. (2000). Climate extremes: Observations, modeling, and impacts, Science, 289, 2068–2074. https://doi.org/10.1126/science.289.5487.2068.
36. Stott, P.A., Gillett, N.P., Hegerl, G.C., Karoly, D.J., Stone, D.A., Zhang, X., & Zwiers, F. (2010). Detection and attribution of climate change: A regional perspective, Wiley Interdisciplinary Reviews: Climate Change, 1, 192–211. https://doi.org/10.1002/wcc.34.
37. Climate Communication. (2011). Current Extreme Weather and Climate Change.
38. Coumou, D., & Rahmstorf, S. (2012). A decade of weather extremes, Nature Climate Change, 2, 491–496. https://doi.org/10.1038/nclimate1452.
39. Parry, M., Canziani, O., Palutikof, J., Linden, P van der, & Hanson, C. (2007). Climate Change 2007: Impacts, Adaptation and Vulnerability. Contribution of Working Group II to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change. Cambridge University Press : Cambridge, UK. doi:https://doi.org/10.1256/004316502320517344.
40. Trenberth, K.E., Dai, A., Van Der Schrier, G., Jones, P.D., Barichivich, J., Briffa, K.R., & Sheffield, J. (2014). Global warming and changes in drought, Nature Climate Change, 4, 17–22. https://doi.org/10.1038/nclimate2067.
41. Dai, A. (2011). Drought under global warming: A review, Wiley Interdisciplinary Reviews: Climate Change, 2, 45–65. https://doi.org/10.1002/wcc.81.
42. Trenberth, K.E. (2011). Changes in precipitation with climate change, Climate Research, 47, 123–138. https://doi.org/10.3354/cr00953.
43. Dai, A. (2013). Increasing drought under global warming in observations and models, Nature Climate Change, 3, 52–58. https://doi.org/10.1038/nclimate1633.
44. Somerville, R., Trenberth, K., Meehl, J., & Masters, J. (2012). Heat waves and climate change, Climate Communication Science Outreach, 1–14.
45. Wang, L., Huang, J., Luo, Y., Yao, Y., & Zhao, Z. (2015). Changes in extremely hot summers over the global land area under various warming targets, PLoS One, 10, 1–11. https://doi.org/10.1371/journal.pone.0130660.
46. Fankhauser, S. (2009). The costs of adaptation, WIREs Climate Change, 1, 1–8. https://doi.org/10.1002/wcc.014.
47. Malcolm, J.R., Liu, C., Neilson, R.P., Hansen, L., & Hannah, L. (2006). Global warming and extinctions of endemic species from biodiversity hotspots, Conservation Biology, 20, 538–548. https://doi.org/10.1111/j.1523-1739.2006.00364.x.
48. Charlesworth, S.M. (2010). A review of the adaptation and mitigation of global climate change using sustainable drainage in cities, Journal of Water and Climate Change, 1, 165–180. https://doi.org/10.2166/wcc.2010.035.
49. Panwar, N.L., Kaushik, S.C., & Kothari, S. (2011). Role of renewable energy sources in environmental protection: A review, Renewable and Sustainable Energy Reviews, 15, 1513–1524. https://doi.org/10.1016/j.rser.2010.11.037.
50. Edenhofer, O., Pichs-Madruga, R., Sokona, Y., Farahani, E., Kadner , S., Seyboth, K. Adler, A., Baum, I., Brunner, S., Eickemeier, P., Kriemann, B., Savolainen, J., Schlömer, S., von Stechow, C., Zwickel, T., (2014). Climate Change 2014: Mitigation of Climate Change. Contribution of Working Group III to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change. Cambridge University Press: Cambridge, UK doi:https://doi.org/10.1017/CBO9781107415416.
51. Yamasaki, A. (2003). An overview of CO_2 mitigation options for global warming — Emphasizing CO_2 sequestration options, Journal of Chemical Engineering of Japan, 36, 361–375. https://doi.org/10.1252/jcej.36.361.
52. Farhani, S. (2013). Renewable energy consumption, economic growth and CO_2 emissions: Evidence from selected MENA countries, Energy Economics Letters, 1, 24–41.
53. Bayindir, K., Gozukucuk, M., & Teke, A. (2011). A comprehensive overview of hybrid electric vehicle: Powertrain configurations, powertrain control techniques and electronic control units, Energy Conversion and Managemen, 52, 4702–4712. https://doi.org/10.1016/j.enconman.2010.09.028.
54. Pérez-Lombard, L., Ortiz, J., & Pout, C. (2008). A review on buildings energy consumption information, Energy and Buildings, 40, 394–398. https://doi.org/10.1016/j.enbuild.2007.03.007.
55. Swanson, GA., Carlson, CA., Blocker, M., Plummer, J., Snyder, B., & Wehr, Z. (2015). Performance and energy savings of variable refrigerant technology, Minnesota Department of Commerce, Division of Energy Resources.