Primenljiva inženjerska rešenja za smanjenje ugljen dioksida u atmosferi korišćenjem prirodnih i veštačkih skladišta

Marija Najdić¹, Stefan Munitić²

¹Visoka turistička škola strukovnih studija, mnajdic@visokaturisticka.edu.rs

²Nezavisni istraživač

Apstrakt: Rukovodeći se Okvirnom Konvencijom Ujedinjenih nacija o klimatskim promenama (UNFCCC) iz 1992. godine, kao i Kjoto protokolom 1997. godine, Ujedinjene nacije su napravile ambiciozan plan da će od 2015. godine glavni ciljevi sveta i svih država članica UN-a, biti put ka klimatski bezbednoj ekonomiji i promovisanju ekonomskog razvoja zemalja trećeg sveta, a koji se u znatnoj meri oslanjaju na usaglašavanje sa ciljevima održivog razvoja i na Pariski sporazum o klimatskim promenama. Tehnologija industrijskog vremena koja koristi fosilna goriva za proizvodnju energije je i dalje uobičajena praksa koju mnogi, čak i visoko razvijene zemlje koriste. Prekomerna upotreba i masovna nekontrolisana eksploatacija prirodnih resursa, među kojima su najčešće uništavanje šuma, uglja, ulja i prirodnog gasa, može dovesti do povećanog i neuravnoteženog emitovanja ugljen-dioksida u atmosferu Zemlje, što može dodatno dovesti do povećanja nivoa Zemljine temperature. U ovom radu ćemo izložiti studiju slučaja projekta Weyburn-Midale ugljen-dioksida, koji se smatra najvećim svetskim projektom za odvajanje i skladištenje ugljenika u veštačkim skladištima, koji se nalazi u Kanadi, u Midaleu, Saskatchewan. Pored toga, kao moguću opciju, predstavimo podatke o pošumljavanju u regionu Amazona u Latinskoj Americi, kao jedan od najambicioznijih planova za obnovu ekosistema, kao i projekat pošumljavanja u Shandongu, u Kini, koji doprinose i okruženju i ekonomskom razvoju regiona. Sve ove opcije trebaju da pokažu da su dovoljno primenljive u smanjivanju zagađenja ugljen-dioksidom u atmosferi. Obe opcije, veštačka skladišta, kao i prirodni načini smanjenja zagađenja ugljenikom kroz povećanje prirodnih prostora za skladištenje, trebali bi se posmatrati kao dugoročni plan koji može koristiti visoko razvijenim zemljama, i istovremeno biti održiv i pristupačan zemljama sa manjom ekonomskom snagom.

Ključne reči: Veštačka skladišta, Prirodna skladišta, Skladištenje ugljenika, Održivi razvoj, Ekonomski razvoj, Ujedinjenje Nacije.

Feasible Engineering Solutions to Reduce Carbon Dioxide Pollution in the Atmosphere Using Natural and Human Made Sinks

Abstract: Following the United Nations Framework Convention on Climate Change (UNFCCC) back in 1992, as well as the Kyoto Protocol in 1997, the United Nations made an ambitious plan, that from 2015 onwards, the main objectives of the world and all member states of the UN, are to pursue the climate safe economy and to promote the economic development for the third world countries, both of which highly rely on Sustainable Development Goals and the Paris Climate Agreement. The Industrial age technology that uses fossil fuels to produce energy is still the common practice that many, even the highly developed countries, use. The excessive usage and massive uncontrolled exploitation of natural resources, amongst which the most common are deforestation, coal, oil and natural gas extraction, can lead to increased and unbalanced mitigation of carbon dioxide content in the Earth's atmosphere, which can further lead to increased Earth's temperature. In this paper we will discuss the case study of Weyburn-Midale Carbon Dioxide project, viewed as the largest in the world human made carbon capture and storage project, located in Canada, in Midale, Saskatchewan. In addition, as a viable option, we will also present data on reforestation in the Amazon region in Latin America, as one of the most ambitious plans to restore the ecosystem, as well as a project of afforestation in the Shandong, China, which reflects both on environment and economic development of the region. All of these

options should show that they are feasible enough to minimize carbon dioxide pollution of the atmosphere. Both options, human made sinks, as well as the nature's path and its own way to reduce carbon pollution by increasing the amount of natural sinks, should be seen as a long-term plan that can benefit highly developed countries and also be sustainable and affordable to the countries with smaller economic power.

Key words: Human Made Sinks, Natural Sinks, Carbon Capture, Sustainable Development, Economic Growth, United Nations.

Introduction

With the increasing temperature of the Earth's atmosphere and the growing threat of global warming that is already upon us, we will analyze the factors behind the global warming and focus our attention on the single most dangerous component, which is Carbon Dioxide (CO₂) particles. Experts in the world have formed 17 Sustainable Development Goals or SDGs that focus mainly on three branches that are considered a baseline for sustainable development. Those are Economic Well-being, Social Inclusion and Environmental Sustainability. For this scientific paper, we shall focus on the Environmental Sustainability and the goal number 13, which is Climate Action. We will show examples of case studies that can beneficially contribute and combat carbon dioxide pollution of the atmosphere. Relying on the United Nations and the Sustainable Development Goals, we will present three options that are considered viable and feasible, two examples of natural sinks and one human made sink. We will also discuss the most intriguing question to date, the question of Carbon Budget. Considering the remaining amount of the Carbon Budget (how much carbon dioxide have we put up in the atmosphere), how much time do we have left and how fast should we be doing all of this regarding de-pollution?

UNFCCC Conventions, Kyoto Protocol and Paris Agreement on climate change

The international environmental treaty on climate change was opened for signatures during the Earth Summit in Rio de Janeiro in 1992, entered into force from 1994 after a sufficient number of countries had signed it. United Nations Framework on Climate Change was the first international document of high importance whose goal was to stabilize greenhouse gas emissions at the level that would prevent irreversible damage to the climate system. When discussing the greenhouse gases, one must take into account that several of them are proven to be the leading cause of global warming. For example, when coal, as a fossil fuel, is burned, a number of gases are released in process. Greenhouse gases from coal include methane (CH₄), released during hard coal production and most important carbon dioxide (CO₂), as well as nitrous oxide (N₂O), which are emitted when coal is used (Smith, Thambimuthu, 1991). It is highly important for countries to ensure that their emissions stay within limits that may later be negotiated and taken into action towards UNFCCC objective of stabilizing greenhouse gas emissions.

Based on the UNFCCC from 1992, the United Nations followed up on climate change focused convention in 1997, with the Kyoto Protocol. It is an extent on 1992 United Nations Framework on Climate Change that focuses furthermore on reduction of greenhouse gases, its stabilization, but now also adds that climate changes are scientifically proven, that global warming is occurring and that it is connected to the human made CO₂ emissions. In article 2 of Kyoto Protocol, it is said that countries should pursue and promote sustainable development and to implement and elaborate policies and measures in accordance with their own national circumstances (UN, 1998).

Further advancements in the field of climate changes led to Paris Climate Agreement, which is to this date the most important document that helps countries unite in their goal of stopping the global warming. The United Nations convention took place in Paris, in 2015, just two months after the United Nations had agreed on 17 different Sustainable Development Goals. What is different from both Kyoto Protocol and United Nations Framework Convention on Climate Change is that Paris Climate Agreement has specified that each country should determine and plan its own contribution in order to stop and mitigate global warming. Following the ratification of the Paris Climate Agreement and all signatories, the world united now has a strong chance to mitigate and to stop global warming.

Raising awareness on negative effects caused by increased temperature

The essence behind the Paris Climate Agreement was to stop the global warming before we go to the point of no return. In order to do just that, we should hold the human activities that generate global warming and increase of the temperature to well below 2 degrees Celsius and to further pursue efforts to limit the increase of the temperature by 1.5 degrees Celsius (UN, 2015). The rise of the global temperature, compared to that of the average pre-industrial age temperature should stay below 2 degrees Celsius and we should aim to keep it well below 1.5 degrees Celsius. Temperature of the pre-industrial age is when we had no human activities to interfere and to warm the planet. The problem for this, however, is that we are already maybe well too late for that. Data that we have from NASA (National Aeronautics and Space Administration) shows that 2016 is the warmest year on the record (NASA, 2017) and we are already at 1.2 degrees Celsius at temperature increase. That means we are already at the halfway on that boundary of 2 degrees Celsius.

The atmospheric concentrations of carbon dioxide, methane, and nitrous oxide have increased to levels unprecedented in at least the last 800,000 years. Carbon dioxide concentrations have increased by 40% since pre-industrial times, primarily from fossil fuel emissions and secondarily from net land use change emissions. The ocean has absorbed about 30% of the emitted anthropogenic carbon dioxide, causing ocean acidification (IPCC, 2013).

Potential threats behind the temperatures increase include those that can be potentially devastating for both human kind and animal and plant life alike. First and foremost dangerous threat is that of rising sea levels. Ice sheets in Antarctica and also the ice sheets in Greenland could melt and degrade so much that can raise the ocean level by several meters. Many coastline cities and low-lying countries that are at sea level could potentially fully flood. Droughts and floods are yet other global warming connected threats. Along with rising temperatures, new diseases related to temperature can also occur. The prime example behind diseases and storms connected with global warming is the Zika virus that has emerged in South America. El Nino storm created the perfect climate for the virus to emerge (Scientific American, 2016). With the addition of heat waves, loss of human productivity, crop failure due to rising temperature, these are all the risks that have led the entire world to band together, with the common agreement to stop global warming and to keep the temperature well below 2 degrees Celsius, and to pursue efforts to keep it well below 1.5 degrees Celsius.

Some risks of climate change are considerable at 1 or 2°C above preindustrial levels. Global climate change risks are high to very high with global mean temperature increase of 4°C or more above preindustrial levels in all reasons for concern and include severe and widespread impacts on unique and threatened systems, substantial species extinction, large risks to global and regional food security, and the combination of high temperature and humidity compromising normal human activities, including growing food or working outdoors in some areas for parts of the year (IPCC, 2014).

Reducing Carbon dioxide concentration in the atmosphere and Carbon Budget

Carbon dioxide is the most important of all greenhouse gases, simply because it is the main anthropogenic, or human made gas being released, by as much as around 80% due to energy use and industrial purposes, and around 20% from deforestation and land use changes. Carbon-based energy that we get from fossil fuels by combustion, carbon from it is oxidized and combined with O₂, or oxygen in the air and it is produced as a carbon dioxide while releasing energy. Other way is releasing carbon and carbon dioxide from biological storage, or when we cut down forests for land use changes, we release carbon dioxide from trees and soils into the atmosphere.

The fate of fossil fuel carbon dioxide released into the atmosphere depends on the exchange rates of carbon between the atmosphere and three major carbon reservoirs, namely, the oceans, shallow-water sediments, and the terrestrial biosphere (Broecker, et al., 1979). Basically, Carbon Budget tells us how much more of carbon dioxide we can emit into the atmosphere and still be safe (limit of 2 degrees Celsius or well below 1.5 degrees Celsius temperature). The atmosphere and the planet itself are capable of cleaning and to removing carbon dioxide particles, but our constant pumping of the carbon dioxide is simply making the planet unable to clean itself up. Some of the carbon dioxide is absorbed by soil, some is being dissolved in the ocean, but at the rate at which we are pumping the carbon dioxide into the atmosphere is just overwhelming the planets capabilities. That means that carbon

dioxide is staying into the air faster than it is being removed by the trees, soil or oceans. The concentration of carbon dioxide in the air is best explained by the Keeling Curve, which shows us the rapid ongoing change in concentration of carbon dioxide in the atmosphere since 1950's when it was first measured.

Graph 1. Carbon dioxide concentration on July 2nd, 2018

Source: <https://scripps.ucsd.edu/programs/keelingcurve/>

The latest reading shown in Graph 1 is that as of July 2nd, 2018, carbon dioxide concentration is at its maximum since the measure was first taken. The high-accuracy measurements of atmospheric CO₂ concentration, initiated by Charles David Keeling in 1958, constitute the master time series documenting the changing composition of the atmosphere and these data have iconic status in climate change science as evidence of the effect of human activities on the chemical composition of the global atmosphere as they provide a true measure of the global carbon cycle, an effectively continuous record of burning fossil fuel. They also maintain an accuracy and precision that allow scientists to separate fossil fuel emissions from those due to the natural annual cycle of the biosphere, demonstrating a long-term change in the seasonal exchange of CO₂ between the atmosphere, biosphere and ocean (Le Treut, et al., 2007). More carbon dioxide in the atmosphere means that there is more human made warming. It is currently at 409.28ppm (parts per million). It means there are 409.28 molecules of carbon dioxide per million molecules of in the atmosphere as a whole, including all other atmospheric gases. So currently there is a difference of around 100 parts per million molecules of carbon dioxide more than it was back in the 1950s, which shows us that human made warming has been increasing rapidly. When all this is combined, the fact that we have increased the global temperature and that we have increased the level of carbon dioxide particles in the atmosphere, all leads us to the question of how much more carbon dioxide we can still emit before trespassing that limit and boundary. When we look the carbon budget, we can realize that we are already at the limit of breaking it. Looking back from the industrial age and the start of our fossil fuel burning all up until now, our limit of the Carbon Budget is around 3,600 billion tons of carbon dioxide and still be probably below 2 degrees Celsius of temperature increase. But the side note of that is that we have already emitted around 2000 billion tons of carbon dioxide so far. So what that means is that we have around 1,600 billion tons of carbon dioxide left to emit in our budget and still probably be below 2 degrees Celsius, not taking into account the other greenhouse gases that also go into our Carbon Budget because they are also heating up our planet. Which all leaves us with very little budget remaining in our Carbon Budget for carbon dioxide emission. With other gases in account, we would have around 850 billion tons of carbon dioxide remaining to emit. That would leave us with 66% probability to remain below 2 degrees Celsius. So if we limit our future carbon dioxide emissions to 850 billion tones, we would have 66% probability of staying below 2 degrees Celsius. But if it is said that it should be pursued to stay well below 2 degrees Celsius and even well below 1.5 degrees Celsius, 850 billion tones if not enough. On the important note, we are currently emitting around 36 billion tons of carbon dioxide every year, that number divided by the remaining budget leaves us with only 24 years left at the current rate, but that rate is constantly increasing.

Keeling Curve, shows us that we must stabilize our carbon dioxide emissions at the current rate of around 410 parts per million, and pursue efforts to reduce it in the future to around 350 parts per

million by capturing the carbon dioxide that is already in the atmosphere and getting it back into the soils or the forests or capture it by using chemical processes and store it safely into the ground, but also to stop any new emissions.

Energy system transformation - Human made sinks (Carbon capture and storage – CCS)

In order to reach zero emissions in the future, our current carbon-based energy system must be either replaced with alternative energy system that is non-carbon as a primary system or using a specific set of technologies that would still allow the carbon usage, but capturing it before being released into the atmosphere. Our focus will be on those technologies which would allow us to continue to use carbon-based energy, but with no risk to further pollution from carbon dioxide.

Carbon capture and sequestration, or Carbon capture and storage (CCS) is a specific type of technology which enable us to burn down fossil fuels, coal, oil or gas, safely capturing carbon dioxide, using various chemical processes, and storing it underground. Chemical processes used for this type of technology are absorption, adsorption and membrane separation with new concepts such as chemical-looping combustion and hydrate-based separation. Carbon capture and sequestration provide a mid-term solution to mitigate environment impacts and allow continued usage of fossil energy until renewable energy technologies mature (Hongqun, et al., 2008). The way we use technologies, in order to remove and store carbon dioxide underground, can be used as a term of human made carbon sinks. As the world today uses around 80% of the energy from fossil fuels, our future concept should be a switch to renewable sources of energy as a priority. Human made sink would be best described as a pipe that leads from the factory to under the surface, which would allow to burn coal and afterwards an exhaust of carbon dioxide would capture the carbon dioxide and pump it underground into a geological formation where carbon would be safely stored in a mineral formation and be mineralized in time.

As for the carbon capture and storage, we will present our data on Weyburn-Midale Project, taking place in Saskatchewan in Canada. The first phase of the project was to determine whether the site is suitable to sustain large amounts of carbon dioxide. The whole process can be broken down in four different stages, from site characterization, wellbore integrity with the risks of carbon dioxide leakages, to monitoring and verification, and lastly performance assessment. As this system is viable, as pointed out before, as a mid-term solution until better and adequate renewable technologies can be used, carbon capture and sequestration have a lot of weak spots. The site for carbon storage must be able to sustain large quantities of carbon dioxide over a long period of time, without the risk or leakages and without any risk for possibly contaminating the surrounding area. That alone can be the fact for certain countries not being able to safely implement the carbon capture and sequestration technology. For Weyburn-Midale site, looking at the reports, since the beginning of the project back in October 2000, around 30 million tons of carbon dioxide was injected into the ground. Main motivation behind the project was to determine whether this could be a viable option to use for enhanced oil recovery and a research on carbon dioxide. This particular project between the United States and Canada received much media attention and focus when several allegations occurred that there was a leakage of carbon dioxide in January 2011. Claims have soon been dismissed as false allegation, carbon dioxide not leaking because of injection but rather a natural occurring biogenic carbon dioxide from the processes in the soil (MIT, 2011). For the carbon capture and storage project to be a success, one must first complete a series of phases to see if it can be compatible with the land and geographical status of one's country. Not all countries possess viable storage options for the carbon dioxide and not all countries have economies stable enough to use it as a long term plan in reaching their set limits of carbon dioxide pollution.

Land-use system transformation - Natural sinks (Afforestation and Reforestation)

As mentioned before, there is also a natural way to remove particles of carbon dioxide from the atmosphere using biological processes that occur in nature which includes afforestation and reforestation. Previously stated, around 80% of carbon dioxide pollution is generated from energy system and carbon-based energy. The rest of it, around 20% is from land-use. Altogether, what we are putting up must be mitigated by what we are taking out, which means that anthropogenic carbon dioxide generated from either energy system or land-use system must be somehow mitigated and

removed. Carbon dioxide sources must be balanced by the sinks. Within the Kyoto Protocol, the Clean Development Mechanism (CDM) is an instrument intended to reduce greenhouse gas emissions, while assisting developing countries in achieving sustainable development, with the multiple goals of poverty reduction, environmental benefits and cost-effective emission reductions, the CDM allows for a small percentage of emission reduction credits to come from afforestation and reforestation projects (Zomer, et al., 2008).

Afforestation is a term used when a new forest is being created in a place where there was degraded land before. It is human affected natural sink for carbon dioxide absorption. Now the question is, what can be achieved within a global, large scale afforestation program that is economically, politically, and technically feasible. We estimated that, of the areas regarded as suitable for large-scale plantations, only about 345 million ha would actually be available for plantations and agroforestry for the sole purpose of sequestering carbon. The maximum annual rate of carbon fixation (1.48 Gt/yr) would only be achieved 60 years after the establishment of the plantations - 1.14 Gt by above-ground biomass and 0.34 Gt by below-ground biomass. Over the period from 1995 to 2095, a total of 104 Gt of carbon would be sequestered. This is substantially lower than the amount of carbon required offsetting current carbon emissions (3.8 Gt/yr) in order to stabilize the carbon content of the atmosphere (Nilsson, Schopfhauser, 1995). With the analysis provided, it is seen that afforestation can be used to capture the carbon dioxide from the atmosphere, but not by the amount needed to reach the zero emissions.

One of the largest projects regarding afforestation is placed in the Shandong region of China. China has a standing problem with soil erosion and desertification (Cao, et al., 2011). As for the Shandong region in China, the World Bank reports that outcomes were highly satisfactory, the risk to development outcome was low, the Bank performance was satisfactory, and Borrower performance was highly satisfactory. Projects designed around coherent national policy frameworks and local development strategies enjoy strong political support which, in turn, greatly enhances their chances of success. Integrated afforestation approaches which include mixed species planting, the retention of ground cover, the inclusion of economic activities, and the promotion of natural regeneration are ecologically sustainable, financially viable, and more resilient to pests and diseases (Worldbank, 2017). Positive outcome on Shandong, China, shows us that afforestation is a good way to mitigate and capture the carbon dioxide from the atmosphere while also reaping the benefits of developing the local communities, promoting ecosystem and overall economic activity, while staying sustainable and financially viable.

Next to the afforestation is reforestation, or replanting the forests where they used to be. Connected to the poor land-use management and deforestation, reforestation aims to replant the forest and bring balance to the ecosystem where it once was. Reforestation of these abandoned lands, both natural and managed, has been proposed as a means to help offset increasing carbon emissions to the atmosphere (Silver, et al., 2011). Widely considered as the “lungs of the planet”, Amazon rainforest in South America is known for its effect on cleaning the Earth’s atmosphere from carbon-based pollution and negating the effects of global warming. In recent years, Amazon rainforest has been widely damaged, and massive deforestation took effect when removing the trees in order to make room for farmlands, crop plantations and pastures. On the other hand, with deforestation, the biodiversity of the region is also suffering from deforestation, and many species of mammals, reptiles and birds are losing their natural habitat. Reports say that if these rates of deforestation continue, there likely won’t be any rainforests left in the next 100 years (Onegreenplanet, 2017).

Brazil has about two thirds of the Amazon rainforest and is the country with the richest biodiversity in the world. Its main nationally determined goal is to reach zero deforestation, to improve satellite monitoring of the Amazon rainforest, to protect certain areas with implementing penalties and fines and the restriction of credits. Regarding the reforestation and land-use management, Brazil plans to restore 15Mha of degraded pasture lands and to promote additional 5Mha of integrated cropland, livestock and forestry. Brazil further plans to eliminate illegal deforestation in the Amazon region by 2030 and also to restore over 12Mha of forests in all biomes in order to enhance sustainable forest management. As for the rest of the Amazon rainforest biome, tropical rainforests are often considered to be the “cradles of biodiversity”. Though they cover only about 6% of the Earth’s land surface, they are home to over 50% of global biodiversity. Rain forests also take in massive amounts of carbon dioxide and release oxygen through photosynthesis. They also store very large amounts of carbon, and so cutting and burning their biomass contributes to global climate change (PSU, 2017). Benefits of reforestation are

closely connected to the sustainable development and also growth in economy and by promoting healthy reforestation, specifically in the Amazon rainforest region, where the current scale of deforestation in tropical regions and the large areas of degraded lands now present underscore the urgent need for interventions to restore biodiversity, ecological functioning, and the supply of goods and ecological services previously used by poor rural communities (Lamb, et al., 2005).

Conclusion

All member states of the United Nations agreed on to limit and to control human made global warming, to pursue climate safety, in the context of sustainable development. Greenhouse gases are one of main reasons behind global warming, and when you add to that deforestation and cutting down the forests, ocean acidification connected to carbon dioxide generated while burning down fossil fuels, and along with it the ecosystems general pollution and the depletion of fresh water. When it is talked about putting the greenhouse gases in the atmosphere, that is causing the global warming, especially carbon dioxide, nitrous oxide, methane and other industrial chemicals, those chemicals that remain in the Earth's atmosphere, when the solar radiation generated from the Sun hits Earth and is reflected back, it is captured by those greenhouse gases warming the planet.

Since 2015 and the Paris Climate Agreement, we have realized that our goal and main objectives are to pursue climate safe economy, to stabilize and to reduce the greenhouse gas emissions from carbon-based energy from fossil fuels, mainly carbon dioxide as the biggest anthropogenic or human made pollutant, from the atmosphere so that we have a chance to stay below 2 degrees Celsius or even well below 1.5 degrees Celsius, all in accordance with the goals set by the Paris Climate Agreement. We must turn our focus to staying within our Carbon Budget, and also to turn our emissions down. All of that can be achieved in either short term plan, where each country or member state of the United Nations should communicate with other countries, prepare and maintain its own Nationally Determined Contributions that it attends to achieve. On the long term plan, all countries should contribute by formulating and communicating low greenhouse emission development strategies. What can be done in the way to promote less emission is to work on energy system transformation and also on land- use system transformation as shown in cases regarding Canada, China and Amazon.

As a negative thing that increases carbon pollution, we should aim to stop deforestation, and turn our attention to afforestation and to create new forests through land management. But, if we change our habits, and add with the afforestation other means to capture the carbon dioxide, and also replace and reduce our current usage of carbon-based energy and fossil fuels with human made sinks and carbon capture and sequestration technology, while also promoting renewables as a mean to produce energy, our carbon pollution in the atmosphere would be lowered substantially.

References

1. Broecker W. S, Takahashi T, Simpson H.J, Peng T.H, 1979, Science , Vol. 206, Issue 4417, Washington, USA, pp. 409-418;
2. Cao S, Chen L, Shankman D, Wang C, Wang X, Zhang H, Excessive reliance on afforestation in China's arid and semi-arid regions: Lessons in ecological restoration, 2011, Earth-Science Reviews, Volume 104, Issue 4, Elsevier Ltd., New York, USA, pp. 240-245;
3. Hongqun Y, Zhenghe X, Maohong F, Rajender G, Slimane B.R, Bland E.A, Wright I, Progress in carbon dioxide separation and capture: A review, 2008, Journal of Environmental Sciences, Volume 20, Issue 1, Elsevier Ltd., New York, USA, pp. 14-27;
4. IPCC, 2013: Summary for Policymakers. In: Climate Change 2013: The Physical Science Basis. Contribution of Working Group I to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change [Stocker, T.F., D. Qin, G.-K. Plattner, M. Tignor, S.K. Allen, J. Boschung, A. Nauels, Y. Xia, V. Bex and P.M. Midgley (eds.)]. Cambridge University Press, Cambridge, United Kingdom and New York, NY, US.
5. IPCC, 2014: Summary for policymakers. In: Climate Change 2014: Impacts, Adaptation, and Vulnerability. Part A: Global and Sectoral Aspects. Contribution of Working Group II to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change [Field, C.B., V.R. Barros, D.J. Dokken, K.J. Mach, M.D. Mastrandrea, T.E. Bilir, M. Chatterjee, K.L. Ebi, Y.O. Estrada, R.C. Genova, B. Girma, E.S. Kissel, A.N. Levy, S. MacCracken, P.R. Mastrandrea, and L.L. White

- (eds.)). Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA, pp. 1-32.
6. Kyoto Protocol to the United Nations Framework Convention on Climate Change, United Nations, 1998, 2.
 7. Lamb. D, Erskine P, Parotta J, 2005, Science , Vol. 310, Issue 5754, pp. 1628-1632;
 8. Le Treut, H., R. Somerville, U. Cubasch, Y. Ding, C. Mauritzen, A. Mokssit, T. Peterson and M. Prather, 2007: Historical Overview of Climate Change. In: Climate Change 2007: The Physical Science Basis. Contribution of Working Group I to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change [Solomon, S., D. Qin, M. Manning, Z. Chen, M. Marquis, K.B. Averyt, M. Tignor and H.L. Miller (eds.)]. Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA.
 9. Nilsson S, Schopfhauser W, The carbon-sequestration potential of a global afforestation program, 1995, Climatic Change, Volume 30, Issue 3, Springer, Berlin, Germany, pp. 267–293;
 10. Paris Climate Agreement, United Nations, December 2015, 3.
 11. Silver L. W, Ostertag R, Lugo E. A, The Potential for Carbon Sequestration Through Reforestation of Abandoned Tropical Agricultural and Pasture Lands, 2011, Restoration Ecology, Volume 8, Issue 4, The Journal of the Society for Ecological Restoration, John Wiley & Sons, Inc., Washington, USA, pp. 394-407;
 12. Smith I.M., Thambimuthu K.V., Greenhouse gas emissions, abatement and control; The role of coal., 1991, IEA Coal Research, London, UK, 354.
 13. Zomer J. R, Trabucco A, Bossio A. D, Verchot V.L, Climate change mitigation: A spatial analysis of global land suitability for clean development mechanism afforestation and reforestation, 2008, Agriculture, Ecosystems & Environment, Volume 126, Issues 1–2, Elsevier Ltd., New York, USA, pp. 67-80;

Internet

1. <http://climate.nasa.gov>.2017 (NASA's Goddard Institute for Space Studies - GISS)
2. <http://documents.worldbank.org/curated/en/731241486394432449/China-Shandong-Ecological-Afforestation-Project>
3. <http://sequestration.mit.edu/tools/projects/weyburn.html>
4. <http://www.e-education.psu.edu/geog30/node/395>
5. <http://www.globalcarbonproject.org/products/publications.htm>
6. <http://www.onegreenplanet.org/environment/project-is-planting-trees-in-the-amazon-rainforest/>
7. [http://www.scientificamerican.com/article/el-nino-and-global-warming-blamed-for-zika-spread/December 2016](http://www.scientificamerican.com/article/el-nino-and-global-warming-blamed-for-zika-spread/December%202016)
8. <http://scripps.ucsd.edu/programs/keelingcurve/>