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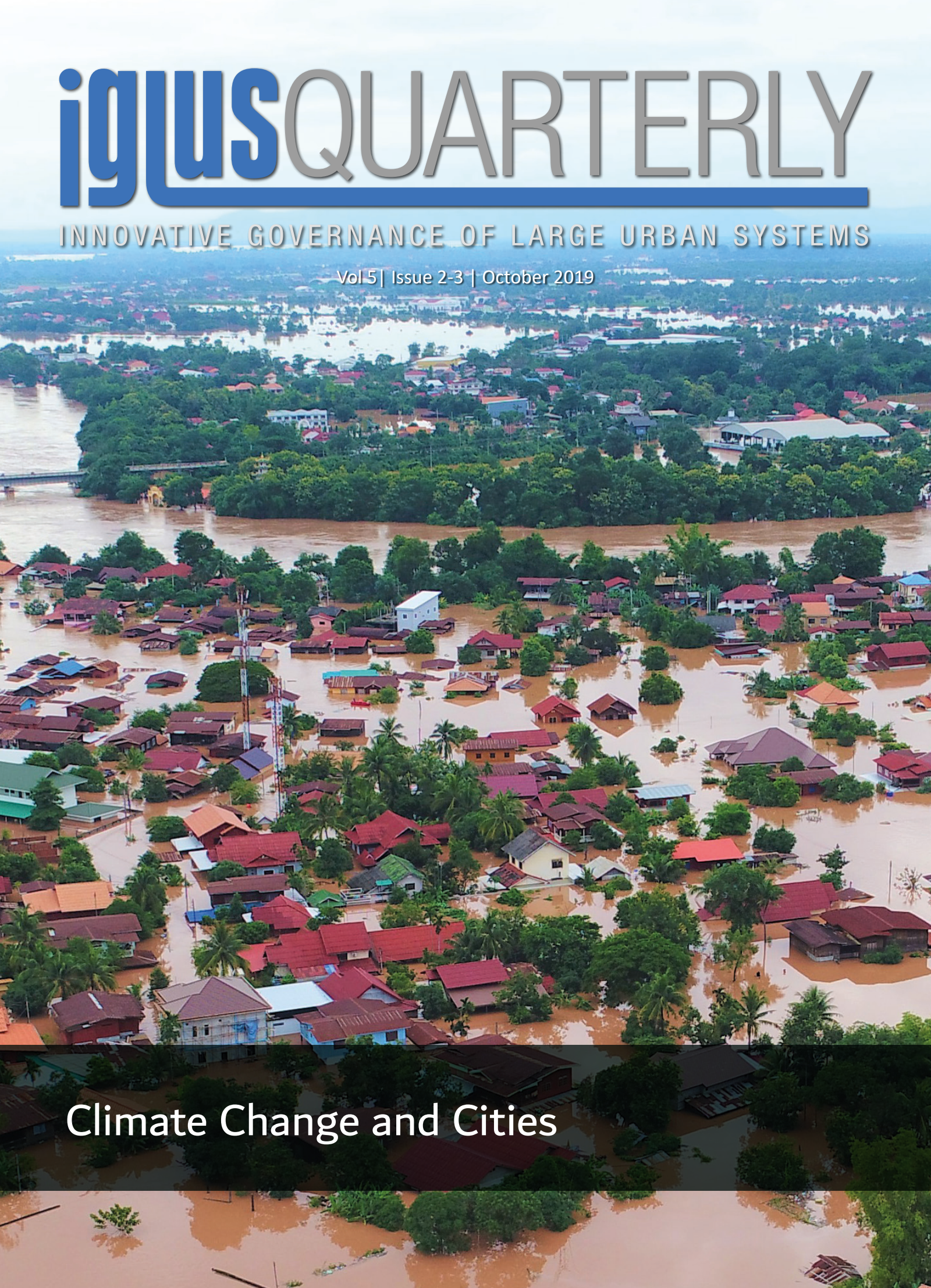

Climate Change and Cities

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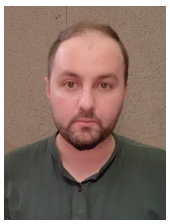

The editor of this issue:
Numan Yanar

Our planet is warming under dramatic environmental pressure and its climate is changing. The impacts of climate change are becoming more costly and more damaging day by day. Unfortunately, cities are main culprits. According to UN Habitat, cities consume 78 percent of the world's energy by producing the majority of greenhouse gas emissions. By considering the consequences created by the cities, we have prepared this IGLUS Quarterly issue with key articles written by experts from cities around the world. We hope that we can bring new perspectives to readers and bring awareness about climate change to the citizens of the Earth.

The issue opens with an article by Turkish-Canadian journalist/broadcaster Üstün Bilgen-Reinart, which discusses the role of city-dwellers on climate change, providing examples from urban areas. The article provides a great overview for the human approaches with real-life examples, as improvements start with the awareness of individuals.

In the second article, Sevil Veysel and Prof. Amir Reza Vakhshouri present an overview on the effects of petrochemicals on climate change, particularly in Azerbaijan. The article analyzes the importance of petrochemicals for the citizens, and correlates it with the urbanization–climate change nexus.

One of the main reasons for climate change is the misuse of the energy sources. Using non-renewable energy sources creates carbon pollution and brings a higher negative impact to our environment; hence the need to switch to renewable energy worldwide. Switching to wind and solar energy is especially important due to their environmentally friendly processes. In the third article, Duygu Akyıl and Prof. Burak Barutcu present an overview about the impact of global warming on wind and solar energy by giving perspectives for Turkey.

The next article comes from Pakistan. Muhammad Taimur Siddique and Prof. Anjum Rasheed discuss the causes of greenhouse gas emissions (GHGs) and their effects on climate change in the age of urbanization. They discuss the effects of industry, transport, building, energy generation, agriculture, waste and land use, land use change, and forestry for emission of GHGs by also touching on the requirement of national development goals to mitigate climate change.

The fifth article focuses on the effects of climate change on hydrology and water resources. Reducing the effects of climate change carries great importance for the optimization of the water–energy nexus. Kristal Aubrey S. Bornillo and Henrison C. Sanchez Henrison C. Sanchez summarize cost-effective climate models, which are effective in reducing the consequences of climate change on hydrology and urban water resources.

In the next article, Yasin Alperen Çelebi offers a detailed overview of the implementation of solar power in urban areas. The article takes a region-based approach and discusses the challenges of implementing solar powers in cities.

The seventh and eight articles are letters from Onlaya Sengthammavong and Meriç Köstekçi, respectively. Sengthammavong's letter briefly covers the unfortunate flooding in Laos, where cities are being damaged and people are dying, as heavy rains are becoming more severe and fierce as a result of climate change. The letter focuses on the cities of Laos and rainfall in those cities under the effect of climate change. Unlike the other articles in this issue, Meriç Köstekçi's letter focuses on more technical aspects for the prevention of climate change in urban areas. The article focuses on the importance of statistical tools, regression analysis, and spatial statistics for climate and climate change studies in cities.

As climate change is a severe problem that effects urban life with severe consequences, we have combined the second and third issues of Volume 5 in this one. We sincerely hope that you enjoy the articles of this climate change issue of *IGLUS Quarterly*. We invite you to join the discussion at iglus.org. If you feel that there are innovative practices underway in your city/region and you would like to contribute to an upcoming edition of *IGLUS Quarterly*, we encourage you to contact us at umut.tuncer@iglus.org. For inquires and questions about the content of this issue, you may also contact me at numanyanar@hotmail.com.

Climate Change and City Folks

Üstün B. Reinart

Author's Profile

Üstün B. Reinart is a Turkish/Canadian writer, researcher and ecological activist. A graduate of the University of Winnipeg in Manitoba, Canada, she worked as a TV journalist for the Canadian Broadcasting Corporation for fifteen years, before returning to Turkey to teach English at the Middle East Technical University. Author of three books, two oral histories : Night Spirits (the Relocation of the Sayisi Dene in Northern Manitoba), and « Biz Topragi Bilirik » (We know the land – the story of the resistance of villagers of Bergama to the first gold mine in Turkey), and Porcelain Moon and Pomegranates, a memoir.
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As I write this, the hottest summer temperatures ever recorded are scorching European cities. In July 2019, the mercury climbed to an unprecedented 45 C in France. The newspapers called it a Killer Heatwave. Massive fires devoured the Southeastern coast of Turkey and more than a hundred people died in Monsoon floods in South Asia. Already, climate change is playing havoc with the world.

The world is now urban. In most countries, it is hard to know where a city ends and the countryside begins. Cities sprawl, devouring energy and spewing out wastes and carbon, encroaching on land previously covered with vegetation and reducing its potential to absorb CO_2.

I am writing this in Ibrahimpasa, a Central Anatolian village near Ürgüp in Turkey. I know many villagers who recently moved to high-rise apartment blocks on the outskirts of the city of Nevsehir, 12 km away, abandoning their fields and orchards, seeking jobs in the tourism or service industry along with the comfort of central heating and the status of urban living. One of them, Pakize, has told me she misses her family's vineyards and vegetable garden but her husband is now a construction worker, and their apartment with central heating is easier to clean than a village house. Driving to a super market once a week to shop for groceries is less work for her than tending fields. What is more, she hopes that city life will offer her children a more prosperous future than the village.

Pakize considers extreme weather events as God's will. Little does she realize that the fury of construction around the high-rise block where she and her family live contributes to deforestation and warming. Her family is only one of tens of thousands of rural families in Turkey and millions in the world, migrating to cities.

Unlike Pakize, many of those urbanized people in Turkey are aware of climate change and are concerned. A survey by the academic and social research company Konda, released in July 2019 reveals that 6 out of 10 people in Turkey are aware of an increase in catastrophic weather events, and 7 out of 10 think climate change plays a role in those events. (Konda, 2019) 23 % of the people in Konda's survey said they were not particularly concerned and did not know when the effects of climate change would be felt. Konda's interpretation of that point of view was that a deep ignorance lay behind that indifference (p.13).

Yet, Konda's research also shows the contradiction people are caught in: Most say their fundamental need is economic. They want jobs, economic security, a comfortable residence and a car. They want the national and municipal governments to deal with climate change, and think those in power are not paying enough attention to the climate crisis (Ağırdır, 2019).

Poor quality, badly insulated, and steel-reinforced high-rise concrete apartment blocks around megacities throughout the world now create sprawling suburbs dependent on cars. Unplanned and market driven urbanization processes do not favor compact, pedestrian-oriented residential and mixed-use neighborhoods with solar energy and a low carbon public transport system.

Economies relying on grandiose projects such as hydroelectric power stations, airports, mines and apartment blocks are increasing carbon emissions, contributing to deforestation, creating Urban Heat Islands and exacerbating the climate crisis. Landfill sites with urban wastes produce methane. The production of cement for residences produces greenhouse gases. As populations in cities grow, the demand for water increases. Food has to be transported from distant production centers. Production, transportation and consumption of goods rely on fossil fuels.

A vicious circle continues to grow and to exacerbate climate change. The infrastructure and social texture of many cities are not strong enough to cope with these pressures and cannot tackle the inequalities, urban poverty and xenophobia that increase under stress.

City life is increasingly inegalitarian (David Harvey, 2015). In mega cities of the developing world, more than 70% of urban populations live in slum-like conditions, and this number is expected to increase to two billion over the next 30 years (Little and Cocklin 2009, 77).

In megacities from Istanbul to New York to Sao Paulo, construction booms produce luxury high-rise apartment blocks for the wealthy to invest in (while not necessarily occupying them), while the poor are displaced from city centers and resettled in poorly constructed residences in the periphery (David Harvey, 2014).

Low income people without insurance or legal protection will continue to be affected more from health problems, loss of jobs and loss of homes due to extreme heat, unseasonable rains, floods, storms, wildfires and rising sea waters caused by climate change. The social and regulatory infrastructure of many megacities especially in the developing world cannot deal with such stresses.

Furthermore, climate change contributes to the refugee crisis. The Norwegian Refugee Council reports that in 2018 more than 17,2 million people fled disasters in 125 countries, and 61% of that displacement was caused by climate change and natural disasters. The IPCC predicts that 200 million people will be forced to migrate in the next 30 years due to droughts, a rise in sea levels and floods.

Refugees are among the most vulnerable residents of a city. Local people often view them as competitors for strained resources, especially during times of economic or climatic stress. An influx of refugees places new burdens on health and social services, transit infrastructure and the job market. Instances of xenophobia increase as people blame the refugees for deteriorating conditions.

Cities ranging from Vancouver, Oslo, Dubai or Hong Kong, that have ratified the Paris Agreement and pledged to reduce carbon emissions are adopting climate action plans aimed at reducing greenhouse gas emissions (Asarpota 2019).

Ümit Sahin, the coordinator of Istanbul Policy Centre Climate says increasing agricultural areas inside the city could also be a valuable step and cites Barcelona as a city where markets sell produce harvested from urban gardens. Toronto now requires all new buildings over 2,000 square meters to include roofs with vegetation on them to slow down the urban heat island effect and reduce the incidence of heat waves. More recycling and less urban waste would be another useful step and passive buildings that reduce heating and cooling by 90% would also be effective (Sahin, 2017).

As heat waves, floods and wildfires rage through the world, governments and municipalities also have to set up mechanisms to alert citizens of public health risks. In wealthy countries, ministries of health and municipal administrations regularly issue alerts, suggesting means of protection. During the summer heatwave in France this summer, the country issued a red alert – signaling the highest level of health risk.

This winter, Quebec launched an online course for health professionals and interested citizens, on the health risks posed by climate change. (Beaudoin. 2019) During summer heat waves, Montreal implements an Extreme Heat Action Plan, using the mass media to issue alerts and extending the opening hours of large cooling and air-conditioned spaces such as pools, libraries, community shelters for the old and the sick to take shelter.

City workers even go from door to door to check on people and to hand out bottled water to keep them hydrated (Lau, 2019).

Unfortunately, no system of public alerts exists in Istanbul and many other megacities of the developing world. No thresholds have been determined for yellow, orange or red alarms (Sahin, 2019).

In Turkey there is not even a mechanism to determine the number of deaths caused by heat waves or cold spells. It is likely that some vulnerable people such as the old or the very young die. But the real cause of the deaths – climate change – is not recorded (Sahin, 2019).

At times of war, populations have been known to get into a survival mode and change their daily habits of consumption, transportation and production. Climate change is a global emergency that calls for the survival mode all over the world. But even as extreme heat scorches our cities, climate change may seem too large and abstract to many city folks worried about paying their bills and making ends meet. The affluent find ways to protect themselves and have a good time, while an informed and caring minority may feel powerless, angry and sad.

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The Effects of Petrochemicals on Climate Change and the Case of Azerbaijan

Sevil Veysel[a], Amir Reza Vakhshouri[a]

Abstract: *The main purpose of this article is to briefly describe the effects of petrochemicals on climate change, particularly in Azerbaijan. This paper first deals with the definition of petrochemicals and their importance in modern life, and then discusses their impacts on urbanization and on climate change.*

Authors' Profiles

Sevil Veysel is a senior chemical engineering student at Baku Higher Oil School, Azerbaijan. Sevil is balancing the final year of her undergraduate degree with her part-time role at TechnipFMC, a global subsea technology company.
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Amir Reza Vakhshouri is currently an associate professor in the Chemical Engineering Department at Baku Higher Oil School, Republic of Azerbaijan. He obtained his bachelor's degree in applied chemistry from Tabriz University, Iran, and his master's degree from Tabriz Azad University. He received his PhD degree in polymer chemistry at the Institute of Petrochemical Processes from Azerbaijan National Academy of Sciences. In addition to his academic background, he has over 15 years of experience in various industries.
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Introduction

Today, more than 85 percent of the world's energy comes from fossil fuel sources and approximately 60 percent of energy consumption is contributed by oil and natural gas (Dudley B. 2019). Oil and natural gas are the main sources for petrochemicals due to their economic benefits and readily available capabilities. Approximately 5 percent of oil and natural gas sources are required annually for petrochemicals manufacturing processes. On the other hand, petrochemicals comprise about 40 percent of the total world's chemical market (Sharma et al. 2017).

One of the most significant segments in the manufacturing sector is the petrochemical industry, which has various connections with other sectors. The main group of petrochemicals is derived from petroleum and natural gas by direct and/or indirect methods as by-products. Nowadays, petrochemicals are the major part of society that have a wide range of uses, such as the production of food, clothing, shelter, leisure, etc. Generally, petrochemicals are used in various industries, such as in the production of polymers, plastics, synthetic fibers, soaps and detergents, synthetic rubber, pharmaceuticals, pesticides, solvents, fertilizers, paints, explosives, flooring, and insulating materials. More simply, petrochemicals can be seen in daily life such as aspirin, luggage, automobiles, clothes, boats, recording discs/tapes, and aircraft (Monticello D. J. 2001).

There is huge demand in the market to deal with the tremendous increase in the number of vehicles for petrochemical products: gasoline, diesel, and lubricants. They can also be used in pharmaceuticals as food-grade lubricants, and may also be used in beverage industries in the processing of food plants. Petroleum jelly is obtained from oil and used as a lubricant, protective covering, and ointment base. Additionally, petrochemicals are

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used in preservatives and food additives to keep canned food fresh longer. There are some petroleum derivatives in cosmetics and perfumes. Flexible rubber shoes, which stay intact in all weather, are made using petrochemicals. One of the most important applications of petrochemical products is the production of dyes, paints, adhesives, and sealants with various properties and stabilities for various fields. There are also commercial polymers such as polyethylene, polypropylene, PVC used in garbage bags, photographic film, construction components, packaging of food, etc. (Naderpour N. 2008).

Alongside all these widespread uses, it is inevitable that petrochemicals also have various effects, both short-term and long-term, on the environment. This article briefly reviews the main problem of the petrochemicals that generate carbon dioxide. Carbon dioxide has long-term effects on our environment. It is one of the main causes of the global warming and can be produced from all energetic usage of oil, natural gas, and coal.

Hazards Associated with Petrochemical Industries

It is undeniable that society depends on petrochemicals. While many useful products are made from petroleum products, they can also be dangerous to the ecosystem of earth and be harmful to the health of living beings. There are unfavorable effects of chemicals released into the environment, such as air, water, and soil pollutions. As mentioned, the most important source of the greenhouse gases is petrochemical industries that cause global warming. Petrochemical industries must also deal with issues such as ozone layer depletion, acid rain, air pollution, and other environmental problems (Skjaerseth J. B. and Skodvin T. 2003). One of the main reasons for environmental pollutants are aromatic compounds that are found in petrochemicals and introduced to society through natural oil seeps, emissions and industry waste products, accidental spills from oil tankers, oil storage wastes, petrochemical industrial emissions and effluents, coal tar processing wastes, and so on (Wenpo R. et al. 2011).

Some toxic, foul odor, or combustible substances are also released during the production of petrochemicals. The areas near to petrochemical industries cause noise pollution and this is one of the main reasons for headaches, uneasiness, annoyance, stress, displeasure, impatience, hypersensitivity, extreme anxiety, endangerment, violence and angry feelings. Dealing with refining processes such as hazardous waste, coke dust or catalysts, tank bottoms and oil sludge from treatment processes can cause contamination of soils. Petrochemical industries can also cause biodiversity losses and destruction of ecosystems. These effluents are coming out with the petrochemicals industries, which contain a large amount of polycyclic and aromatic hydrocarbons, metal derivatives, phenols, sulphides, Surfactants, naphthenic acids, and other chemicals. These industries also cause water pollution when purification systems are inefficient. This pollution is fatal to both aquatic and terrestrial life. The effects of the petrochemicals can also take place in different ways that can be absorbed through the skin or may be ingested. They are also harmful to human life through accumulation in tissues or organs and cause brain, liver and nerve damage, cancers, defects of birth, asthma, and hormonal disorders. Skin irritation, ulcers and allergic dermatitis are the chronic effects of exposure (Mehlman MA. 1992).

Climate Change

People are increasingly moving to cities in search of job opportunities and prosperity. Approximately half of the global population already lives in cities and that proportion will increase to about two-thirds by 2050, (National Geographic, Urban Threats). However, population growth in cities is causing some of the most pressing problems facing the world today, such as poverty and environmental degradation. One of the main problems of intensive urban development is the greater poverty, caused by the inability of local governments to provide all people with services. Another main problem is air pollution, which is caused by concentrated energy use and has significant effects on human health. Automobile exhaust produces elevated levels of carbon dioxide and other pollutants in urban air. Uncollected waste occupies a lot of space and cause multiple health hazards. The development of urban areas can increase the risk of environmental hazards such as flash flooding. Animal

populations are inhibited by toxic substances and the loss of habitats and food sources. Increasing urban areas also causes deforestation. Generally, the increasing population density and the demands of urban environments cause air pollution, poor water quality, insufficient water availability, water disposal problems, and high energy consumption.

The main problem is global warming, which is connected to the greenhouse effect (Booth, M. et al. 1997). It was first reported by Arrhenius in 1896, who argued that there are specific gases in the earth's atmosphere that the main part of them is water vapor. Besides steam, there are methane, carbon dioxide, ozone, dinitrogen oxide, and halogenated hydrocarbons as well. These gases permit the transmission of the sun radiation. Without a natural greenhouse effect, the average temperature on the earth's surface would be -18 °C, compared with its actual value of +15 °C. The natural occurring greenhouse effect is a beneficial phenomenon, which is naturally formed by plants and animals on earth, but life cannot exist when this effect is too strong or too weak. For instance, if the amount of carbon dioxide decreased in large amounts, the temperature on earth would be approximately -60 °C. Venus contains excessive carbon dioxide, and the temperature there reaches approximately +430 °C (Dagobert, 2000).

These days, too much of these naturally produced greenhouse gases (also called anthropogenic gases) are generated to deal with human activities. Carbon dioxide is an anthropogenic gas and it is followed by methane, dinitrogen oxide, ozone, etc. These gases are produced by petrochemical industries, vehicles, power plants, heating systems, and burning of tropical forests. It is generally recognized that global temperatures will increase due to the increase of anthropogenic gases in the atmosphere.

As a case study, we can talk about Baku, the capital city of the Republic of Azerbaijan. Azerbaijan is located in the South Caucasus in the region of Eurasia at the crossroads of Eastern Europe and Western Asia. It is bounded by the Caspian Sea to the east. Azerbaijan is one of the world's ancient oil-producing countries and is a major oil and natural gas supplier in the Caspian Sea region. The largest hydrocarbon basins are located offshore in the Caspian Sea (The Oil and Gas is Power, Azerbaijan). For all its natural oil and gas resources, there are numerous petroleum and petrochemical companies in Azerbaijan, approximately 96 percent of which are located in Baku. One local company is the State Oil Company of Azerbaijan Republic (SOCAR), whose headquarters are located in Baku. The company produces oil and gas from onshore and offshore fields in the Azerbaijani segment of the Caspian Sea. Global oil and gas companies that operate in Baku include Technip FMC, Technip,

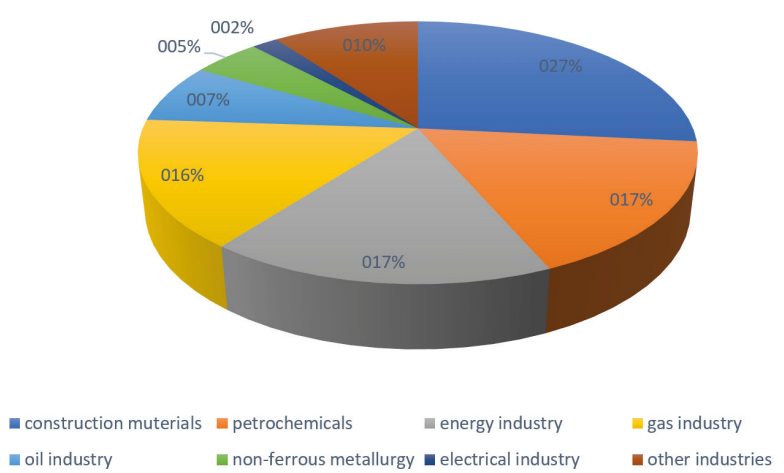

Figure 1. Distribution of air pollution by different industries in Azerbaijan (%)

FMC technologies, BP, Schlumberger, Halliburton, KBR, and Total. Fig. 1 shows that approximately half of Azerbaijan's industrial waste comes from the oil and gas industries (Mammadov Q. 2008). The most common hazardous waste is petroleum sludge, produced by petroleum industries, which is a major environmental problem in oil-rich countries. Petroleum sludge is formed during the exploration and production of oil such as drilling fluid, wastewater from petroleum, and bottom tank sludge. Approximately 50 tons of petroleum sludge is produced daily in Azerbaijan from 105,000 oil barrels (Olufemi A. J., Augustine A. 2018). Petroleum sludge contains hydrocarbons, paraffin, water, asphaltenes, and inorganic solids (sand, iron oxide, and iron sulfides). Petroleum sludge is classified as a liquid form of hazardous waste, which means it cannot be disposed of directly to a landfill (Speight J. G. 2007). Baku has many onshore wells and oil sludge basins are formed due to petroleum production. The light fractions in the oil sludge are mixed with air, which increases the level of anthropogenic gases in the atmosphere and leads to global warming. To deal with global warming, the productivity of the natural food chain is decreasing. It poisons the food chain, destructs the green areas, pollutes the seawater, etc. Generally, it causes serious problems in environment and human health. On the other hand, there are many petrochemical companies in Baku, and they give various kinds of hazardous gases to the atmosphere. Because of urbanization, the city is developing and the population is increasing, which results in an increasing number of vehicles and deforestation levels. These problems increase the amount of carbon dioxide in the atmosphere.

Plans and Activities

One of the major problems in the Soviet Union was the lack of proper waste management systems. This problem increased the amount of oil sludge in the environment, which caused soil, water, and air pollution. After Azerbaijan achieved independence, one of the most important government programs was to clean the contaminated lands. One of the largest projects in the world was the removal and cleaning of the land called the "Black City," which has been transformed into a beautiful and modern place now called the "White City" (Fig. 2).

On the other hand, special plans have also been taken to reduce greenhouse gas emissions. One of the important activities is to increase green space within the urban area, within the oil refinery and pethrochemical units, and also create a green belt at the entrance area of the city to balance carbon production and emissons. Other plans include removing old units and wells and replacing them with green space.

Since 2008, some modernization works have been carried out in oil refinery units and petrochemical companies in Azerbaijan to deal with the environmental prob-

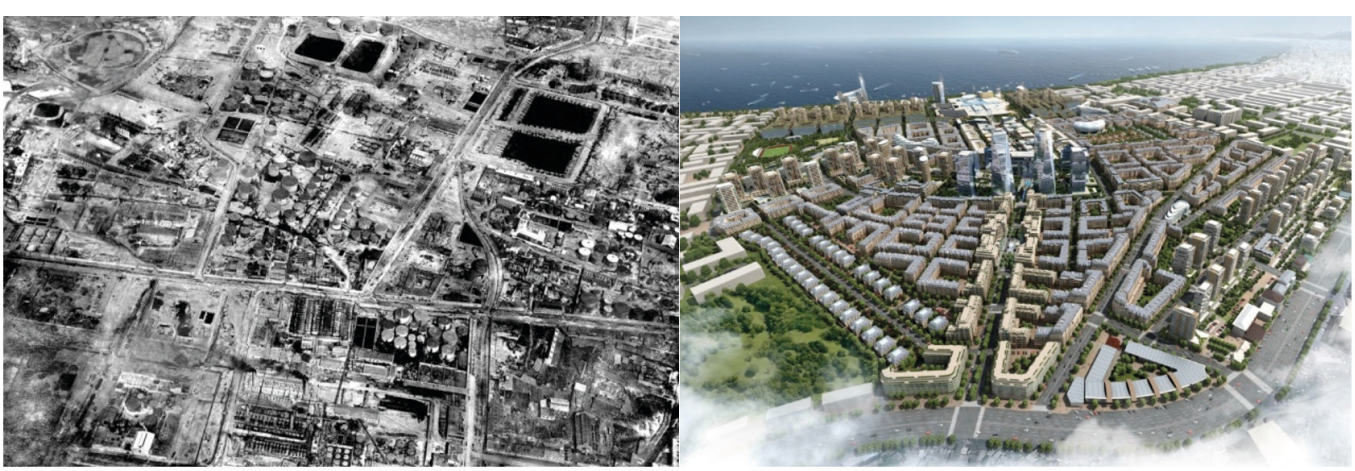

Figure 2. Baku "Black City" and "White City"

lems. These programs improve equipment performance and consequently reduce and control pollutants.

Conclusion

The petrochemicals industry plays an important role in different manufacturing sectors. However, concerns about the potential environmental hazards have increased, as these industries release large quantities of toxic and deleterious substances as effluents into the atmosphere and generate solid waste that is difficult to treat and dispose of. Emissions of harmful substances from petrochemical industries have decreased significantly in recent years due to the use of environmental and technological developments, along with increased awareness of the safety aspects of plant operation. It is essential to develop control and preventive measures that are to be taken at the planning stages in these industries.

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Impacts of Global Warming on Wind and Solar Energy: Turkey's Perspective

Duygu Akyil[a], Burak Barutcu[b]

Abstract: *Renewable energy sources, especially wind and solar energy, are becoming increasingly important due to the environmental damage caused by the use of fossil fuels, and their usage is being promoted worldwide However, with the effect of increasing global warming, there is a possibility of modification of the regimes of solar and wind resources on Earth. If global warming continues to increase in coming years, there is potential for these resources to decline in many parts of the world, including Turkey.*

Authors' Profiles

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Introduction

The rapid growth of the worldwide human population has caused a rapid decline in traditional energy sources. The continuum of human civilization depends on the constancy of these energy sources. In this case, worldwide energy demand is developing by 2040, according to The International Energy Agency's (EIA) New Policies Scenario, due to increased incomes and the worldwide population growth of 1.7 billion people in urban zones of mostly growing economies (IEA, 2018).

The damage caused by fossil fuels to nature and the decline of fossil fuels has led people to think more carefully about alternative options. Therefore, the tendency to use renewable energy is increasing day by day due to a key way of reducing carbon emissions from fossil fuel burning. In view of the fact that two-thirds of greenhouse gas emissions originate from the energy industry, The Intergovernmental Panel on Climate Change (IPCC) has called for an instant transformation of the world's energy system with huge renewable energy uptake (IPCC, 2018). The integration of renewable energy in power systems broke records in 2017 and 2018, as many jurisdictions deployed higher rates of renewable energy power, for longer durations, than ever before (IRENA, 2019). This shows that renewables will be replaced with the traditional energy sources. Annual renewable capacity additions will exceed 600 gigawatts (GW) per year, 84 percent of which will come from solar and wind technology (IRENA, 2019). This demonstrates the importance of wind and solar energy in terms of renewable energy sources, but the sustainability of these

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sources may change from region to region as global warming occurs around the world.

Wind and Aeolian Energy

Wind, as a renewable energy source, provides national and sustainable energy supply for all countries. Thus, wind energy – also called Aeolian energy– is one of the fastest growing industries and every year it increases its yearly installed capacity. While global capacity for newly installed wind power plants was 51.3 GW in 2018, this was further increased with the installation of wind power plants that together had a capacity of 591 GW (GWEC, 2018). This growing interest in wind energy worldwide will continue to rise in the following years.

Winds are quantified by two parameters: speed and direction (Shen et al. 2011). Winds come in all directions or speeds and show seasonal, daily, and hourly changes due to the different radiation of the Sun on the Earth's surface. Also, the Earth's surface is heated in different proportions because of topographic structures such as mountains, valleys, water bodies, vegetation, and desert lands. As a result, the winds vary with altitude, depending on topography and atmospheric conditions. However, these conditions mean that the winds have a semi-continuous structure on a global scale.

The Sun and Solar Energy

The Sun is an enormously powerful and inexhaustible energy source, and sunlight is by far the largest source of energy received by the Earth. Solar energy is a clean source of energy that is produced directly from sunlight, without any harmful gas emission. With increasing population and industrialization, the world's solar energy demand is also increasing.

Why does Climate Change Limit Wind and Solar Energy?

One of the effects of global warming is on wind and solar energy potential from renewable energy sources. If significant modifications occur in the near-surface atmospheric flow and storm conditions in a globe warmed by greenhouse gases, this may influence wind energy, or at least its spatial manifestations (Pryor and Barthelmie, 2011).

The main issues that change wind energy potential are urbanization, climate change, global warming, and change of land regulations. Urbanization plays an important role in wind potential. The destruction of green areas triggers the creation of city heat islands, with an associated increase in construction sites and tall buildings (EPA, 2019). Thus, mega cities are one of the irrefutable cause of global warming and climate change. The amount of water vapor in the air increases with the warming world, especially in coastal areas, which causes a decrease in the amount of direct solar radiation reaching the Earth. Water vapor causes the scattering, reflection, and absorbing of the photons coming to the Earth and reduces the heat flux reaching the ground in total. Wind energy, like the other terrestrial renewable energy sources, depends on solar energy. The inequality of heating and cooling caused by solar energy results in different heating and cooling over regions, which ends up with high- and low-pressure zones. These pressure zones create pressure gradients between them. Climate change weakens the pressure gradient force. This is one of the most important parameters affecting wind formation because the pressure gradient force, the force that triggers the wind, depends on the temperature gradient. Wind does not occur unless the temperature difference exists. Global warming causes a decrease in the temperature difference and therefore a decrease in wind speed. In this case, winds are affected by global warming and climate change, which are common problems for humanity. That is, wind conditions are dependent on climate change like many other atmospheric elements.

Studies on climate change and consumption of energy resources have generally focused on the impact of energy use on global warming and climate change, while studies on the impact of climate change and global warming on renewable energy sources have remained in the background. A new study published in Nature Geoscience claimed that future climate change may lead to a reduction in wind resources in the Northern Hemisphere (Karnauskas et al. 2018). That is, due to global warming, there may be long-term changes in the amount of the energy generated from wind power in the Northern Hemisphere. In the Southern Hemisphere, in

severe climate change scenarios, average wind speed is predicted to increase. Most of the established wind power plants and consumption are located in the Northern Hemisphere, which means that part of the Earth will be more affected in terms of energy generation from winds. Some studies have emphasized that wind speeds have declined in the last 30 years around the world by 5–15 percent, and are usually anticipated to continue to decline during the 21st century (Vautard et al. 2010, McVicar et al. 2012). Thus, climate change, whether it is global or regional scale, brings slower winds.

With changing climate, solar resources may no longer be stable over time. According to the study of Karnauskas, solar power in Europe will increase greatly due to global warming, but could decrease elsewhere (Karnauskas et al., 2018). Another study found that changes in the production of solar power plants will indicate significant regional variations. Thus, the output of solar power in Europe is likely to rise considerably, but fall in many areas of world, such as Western America and the Middle East (Crook et al. 2011). The reasons for all of these are the lands, which are warming up more quickly than the ocean.

Because of the occurrence of the significant changes in the frequencies, severities and spatial distribution, there is a need to repeat the analysis of renewable energy sources with the changing climate. Previous analyses will become incorrect over time for all regions on the Earth.

The results of the study conducted by researchers at the Karlsruhe Institute of Technology (KIT) using spatially and temporarily resolved climate models show that climate change poses great risks for wind power generation in Europe (Moemken et al., 2019). It is predicted that the average wind energy production of the entire European continent will decrease, although stronger seasonal fluctuations and lower wind phases are expected to occur. The change of ground shapes (orography) is one of the main reasons for the change of wind parameters because the transformation of green areas into construction sites changes the climate. For instance, the difference in temperature between land and sea is the main reason for the formation of land and sea breezes, which are important for wind farms located on the coast in terms of wind energy potential.

Turkey's Profile: Effect of Global Warming on Wind and Solar Energy

Turkey is a country that borders the Mediterranean, Aegean, and Black Seas and has many renewable energy resources (How is 100% Renewable Energy Possible for Turkey by 2020?, 2011). Due to its geographical location (36–42 latitude and 26–45 longitude) and mid-latitude region, the country is affected by the overall flow of synoptic-scale systems. Since it is located at the intersection of different weather patterns, the coastal areas in particular have high wind energy potential. Also, Turkey is located in a significant position geographically, as the east and south-east sides of Turkey are advantageous for solar energy potential. According to the European Wind Atlas data, Turkey is among the 19 European countries with the most eligible land, qualified wind power, appropriate plant location, and technical power. According to the Turkish Wind Energy Association, at the end of 2018 the cumulative installation of wind power plants in Turkey was 7369.35 MW and the annual installation of wind power was 497.25 MW (TÜREB, 2019). The total annual installations of wind power plants in Europe was 11.7 GW at the end of 2018, and Turkey is one of the leading countries, with 497 MW (Wind Energy in Europe, 2018). On the other hand, Turkey's solar energy potential is equivalent to the sum of the potential of all European countries. According to a study conducted by Renewable Energy General Diroctarete (YEGM) Turkey's average sunshine duration is 2640 hours per year, and the average total solar radiation is found to be 1311 kWh/m2 per year (EIEI, 2019). However, Turkey is also inevitably affected by global warming. The Ministry of Energy and Natural Resources report that Turkey's total installed solar energy reached 5 GW at the end of 2018 (SHURA, 2018). Figure 1 shows the cumulative installed capacity of onshore wind energy and the solar energy from 2007 to 2017 in Turkey according to data from the Republic of Turkey Ministry of Energy and Natural Resources.

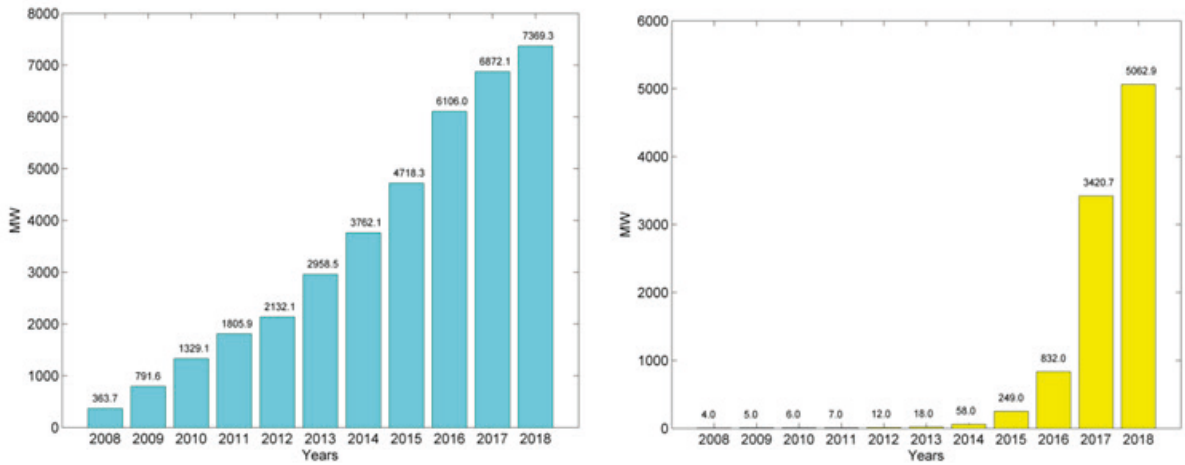

Figure 1. Cumulative installed capacity of onshore wind energy and solar energy in Turkey (blue: wind, yellow: solar).

Conclusion

Wind energy and solar energy have been proposed as solutions to global warming. Unlike fossil fuels, wind and solar energy are regarded as green energy sources because they are produced from inexhaustible resources. In addition, these types of energy are advantageous options for climate change by reducing carbon emissions. Therefore, there is increasing interest in renewable energy sources around the world and this interest is supported by high installed power in both solar and wind power plants. However, some changes should be expected in the global wind and solar energy potential with climate change and global warming due to the change of heat in the land and sea, and this change should be taken into consideration in the wind and solar energy policies to be developed in terms of sustainability.

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Climate Change and Greenhouse Gas Emissions in Pakistan: A Consequence of Urbanization

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Abstract: *Climate change is a global issue that has arisen from rapid urban development, led to extreme weather events, and negatively impacted both food security and the water availability. The impacts of climate change are being faced both at the regional and global levels. Pakistan is among the most vulnerable countries in the world, despite the fact that it contributes less than 1 percent of global greenhouse gas (GHG) emissions. Development sectors such as industry, transport, building, energy generation, agriculture, waste and land use, land use change, and forestry are all responsible for emission of GHGs. Climate risk management through mitigation and adaptation are crucial to address this issue. The Pakistan Government needs to realize that 'development as usual' is no longer a viable option. Implementation of climate change policy must be prioritized and integrated into all sectorial policies. Climate change mitigation and adaptation need to be incorporated into policies, plans, and programs, and development choices must be climate-friendly.*

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Introduction

Climate change is a global issue and its impacts are cutting across all sectors of life. It is the greatest challenge that humanity has ever faced. Rapid urbanization is the highest contributing factor towards aggravating the intensity and impacts of climate change. It has been estimated that about 55.3 percent of the world's population lives in urban areas. Of the 36 fastest-growing cities, 28 are in South Asia, with seven in Africa and one in North America (UN, 2018). This shows the vulnerability of developing countries to the consequent environmental and climate change threats. Rapid urbanization and indiscriminate economic growth are leading to compromises regarding environmental protection and sustainable development. The average global atmospheric concentration of CO_2 has increased from 280 ppm during pre-industrial times to more than 413 ppm in 2019 by volume and is growing faster every day (US-EPA, 2017). Total global GHG emissions, excluding land-use change emissions, were 49.2 $GtCO_2$ eq in 2017, with an increase of 1.1 $GtCO_2$ eq emission in 2016 (UN Environment, 2018).

Pakistan is facing a number of climate-change-related threats, including rapid glacier melting, sea level rise,

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energy crisis, and water and food insecurity (Ministry of Environment, 2011). It has been projected that there is an increased risk of flooding, glacier melting, and landslides in Pakistan due to climate change (Planning Commission, 2010). Pakistan has been ranked as the seventh most affected country by the impacts of climate change from 1997–2016 (German Watch, 2018). Pakistan ranks 31st on the list of global GHG emitters (ADB, 2017). The prime drivers of climate change are emissions of GHGs from energy generation, industry, transport, agriculture, residential and commercial energy consumption, and land-use change. Pakistan's GHG emissions are projected to increase to 1603 million tons of CO_2 eq. by 2030 (Ministry of Climate Change, 2016).

Along with ongoing economic growth, the 2700 km China–Pakistan Economic Corridor (CPEC) is a major development program being implemented by China and Pakistan with the aim of connecting the Gwadar Port in Pakistan to China's northwestern region through a network of highways, railways, and pipelines. Other than transportation infrastructure, the economic corridor will provide Pakistan with telecommunications and energy infrastructure for which coal-fired power plants with a capacity of over 10,400 MW are being installed. Under the CPEC, Gwadar Port is also planned to be expanded with additional infrastructure projects. Gwadar Port and other CPEC project would lead to an increased rate of emissions in Pakistan.

Drivers of Climate Change in Pakistan

Transport

At the global level, the direct emissions of CO_2 from the transport sector were approximately 6.7 $GtCO_2$ in 2010, with this figure estimated to increase to 9.3–12 $GtCO_2$/yr by 2050 (IEA, 2012a). There has been a tremendous increase in the number of motor vehicles in Pakistan, from 3.84 million in 1996 (PBS, 2015) to 21.5 million in 2017 (PBS, 2017), with an increase of 460 percent. Approximately 57 percent of total fuel oil consumption in Pakistan is consumed by the transport sector, compared to 53 percent globally (IEA, 2012a). The transport sector contributes to approximately 35.4 Mt of CO_2 eq., with projected emissions of 80.7 Mt CO_2 by 2030 (IISD, 2016).

Industry

Industrial activities are responsible for close to 30 percent of global GHG emissions. GHG emissions from global industries and waste/wastewater grew from 13 to 15.44 $GtCO_2$ between 2005 and 2010 (IPCC, 2014). Industrial emissions of GHGs grew at the fastest rate in Asia from 2005–2010. Considering the ongoing economic growth of Pakistan, emissions from this sector would increase from 59 $MtCO_2e$ in 2012 to 196 $MtCO_2e$ by 2030 (IISD, 2016).

Energy Generation

The energy supply sector is the largest energy user. It is also the largest contributor of GHGs emissions globally, with approximately 35 percent of GHGs coming from this sector in 2010. Growth of GHGs from energy generation accelerated from 1.7 percent per year in 1990–2000 to 3.1 percent in 2000–2010 (IEA, 2012b; JRC/BPL, 2013). The energy generation sector of Pakistan accounted for 51.58 $MtCO_2e$ emissions in 2012. It has been projected that the sectorial emissions will increase to 101.67 $MtCO_2$ by 2030 (IISD, 2016) to meet the energy demand.

Residential, Commercial and Agriculture Energy Consumption (RCA)

GHG emissions for RCA have doubled since 1970, to 9.18 $GtCO_2$ at the global level (IEA, 2012b; JRC/BPL, 2013). Emissions from this sector are projected to increase from 29 $MtCO_2e$ in 2012 to 61 $MtCO_2$ by 2030. The RCA sector contributes to approximately 9 percent of Pakistan's national GHG emissions (IISD, 2016). The increased emissions are due to meeting the demand of growing populations in developing countries to access adequate housing, electricity, and cooking facilities. Energy intensity is a major issue to be dealt with.

Agriculture

Agriculture contributes to 5.0–5.8 Gt CO_2eq/year of global GHGs emissions. The main GHG emissions from this sector are CO_2, CH_4, and N_2O from this sector

(Paustian et al., 2004). Livestock contribute to 40–50 percent of agricultural GDP and are responsible for 5.6–7.5 $GtCO_2$ eq/year (Herrero et al., 2016). The agriculture sector is the highest contributing sector to Pakistan's GHG emissions, with 165 $MtCO_2e$ in 2012 (42 percent of the total) (IISD, 2016).

Land Use, Land Use Change, and Forestry (LULUCF)

It is estimated that global deforestation leads to an emission of approximately 7 billion metric tons of CO_2 annually to the atmosphere. Emissions from the LULUCF sector were estimated to be 10 $MtCO_2e$ in 2012 and are projected to rise to 15 $MtCO_2e$ by 2030 (IISD, 2016). During 1990–2015 there was a net loss of approximately one million hectares (FAO, 2009) representing a reduction in carbon stock of over 100 mega tons CO_2. The rate of deforestation in Pakistan is estimated to be 27,000 hectares per year (FAO, 2009).

Impacts of Climate Change

The enhanced GHG effect is likely to boost the Earth's average temperature by 1.0–3.7°C over the next century (Anderson et al, 2016). Climate change of that magnitude would have serious impacts on the survival of human beings. Greenhouse gases lead to global warming by changing the energy balance of the atmosphere. This variability of air and water temperature exacerbates immense changes in the global climate, like sea-level rise, hurricanes, storms, higher precipitation, floods, and droughts. Climate-driven disasters like flooding, hurricanes, heat waves, and droughts have led to the displacement of millions of people around the world. Climate change also involves the shifting of wildlife populations and habitats and other wide-ranging effects.

Temperature Rise

In 2017, the global average temperature increased by about 1°C above pre-industrial levels, with many regions suffering higher temperature rises (IPCC, 2018). Average annual temperature has increased by 0.6°C in Pakistan during the last century, with a higher temperature increase in northern areas (0.8°C) than in southern areas (0.5°C). Between 2001 and 2010, the average temperature in Northern Areas of Pakistan increased by 1.3°C, compared to the average temperature rise across the country of 0.6°C (Rasul et al., 2008). A temperature rise of 2°C to 4°C is projected during 2021 to 2100 (Ikram et al., 2016).

Heat waves are a devastating natural hazard. During the last 30 years, the number of days with heat waves per year has increased nearly five-fold of the average. About 1200 people died due to heat waves in Karachi in 2015 (ADB, 2017).

Change in Precipitation

Floods are the most common natural disasters on Earth and are the result of shifting the rainfall patterns due to global warming. Higher temperatures lead to increased evaporation and evapotranspiration. Warmer air has higher capacity to hold water vapors, implying that precipitation volume for a certain time period has increased. A high volume of rainfall during a short time span increases flood risk.

The average precipitation increase in Pakistan during last century has been 25 percent (ADB, 2017). Summer monsoons in Asia provide the rainfall required for sustainability (Annamalai et al., 1999); however, variability has been observed in monsoon patterns, leading to extreme weather events. Monsoons in the Asian region have been significantly affected by 'atmospheric brown clouds' and other pollutants coming from anthropogenic sources (Ramanathan et al., 2007). These brown clouds also cause global warming, leading to glacial melting in the Himalayas. Monsoon rains in South Asia have been delayed by 20 to 30 days, affecting livelihoods and food and water security (Krishnamurthy & James, 2003). At the global level, floods occurring from 1980–2009 have affected more than 2.8 million people and caused approximately 500,000 deaths (Hirsch at el, 2012).

Drought

Drought is usually caused by a reduced rate of precipitation and an increase in the potential of evapotranspiration due to warming climate (Wan at el, 2018). Droughts pose a great challenge to the affected communities in terms of water security, food security, desertification, and land degradation. Nearly 1.3 billion people

around the world are associated with the agriculture sector, so severe droughts could lead to water shortages that have long-term impacts on associated communities (The Climate Reality project, 2016).

Water scarcity is the cause of conflict among many countries, and this could increase in the future. Approximately, 40 percent of people around the globe are affected by water scarcity and 700 million are at risk of being suffered by drought in 2030 (UNCCD, 2019). If water levels drop in already water-stressed regions due to climate change, production losses in sectors such as agriculture and energy generation are likely to increase. Approximately 20 percent of population lives in arid or semi-arid regions, where average rainfall has decreased. These regions are more prone to have water scarcity because of rapidly growing population and unstable climate (Gourbesville et al, 2008). The risk of hydrological and agricultural drought increases with the temperature rise globally. It is projected that 75–250 million people in Sub-Saharan Africa will be exposed to water stress along with nutritional risk caused by water contamination (WHO, 2014).

There had been severe droughts in Pakistan, with the worst occurring between 1998 and 2002 affecting 3.3 million people (Ahmad et al., 2004). Approximately 50–60 percent of population is directly affected in the drought areas of Balochistan. Losses of crop yields were reported to be 50–80 percent between 2011 and 2015. During same period, the average number of livestock was reduced by 37 percent due to prolonged drought in many areas of Balochistan (BUITEMS/UNDP, 2015). Approximately 30 percent less than average rainfall was observed during 2013 and 2014 in the Thar area, which led to a drought-like situation with a number of casualties (Shaikh, 2014). The mortality rate of livestock was 70 percent, with 300,000 dead livestock mainly due to unavailability of water and food (Hands Pakistan, 2014).

Food Insecurity

Climate change has adversely affected the agricultural sector, decreasing crop yield on a large scale, and is responsible for food insecurity and extreme poverty. Food insecurity is a growing concern throughout developing countries. More than 825 million people are malnourished worldwide (FAO, 2019). Increases in temperature and variations in precipitation pattern are expected to reduce crop yield in regions where food availability is already a problem. At the global level, climate change will lead to a 1–7 percent decrease in cereal production by 2060, mainly in developing countries of South Asia and Sub-Saharan Africa. Reduced production of staple food leads to higher prices and increased food insecurity when the population is almost double (Parry et al., 2009).

Pakistan ranks 75th among 113 countries on the Global Food Security Index. In 2016, wheat crop yield was severely affected in areas of Punjab, Balochistan, and Sindh due to temperature rise and change in precipitation. An estimated 900,000 people were vulnerable to food insecurity in FATA during 2017 and the average susceptible population of Pakistan was 1.4 million during 2014–2017 (NDMA & WFP, 2017). Crops are particularly sensitive to changes in temperature, precipitation, and the availability of irrigation water. It is expected that the length of growing season for wheat will decrease with increasing average temperatures in all agro-ecological zones in Pakistan. It has been projected that by the end of this century, wheat crop yield will be reduced by 3.4–12.5 percent in semi-arid irrigated areas, 3.8–14.5 percent in arid areas, and more than 16 percent in rain-fed areas. Rice yields are expected to decline by 12–22 percent by the end of the century (GCISC, 2009). The projected food insecurity may lead to climate-induced migration.

Glacial Melting

Melting of glaciers and ice sheets has been accelerating during the last few decades due to the accumulation of GHGs in the atmosphere. Heat is continuously trapped by the GHGs, increasing the temperature due to which glacier mass is lost continuously, dropping from 226 Gt/year in 1971 to 275 Gt/year in 2009. The level of ice in the Antarctic region dropped from 30 Gt/year in

1992–2001 to 147 Gt/year during 2002 -2011. Greenland's ice sheet loss its concentration from 34 Gt/year in 1992–2001 to 215 Gt/year in 2002–2011 (Climate.gov, 2018).

Due to the increased trend of glacier melting, 52 lakes in Pakistan have been declared as potentially dangerous (Ministry of Environment, 2011). Pakistan's water resources originate from glaciers in the Himalayas and the Tibetan Plateau. Glacier melting will lead to an irreversible water scarcity in the region. About 5.9 Km of the length and 17 percent ice mass of Siachin Glacier was reduced from 1989 to 2009, as shown in Figure 1.7 (Rasul et al., 2012).

Sea Level Rise

Sea levels have been rising over the last century, at an accelerated rate during the last few decades. Changing climate is affecting the oceans and their level has been rising since 1990 at a rate of 0.04–0.1 inches per year (NOAA, 2018). Communities living on islands are at high risk due to sea level rise. A 30–50 cm sea level rise will affect a low island by 2050, whereas the 1-meter sea level rise expected by end of this century would make some of these islands uninhabitable (Parris et al., 2016).

It is projected that a sea level rise of about 2 meters could submerge an area of 7500Km^2 in the Indus basin. Sea level rise in the coastal areas of Karachi has been observed to be 1.1 mm/year (Rabbani et al, 2008). Sea level rise would make the coastal areas vulnerable to frequent storm surges, floods, destruction of wildlife habitats and intrusion of saline water affecting the socio-economic conditions in the area.

Combating Climate Change

Climate Change Mitigation

Determined mitigation strategies are crucial to minimize the intensity of climate change. The Paris Agreement on Climate Change is a milestone in bringing the international community to achieve common objective of combating climate change. Pakistan, being a developing country, requires equitable international cooperation by the developed countries.

Incorporating mitigation plans into the design stage at all levels of development sectors would help lower GHG emissions. Mitigation strategies for energy generation have higher potential for decarbonization than other sectors. Conversion of coal-fired power plants would also help improve air quality with reduced health costs. Electricity transmission and distribution systems also need to be improved for efficiency. A low-carbon transport system requires investment in public transport systems, road-to-rail switching, increased vehicle efficiency, road-to-friend shift, and use of cleaner fuels. Effective implementation of mitigation action in the transport sector would lead to a 20–50 percent reduction in 2010 baseline GHG emissions by end of 2050 (Sims et al., 2014). Energy efficiency and process efficiency must be prioritized for the industrial sector in order to reduce GHG emissions arising from energy intensity. Cleaner technologies and innovative products need to be introduced in order to lower industrial contribution to GHG emissions. Globally, GHG emissions from Asia are the highest in the world due to rapid economic growth in that region.

The agriculture sector, which is usually overlooked as a source of emissions, must make serious efforts to introduce climate-friendly measures. Mitigation measures for agriculture that must be adopted include climate-friendly rice cultivation, improved irrigation, appropriate fertilizer application, manure management, and restrictions on crop-residue burning. Such measures would require extensive programs for farmers' capacity building and skill development and nation-wide policy implementation.

Although the high mitigation cost is a barrier for developing countries to cope with the climate change, it could be overcome through imposing carbon tax on fuel and changes in infrastructure. Reduced health costs as a co-benefit of climate change mitigation would also help governments implement effective policies and change societal behavior.

Adaptation to Climate Change

Climate change adaptation is indispensable for co-existence with the changing climate. It will help vulnera-

ble communities deal with the unavoidable impacts of climate change. The expected impacts need to be anticipated for taking proactive measures to develop climate resilience. There must be an early warning system in place for timely action on rescue during a climate-driven disaster. Efficient water consumption, introducing heat-resistant and drought-tolerant crops, plantation, flood protection infrastructure, and defense against sea level rise are a few adaptation measures to be applied in the relevant vulnerable areas.

Conclusion

Coping with the climate change, along with economic growth, has become a real challenge for Pakistan. While moving towards aggressive development, climate change mitigation should be considered as an important component of all development programs. Low-carbon emission should be the priority to achieve national development goals.

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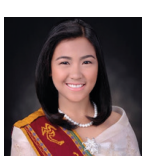
Climate Change and Its Impact on Hydrology and Water Resources in Urban Areas

Kristal Aubrey S. Bornillo[a], Henrison C. Sanchez[a]

Abstract: *Growing urbanization and increased human activities have intensified global warming, which has caused variations in the world's climate. Climate change affects hydrological processes such as precipitation and evapotranspiration, which affects the quality and quantity of water resources. The effects of climate change vary from region to region, with varying effects all over the world such as drought and flooding. Global climate models (GCM) and regional climate models (RCM) are widely used for projecting the effects of human activities on climate change. The data from these models are then used in hydrological models in order to determine the effects of the projected climate change on hydrology and water resources. These methods are widely used and are essential for climate change projections and planning for actions that will alleviate the effects of climate change on hydrology and water resources.*

Authors' Profiles



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Climate Change and its Impact on Hydrology and Water Resources

Climate change is the long-term change in global or regional temperature and normal weather patterns as a result of global warming (Olsson et al., 2016). Greenhouse gases (GHG) occur naturally and are essential to life on earth by trapping some of the sun's warmth from reflecting back into space, making Earth livable (Gautam & Singh, 2015). However, according to the Intergovernmental Panel on Climate Change (IPCC), increased human activities such as burning of fossil fuels, deforestation, large-scale agriculture, and urbanization have altered the balance in this mechanism, trapping more heat in the earth's atmosphere and consequently increasing the planet's overall temperature; this is known as global warming (United Nations, 2019). Over several decades, studies have shown that climate variability has significant impacts on the hydrological cycle, which affects water resources and society.

Water is essential in all societal sectors and fast-growing populations and continuous industrialization have led to higher demand for water use, especially in urban areas. Although cities cover only 2 percent of the earth's surface, they are major contributors to climate change due to high human activities and less vegetation, resulting in a relatively high carbon footprint. Urban areas

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account for 71–76 percent of the world's carbon dioxide from global final energy use and a significant portion of total greenhouse emissions. At the same time, urban areas are also heavily affected by climate change, especially those that lack good management and planning. Among the projected impacts are altered precipitation and runoff patterns in cities, flooding, sea level rise and resulting saline ingress, storm surge, and constraints in water availability and quality due to drought.

The effects of climate change on the hydrological process, such as in precipitation and evapotranspiration, has led to regional redistribution of water resources due to modified tracks of cyclones and storms as well as higher extreme intensities in a warmer atmosphere. Moreover, the increase in the planet's overall temperature has caused a significant meltdown of glaciers and other sea ice, resulting in an observed increase in sea level. This increase in sea level may cause the intrusion of salt water into estuaries and coastal aquifers and flooding of low-lying coastal areas (Kumar, Sahai, Kumar, & Patwardhan, 2006). This is the case for Jakarta, Indonesia, which is rapidly sinking due to the increase in sea level and over-extraction of groundwater. Models have projected that, by 2050, about 95 percent of North Jakarta will be submerged (Mei, M. and Hidayat, R., 2018). Several studies have shown that climate change impacts on water resources differ from region to region, which may cause either flooding or drought all over the world, considering that water is not well spatially distributed (Gosain, Rao, & Arora, 2011; Greve et al., 2014). It was recently reported that Chennai, the sixth largest city in India, is facing drought due to a shortfall of monsoon rains (Keneally, M., 2019). In places with higher temperatures and low precipitation, water supply is low and water demand is high; this causes a deterioration in water quality in freshwater bodies, exerting more strain on the lack of balance between supply and demand (Milly, Dunne, & Vecchia, 2005). Hence, the "dry gets drier, wet gets wetter" (DDWW) paradigm, which literally means that dry regions dry out further, whereas wet regions become wetter as the climate warms. However, Greve et al. (2014) showed that this is not always true on land areas. Only 10.8 percent of the global land area showed a robust DDWW pattern and 9.5 percent of the global land area follows the opposite pattern; that is, dry gets wetter and wet gets drier. Hence, Greve et al. (2014) concluded that aridity changes over land. Although there are different effects on oceanic and land areas, this still proves that climate variability affects the hydrologic cycle, which in turn affects the regional water distribution and resources.

The link between climate change and water resources is illustrated in Fig. 1. Climate change affects the hydrologic processes, which causes redistribution of water in time and space. The change in water resource system within a region changes its ecological system and its processes. With the apparent impact on the environment and availability of water resources, people find ways to adapt to the changes brought by the variation in climate, which often leads to increased human activities. As stated earlier, the IPCC reported that an increase in human activities brings an increase in the emission of GHG, which increases the planet's temperature, leading to climate variability and worsening its effects. Climate change is now recognized as one of the most serious challenges facing the world today. The longer we delay collective action to control our activities and emissions, the harder it will be to break this cycle, until there will

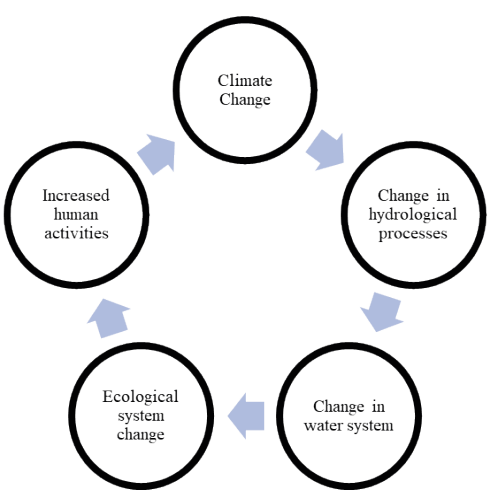

Figure 1. The relationship between climate change and water resources.

come a time that the damage done to our environment will be irreversible, putting future generations at great risk.

Various research methods have been developed to anticipate future climate patterns and alleviate its effects on society and the environment, especially water resources. One such method is GCMs, which are computer-run mathematical representation of the physical and dynamic processes of the atmosphere, cryosphere, ocean, and land surface and their interactions. GCMs are mainly used to obtain projections of the response of climate to current and future human activities. However, due to their coarse resolution, GCMs cannot be directly used at local or regional scales. Therefore, there is a need to downscale the results from a GCM in order to predict local responses. The best way to downscale the data is to finely resolute them to an RCM. From RCMs, regional predictions can be made and data can be used as input in hydrological models in order to determine the effect of the projected climate on the hydrological processes (Gautam & Singh, 2015; Mehan, Kannan, Neupane, Mcdaniel, & Kumar, 2016). Hydrologic models are widely used as cost-effective methods for evaluating the best alternative management plan within a shed (Lenhart, Eckhardt, Fohrer, & Frede, 2002). The quantitative estimation of the impact of climate change in hydrology is essential for identifying potential water resource problems and in planning decisions (Brekke, Miller, Bashford, Quinn, & Dracup, 2004). The use of RCMs in region-specific assessment of the anticipated impacts of climate change on water resources has been widely used in many studies, despite being computationally expensive and rather complex to implement. With further advancements in contemporary and future technology, it is expected that more cost-effective climate models will be developed for more accurate projections of the effects of human activities on climate change and to provide people with better adaptation plans and enable them to take the actions needed for a sustainable low-carbon future.

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The Challenges of Implementing Solar Power in Urban Areas During Climate Change

Yasin Alperen Çelebi

Abstract: *As urbanization and climate change continue to be global trends, increasing energy demands require feasible, efficient, and eco-friendly solutions. One of the preferred solutions for such problems is solar power, the fastest growing market in the energy sector. However, implementing solar power in urban areas has certain challenges, which each city approaches in its own way.*

Author's Profile

Yasin Alperen Çelebi is an electrical and electronics engineer from Ankara, Turkey. He graduated from Middle East Technical University (METU), specializing in power systems. His interests include renewable energy, smart-grid power systems, and computational intelligence, which consists of not only their technical aspects, but also their social, political, and economic impacts on society.
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Introduction

More than 55 percent of the world's population lives in urban areas and this number is expected to reach 70 percent by 2050. Among this 55 percent, around 8 percent live in megacities. The United Nations defines a megacity as a metropolitan area with more than 10 million people. By this definition, there were 33 megacities in 2018 – more than triple the number in 1990 – and this number is expected to be 43 in 2030 (UN, 2018).

As urbanization continues to be a global trend, the energy demands of metropolitan areas continue to rise. Primary energy consumption grew at a rate of 2.5 percent in 2018, with a 10-year average rate of 1.5 percent (BP,2018). One study suggests that a 1 percent rise in urbanization leads to a 0.72 percent rise in non-renewable energy consumption (Mrabet, Alsamara, Saleh, Anwar, 2016.). According to the Intergovernmental Panel on Climate Change (IPCC), urban areas consume between 67 percent and 76 percent of global energy and generate about three-quarters of global carbon emissions (IPCC,2015). Carbon emissions strengthen the greenhouse effect, trapping the excess heat in the Earth, which is the main reason for climate change.

Providing rising energy demands while slowing down climate change requires clean, sustainable, and efficient solutions. One of these solutions is the implementation of power networks with renewable energy generation techniques, among which solar panels are the most popular due to their modularity, versatility, and the rapid increase in affordability and effectiveness. Solar power is

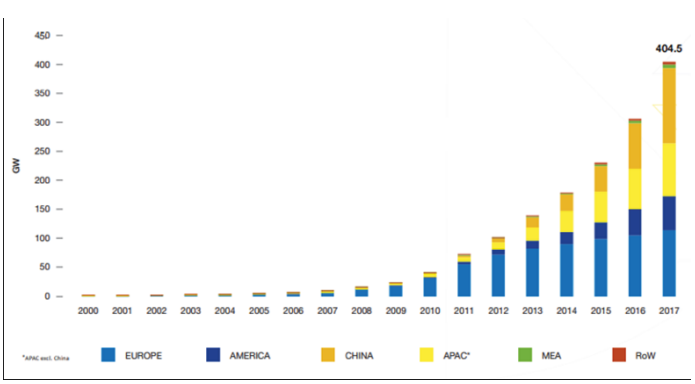

Figure 1. Evolution of total solar PV installed capacity (2000–2017) (Image Taken From: http://www.solarpowereurope.org/wp-content/uploads/2018/09/Global-Market-Outlook-2018-2022.pdf?).

the fastest-growing market in renewable energy, with a nearly 400-fold increase from 2000 to 2017 period (SolarPowerEurope, 2018). Most of this growth originates from China, the country with the most megacities (six).

The modularity of solar panels increases the available locations for very distinct locations and improve it gradually, making it a good choice for being able to catch up with the fast pace of urbanization. New materials and production techniques are being continually developed to maintain the sharp decrease in solar power costs and the increase in solar cell efficiency and lifespan.

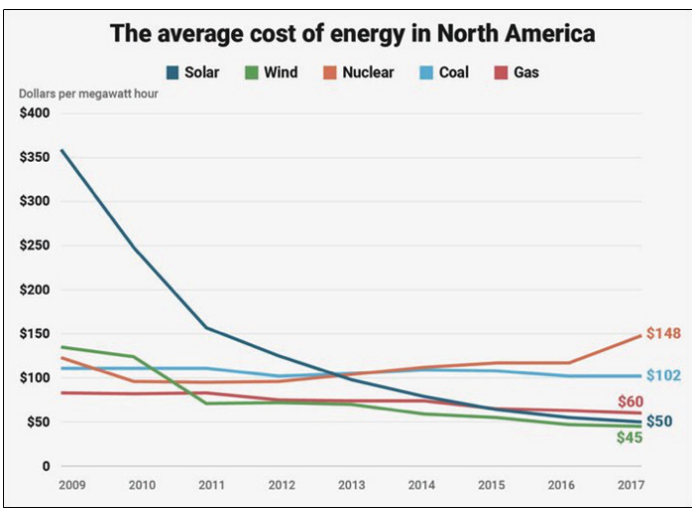

Figure 2. The decrease of solar energy cost compared to other energy costs in North America (Image taken from: https://www.businessinsider.com/solar-power-cost-decrease-2018-5).

Benefits of Solar Power in Cities During the Climate Change

Among the many benefits of solar power technology for urbanization is a reduction in the effects of climate change on cities. Others include self-sufficiency, economic stimulus, and improvement of life quality. Urban solar power can be utilized for lighting, transportation, charging stations, heating, cost reduction, storage of excess power for later usage, and extra revenue.

To begin with, solar power decreases CO_2 emission and fossil fuel usage significantly. Data obtained by the IPCC suggests that solar power systems generate around 20 times less gCO_2eq/kWh (grams of carbon dioxide equivalent per kilowatt-hour of electricity generated) lifecycle emission than coal plants, and 10 times less than gas plants. Almost all of the emissions of solar systems come from infrastructure and supply chains (IPCC, 2014).

Another issue is air pollution. The most important reason for China's heavy investment in solar power technology is the widespread health problems caused by heavy smog in cities. In fact, the smog is so bad that it renders tens of billions of USD worth of solar panels useless by blocking the sun and reaches across the Pacific Ocean, polluting California's air from thousands of miles away (Lin, Horowitz, Payton, Fiore, Tonnesen, 2014).

Studies have shown that the current solar technology could supply the world's entire electrical demand using solar panels covering an area the size of Spain. Providing this amount of power would decrease the global temperature by 3 degrees Celsius. Although such a grand effort is not feasible, high-intensity solar power investments in urban areas would have significant changes to local climate conditions, particularly the urban heat island effect, which is the temperature difference between an urban area and its surroundings. It is the result of the waste heat caused by the human interaction in densely populated urban areas, such as surface heat of buildings and roads, industrial outputs, and air conditioning. A simulation conducted in Tucson and Phoenix metropolitan areas with high solar panel coverage ended up decreasing cooling energy demand by up to 14 percent and lowering temperature levels by up to 0.4 degrees (Salamanca, Georgescu, Mahalov, Moustaoui, Martilli, 2016).

Tucson and Phoenix have a relatively low amount and density of population (535,000 and 1.62 million, respectively, in 2019) compared to many metropolitan areas worldwide, so the implementation of solar power for other cities could have greater impacts on local temperature changes.

Challenges

Coastal Regions

The urbanization process tends to be more intense in coastal regions. Roughly 40 percent of the world's people live within 100 kilometers of the coast. Eight of the

10 largest cities and three-quarters of all megacities are located by the sea. This is mainly because ports generate commerce, transportation and job opportunities. However, it has some drawbacks for solar power. Firstly, people who live by the sea use air conditioning more than people who live inland, increasing the load demand and heat island effect. Secondly, the high salt content and air humidity by the sea increases the corrosion of solar panels.

Humidity decreases the effectiveness of solar panels in three different ways (Mekhilef, Saidur & Kamalisarvestani, 2012). Firstly, the nonlinear effect of water particles in the air disrupt the reception of the solar radiation by solar cells, decreasing the power efficiency. Secondly, humidity is one of the most prominent factors in atmospheric corrosion due to its ability to absorb atmospheric gases and particles. As a result, atmospheric corrosion occurs more rapidly in humid climates. Thirdly, weather events that occur in a humid climate, such as humid heat waves and intense rainfalls, decrease efficiency by physical degradation or obstructing the process, like clouds and rain.

Studies have shown that humidity can cause a loss of efficiency for solar panels of up to 60 percent.

Timeline

As solar power production increases, power grid management is becoming more difficult, due to a phenomenon called the Duck Curve. The term was first expressed in 2013 by California Independent Systems Operator (CAISO), but similar patterns have been shown across the world.

Energy demand peaks after sunset, when solar power is no longer available, and solar energy production is highest at midday. CAISO researchers observed that as solar power production facilities are installed year after year, the midday demands get lower and lower each year, creating a graph that resembles a duck, hence "Duck Curve" (The Electricity Journal, 2016). Moreover, energy demand difference between seasons and energy demand change through the day is more significant in urban areas than rural areas, strengthening the Duck Curve.

Daily load demand with such sharp changes creates two main problems. Firstly, the balance between energy production and consumption must be preserved. The excess power caused by solar panels during midday may overload the power grid, causing power outages and damage to grid infrastructure. Secondly, power plants, especially those that produce non-renewable energy, are financially feasible only if they operate at all times, so they cannot be shut down to sustain load balance. Moreover, it is not feasible to turn off solar power plants when their power generation rate is the highest during the day.

Various approaches exist to tackle these challenges, such as price regulations and load shifting, but the most popular is the storage of the excess solar power and the distribution of that power throughout the entire day. This is not a new concept, but it has become more feasible with the rise of electric vehicles and long-term batteries.

Finances and Organization

Despite decreasing costs and increasing efficiency, solar power is still expensive compared to fossil-fuel generated power. The initial costs are higher and it takes longer

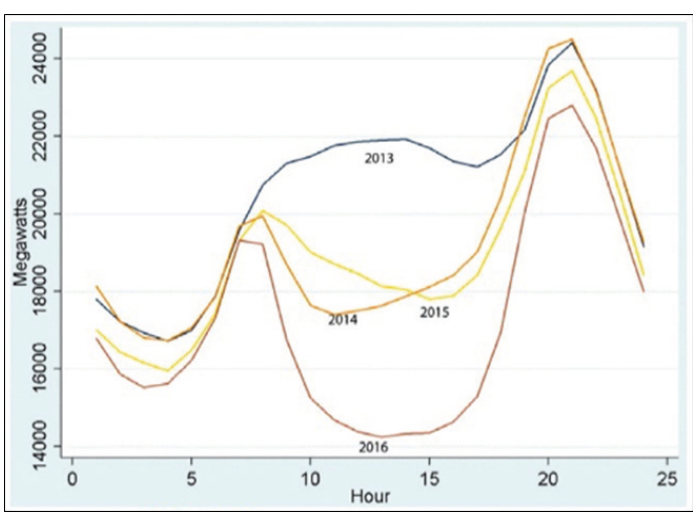

Figure 3. The change of load demand curve/formation of the "Duck Curve" with the introduction of solar power (The duck has landed) (image taken from: California's 'Duck Curve' Arrives Well Ahead of Schedule. The Electricity Journal, Volume 29, Issue 6, July 2016.)

time to cover costs and generate fiscal revenue. For these reasons, solar power projects are either done by large corporations or relatively smaller corporations subsidized by government contracts. Placement of solar panels in small households may require more installation costs per unit energy compared to large scale solar facilities. For this reason, many households prefer third-party ownership agreements. The two most common models for such agreements are power purchase agreements (PPA) and solar leasing. The installation costs are handled by the solar corporation and the household agrees to make regular payments. The difference between the two models is that solar leasing is a fixed rent/lease payment while PPA payments are based on per unit consumption (EnergySage, 2019).

The impact of the absence of a viable financial structure model can be explained through India's ambitious solar rooftop (SRT) projects and the failure to achieve the defined goals. From the goal of achieving 40 GWh of SRT power capacity by 2022, only 1222 MW had been installed by July 2018. A study conducted in five Indian cities (Devi, Narayan, Mandal, 2018) shows that the failure is the result of three main factors: (1) a lack of clear, objective, and accessible information for installation; (2) the absence of customized financing options; and (3) a lack of coordination in institutional priorities and processes. First of all, the households' knowledge of solar power was limited and public initiatives to increase awareness about solar power had failed. Thus, household owners had to rely on sources of information that are not necessarily objective and unbiased, such as online sources with very limited internet coverage, friends, family, and relatives. This leads to distrust of solar power vendors, making it difficult to reach deals. Secondly, the different conditions and regulations for each city required flexible financial offerings for householders, considering the unique characteristics of the product and the risks associated with it. Considering these issues, banks asked consumers to provide their houses – which are several times more valuable than the actual solar system – as collateral. Thus, the majority of the households that installed solar panels on their rooftops had to rely on government subsidies and refrain from involving banks. Finally, the lack of coordination between consumer, company, and government agencies hindered the installed solar capacity efficiency. This situation manifested itself differently for different cities. For one city, the grid network failed, another was restricted by municipality restrictions, and the third suffered institutional failures, such as delays, billing complications, and a lack of skilled public personnel to provide information and guidance. All of those issues caused major financial losses to both consumers, public services, and vendors.

As a result, among 1808 households surveyed across the cities of Bengaluru, Chandigarh, Chennai, Jaipur, and Nagpur, only 325 households had installed SRT. The overwhelming majority of the households (1260) did not even consider installing the system.

Pollution and Health Hazards

Despite being much more eco-friendly than other power generation systems, solar power still contains serious risks of health and environment hazards. Some of these risks involve the material properties of solar panels. Solar panels contain toxic materials including cadmium, lead, silicon tetrachloride, and hexaflourethane. This may not seem a great danger given that large solar installations are usually built in non-fertile lands far away from residential areas, but the implementation of solar power in high urban density areas, along with production and recycling processes, puts more and more people at risk over time.

For example, a study at Tsinghua University revealed the hazardous potential of perovskite solar cells. Perovskite solar cells are the fastest-growing solar technology, providing a cheap and effective alternative to silicon-based solar cells. However, they usually contain lead to absorb the sunlight for electricity generation. The high toxicity of lead, along with long degradation time, means that perovskite is not a viable choice in high-density population areas due to the risks of lead poisoning. Moreover, the perovskite tends to dissolve in water, meaning that rain and humid air could release it from solar panels and contaminate air, rainwater, and soil via rainfall (Zhang, 2019).

Solar Panel Glare

The reflection of sunlight from solar panels' surfaces to the surroundings (roads, buildings, people, etc.) can disrupt the daily flow of city life. Solar glare above a certain level causes visual discomfort, nausea, loss of concentration, or even sight loss in the case of long-term exposure. These effects hinder the ability to perform daily tasks, increase the risks of traffic accidents, and cause health problems. Moreover, reflected sun glare can be absorbed by buildings, increasing the cooling energy demands.

A probability model simulation conducted by Texas A & M University, analyzing the reflecting radiance for different solar power and test environment conditions (installed capacity, material, surrounding objects/buildings, etc.), showed that solar panels can cause disturbing or intolerable glare for vision comfort during daily city activities, with early morning and late afternoon being the most dangerous time periods due to the incident angle of radiance (Lanib, Baltazar, 2016.).

Anti-reflective coating, proper location, and alignment of solar panels can reduce the risks of solar glare in urban areas. The list of mitigation methods proposed by the Municipality of London in 2017 for the design stage includes:

- Change the shape, orientation, and material of building surfaces to be less reflective

- Plantation (less effective in winter)

- Shading structures and devices (canopy, louvers, motorized blinds, etc.)

These mitigations can not only decrease solar glare, but also negate the urban heat island effect.

Conclusion

The future effects of climate change will be most significant in urban areas. Rising sea levels, weather events with higher intensity and unpredictability, and sharp increases in temperature and humidity will make the present urban settlements less habitable in coming years. It is expected that 15 of world's top 20 megacities will succumb to these occurrences, which would cause a massive shift of people and capital with significant economic, social, and political impacts on the world. Some of the results are already visible; for example, Indonesia is planning to move its capital from Jakarta – a megacity with around 11 million people – to East Kalimantan because the former is sinking. The 2018 hurricane season was the costliest ever for the United States, with more than US$300 billion in damage and dozens of casualties, wreaking havoc on American cities. Climate refugees/migrants from poor agrarian communities, who cannot afford to make a living due to their lands being rendered useless by intense droughts and floods, are moving to wealthy urbanized regions, which leads to social tension, heavy burden of cities' infrastructure and economy, and political instability. Some scientists have gone even further, claiming that the main catalyst of the ongoing Syrian Civil War is the multi-year drought between 2006–2010, caused by climate change. During that period, most of the harvests failed, which led to mass rural–urban migration within the country, contributing to the already unstable political atmosphere and stagnating economy – the two main factors of the Civil War (Müller, Yoon, Gorelick, Avisse, Tilmant, 2016.).

Countries around the world are taking different approaches to tackle this challenge (Muggah, 2019). Some are fighting the outcomes, like strengthening the infrastructure, building sets, dams, dykes, and relocating the population. Others are focused on reducing the factors that cause the climate change; for example, investing in renewable energy projects to reduce carbon emission, forming diplomatic initiatives, and making resolutions (whether they follow them or not is a different matter). Not all countries are taking such measures for the sake of the environment; some, like China and Saudi Arabia, see this trend as an opportunity to change their fossil-fuel-dependent economies. Regardless of the differences of approaches or purposes, solar power is the leading actor of the struggle against climate change as the safest and cheapest option. However, it is not perfect; while many people view solar power as "an energy miracle", the challenges of this technology require constant effort, careful planning, and reasonable understanding.

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Flooding in Lao People's Democratic Republic

Onlaya Sengthammavong[a]

Abstract: *Growing urbanization and increased human activities have intensified global warming, which has caused variations in the world's climate. Climate change affects hydrological processes such as precipitation and evapotranspiration, which affects the quality and quantity of water resources. The effects of climate change vary from region to region, with varying effects all over the world such as drought and flooding. Global climate models (GCM) and regional climate models (RCM) are widely used for projecting the effects of human activities on climate change. The data from these models are then used in hydrological models in order to determine the effects of the projected climate change on hydrology and water resources. These methods are widely used and are essential for climate change projections and planning for actions that will alleviate the effects of climate change on hydrology and water resources.*

Author's Profile

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Current warm weather is expected to become even hotter in the future due to global warming. Climate change impacts range from rises in sea levels, flooding, and water scarcity to the spreading of water-borne disease. According to The United Nations, the Climate Change Conference agreed to reduce the level of CO_2 by not allowing the global average temperature to increase by more than 2°C compared to pre-industrial levels (Demirbas, 2007). Sources of CO_2 come from coal-fired power plant, cement and steel-making industries adopting the post-combustion process, and also by human activities (International Energy Agency , 2010). Recently, the world lost part of one of the world's largest sources of oxygen supply, the Amazon rainforest, due to two weeks' worth of fires that destroyed plants, trees, and animals (Alexandria, 2019). Laos is a landlocked country in Southeast Asia, but is now is a land-link country besides Thailand, Vietnam, Cambodia, China, and Myanmar (United Nations Development Programme, 2019). Several years ago, the weather in Laos was good, with fresh air and beautiful scenery. As the world has changed, the weather has changed, too. Laos has a tropical climate that is divided into two distinct seasons: a rainy season from the start of May to mid-October, followed by a dry season between mid-October and the end of April (United Nations Development Programme, 2011). Temperatures and rainfall change significantly over the year and also according to latitude and altitude. Temperatures from November to February are lower and cool breezes bring from the humidity of the rainy season. Temperatures drop to as low as 15°C between December and January. From March to May, the temperatures slowly increase to the highest levels to 38°C (Loire, 2019).

The most serious aspects of Laos's natural climate include flooding caused by heavy rainfall during the raining season, drought caused by extended dry seasons, sudden flash-floods in the mountainous parts of the country, landslides and large-scale land-erosion on slopes, occasional windstorms (United Nations Development Programme, 2011). The southern region of Laos was recently devastated by severe floods after two consecutive tropical depressions brought the heaviest rainfall in

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a decade to hit the region. The Khammuan, Savannakhet, Attapeu, Salavan, Champasak and Sekong provinces were affected, including 2,382 villages, 126,736 households, and 616,145 people; 1,779 houses were destroyed and 514 were damaged. In addition, 90,000 ha of paddy fields and 11,000 ha of other plantations were destroyed, and 630 km of roads and 47 bridges were damaged, according to the report. Many districts in six provinces are still affected by flooding. Authorities and members of rescue teams are continuing to move people in at-risk areas to safe locations. Laos' Meteorology and Hydrology Department said no storms are forecast in the next few days but there will be rain in some parts of the country. (Xinhua, 2019). Here are updates from the affected provinces (Yap, 2019):

Attapeu: The levels of water continue to rise in Attapeu. Samakhyxay District has seen 18 villages affected by flooding of tropical storms, although rain is weakening. In 2018, Sanamxay District was affected by flooding of the dam collapse and was completely inundated, according to local media

Champasack: Champasack Province has been hit by strong rains and heavily flooded. The city of Pakse was completely inundated and the river burst its banks in several parts of the city. Furthermore, Patoumphone District was severely flooded in 14 villages. One person died while two people are missing, according to the Social Welfare Department.

Salavanh: The Xedon River has now risen to over 13 meters, which is above the danger level. Lao authorities are unable to provide figures for the levels of other rivers, according to provincial media. The situation in Salavanh improved as floodwaters began to recede.

Xekong: The severity of the situation in Xekong remains unclear. However, Dakcheung District has been affected by major road damage and residents unable to access clean drinking water. According to reports by the Provincial Department of Education and Sports, all schools have been closed until further notice. The level of the Xekong River is falling, but it is still raining.

Savannakhet: According to reports by rescuers, Xepon district has been worst affected by floods, with over more than 100 homes completely inundated and families have been evacuated as waters rise. The floods have resulted in the death of one person.

Khammuan: Official information on the situation in Khammuan has not yet been reported. However, reports state that many villages in various districts have been affected by the floods.

The province is now in urgent need of assistance from the local, national and international community, especially with regard to food, clean water, clothing, and boats or flotation devices to assist in the evacuation of residents trapped in flooded homes. In addition, the Lao population is an important force. Every party of Lao PDR, whether government or private, is paying donating necessary supplies and preparing foods and drinking water to donate for the population who have been affected by the flooding (Xinhua, 2019). According to a word as "The heart of Lao people is greater than the flood". Not only this, The prime minister of Laos has urged the related parties to resolve the issue as soon as possible (United Nations in Lao PDR, 2019).

The purpose of this letter is to urge all people to protect the environment, protect our world, and protect your life because climate change is the most serious issue affecting the world today.

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Statistics for Climate Change in Cities

Selcuk Meric Kostekci[a]

Abstract: *Among the significant changes that megacities have caused, climate change is one to which we must pay particular attention. It is essential to understand climate change if we hope to survive as a species. In this context, statistical research provides valuable tools to assist scientists in their efforts to analyze climate and its changes. Although, a wide variety of statistical tools are being utilized to this end, the present article focuses on application of regression analysis and spatial statistics regarding climate and climate change studies.*

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Selcuk Meric Kostekci obtained his Bachelor's Degree from the Statistics Department of Middle East Technical University. He is a freelance data analyst and statistician. He is currently a graduate student in the Industrial Engineering Department of the same university. He is also an activist for protecting natural life.
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Statistics and Climate Change for Urbanization

In today's modern world, urbanization has increased rapidly. One of the results of this is accelerated climate change.

Climate Systems

Climate systems are complex, nonlinear ever-changing systems with a high level of uncertainty. They are chaotic, and modeling and interpreting their behavior often poses formidable challenges. Under such circumstances, statistics provide valuable tools to assist climate researchers. Statistical research assists scientists find ways to combine data from different sources, and to analyze and interpret the information and resolve uncertainties that arise from the application of complex procedures.

Global Temperatures

Global temperatures are a vital source of information on any research regarding climatology. But how do we measure global temperature? Measuring the temperature of a single point on Earth at a particular time is not challenging, as one can calculate average annual temperate by using daily observations. Measuring (estimating) on a global scale, however, poses certain challenges that require careful applications of statistical methods. Assume that the world's surface consists of a number of grids where temperature and temperature anomaly measurements are taken. Although average temperature values can be measured on grids with a measurement source (weather stations, observatories for land or buoys, satellites for oceans, etc.), values for empty grids need to be estimated. Such estimation can be accomplished by applying spatial statistics methods (a set of statistical techniques taking account of physical location of dependent variables in their mathematical models). While considering data is spatially dependent, temperature values can be estimated for both land and ocean in spatial statistics. After this procedure, there will be uncertainties that need to be resolved for the sake of the research. Gluttorp pointed out prominent uncertainties during the process: (1) errors caused by measuring, (2) poor selection of measurement stations, and (3) missing measurements (Gluttorp, 2017). To deal with uncertainties, the Hadley Center for Climate Prediction and Research utilized the Bonferonni method with a 95 percent confidence level (that is, a confidence interval that contains all true temperatures with 95 percent probability) to check whether there was global warming in 2015 and 2016 (Gluttorp,

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2017). The time span was between 1850 and 2016. The experiment was simulated 10,000 times by repeated drawings from sampling distribution. Fifty-eight percent of the simulated events showed that 2016 was the warmest year, while 2015 was the warmest for the other 42 percent (Gluttorp, 2017).

Global Climate Models

Climate researchers have not limited their studies to estimation of global temperatures; they have also concentrated on understanding better global climate behaviors. Such efforts have led to GCMs (general circulation models or global climate models). GCMs are complex mathematical models used to simulate climate on multi-dimensional domains. These models help us understand climatic behaviors on a global scale as well as the interaction between factors that play a key role in climate change. They are constructed using many pieces of information represented by variables and parameters that are obtained from both climatic and physical domain/processes, such as (1) temperature, humidity and precipitation represent some of the climate variables, while (2) solar radiation, cloud cover represent physical parameters. Considering the size of the model, multivariate regression analyses (that is, a set of statistical models used to check interrelations among variables) are often used to model GCMs to understand the factors behind climate and climate changes. In time, however, multiple GCMs have come forth, leading to the question of which GCM would be the best to understand climate? To address this problem, and to develop better GCMs, the Coupled Model Intercomparison Project, a worldwide effort to develop, and compare existing GCMs, was established in 1995. An effective way to validate CGMs would be using multivariate spatio-temporal distributions, a type of statistical distributions that show how climate variables interact with each other and how climate variables interact with time and space in joint forms (Jun, 2017). Philbin and Jun's spatial analysis of temperature and precipitation supports Jun's previous argument. Using joint distributions of temperature and precipitation in spatial analysis, GCMs were able to validate, and eventually show, that GCMs perform similarly except on the equatorial and mid-latitude zones on Earth (Philbin & Jun, 2015).

Conclusion

This article has briefly discussed the role of statistics in climate systems and the major tools offered by statistics in that regard. We are still far from perfectly understanding climate change and its impacts, so great responsibility falls on climate scientists and statisticians to improve/develop scientific methods that will help save our planet.

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