The Nexus between Climate & Energy: Global warming impacts and Mitigation of Greenhouse Gases

Anthony Chen
Climate & energy Technology Group, UWI

Basic science

Science has demonstrated clearly that the earth is warming. Worldwide and local data show this increase and independent studies done since 2007 have confirmed the findings of IPCC (2007). Studies with multiple climate models attribute the changes in the earth's temperature to natural and man-made causes. The man-made causes have been mainly the generation of generation of greenhouse gases such as carbon dioxide, methane and nitrous oxide since the industrial revolution. GHGs allow shortwave radiation from the sun to pass through the atmosphere and warm the earth, while they trap some of the longwave radiation from the earth and keep the earth warm. Without the natural occurrence of GHGs the earth would be 30^o cooler. Additional manmade GHGs are making the earth warmer than usual. Of these carbon dioxide is the main driver, the largest emission coming from power plants. This is the nexus. If the nations of the world wish to avoid the dangerous consequences of global warming, they will have to drastically reduce GHG emissions from all sources, especially carbon dioxide from power plants. They will have to turn to energy sources such as renewable energy and nuclear energy.

To amplify these points I will discuss the consequences of warming, especially sea level rise, and how agreement to mitigate GHGs will affect our energy supply.

Impacts of Global Warming

The consequences of warming have been changes in climate driven by changes in the atmospheric and ocean circulation systems and melting of polar caps and glaciers. The changes in the climate of Jamaica will include

Warming
More hot nights
Less cool days
Less, but more intense rainfall, especially during the latter half of this century
Drying
More extremes leading to more frequent droughts and floods

All the above have consequences for domestic water supply, agriculture, health, tourism and our bio-diversity. However the most dangerous impact may be rising sea levels due to the melting of the polar ice caps and glaciers, which will be discussed in more detail shortly. Consider that most of our major towns, our airports and hotel facilities are located near the coasts.

Sea Level Rise

IPCC (2007) has projected that sea levels will rise anywhere from 18 to 59 cm by the end of the century (IPCC Chap 10. Fig 10.33). This projection, if anything, is comforting. The mild projection is due to the inadequacy of the IPCC global models of sea level rise, especially in simulating ice dynamics and sea level rise. Modelling at sub-grid scale is extremely difficult. For example we simulate precipitation like water falling from a tipping bucket. The melting of polar caps and glaciers is modelled as the melting of a giant block of ice. Models do not take into consideration ice dynamics or the movement of ice. But these processes are important. Let us examine, for example, what happens when ice shelves melt.

An **ice shelf** is a thick, floating platform of ice that forms where a glacier or ice sheet flows down to a coastline and onto the ocean surface. The ice behind the shelves rest on bedrock and and extend hundred of miles behind the shelves to the top of mountains. The weight of the ice produces shear stresses at the boundary with bedrock. When shear stress or force is applied to a the ice it will first deform elastically and will then continue to deform plastic-like, with a permanent alteration of shape and it will creep down the slopes producing ice streams. Ice shelves butress the the plastic flow and limits the rate of dicharge of ice. However when the warm oceans melt the ice shelves, resistance to the flow is lessened and the ice streams begin to move more rapidly. IPCC models do not include the melting of ice shelves, nor the ice stream dynamics.

On August 18, 2011 a NASA research leading to the first complete map of ice flow in Antartica was reported. Quotes from the report:
"We are seeing amazing flows from the heart of the continent that had never been described before."… Like viewing a completed jigsaw puzzle, the scientists were surprised when they stood back and took in the full picture. They discovered a new ridge splitting the 5.4-million-square-mile landmass from east to west. The team also found unnamed formations moving up to 800 feet annually across immense plains sloping toward the Antarctic Ocean and in a different manner than past models of ice migration. "The map points out something fundamentally new: that ice moves by slipping along the ground it rests on," said Thomas Wagner, NASA's cryospheric program scientist in Washington. "That's critical knowledge for

predicting future sea level rise. It means that if we lose ice at the coasts from the warming ocean, we open the tap to massive amounts of ice in the interior."

James Hansen of NASA, and his colleagues from Columbia University Earth Institute, University of Sheffield, Yale University, Lab. Des Sciences du Climat et l'Environnement/Institut Pierre Simon Laplace, Boston University, Wesleyan University and the University of California, argue that to get a more accurate estimate of how global warming will affect sea level rise we must look at past records of glacial and interglacial periods. To do this they turned to the science of paleoclimatology.

Basics of Paleoclimatology

Paleoclimatology is the study of changes in climate taken on the scale of the entire history of Earth. It uses a variety of proxy methods from the Earth and Life Sciences to obtain data previously preserved within, e.g., rocks, sediments, ice sheets, tree rings, corals, shells and microfossils. If we can reconstruct the climate of the past we can use similar occurrences of climate like the one we are now experiencing to estimate how our climate may change. This is similar to forecasting weather by analogy in meteorology. In meteorology if we have historical records of weather patterns similar to the present, we can predict how our present weather will evolve in the future since we know how the weather evolved in the past. So we do likewise in paleoclimatology. If we know how carbon dioxide levels affected climate in the past, we can use past levels of CO2 similar to ours to determine how our climate will respond. The fact that the present levels of CO2 is rising due to man-made activities, and not due to natural causes as in the past, does not matter since the physical properties of CO2, viz., the ability to absorb longwave radiation from the sun, are the same in both cases.

To apply this method in paleoclimatology we need records of past times, past temperatures, greenhouse gas concentrations and sea levels. How are these reconstructed?

Radiometric dating of rocks and radiocarbon dating of dead animals and plants are well established (See for example, http://people.hofstra.edu/j_b_bennington/2cnotes/dating.html) and (http://www.fmi.uni-sofia.bg/fmi/contmech/kmarkov/history/Carbon.html)

How are sea level, temperature and CO2 concentrations estimated? Proxy measurements can be used to reconstruct the temperature record before the historical period. Quantities such as tree ring widths, coral growth, isotope variations in ice cores, ocean and lake sediments, cave deposits, fossils, ice cores, borehole temperatures are correlated with climatic fluctuations.

For example, for the purpose of measuring temperature the most useful material in the sediments is the shells of the microscopic animals called forams, and the most useful characteristic of the forams is their proportion of oxygen isotopes. O^{16} has 8 protons and 8 neutrons and is the most common isotope of oxygen. O^{18} has 8 protons and 10 neutrons and is much less than 1% of oxygen. Shells of forams found in sediments were made of CaCO3. The oxygen atoms were incorporated into the shell as they moved in the water surrounding the shell, the faster they moved, the more they were incorportated into the shell. As the temprature of the water increased the lighter O^{16} isotope moved faster and more of them were incorpoated into the shell than at a lower temperature. Thus at a higher temperature the ratio of O^{16} to O^{18} is greater than that ratio at a lower temperature.

It is possible to calibrate the ratio with temperature and therefore use the ratio of O^{16} to O^{18} as a thermometer.

How are past carbon dioxide concentration measured? Ices at the polar caps and in Greenland have been there for thousands of years and they contain bubbles of air trapped from those times. Ice cores have been drilled in Antarctica and Greenland to examine the variation of the composition of air bubbles trapped in the ice, representing global atmospheric conditions as much as 160,000 years BP. The first and deepest ice core was drilled at Vostok in central Antarctica, originally by a French-Russian team. Drilling of the core still continues, and it is expected that, when drilling is completed in a few years time, an age of up to 500,000 years will have been reached. CO2 concentrations prior to this time can be determine from subtle methods such as using present known forcing relationships between CO2 and temperature and deducing past CO2 concentrations from past temperatures.

How are sea levels determined? If the past level being investigated is under water, the level at a given time can be determined by analyzing the remains of the tiny creatures known as diatoms. Diatoms are single-celled organisms which secrete intricate skeletons, and their remains are preserved in the sediments of both sea and loch. The diatoms preserve a record that shows both rise and fall of sea level. By taking cores of material from various sites it is possible to examine the changes between fresh water diatoms and marine diatoms. Fresh water diatoms would have been in a river above sea level and marine diatoms in the sea. Once the diatoms are dated it is possible to see when and how sea levels have changed.

Forams and diatoms preserved in salt-marsh sediments have been used to produce high-resolution records of Holocene relative sea-level change. Changes in sea level can also be obtained by examining marine fossils which remained on land when sea levels fell in the past, and from geological observations of former sea shelves.

What paleodata tell us

What do paleoclimate scientists tell us about past sea level rise, ice and CO2? The solid earth is both a source and a sink for carbon dioxide. Carbon dioxide source occurs at the edge of moving continental plates. As the continent s move (several cm per year) they ride over the ocean crust. Intense heat and pressure due to the overriding continent causes melting and metamorphism of the ocean crust, producing carbon dioxide and methane from calcium carbonate and organic sediments on the ocean floor. The gases come to the surface in volcanic eruptions and gas vents.

The main sink or the return of Carbon dioxide to the earth comes from the weathering of rocks. Chemical reactions combine CO2 and minerals which are then carried by streams and rivers to the ocean and precipitate as carbonate sediments.

The Indian Ocean is a rich source of deposited carbon sediments due to the major rivers of the world flowing into it. During the period 60 My (million years) to 50 My before the present, what we now know as India, and which was not yet a part of Asia, moved rapidly towards Asia at about 20 cm per year, faster than average. CO2 probably increased rapidly during this period as the carbon rich sediments on the ocean floor were subducted beneath the moving Indian continental plate. This led to increasing temperatures. Then 50 My ago India crashed into Asia with the Indian plate sliding under the Asian plate. The colliding continental plates began to push up the Himalayan Mountains and Tibetan plateau exposing large amounts of fresh rocks for weathering. With the movement of the Indian plate stopped or slowed, CO_2 emissions declined and earth began a long-term cooling trend due to the loss of CO_2 by weathering of rocks.

The cooling continued and the planet remained nearly ice-free until about 40 My ago, but large scale glaciations (Antarctica glaciation) did not start until about 34 My ago. CO_2 concentration about 50 My ago was about 1400 ± 500 ppm . CO_2 concentration 34 My ago when large ice sheets began to form was 450 ± 100 ppm. These measurements, which were supported by several indirect ways of measuring past CO_2 levels, were published by Hansen et al in 2008 in a paper called *Target Atmospheric CO2: Where Should Humanity Aim*?

The key point here is that the transformation from water to ice and from ice to water is completely reversible and occurs at a fixed temperature, i.e, 0º. By reversible in physics we mean that every step of the process can go either way, without a change in the surrounding environment. When the concentration of CO_2 was decreasing in the past and reached 450 ± 100 ppm, the temperature was such that large amounts of water turned into ice and snow. So in the reverse process when CO_2 concentration is increasing and reaches 450 ± 100 ppm, the temperature will be such that large amounts of ice will turn to water. Remember that it is CO_2 is what drives the temperature by the greenhouse gas effect. So what Hansen et al is saying is that since large glaciations started when CO_2 decreases to 450 ± 100 ppm, then in the reverse process large scale glaciers will become water when CO_2 concentration increases to 450 ± 100 ppm. Taking the plus or minus uncertainty into consideration the lower value of the range when mass melting of glaciers could occur is 350 ppm.

Tipping level and point of no return

Where are we on the scale now? CO_2 has increased unnaturally and exponentially from the time of the industrial revolution from approximately 280 ppm to 390 ppm. In other words we have gone above the lower limit.   Thus barring prompt policy changes, some critical level will be passed, in the opposite direction (increasing CO_2) within decades when large scale melting will occur with no point of return. Hansen et al distinguishes between a tipping level and a point of not return. The *tipping level*, the global climate forcing that, if long maintained, gives rise to a specific consequence, and the *point of no return*, a climate state beyond which the consequence is inevitable, even if climate forcings, such as CO_2, are reduced.   We may have very well passed the tipping level and may soon be approaching the point of no return, i.e., in the next few decades, not centuries to come.

This is a very serious situation when you think about. Once we pass the point of no return the ice will keep melting, even if we cutback drastically on GHG. The melting process will feed on the warming until all the ice melts in a process called positive feedback.   The positive feedbacks include a changing albedo, rising ocean temperatures and melting of the permafrost or tundra. As the ice melts and become warmer its colour will become darker and reflect less radiation to space, so that there will be unbalanced incoming radiation forcing the warming. As the ocean becomes warmer it will release more CO_2, which will increase the warming. Methane hydrate is frozen methane enclosed in ice crystals. Large amounts are found in artic tundra. As the permafrost melts, it will release more methane into the atmosphere. Methane is a GHG more potent than CO_2 in trapping radiation from the earth and re-emitting it back to the earth, causing additional warming.

Even worse could be the release of methane from methane hydrate located on the continental shelves, in the top hundred meters of ocean sediment. This is the largest source of methane hydrate.

The Nexus

This then is the nexus between climate change and energy. If humanity wishes to preserve a planet similar to that on which civilization developed and to which life on Earth is adapted, paleoclimate evidence and ongoing climate change suggest that CO2 will need to be reduced from its current 390 ppm to at most 350 ppm. To reduce CO2 emissions require a change of our main energy source from fossil to clean energy in order to mitigate the emission of GHG.

Inaction at Durban and after

The parties to the UNFCCC are meeting about in Durban to try to arrive at an agreement for reducing GHGs worldwide. Some, like the EU, are advocating a limit of 450 ppm. Others, like AOSIS, who members are most endangered by sea level rise, are calling for a return to 350 ppm.

There is no expectation that there will be any agreement on reduction of CO2 levels to 350 ppm or even 450 ppm at the Durban meeting. For one, the dangerous consequence of the complete melting of the polar ice caps and Greenland, with sea level rising over 75 meters, will take centuries; it is far into the future. These worries are not sufficient to counter the political and monetary interest of those who do not wish to see a reduction in the use of fossil fuel, such as those in the oil and coal industry.

When will the world act?

The main polluters in the past are the USA and Europe. Because CO2 and other GHGs such as methane have very long half lives, most of the pollution now in the atmosphere came these countries. They should therefore be the first to cutback. When will concerns in these countries start to counter the political and monetary interests? Perhaps it will start when the environmental consciousness of the world is raised to a level which will cause citizens to become more proactive, and they in turn will cause the geopolitics to change. I personally think that the turn around will come when climate change begins to impact more dangerously on lives. We have already begun to see large scale flooding in Thailand and Pakistan, large scale drought and flooding in China and forest fires in Australia. These may be due partly to natural causes and partly to climate change. But when events like these which naturally occur every 100 or 50 years become more frequent, then the world, will take action to reduce GHG emissions. Model results project that we will see amplification of these extreme events by the 2^{nd} half of the century if the world continue emitting GHG as usual, and perhaps we are already be seeing the effects of global warming on extremes in climate.

Sea Level Rise this century

But the greatest concern, especially to us as islanders, will be sea level rises during this century. Let us look at what the data tells us about the melting of ice. Figure 1 shows us the changes in mass of Greenland and Antarctica, deducted from gravitational measurements. It is obvious that the mass is changing due to melting and runoff into the ocean. If the melting is a linear process with time (a straight line) then the melting will be slower. However if the melting is non-linear then it will accelerate with time. The diagram shows that a 10 year doubling time can be fitted to the graph, i.e., the mass of ice melted will double in 10 years. So can a 5 and 7 year doubling time for melting be fitted. However the time series is too short for even a linear (straight line) relationship to be excluded.

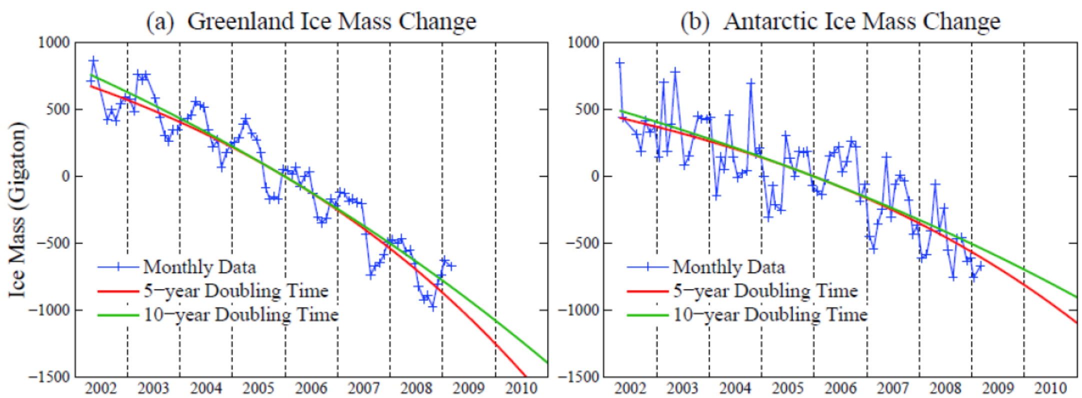

Fig. 8. Greenland (a) and Antarctic (b) mass change deduced from gravitational field measurements by Velicogna (2009) and best-fits with 5-year and 10-year mass loss doubling times.

Fig 1.

Because of the positive feedbacks mentioned above it is likely that the process will be non-linear, i.e., that there can be a doubling of mass loss in 10 years or less. In other words, the changing albedo, more CO_2 from warming ocean and release of methane from methane hydrate will all cause the melting to accelerate. Figure 2 show how the melting would proceed over the century if the doubling time for melting were 10 years. A rise of 5 meters (or 16 feet) would occur over the century.

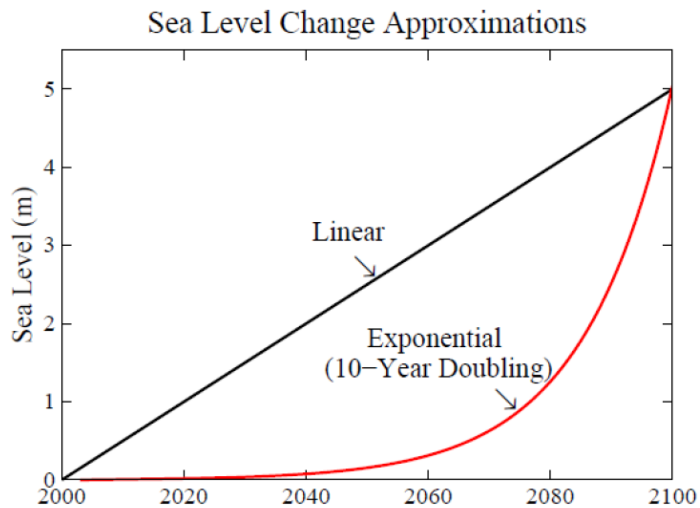

Fig. 7. Five-meter sea level change in 21st century under assumption of linear change and exponential change (Hansen, 2007), the latter with a 10-year doubling time.

Fig. 2

Paleoclimate data also support the likelihood of this much rise. Fig. 3 shows global temperature relative to peak Holecene temperature. Holecene refers to the interglacial period that we are now in. The Eemian refer to the interglacial period before the last ice age. (The ice ages were brought about cyclical changes in the earth's tilt, changes in the earth's orbit and in wobbling about the earth's axis.) Temperatures are based on ocean core records, which are more accurate that previous temperatures based on ice core records. With global warming so far, our present temperature is close to the peak temperature during the Holocene. The diagram show that we are less than 1ºC below the peak Eemian temperature and Fig.4 show that temperatures can increase by 1ºC between 2020 and 2040 if we continue emitting CO_2 as usual (A2 scenario), making our temperature then comparable to the Eemian temperature.

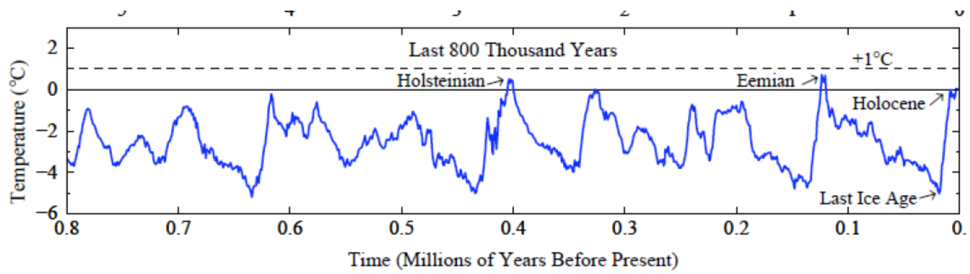

Fig. 3

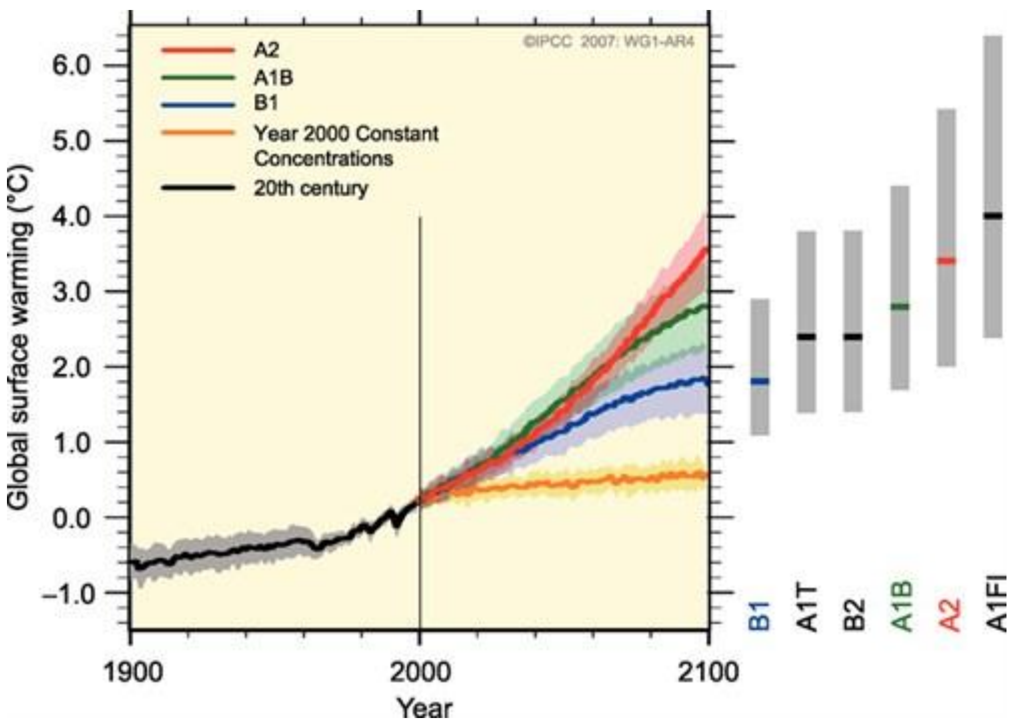

Fig. 4

What happened during the Eemian? Sea level at peak was probably 4 to 6m (13 to 20 feet) higher than today (references in Overpeck et al., 2006), with much of this extra water coming from Greenland but some likely to have come from Antarctica (Wikipedia, 2011). That is, if temperatures rise 1ºC above the present conditions, as expected between 2020 and 2040 if we continue emitting GHG as usual, conditions will be ripe for a 4 to 6 meter rise in sea level this century. The rise would lag behind the temperature rise because melting ice will initially cool the ocean, which will in turn slow down the melting of ice, but there would be definite signs of accelerated sea level rise when the 1ºC increase in temperature occurs.

So my guess is that we will start to see dangerous impacts or signs of dangerous impacts in 10 to 20 years. In another 10 years, data on mass loss from Greenland and Antartica should say definitley if the melting is linear or non-linear. In about 20 years we will reach temperatures comparable to the Eemian if we continue business as usual. So 10 to 20 years is the time I see nations of the world, including Jamaica, agreeing to reductions of GHG. What will this imply?

Implication of late mitigation

The steps necessary to keep CO2 levels at 450 ppm are indicated in Fig. 5. The scheme of reduction, which should have started in 2012, is taken from UNDP (2007) and is based on a model from the Potsdam Institute for Climate Impact Research.

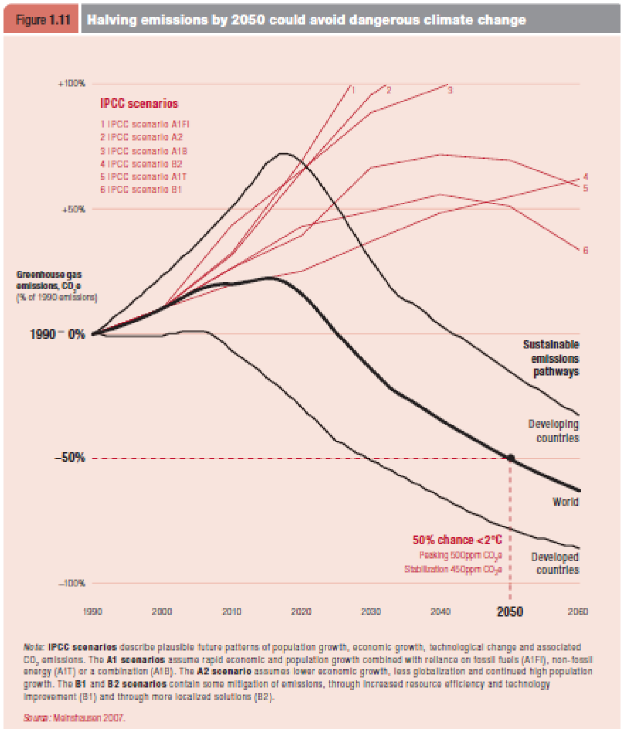

Figure 5. A Scheme for reducing emissions by 2050 and avoiding the dangerous consequences of climate change

The cuts from a 1990 base-year proposed by UNDP are given by the black lines in the diagram. The lines in red are the emission scenarios looked at by IPCC for its 4th assessment. The emission pathway is for the world as a whole *(heavy black line)* and then a differentiation is made between emissions from developed *(below the heavy back line)* and developing countries *(above the heavy black line)*. The details are

- Emissions for the world should start decreasing by 2020 and be reduced to around 50% of 1990 values by 2050.
- High-income countries should start reducing emissions by 2012 and reach 30% cuts relative to 1990 values by 2020 and at least 80% cuts by 2050.

- Emitters in the developing world maintaining a trajectory of rising emissions up to 2020, peaking there at around 80% above 1990 levels and cutting back to 1990 levels by 2040.

The reason for the need for such drastic cutbacks is that CO2 and other GHGs which are already in the atmosphere will remain there for a century or more so that the additional amounts put there by the world as a whole can only increase by a certain amount up to 2020 and need to be cut back thereafter.

To cut back to 350 ppm would require much more drastic steps. Since, according to my assumption, cutbacks will not start until 10 to 20 years time, it means that cutback then will need to be even more drastic.

Higher cost of fossil fuels

When the cutback comes renewable energy will become the energy of choice, as well as nuclear. Perhaps because of fear of radioactivity the use of nuclear power will be limited. One way to cutback would be to establish a ban on the use of coal and on new exploration for oil and gas. Whatever the method of cutting back, the cost of fossil fuel will become even more expensive than it is now. It is expensive now because of the need to drill deeper and to use more sophisticated technology, such as extracting gas from shale. When an agreement to cut back is reached few companies will be encouraged to engage in new explorations for oil and gas or to establish new coal fields. There will be worldwide competition for whatever fossil fuel is left, making the cost of fossil fuel very expensive. The worst scenario would be for Jamaica to be left with relatively new fossil fuel plants which would require the use of expensive fuel for the remainder of their lifetime of about 30 years. Those who have been ahead of the game in using renewable energy will be at an advantage. They will not be stuck with fossil fuel plants which need expensive fuels to run.

Cutback will be required by all countries, developed and developing.   The CO2 footprint of CARICOM (if you exclude Haiti) is greater than that of Austria, Denmark, Norway, Portugal and Sweden. That is largely because of the large emissions from T&T. However Jamaica's footprint on a per capita basis is not much different from Portugal or Sweden. That is because of our inefficient use of energy. If these European countries are required to cut back, we will be required to cut back too. The message therefore is that in planning Jamaica's energy future, climate change must be part of the equation because when worldwide cutback in fossil fuel comes its cost will be prohibitively high and because we are polluters like the rest of them.

Will Renewable Energy be ready for Jamaica

The question then is whether or not renewable energy systems are or will at a stage in their technological development to be applied to small developing countries like Jamaica when we need them. This will be one the purposes of this lecture series, to explore the options for renewable energy systems using solar, wind, wave, hydro and biomass power.   We already know that hydro and wind power can compete with fossil fuel, that solar water heaters are more economical that electric water heaters in the long run and that solar photovoltaic grid tied systems make economic sense if net metering were allowed.   Technologies such as solar thermal, wave energy and fuel cells are technically feasible. With more R & R, improved manufacturing techniques and market volume, these technologies are expected to become economically viable. To quote from IEA release of a new study:

“Renewables are now the **fastest-growing sector of the energy mix** and offer great potential to address issues of energy security and sustainability, but their rapid deployment is also bringing a host of challenges”. One of these challenges is firming the variable nature of renewable energy system. Viable technical solutions to the problem of firming renewable energy, such as pump or gravity storage and hydrogen storage, are available. Issues like these will be addressed in the remainder of the series.

Will Jamaica be ready for renewable energy?

The question also is Will Jamaica be ready for renewable energy? We have to be ready. But for this to be so we need a paradigm shift in our thinking. Our thinking at the moment is that our carbon footprint is small and we do not need to cut back on GHG emissions. So our target for renewable energy is to have only 20% renewable in our energy mix by 2030 and JPS’s 20 year expansion plan does not include RE. No, that’s not the way to go. We have to see that our per capital GHG emission is not much lower than that of Sweden or Portugal and that, excluding Haiti, CARICOM’s per capita GHG emission is higher than that of Austria, Denmark and Norway. We have to realize that once there is a worldwide cut back on GHG emission, the cost of fossil fuel will become prohibitive and so we need to prepare for that eventuality. We need to see that renewable energy can form much more than 20% of our mix and that renewable energy can be a source of energy security and eventually energy independence.

What Action is necessary

Urgent action need to be taken by Jamaica to answer questions such as

- What studies have been done and what studies do we need to do re renewable energy?

- To what extent will research and development, improved manufacturing technology and market volume reduce the cost of these renewable energy options?
- Are there alliances that we can make to further the goal of adding more renewable options to our energy mix?
- How much renewable energy can we practically add to the energy mix?
- What of the nuclear and fossil fuel options?
- How can we introduce clean and renewable energy into our mix, without too much of a burden on our citizens?

The lecture series seek to develop a work programme to drive the climate change and energy imperatives. We see this as a call to action to make renewable energy a major part of our energy mix.

Summary

We have looked at the nexus between climate change and energy. Climate change is due to global warming, which in turn is driven by man-made GHGs especially those emitted from power plants. One of the dangerous consequences of climate change is the melting of ice and rising sea level. Feedback effects can lead to a 5 meter rise this century and a point of no return can be reach which will eventually lead to complete melting of the polar ice caps and Greenland leading to a 75 m rise in sea level. Once a point of no return is reached, perhaps just a few decade in the future, no amount of mitigation will stop the melting, again because of positive feedback mechanisms such as changes in albedo, CO2 emissions from warming ocean and methane release. To avoid dangerous consequences, CO2 emissions must be cut back almost immediately so that CO2 concentration in the atmosphere can return to 350 ppm. However no agreement to cutback to these levels will be made at COP UNFCCC meetings until maybe 10 to 20 years time because of powerful opposition, especially from oil and coal interests. When an agreement for cutback is reached, the cost of fossil fuel will then be prohibitively high. Jamaica must not be caught with its pants down in this scenario; it should not be left with relatively new fossil fuel power plants at that time because the cost of fuel for these plants will drain the economy, even more than now. We need put ourselves in the position to have much more than 20% renewable energy by 2030. We must take action to find the way.