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A Review of the Climate-Change-Impacts' Rates of Change in the Arctic*

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ABSTRACT

Climate Change is a global phenomenon that has a global scale impact. The current trend of climate change towards the warming of the globe has resulted in various changes in the geological, climatology, social, economical, and biological processes worldwide. Temperature of the globe has increased due to various factors, but anthropogenic plays a major contribution through the heavy input of Greenhouse gases. One of the world's most remote regions that have been affected by most of the anthropogenic stresses on environmental services is the Arctic Region. The Arctic Region has shown various drastic changes and has shown to be effected by various anthropogenic activities that take place elsewhere. These changes include the ozone hole (*resulting from ozone degrading compound emitted heavily by anthropogenic demands*), *the accumulation of various persistent and volatile pollutants* (*i.e. POPs*), *and the meltdown of the polar ice* (*among others*). *These drastic changes are well perceived and well projected for future preparations. However, the question still remains if these impacts would only accelerate change. This paper aims to discuss if these changes are accelerating or happening at a constant rate. In addition, this paper aims to only focus on changes due to global warming and climate changes phenomenon.*

Keywords*: *Climate Change Impacts, Rates of Change, Causal Network, Arctic Ecosystems

1. Introduction

Climate Change is one of the biggest threats to the nature and humanity in the 21st century, influenced by both anthropogenic activities and natural phenomenon. It was calculated that the increase fossil fuel use with enhancement global warming will lead to the extinction of civilizations as time increases [1]. Hence the problems associated with Climate Change are one of the major obstacle to Sustainable Development. With an increasing release of Green house gases (GHG), which is the major cause of global warming and a key role in regulating Earth's temperature, it is vital to respond by achieving greater understandings on the impacts of climate change.

The impacts of Climate Change have been widely acknowledged to be deteriorating ecosystems services. Coral Reefs have been found to degrade due to increasing oceanic temperatures [2], while melting ice sheets caused problems for Arctic organisms [3]. Although several studies have been made on the opportunities and adaptations required meeting climate change challenges [4,5], however, the question remains whether the rates of change caused by climate-change led impacts will be constant or accelerating. Acknowledging the rates of change of the effects resulted from climate change led impacts is vital towards setting goals for sustainable development. Since if the rates are accelerating, it may require leading agencies to contribute to reducing the effects of Climate Change while combating Climate Change itself. Hence the aim of this paper is to review the impacts of climate change to glimpse the prospects of the rates of change that may result.

The Arctic Region is one of current most remote places on the planet. However, due to the effects of vorticity, the location, the Arctic Oscillation, and various other factors that made the Arctic vulnerable to change. The characteristics of the Arctic Ocean are similar to that of the Mediterranean Sea, where it is heavily influenced by "land-ocean interactions with restricted exchange with other oceans" [6]. It is the Arctic region's vulnerability to change that has given the Arctic a reputation for being the global health meter. Hence the aim of this paper is to determine whether changes caused by climate-change led impacts will be accelerating or not in the Arctic regions. To do so, this paper will explore the climate change im-

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pacts on the Arctic Ecosystem through literature studies. A prognosis of the rates of change resulted from the impacts incurred by climate change will then be determined by performing a causal network assessment of the climate change impacts, where a cause-effect diagram will be constructed. By understanding the impacts and the rates of change associated with climate change in the Arctic regions, future paradigm of the global climate change impacts can then be perceived which would allow a greater possibility to move towards sustainability.

In order to assess the rates of change, it is required to understand the relationships that exist between climate change and its impacted entities. One common technique is to apply Causal Networks. Causal Networks are a diagrammatic representation of relationships demonstrating the causality in relationships. There are a number of ways of performing a causal network analysis. It can be as simple as constructing a form of Directed Graphs or as complex as performing systems dynamics and data mining tasks. However, since this paper will require not only the understanding of the impacts from climate change, but how the impacts are interrelated, where the more related they are the more probable that the rates of change will not be constant. Meanwhile, there is limited resource in terms of time and data availability. Thus, for this paper, a Cause and Effect diagram will be conducted. A Cause and Effect Diagram is a type of Directed Graphs where elements are textually stated and with their relationships represented using arrows, often without quantitative data [7]. The Cause and Effect diagram does not give a lot of information but it does present a general idea of the problems, which would allow a first stance perception of an issue – in this case climate change impacts.

In order to assess and construct a Cause and Effect Diagram, it is mandatory to understand the impacts of climate change on the Arctic ecosystem. Hence the impacts of climate change on the indigenous people and the society, biodiversity and biological processes, the Arctic climate and physical geography, and the Arctic economical trends and transitions are reviewed.

2. Climate Change Effects on Indigenous People and the Human Health

The situation is the same across the North for indigenous people from Canada's Arctic to Siberia. The Polar Regions are experiencing some of Earth's most rapid climate change, even though they have contributed the least to the world's greenhouse gas emissions and have the smallest ecological footprint on earth. Indigenous people are affected by climate change and the effects varying depending on different locations and ecosystems in which they live, because their culture and the whole ecosystem that they interact is dependent on the cold and the conditions of the Arctic region. For example, the ice is diminishing and animal migration routes in the Arctic are changing. Indigenous people depend on natural resources for their livelihood and they often inhabit diverse but fragile ecosystems. For indigenous peoples around the world, climate change brings different kinds of risks, to cultural survival and undermines indigenous human rights [8].

Climate change also increased health risk and contributed to increase mortality in many regions of the world. Many present human diseases are linked to climate fluctuations. Some evidence is mounting that the changed in the broad-scale climate system may already be affecting human health, including mortality and morbidity from extreme heat, cold, drought or storms, changes in air and water quality and so on. Changes in climate would also create new challenges for community health. Drier summer conditions and the projected increase in forest fire incidence would likely lead to increased lofting of dust and dust-borne organisms and an increase in forest fire incidence. The poorer air quality resulting from increases in smoke and dust would likely increase respiratory illnesses such as asthma [9]. Impacts on the health are not only due to climate change, but may also be due to releases of greenhouse gases, *i.e.* incomplete combustion emissions from internal combustion engines [10] which can cause various health problems under specific environmental conditions [11].

The other aspects influenced the indigenous people is that climate change induced the culture transformed. For example, people live Arctic has already adapted to the environmental but as the weather gets warmer, the people are becoming stressed. The routes across the ice become dangerous when the ice thins [3].

3. Effects of Climate Change on Biodiversity and Biological Processes

Climate change is expected to increase during the next hundreds of years, contributing to many changes such as physical, ecological, economical and social but many of them are already taking place. The increase on precipitation, shorter and warmer winters, decreases in snow and ice cover, rising of the sea levels are projected changes that will likely persist in the long term (see section 4).

Changes related to climate change or the Arctic may cause "cascade-impacts", therefore involving many species of animals and plants. Comparing with other warmer regions, the systems in the arctic have generally less species, but such species develop important and similar roles, so if the species are displaced, there can be terrible consequences for other species that depend upon them [12].

3.1 Changes in Habitat and Distribution

Annual average temperature in the Arctic has increased almost twice the rates as that the rest of the world on the past years, with many variation between different regions.

Because of such warming environment, increased atmospheric CO_2 concentrations and other green house gases due to human activities, mainly the burning of fossil fuels and increased UV irradiance the temperature is projected to increase. It is assumed that the distribution of species or the habitat in the Arctic will move towards the north and that local species will migrate [13] which leads to the gretest impact of climate change; the dominance of species that favours the changed environment [14]. Many ecosystems and species have been recently affected on its distribution, for example the Marine Environment which is a highly climate-dependant system; therefore, climate variations are having important consequences on marine species [15,16].

Polar bears population which is very dependent on sea ice has decreased around 15% in both average weight and number of cubs during recent years [3]. The increased temperatures and increased rains of spring cause the collapse of dens resulting in the death of cubs and females. Also the early break-up of the ice in the spring separate the den sites from feeding areas so the young cubs can't swim long distances from dens to the feeding areas. Polar bears cannot survive if there is a big loss of the ice cover during the summer, so their only option would in a nearly future will be to change to a land – based lifestyle during the summer which means competition with brown and grizzly bears, resulting as an additional threat to their survival. The loss of polar bears is very likely to have fast consequences for the ecosystem that they are currently occupying.

3.2 Changes in Abundance

Climate change is projected to affect individual organisms' size, structure and abundance. Organisms' physiological responses and depend upon the dynamics of the populations and competitiveness between species. Physiology and Biochemistry are very important because they are key elements for the response of the organisms to changes in environment.

Phenology studies the relation between climate factors and life cycle of organisms, and it is also crucial for the diversity of the Arctic, unexpected events in climate will also affect the size of populations. The most important impacts related to such issue consist on how changes will affect interaction between pairs of species, and if one of the species changes its phenology more than others, this will probably increase the effects of competition [17].

3.3 Changes in Migratory Habits

The climate affects the migration and survival of animals that are an important source of native diets, the ability of goods to arrive from the south, the stability of homes on the permafrost and the ice-thickness to make travel over land and sea safe [3].

Climate change is expected to cause the northward expansion of forests into the Arctic tundra, and of tundra into polar deserts. Such changes are likely to take place this century in areas where suitable soils and other conditions exist. This is expected to result in the area of tundra becoming smaller than it has ever been during the past 21 000 years, reducing the breeding area for many birds and the grazing areas for certain land animals [3]. However, the possibility of migration is dependent on various factors. According to [14] insects and birds will be able to migrate but would have been a challenge for flightless species.

The total number of species in the Arctic is projected to increase under a warmer climate due to migration of species from the south. Many of the adaptations that enable plants and animals to survive in the Arctic environment also limit their ability to compete with species that move in from the south. Moreover, Arctic species are limited in their northward migration by the Arctic Ocean, which enhances the likelihood of bioinvasive success. These northern species may be reproducing less successfully due to temperature-induced habitat changes, while changes affecting breeding grounds and access to food may cause seasonal migrations to take place earlier in spring and later in autumn. Changes in the ranges of certain bird [18], amphibians, and invertebrate species have been observed [13]. At present, there are more varieties of moss and lichens in the Arctic than anywhere else in the world. This type of vegetation is particularly likely to decline as the Arctic [3]. Under a CO_2-doubled climatic forcing, migration fates of vegetation have also predicted in a variety of scenarios [19].

The geographical spread of animals can generally shift much faster than that of plants, and large migratory animals such as caribou can move much more readily than small animals such as lemmings. In addition to mobility, the availability of food sources is another factor that influences the pace at which different species will shift northward. All of these differences will result in the break-up of currently interdependent communities and ecosystems and the formation of new ones, with unknown consequences [3,13].

3.4 Problems with Bioinvasion

Invasion of non-indigenous species have caused important problems during the past years. With a changing climate in terrestrial ecosystems, species seem to be more likely to survive in the Arctic and therefore new species will probably arrive, and some of them will establish and form reproducing populations. There is not yet a clear establishment of classifying such new species as "native" or "non-native" when the reason of a rapid change in climate is driven anthropogenically, but it stills need to be remembered that at least 1% of the species that are introduced into the Arctic environment are likely to become "invasive species" [3]. An example of this has been

portrayed in British Columbia where invasive species that are often aggressive and highly adaptable, have been continually introduced in low elevation protions of British Columbia; most of which are plants and noxious weeds [14]. Such introduction can lead to resource competence and disease spreading, for wildlife and people.

On the aquatic environment one of the major problems is caused because of the thinning of the sea ice and the opening up of the Arctic Ocean to more shipping so the possibility of introducing non-native species through ballast has increased and for that reason environmental risks. It is under great concern not only because of the problems that it creates, but also because 80% of the worlds total cargo is transported by ships [20], while many thousands of marine species are being transported through ballast water [21]. Ballast water becomes a problem when organisms that came with the ballast water survived the journey and started dominating in the new habitat [20]. In addition various kinds of bacteria and viruses may spread due to the results of the depletion of the Oxygen in the water, allowing them to grow during the journey [22]. In fact, it was said that most of the aquatic species do not survive the voyage, which is often shorter than the long voyages at sea [20]. Despite this fact, if the water quality remains favorable, towards certain species, for the whole voyage and at the destination, this may give the higher possibility for success in bioinvasion, since its success would require the organism to stay alive during the voyage, to be able to adapt to the new environment and to out compete the local species [23].

4. Arctic Climate and Geographical Impacts due to Global Warming

It is believed by various scientists that global warming will be manifested through Arctic's regional changes. There have been various climate models predicting temperature changes in the Arctic regions. R. W. Mcdonald R. W. *et al* (2005) stated that in the 20th century, the Arctic has been at its warmest comparably to the temperatures of the past 400 years, where there would be an approximate increase of 5°C or more at the pole and 2–3°C increase at the arctic margins, whilst decreasing the temperature contrast between the Arctic and the equator. [24] have used various global climate models to predict scenarios of climate changes in the Arctic region and suggests that there will be a 5°C increase during the spring (Mar – May), 1–2°C duing summer (Jun – Aug), 7–8°C during autumn (Sept – Nov) and 8–9°C during winter for the 2030 AD–2060 AD period. In addition, some studies suggest temperature change is greater over land than the ocean [25], while some suggest a similar trend. According to [6] the Eastern Arctic Ocean's temperature in spring indicates a warming of 2°C per decade while the Arctic land mass indicates a warming of 2°C per decade in winter and spring.

The changes in temperature have caused changes in the pressure over the Arctic Region. [24] suggested that there will be a decrease in 1–2 mb of sea level pressure in the Arctic region where these projected decreases of pressure are in the autumn and winter. Studies on the Arctic Oscillation have also shown anomalies in the pressure of the Arctic region. Arctic Oscillation is a climatic index which indicates atmospheric circulation over the Arctic, taking considerations of various factors including pressure and vorticity, among several others [26]. The Arctic Oscillation index has been found to be gaining a positive shift since the 1980s and especially in the 1990s, indicating increasingly lower sea-level pressure. These values have been found to be distributed symmetrically over the pole while higher pressures are evident over the North Atlantic and North Pacific during the winter and over Siberia and Europe during the summers. Normally the Arctic Oscillation index value would be shifting between positive and negative values, but some research studies suggest that GHG warming is the culprit for locking the Arctic Oscillation index value to a positive position [6]. In addition, it is also suggested that the temperature changes in association with the Arctic Oscillation is large enough to effect the polar circulation. The changes in Arctic Oscillation, especially on the average sea level pressure, have allowed increase in precipitation, including increase cyclonic activities. [25] discussed models for projecting climate change scenarios for global impact studies and projected that during winters there would be increases in precipitation in middle and high northern latitudes. In addition, there would also be large precipitation increases in the northwest of North America. [24] suggested that polar low pressure systems would be more common, causing an increase in mixed phase precipitation, while warmer temperatures may contribute towards enhanced hydrological cycles over the arctic, increasing the stratification of the upper ocean. It had been projected that precipitation during 2030–2060 are generally higher that present by 1 cm per month. The changes in the Arctic Oscillation would allow the Arctic region to become wetter and in combination with warming of the Arctic atmosphere, freezing mist and drizzle generation would increase. In addition, current trends in the Arctic Oscillation Index indicate a greater tendency for cyclonic activity and the poleward-propagating extratropical cyclones will have fewer tendencies to decay. [6] suggest that, under the condition of 1% CO_2 concentration increase per annum for 80 years, precipitation would increase by 0.5–1 m per annum for Arctic and subpolar regions.

Other geographical impacts of climate change on the Arctic region include the decrease in ice volume and extent, decrease in permafrost areas, fresh water discharge, among others. [6] suggests that the mean annual river

discharge will increase by 20% for the Yenisei, Lena and Mackenzie rivers with 12% decrease for the Ob River, where Yensei, Lena, Mackenzie, and Ob are the 4 many other major rivers that discharges to the Arctic Ocean. In addition the amplitude and seasonality of flow will change due to decrease snow fall and earlier spring melt. There is also glacial ice mass loss in the Arctic region. Ice mass in Greenland are decreasing at the rate of 53 km^3/layer. [24] have used 4 global climate models to project scenarios of sea ice in the Arctic and resulted in reductions in ice extent and thickness in the Arctic region. It is estimated that by 2050, ice extent will decline by 30% and the ice volume 40%. Data recorded by ships and settlements suggested that the ice extent decline have fall below pre-1950 minima after 1975. Satellites records show that for the past 20 years, the rate of decline of ice extent is at 3% per decade. It is projected with satellites' records' extrapolation that in 2050, the trend of summer minimum ice extent reduction will be at 15% and the volume will be decreased by 40%. [6] suggests that by 2100 permafrost area could be reduced by 12–22%. Approximately 25% of the land in the Northern Hemisphere and under sediments of the continental shelves is permafrost, where discontinuous permafrost regions of the Arctic are the most vulnerable to change.

From these changes of the geographical and climatic changes of the Arctic region, we can see the magnitude of impacts due to climate change on the Arctic regions. It is these changes that will impact the global environment at all scales.

5. Economical Trends due Impacts of the Arctic Region due to Climate Change

Sub-regional impacts: In a region as large and diverse as the Arctic, there are significant sub-regional variations in climate and the warming is more dramatic in some areas than others. For example in some regions such as parts of Canada and Greenland (near the Labrador Sea), have not yet experienced the tangible warming of the rest of the region. Regional variations in future climate change are also projected. In fact the local characteristics of the nature and societies also create differences in types of impacts and the importance of them in each sub-region. This makes the discussion of economic impacts more specific, regional, and controversial because of the interconnections between these regions. As an intuition into the different regional impacts, just some general properties of different arctic sub-regions are presented and the economical impacts will be discussed in general, while different economical impacts can be inspired from different climate characteristics. The regions and their specific changes due to global warming can be classified as follows [27]:

1) East Greenland, Iceland, Norway, Sweden, Finland, Northwest Russia, and adjacent seas: The marine access to oil, gas, and mineral resources is likely to improve as sea ice retreats. A general increase in North Atlantic and Arctic fisheries is likely, based on traditional species as well as the influx of more southerly species.

2) Siberia and adjacent seas: Sea-ice retreat is very likely to increase the navigation season through the Northern Sea Route, presenting economic opportunities as well as pollution risks. Access to offshore oil and gas is likely to improve but some activities could be limited by increased wave action.

3) Chukotka, Alaska, Western Canadian Arctic, and nearby regions: Damage to infrastructure will result from permafrost thawing and coastal erosion. Reduced sea ice will enhance ocean access to northern coastlines. Thawing may cause problems for land transport in winter. Traditional local economies based on resources that are vulnerable to climate change (such as polar bears and ringed seals), are very likely to be disrupted by warming.

4) Central Eastern Canadian Arctic, West Greenland, and adjacent seas: Sea-ice retreat is likely to increase shipping through the Northwest Passage, providing economic opportunities with increasing the risks of pollution due to oil spills and other accidents. More southerly marine fish species such as haddock, herring, and blue fin tuna could move into the region. Lake trout and other freshwater fish will decline, with impacts on local food supplies as well as sport fishing and tourism.

5.1 Major Potential Economical Impacts:

Climate change would have a wide range of impacts on the Arctic Economy. Although it is probably that this would have led to the tradgedy of the commons [28] but may also have led to developmental impacts. The significant economical impacts of the climate change to the arctic regions are being discussed as follows.

5.2 Agriculture and Forestry Development

Treeline is expected to move northward and to higher elevations, with forests replacing a significant fraction of existing tundra, and tundra vegetation moving into polar deserts, thus as potential areas for food and wood production expand northward due to a longer and warmer growing season and increasing precipitation, where suitable soils exist, agriculture and forestry will have the potential to expand northward due to a longer and warmer growing season. More-productive vegetation is likely to increase carbon uptake, although reduced reflectivity of the land surface is likely to outweigh this, causing further warming. The consequent impacts such as emissions from transportation of the agriculture and forestry products and machinery used to handle the related cultivation and process industries may also become of more importance as contributors to speed up the climate change rate.

5.3 Expanding Marine Shipping and Access to Resources

The continuing reduction of sea ice is very likely to lengthen the navigation season and increase marine access to the Arctic's natural resources, though increasing ice movement in some channels of the Northwest Passage could initially make shipping more difficult. Shipping through key marine routes, including the Northern Sea Route and the Northwest Passage, is likely to increase. The summer navigation season is projected to lengthen considerably due to the decline of sea ice. Expansion of tourism and marine transport of goods are likely outcomes that this may result in increased rate of released emissions of GHG and other pollutants to the arctic areas.

5.4 Changes in Fisheries

Some major arctic marine fisheries, including those for herring and cod, are likely to become more productive as climate warms. Ranges and migration patterns of many fish species are very likely to change. Also decreased abundance and local and global extinctions of freshwater fisheries are projected for this century. Arctic char, broad whitefish, and Arctic cisco, which are major contributors to the diets of local people, are among the species threatened by a warming climate.

5.5 Indigenous Communities are Facing Major Economic Impacts

Many Indigenous People depend on hunting polar bear, walrus, seals, and caribou, herding reindeer, fish, etc. that lots of these species are likely to be seriously damaged by climate warming. This results to a shifting towards food imports and the necessity to have an industrialized style of living to be able to earn the related income. It will result in a total change in the economy structure of the region and style of living of the indigenous people.

5.6 Thawing Ground will Disrupt Transportation, Buildings, and Other Infrastructure

Northern communities that rely on frozen roadways to truck in supplies are somehow affected now and may be affected more. Transportation and industry on land, including oil and gas extraction and forestry, will increasingly be disrupted by the shortening of the periods during which ice roads and tundra are frozen enough to permit travel. As frozen ground thaws, many existing buildings, roads, pipelines, airports, and industrial facilities are likely to be destabilized, requiring substantial rebuilding, maintenance, and investment. Future development will require new design elements to account for ongoing warming that will add to construction, maintenance costs, and probably the new materials production emissions.

5.7 Increasing Access to Resources, Industrialization, and Appearance of Sovereignty Claims

Marine access to some arctic resources, including offshore oil and gas and some minerals, is likely to be enhanced by the reduction in sea ice, bringing new opportunities as well as environmental concerns, though increased ice movement could initially make some operations more difficult. As a result, industrialization in the arctic areas is inevitable due to the access to the extracted resources and the high transportation costs to other parts of the world. This will result in a higher rate of release of GHG emissions and other pollutants to the ecosystems nearby and contribute to the rate of climate changes. Also due to resource extraction and the industrialization and the related economic benefits, sovereignty, security, and safety issues, as well as social, cultural, and environmental concerns are likely to arise.

6. Prognostic Overview of the Rates of Change

Climate change will definitely have impacts on the global scale. As illustrated previously, various factors of the Arctic will be affected by the current rising trend of global warming. However, these changes are not happening at the constant rate, and many are influencing acceleration in the rates of change.

If we observed the sea level rise, we can see that estimates of the rise in sea level have been changing by various models over the years. Although it is arguable there may have been a lack of accuracy in these models, however, readings of models recently shows a similar trend. In addition, Recent studies from the department of Meteorology, University of Utah, suggests that efforts in developing climate models in the United States have paid off in climate models with much greater accuracy than before [29]. [25] analyzed 3 different models and projected various changes over a 30 year period with respect to 1961–1990 data. The projection showed varying figures in rise; 12–20 cm in 2020s, 24–38 cm in 2050s and 40–58 cm in 2080s. [6] suggested that they may be an additional of 50 cm in sea level rise to the already estimated rise of 10–25 cm in the past century. One of the Chief of the Arctic Climate Impact Assessment (ACIA), Dr. Robert Corell, stated that "Greenland contains enough water to raise the sea by seven meters" and that the "sea could under these projections rise a meter every 50 years", where this can cause great impacts on many parts of the world as stated by Dr. Robert Corell that "Bangladesh will lose 40% of its land mass." It is also noted that the total Greenland ice can be melted overtime by $3^{o}C$ increase.

The raise in sea level is attributed to many factors, among them, the increasing rate of ice cover, extent, and volume decline. The current rate minimum ice extent

reduction would lead to ice free areas. The Sea of Okhotsk, the Sea of Japan, the Northwest Passage through the Canadian archipelago, and the coast of Alaska will be ice free. The central Arctic Ocean, Greenland Sea, Bering Sea, and Gulf of St. Lawrence will maintain ice cover but there will be a reduction in thickness, estimated at 1.5 m with less compact properties. It is also predicted that marginal ice zone will migrate pole-wards under a warmer climate [24]. Thus due to more exposed oceanic areas and the disappearance of former ice, any newly ice formed would disappear faster due to the salinity content of the ice. [6] suggested that the Arctic Oscillation also contributes towards the variation of the Arctic sea ice distribution. A study of stable isotope data from the Beaufort Sea dating from 1987 to 1997 show a correlation between the increase of ice melt amounts within the water column and the increase in the Arctic Oscillation index. [6] explained that "cyclonic circulation leads to greater ice divergence, new ice leads, enhanced heat flux, reduced ridging", which these factors lead to thinning. Although, there have been discussion of whether the influence of the Arctic Oscillation is significant in terms of thickness distribution change but may not be as significant for ice volume change, but it is also suggested that the sea-ice thinning and the Arctic Oscillation correlation is strong (approximately 80%), due to various dynamic effects. As mentioned previously, the Arctic Oscillation index increase implies lower sea level pressure and increase in cyclonic activity. The increase of Cyclonic activities would further enhance the effectiveness of ice thinning. The Arctic Oscillation index is said to be locked in the positive position partly due to GHG warming. Thus, a continuation of rapid global warming would further imply the enhancement of ice thinning efficiency, which would cause the global albedo capacity reduction and resulting with an accelerated warming. Furthermore, it is suggested by [6] that the change in ice cover would alter the levels of light penetration, mixing levels, the degree of primary production, and the amount of carbon flux.

The Degree of mixing is affected by various factors, including the thermocline and the halocline of the water column. Prof. Terry Callaghan from the Alaska Scientific Research Station stated in an interview that the Arctic region cools the rest of the world through capturing and storing Greenhouse Gases, high albedo, and the cooling of the world's ocean currents. The cooling of oceanic currents relies on the mixing of the oceanic water column that is affected by the stratification. The level of stratification is influenced by thermocline and the halocline of the water column. However, due to the warming of the climate, these stratifications and the hydrology of the Arctic region have been changing recently. The level of stratification and the efficiency at which it is forming is still a scientific controversial discussion due to the variances in the halocline within the Arctic region [6,30]. The increase in glacial melts, increased precipitation, a decline in permafrost, and enhance from the Atlantic lowers the salinity, whereas in some areas the salinity is increasing due to the change in freshwater flow of rivers, e.g. the enhancement of salinification of the Eurasian Basin due to the diversion of river inflow [6]. From these findings, we can say that the general salinity balance has been greatly disturbed by impacts of climate change. These changes will affect the general mixing of the Arctic, which would affect the efficiency of the Arctic to cool down the global oceanic currents. According to [31], the upper oceanic layers of the Siberian coast have shown a decrease in salinity and have been suggested to prevent mixing and preventing the warmer oceanic waters from reaching the surface through the increase in stratification. The effect of oceanic currents and hydrology in general of the Arctic region will also increase the transportation of contaminants towards the Arctic region. This leads to increase in the accumulation of contaminants in the Arctic region and thus threatened various biological species in the region.

The other major impact of climate change that accelerates the changes in the Arctic region is the decreasing permafrost within the region. Permafrost degradation would lead to the increase of the active layer of the soil and hence causing further knock-on effects. The degradation of permafrost would lead to a change in vegetation pattern and other biological processes, while allowing the soil to become drier due to the degrading frozen soil which keeps the moisture to remain within the soil. The dryness, in addition to change in vegetation pattern changes, can lead to increase forest fires risks. In addition, the expansion of forests poleward would decrease the albedo levels and reducing the global cooling trend. Other problems of Permafrost degradation may also include increase sediment loading of water systems and risks of problems associated with waste management, *i.e.* landfills.

The biological importance in the marine environment of the arctic can be sometimes underestimated. Species from the arctic are very dependant to the sea ice. The loss of the cover or increase stratification are results of the rapid temperature increase in the arctic due to climate change and it has the potential to alter the amount of available food in many habitats. The alteration of the primary production either on amounts or in its distribution will decrease the food availability for aquatic biota such as fishes, whales, seals, walrus, etc. leading to population depletion, migration or even redistribution through the food webs. Regional variations in distribution and abundance of sea ice already have significant effects on the reproduction and survival of some species such as polar bear populations.

The increased warming and precipitation are very

likely to increase the amount of persistent organic pollutants and mercury that are deposited on the Arctic. As temperatures raise, snow, ice and permafrost which contain contaminants will melt, leading to the release of these contaminants. The resulting increase in the concentrations of contaminants in ponds and rivers may have harmful effects on aquatic plants and animals and can also contaminate sea waters. Such impacts will be amplified and the levels of contaminants on the Arctic lakes will be accumulated and transferred up to the food web even endangering humans health by bioaccumulation that later can lead to other problems.

There are also important indicators that climate change affected radically terrestrial species. The climate change also had very strong impacts on habitat loss, diversity and migration, indicating that climate change can increase significantly extinction rates and modify the ecosystem in all levels, (global, regional and local) changes in biota and animal migration routes are also very sensitive to climate changes and will also be associated in response to warming. Thawing permafrost, changes in land use, habitat fragmentation are also some important changes that can affect animal success in reproduction, survival and dispersal, leading to specie losses in the Arctic.

By now there is no doubt that natural systems in arctic are changing and the most important thing that we should take into account is to have the adequate knowledge in order to know when keystone species begin to cause collapses of ecosystems and reductions in the ecosystem services. Therefore the monitoring is important for understanding how the biodiversity in the Arctic is changing and whether actions to take in order to understand the complex system responses to impacts of the climate change.

Growing evidence suggests that increases in global temperatures may lead to more rapid and irreversible shifts in the climate system. These could produce large changes in global systems. Since the early 1800's, the human activities have helped to increase concentrations of carbon dioxide by 30%, and methane, a greenhouse gas with 22 times the global warming potential of carbon dioxide, by 140%. And the rising greenhouse gas emissions will lead to changes in other parts of the earth's life support system. The number of people in the world has grown from 2.5 billion to more than 6.2 billion since 1950.The potential impacts of these events are too high to ignore. Human population growth and climate change are critically linked. The size of the population and its activities will be major factors in the extent of warming. And the population size will very much determine the effects on that population of climate change.

Climate change cause many social problems. The number of refugees and displaced people has increased markedly. Refugees represent a vulnerable population with health problems, and large-scale migration because of flooding, drought and other natural disasters. In addition to these factors, the increasing population will put greater stresses on the environmental services, which are being impacted from the global warming phenomenon and thus increase the rate of change. The rate of change in environmental services is further enhanced due to the possibilities of the generation of new ports and cities due to possible increase in the shipping and transportation industry.

In terms of economical effects, there are too many issues that would need discussing, so in this paper the effort is to stick to the side of most important and too concise rather than lots of details. As discussed in the paper, the development of agriculture and forestry and also expanding Marine Shipping and easier access to the natural resources, makes the rate of the changes accelerating, it means day by day the global warming effects such as thawing of sea-ice results in comfortability and feasibility of transportation, agriculture, etc. and the related developments (rebound effect) that helps to much easier further developments and also more GHG emissions. So this cycle is an important issue to consider in this area.

The assessment performed in this section, hence, shows the effects of the impacts in the Arctic regions that are caused by Climate Change and how they are related. From the discussions above, a causal network can be formed as a Cause and Effect Diagram (See **Figure 1**).

Figure 1 shows the causal network that represents the effects of climate-change led impacts and how they are interrelated. The reinforcing cycle of the climate change effect is visualized with the significant factors. This cycle is a growing cycle and can result in an irreversibility point.

The most important contributing factors in this worsening cycle can be counted as follow:

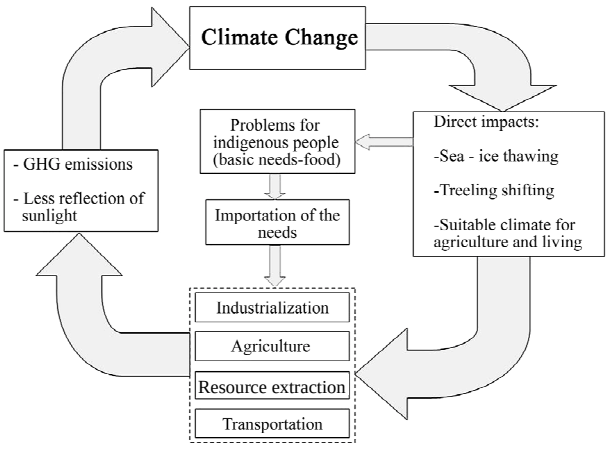

Figure 1. Cause and effect diagram, a form or causal network, showing the relativity between the effects led by climate change impacts

The development of agriculture and forestry in the arctic region may contribute to the absorption of CO_2 at the first glance, but the reduced reflectivity of the land surface is likely to outweigh this, causing further warming. Also impacts of emissions from transportation of the agriculture and forestry products and machinery used to handle the related cultivation and the related process industries are contributors to speed up the climate change rate towards the irreversibility point.

Easiness of direct-route marine transportations across the arctic zone which means less transportation costs and less emission from transporting of merchandize at first which might be a preventive agent for climate change rate, but this means less costs and an incentive for more transportation and therefore more emissions in total (the rebound effect).

Increasing access to resources makes industrialization rate faster and creates a competitive environment through the region. Also the proximity of the arctic with developed countries such as Canada, Sweden, Norway, and Finland makes the change faster and the multinational companies will start their business there leading to more resource consumption etc. and all these comes in the form of a accelerating cycle contributing to both global warming and the appearance of sovereignty claims for the region. So in case of having no international treaties and protocols, we may consider the trend of industrial revolution infect the arctic region.

From these findings and discussions as demonstrated above, we can see that most impacts of climate change on the Arctic region are bound to increase at an accelerating rate of change. Thus the accelerating contribution towards the climate change (the growing effect) can be qualitatively visualized in **Figure 2**.

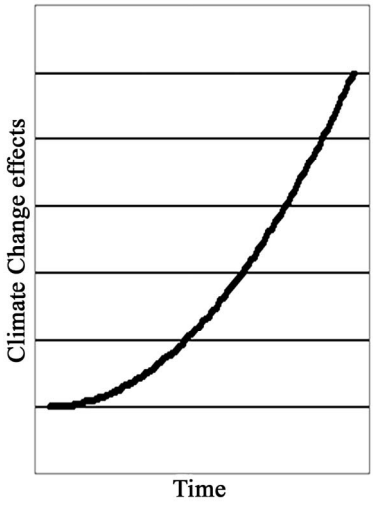

Figure 2. Accelerating rates of change as a result of increasing climate change effects with respect to time

7. Discussions

This paper semi-qualitatively assesses the effects of the climate change impacts in Arctic regions and portrays how the rates of change inflicted by climate change impacts will accelerate in the years to come. However, several human activities that may lower the rates of change have not been discussed. For example, the economical transitions may include more environmental strict abiding laws and well committed emissions cut by the industries. Although, this is not such a strong case in the past, but commitment to respond to the climate change phenomenon is increasing, as has been witnessed in the 2009 Copenhagen Climate Change Summit. Hence further evaluations of this issue should be conducted. Furthermore, if possible, a more quantitative approach to this issue should be achieved but this may become extremely difficult when approaching social and economical issues. Thus the best practice would be to approach this issue semi-quantitatively.

The other main problem is that a lot of this paper uses qualitative assessment, which makes subjectivity unavoidable. It is also the reason why the rates of change are not given quantitatively. This creates obscurity in terms of results. Nonetheless, the logical reasoning and evidences provided throughout previous studies suggests an accelerating rate of change. This means that further studies into this issue is urgently required.

One interesting factor that needs to be put in to consideration is the use of several parameters as determinants for impacts of climate change. For example, some indicators suggesting impacts that may have resulted from climate change (*i.e.* growth inhibition and calcium deficiencies of calcareous organisms) may have been resulted by other major influencing factors. A study by [32] suggests the impacts from recreational boating activities, especially due to exposure to antifouling agents and toxic substances. Hence, perhaps this also means that the global contribution to combat climate change may not be sufficient in solving the aftermath effects of climate change but also all the associated problems that has magnified the effects resulted from the impacts of climate change.

From these discussions, it is mandatory to further review the rates of change caused by climate change, as these effects and changes will like to accelerate even more as the problems paramount synergistically with other problems associated with anthropogenic activities.

8. Mitigation Measures

Several mitigations measures have been reviewed by the IPCC, UNFCCC, and UNEP, as well as several other researches in the field [33]. However, as a result of possible accelerating rates of change, several other mitigations measures are called for. In addition to the mitigation measures of climate change, leading agencies and authorities also need to consider other causes of environmental degra-

dation to slow down the rate of change due to the impacts of Climate Change. Perhaps, it is necessary to perceive the problems in a more holistic perspective, *i.e.* ecological footprints. Although each environmental problem has its own ideosyncracies but the causal network shown in this paper suggest synergistic forces that drive changes in the environment. Measures to reduce ecological footprints can be done through implementing ecological engineering concepts, cleaner production, and industrial ecological and sustainable technological approaches, among others. Most of which have already been mentioned in the global arena. However, one possible mitigation measure that is being left out is the applications of bioregenerative life support systems which can assists in lowering dependency on natural resources and hence promote sustainability [34]. A more detailed evaluation of the rates of change is required if a specified mitigation measure is to be achieved. However if one were to follow the causal network produced in this paper, it is logical that these effects and rates of change can be reduced by taking out Climate Change but because Climate Change cannot be prevented it is the best of the global interest to seek a good response measure.

9. Conclusions

The Arctic Region is exposed to various impacts due global climate changes. As demonstrated in this report, these changes are accelerating due to indirect and direct changes of impacts due to climate changes. These changes can be demonstrated in a Cause and Effect diagram, revealing the importance of the need for international decision and pledge on stopping climate change and the urgent need to devise an exhaustive scheme to preserve the Arctic. However, as discussed above, there needs to be an urgent further study to investigate whether the rates of change will truly be accelerating and by how much it accelerates; to prevent a global catastrophe.

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