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Research Article

The Footprint of Industrialization on Climate Change

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Abstract: Climate change is globally realized, and its repercussions are being felt across different regions. International organizations are making concerted efforts since the 1990s to minimize the vulnerability of climate change through global collaboration. Major agreements in the climate change policy process are the Kyoto Protocol and the Paris agreement that played an essential role in globalizing the concept of climate change. This study divides the analysis period into four policy regimes and analyses climate change across seven different geographical regions. Further, the linkage between countries' degree of industrialization with climate change is examined. Climate change is accessed by calculating temperature and rainfall anomalies for the 1961-90 reference period. Data used in the analysis were from Climate Research Unit (UK) from 1991 to 2018. For climate modelling, the study employed Geographic Information System (GIS) and simple graphical analysis to examine the spatial and temporal patterns. From the spatial analysis, it is observed that countries with a high degree of industrialization also experienced a high level (more than its fair share) of climate change in terms of the magnitude of change. However, results are in sharp contrast when speed of change is analysed. Further, it is observed that climate change is heterogeneous across all regions. Climate change policy measures have decelerated the pace of additional warming in the world.

Keywords: Climate Change, Climate Variability, Industrial Disparity, Spatial Analysis
JEL Classification Codes: Q54, O14, R12

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1 Introduction

Climate change often termed as a distant threat, has already begun to show its visible signs by the emergence of natural disasters in the past few consecutive years. Recent global outbreak of locusts in Africa, South Asia, and Middle East are reasoned for conductive longer than usual rainy season, floods in Indonesia, India, Bangladesh, Iran, and Brazil. Australian bush fires, volcanic eruption in Philippines, earthquakes in Russia, Turkey, India, China, and Jamaica give glaring signals for widespread impacts and consequences[1].

Generally, climate evolves naturally over time, which explains some natural forces intrinsically altering the earth's climate [2]. Changes in natural factors majorly cause the preindustrial era's climate variations. Post-industrial revolution came up with technological progress, increased urbanization, enhanced efficiency, and global integration with significant changes in global temperatures. Primary reason behind these significant changes is the excessive increase in human activities that emits carbon dioxide (CO_2), methane (CH4), nitrous oxide (N2O), and other greenhouse gases (GHGs)[3]. As compared to pre-industrial levels (1750), in 2011, global CO_2 concentration swelled by 40% (278 ppm to 390.5ppm) while CH4 and N2O were picked up by 150 percent (722 ppb to 1803 ppb) and 20% (271 ppb to 324.2 ppb) respectively (IPCC AR5). Unfortunately, the pressing concern is that many of these emissions are permanent and cannot be reversed in centuries to come. Earth's surface temperature will continue to rise even if net CO_2 emissions are marginalized to zero[4].

Industrial activity has played an essential role in economic growth, development, and technological innovation in developed and upper middle income. However, present series of climate change disasters reveals that industrial innovation and progress are coupled with negative externality that affects our ecosystem's standard working capacity. Carbon dioxide is continuously being released and removed from the atmosphere by natural processes. However, excessive release of gases that absorb carbon content in the atmosphere increases the earth's temperature. Multi-disciplinary scientists have analysed several natural and anthropogenic factors responsible for climate change. This fact has also been validated in the current health crisis COVID-19 when more than half of the world has halted production, transportation, and all kind of carbon-intensive activities. Le Quéré et al. (2020) revealed that daily carbon emissions decreased by 17% in April 2020 compared to 2019. International Energy Agency (IEA) also ensures the reduction of 2.6 gigatons of CO_2 emissions globally in 2020.

United Nations Framework Convention on Climate Change UNFCCC came up with several tools and policy measures in its Conference of the Parties (COPs) each year since 1995 (for details, see table 1). However, the Kyoto Protocol and the Paris Agreement (COP-21) are breakthroughs in global collaboration. Developed countries were considered responsible for past century industrial activity and were constrained to reduce their GHGs emissions levels. Kyoto Protocol agreement restricted developed countries to cut their emission by 5% compared to 1990 and country-specific goals for 2008 to 2012. In 2005, the EU also introduced an Emission Trading System (ETS) to strengthen emission reduction further. Through its technical and scientific reports (AR4 & AR5), IPCC assured an increas-

[1] The international disaster database, (CRED) https://www.emdat.be/

[2] Variations in solar energy, volcanic eruptions, and natural changes in greenhouse gas (GHG) concentrations

[3] Increase use of fossil fuels and change in land use activities increases carbon dioxide emissions while agriculture sector is responsible of intensifying methane and nitrous oxide content in the atmosphere.

[4] Climate Change 2013: The Physical Science Basis. Contribution of Working Group I to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change

ing carbon emissions rate from emerging economies (China, India, and Russia). Later, in 2015, the COP-21 included developed, emerging, and developing economies as part of the global climate change process. The world's top GHGs emitters agreed to move forward in decelerating the pace of global temperature and keeping it between 1.5 °C to 2 °C as compared to pre-industrial levels[5].

Table 1: Key developments in climate change policy formulation

Period	Key developments
Post-1990	1972- UN conference on the human environment 1979- First World climate change conference 1987- Montreal Protocol (restrict the use of chemicals that damage ozone) 1988- IPCC was set up
1990-1996	The 1990-IPCC first assessment report was launched 1991- First meeting of intergovernmental negotiating committee IPCC 1992-convection on climate change adopted. Rio Summit Declaration 1994-UNFCCC was established 1995-COP1 takes place in berlin
1997-2004	1997- Kyoto Protocol was adopted 2001-Marrakesh Accords
2005-2014	2005-EU's emission trading system was launched 2007- IPCC fourth assessment report was launched 2009-Copenhagen Summit on Climate Change 2010- The Cancun Agreement was adopted
2015-2019	2016- The Paris Agreement was enforced 2018-Rules for Paris Agreement Decided 2019-UN Climate Action Summit for world leaders in New York

* Source: https://www.unfccc.int/, https://www.ipcc.ch/

Climate change is not confined to geographical boundaries. Carbon emission emitted from one part of the world is homogeneously distributed across space, but the resultant climate and natural disasters impacts are heterogeneous disseminated. Unlike existing literature, present study measures the spatial and temporal spread of climate change across various industrialization levels. Most studies in the past have focused on CO_2 emissions to examine climate change and environmental degradation.Present study analyses temperature anomalies as a measure of climate change.Furthermore,the role of international organizations for climate change has also been included in the analysis by studying the pre- and post-era of a breakthrough in climate change policy framework.Existing research

[5]Both Kyoto Protocol and Paris agreements includes three subgroups for countries. Annex I, Annex II and Non- annex I countries. Detail list of countries and their divisions into these sub groups can be assessed through https://unfccc.int/process/parties-non-party-stakeholders/parties-convention-and-observer-states?field_national_communications_target_id%5B515%5D=515&field_partys_partyto_target_id%5B511%5D=511

on distributional analysis focuses more on impacts and future climate change, based on process-based simulations[6]. However, the present study uses historical climate change data and gives a comprehensive view of industrialization and climate change graphically. QGIS mapping and graphical analysis suggest that as countries become more industrialized, they tend to experience more climate change vice versa. However,the speed of change in developing and least developing economies is higher than in industrialised economies. From a policy perspective, findings suggest that major agreements in climate change policy formulation have slowed the pace of additional warming.

These findings guide policymakers and practitioners about the role of industrialization level, in devising climate change policies. Carbon emissions are homogeneously distributed across space irrespective of the country emitting them thus it is important to have international collaboration for both climate change and industrial policy. Industrial policy that ensures climate resilience and renewable energy technological transfers to developing economies needs to be encouraged as this can facilitate adaption and mitigation efforts across the globe.

Rest of the paper is structured as follows. Section 2 outlines the review of relevant literature. Section 3 examines the theoretical background of industrialization and climate change. Section 4 examines methodology, data description, and data sources. Section 5 discusses findings by analysing climate change and industrialization levels through graphical and spatial analysis. Section 6 elaborates the discussion.

2 Literature Review

The world economic system has been incentivizing production, consumption, capital accumulation, and technological progress. The industrial revolution accompanied by capitalist system led to exponentially high growth levels for the global economy. However, every economic activity directly impacts our ecological system (Burke et al., 2015; Li, 2009), while some economic activities (crops, fisheries) are directly contingent on climate and weather conditions.

Climate variables, particularly temperature, nonlinearly affect economic productivity (Burke et al., 2015), labour supply (Deryugina and Hsiang, 2014), and agriculture yields (Mendelsohn and Dinar, 1999). Initial literature on climate change focused more on GHGs damage functions and abatement costs for world regions. Nordhaus (1991)and Frankhauser and Tol (1996) assumed different climate scenarios, damage functions, and adaptation practices to estimate future carbon emissions cost in monetary terms. Further studies analysed the impact of climate change on different sectors (agriculture, forestry, marine life, energy) have linear[7] (Arnell et al., 2013) quadratic or parabolic[8] (White et al., 1999) relationship with temperature changes. All these models that assumed different damage function forms predicted that each country would suffer from climate change relative to its income level. Experimental and cross-sectional studies on climate sensitivity of different sectors reveal that climate change has a hill-shaped relationship in each sector. It means

[6] Climate models such as by Global Circulation Models (GCMs), regional climate models (RCMs), integrated assessment models (IAMs) and many more are being used to access climate change impacts

[7] Degree of impact is same as temperature increases

[8] Initial climate change may yield benefits until a point where benefits start diminishing with high levels of climate change

that there is a specific optimal temperature for each sector that maximizes revenues for that sector and beyond which revenues tend to diminish (Mendelsohn et al., 2006).

Changes in temperature and precipitation affect output and hinder output growth in developing countries (Dell et al., 2008). With no prior assumption of channels through which temperature affects economic activity, Dell et al. (2008) estimated that temperature changes have a more pronounced negative impact on developing countries economic growth than the rich. At the same time, changes in precipitation do not affect economic growth for both groups. The study examined impact on both level and growth of output. Horowitz (2009) examined the relationship between temperature and income using the econometric method and explored contemporaneous and historical climate factors. Dell et al. (2012) revealed that a 1% rise in developing countries' temperature would lead to decreased agriculture growth by 2.6%, with economic growth falling by 1.3% with each additional warming.

Industrial structure plays important role in economic growth and development of economies. Industrialization can aid or discourage additional warming. As the process involves mechanization and construction of new and expansion of old industries. If these activities are based on fossil fuel consumption, CO_2 emissions surge and further stimulates climate change.Nevertheless, industrialization cushions the negative impact of climate change if it complements expansion and restructuring of industries with climate-resilient technology. Industrialization exacerbates energy demand and industrial waste and this, in turn, affects weather patterns. Appiah et al. (2019) study revealed that in emerging economies when considering renewable energy resources along with industrialization carbon stock emitted is low. However, if population, urbanization, and non-renewable energy resources are employed carbon stocks surges.Li and Lin (2015) examined the relationship between urbanization, industrialization, and CO_2 emission in 73 countries at different levels of development.The study found a positive relationship between industrialization and CO_2 emissions at all income levels.

Asghar et al. (2019) found a long-run positive relationship between industrial growth, energy consumption, trade, and environmental degradation for 13 Asian countries while in short-run unidirectional causal relationship runs from industrialization to environmental degradation. For developed countries Dong et al. (2019) examined that different stages of industrial development affect CO_2 emission. At the initial and intermediate level impact of industrialization is more pronounced on CO_2 emissions however, when industrialization matures in presence of environmental regulations, positive impact reduces.

For sub-Saharan African countries Appiah et al. (2021) study examined bi-direction causality between industrialization, energy use, and fossil fuel consumption. In long run both energy use and industrialization increase CO_2 emission. Opoku and Boachie (2020)examined environmental impact in presence of industrialization and FDI for 36 African countries.Several indicators such as GHGs, CO_2, methane, and nitrous oxide are used to access environmental impact. Results reveal industrialization as an insignificant relationship with environmental degradation while FDI has a significant relationship.

Al-Mulali and Ozturk (2015) found several indicators responsible for environmental degradation fora panel of 14 MENA countries. Industrialization, urbanization, trade openness, and political stability have a long-run positive relationship with ecological footprint.

Liu and Bae (2018) singled out causal linkages between per capita CO_2 emissions, urbanization, industrialization, economic growth, and renewable energy resources in China. Results showed that a 1 percent increase in industrialization increases CO_2 emissions by 0.3

percent. Asumadu-Sarkodie and Owusu (2017) tested the causality between environmental variables and GDP per capita, industrialization, and population for Rawanda. Mahmood et al. (2020) studied role of industrialization and urbanization in environmental degradation of Saudi Arabia. Industrialization is inelastic and has asymmetric effects on CO_2 emission. As industrialization improves so does CO_2 emissions while deindustrialization process slows the pace. Keeping in view existing literature present study aims to analyse the relationship between level of industrialization of economies and climate change.

2.1 Theoretical background

Malthus was the first to coin environmental degradation when he studied the relationship between population and environmental degradation. Simultaneously, development economics theorists suggest that structural transformation is vital for economies to take off and transit from one income level to another. When countries move from low to high income, more resources are diverted from agriculture to manufacturing and services sector. Excessive production and conductive capitalist system encourage profits seeking and thus over exploit resources at environment's cost. Contrary to this, modernization theories such as the Environmental Kuznets curve (EKC) followed by ecological modernization theory (EMT) favoured industrialization as a significant growth and innovation source that ultimately improves environment. However, controversy still prevails on relationship between industrialization and environment. Thus, the present study with revisiting the relationship between industrial activity and climate change using historical data.

3 Research Methodology

The present study is exploratory in nature and uses spatial analysis to capture climatic variables' behaviour according to their industrialization level and uses spatial graphs using QGIS and excel software. Tobler (1969) first law of geography states that *"everything is related to everything else, but near things are more related than distant things"*. Location and geographical factors hold key information that can't be ignored in policy decisions. Thus to minimise loss of information, certain mapping tool such as geographical information system (GIS) is being used. Many studies in the literature have used GIS for environmental (Rahman et al., 2015), meteorological and socio-economic variables mapping. GIS is a computer-based program that integrates spatial information and other socio-economic variables data into meaningful maps. Spatial analysis tools are widely used in urban planning (Kohsaka, 2000), poverty mapping (Vista and Murayama, 2011), land use management, and tourism management (Boers and Cottrell, 2007). Before quantitative analysis, GIS tools explain the visual relationship between variables graphically. In present case, we have first used spatial information of industrialized economies (IEs), newly industrialized economies (NIEs), developing Economies (DEs), and least developing economies (LDEs) through world shape files.In second step climate change data (raster data in GIS) is linked with spatial information of different economies (See figures: 13a to 13h).

The study utilizes United Nations Industrial Development Organization (UNIDO) bifurcation of countries into IEs, NIEs, DEs, and LDEs. Overall, 216 countries, including islands, are used to weigh level of industrialization. The analysis is divided into four regimes with two principal policy interventions to analyse international organizations' role.

Table 2: Major regimes in climate change policy formulation

1990-1996	1997-2004	2005-2014	2015-2018
Regime 1: Pre-Kyoto protocol (R1)	Regime 2: Post-Kyoto protocol (R2)	Regime 3: Pre-Paris agreement and Kyoto protocol enforcement (R3)	Regime 4: Post-Paris agreement (R4)

For climate variables, annual average temperature (°C) and rainfall (mm) is used. Climate variability is measured by deviation of climatic variables from their long-run mean, often known as climate anomalies. As climate variability definition ensures a prerequisite for a benchmark or baseline from which change is calculated. Thus, WMO has defined climate normal as a reference to compare current climate variables. These reference periods show the average behaviour of climate variables in continuous thirty years. Benefit of using thirty years is to minimize extreme events' effects and get insight into climate variables' historical perspectives. WMO (2017) has also updated climate typical with changing climate conditions as the most recent 30 years ending with zero. Current climate standard period is 1981-2010, but year 1961-1990 can be used for long-run analysis. We have used 1961-1990 baseline period for current analysis because major international organizations were formed after 1990s. Therefore, the base period is chosen before any policy measures were enforced to capture climate change organizations' roles effectively. Climate Research Unit (CRU) UK publish various climate variables data set under CRU TS 4.03 with high resolution (0.5°x 0.5°). It covers data for entire world from 1901 to 2018. Several stations are being captured for a single country[9]. Overall, CRU monitors four thousand weather stations around the world.

4 Findings

IPCC reported that anthropogenic factors induced significant sources of past century warming. High GDP growth, technological advancement, massive production, and growing consumption worldwide have left far-reaching negative stimuli on the challenging environment. Present section sheds some light on historical trends of climate variables for the degree of industrialization. The study also examines past trend in CO_2 emissions with varying industrialization degrees as industrialization is directly linked to carbon emission.

Countries have experienced more warming at all industrialization levels than usual in periods beyond the 1990s—warming trend to surge in post-Kyoto protocol period (R2) in all countries. Percentage change of temperature anomalies(difference of annual temperature from the 30-year average) between different climate regimes is calculated (See table 2). First column indicates percentage change between R2 and R1 for IEs, NIEs, DEs, and LDs and vice versa. The last column shows percentage change between R1 and R4. NIEs percentage change in temperature anomaly throughout 1990 to 2018 increased the most,

[9]Complete list of stations considered for each country can be accessed through https://crudata.uea.ac.uk/cru/data/hrg/cru_ts_4.03/ge

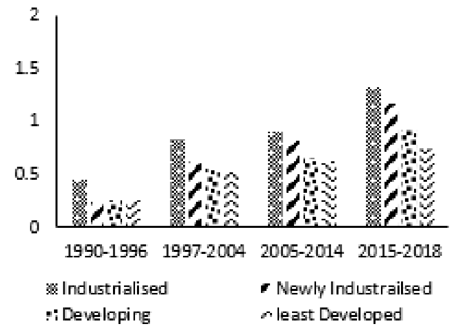
followed by an increase in DEs, LDEs, and IEs in this period. It shows that NIEs have experienced more significant temperature changes from their usual than any other industrialization group (IG). In terms of cross IG comparison, magnitude of temperature anomaly experienced by IEs recorded is the highest, i.e., 1.3°C followed by an increase in NIEs, DEs, and LDEs. In 2015-2018, increase in warming again surged, yet it is slower than warming from post-Kyoto protocol period (See Table 3; Figure 2; Figures 13a-13d). Rainfall anomaly shows fluctuating trend for all IGs. Initially, in 1990-96, rainfall in all IGs declined from the standard period. At same time, most regimes witness more rainfall than the standard benchmark of 1961-90 in R3. In past few years (2015 to 2018), DEs and LDCs received less rainfall than benchmark periods. The volatile behaviour of rainfall anomaly (See Figure 3; Figures 13e-13f) creates uncertainty and serves as a twin challenge to handle in presence of ever-increasing warming.

Table 3: Percentage change of temperature anomalies across levels of industrialization (in %)

Regions	**1997-2004 R2**	**2005-2014 R3**	**2015-2018 R4**	**% change between R1 & R4**
Industrialised	83.5	10.1	46.3	195.5
Newly-Industrialised	154	32.7	42.5	380.2
Developing	125.7	17.6	39.7	270.7
least Developed	114.9	15	19.1	194.4

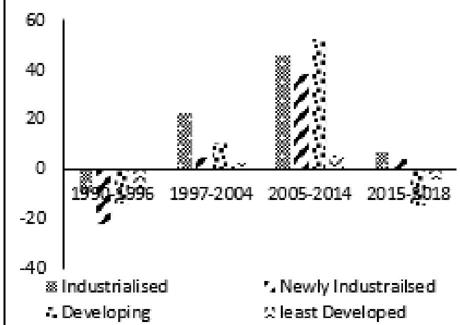
* Source: Author's calculation from Climate Research Unit Database CRU TS 4.033

Figure 2: Temperature anomaly across the level of industrialization



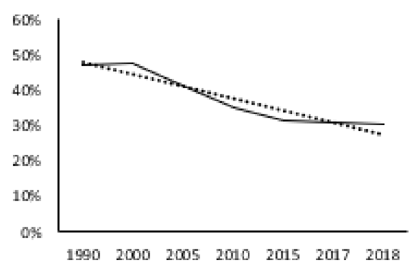
Source: Climate Research Unit Database CRU TS 4.03

Figure 3: Rainfall anomaly across the level of industrialization



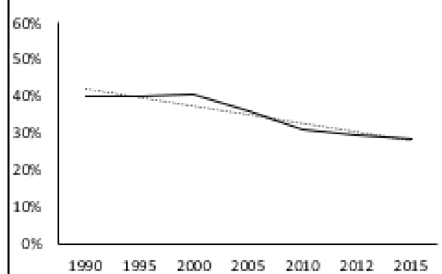
Source: Climate Research Unit Database CRU TS 4.03

Figure 4: The percentage share of IEs in global total carbon emissions (Mton) 1990-2018.



Source: Global atmospheric research (EDGAR), EU

Figure 5: The percentage share of IEs in global total GHGs emissions (Mton CO2eq) 1990-2015.



Source: Global atmospheric research (EDGAR), EU

Global collaboration to address climate change started with central IE member states. Kyoto Protocol, the first international agreement for reducing GHGs, restricted developed countries from cutting their emission by 5% in 1990 and country-specific goals for 2008 to 2012. Most IEs except the US[10] reduced GHGs emissions in this period (see Figure 4 and Figure 5). Besides this, the EU also introduced an emission trading system (ETS) to strengthen emission reduction further. After 2013, most IEs experienced warmer than average temperatures. Before 2006 IEs' share in global carbon emission was 47%, highest among all countries. However, this share reduced considerably after enforcement of the Kyoto Protocol in 2006. As GHGs are irreversible, they exist in atmosphere even if net emission is zero (AR5, 2014). Thus, despite international organizations' concerted efforts, most IEs show a warming trend even though emissions rates have significantly decreased (See Figure 4 and Figure 5). Abban et al. (2020) examined that energy consumption increases carbon emission in HIC by 0.8%. However, renewable energy consumption in IEs has significantly increased (See Figure 12).

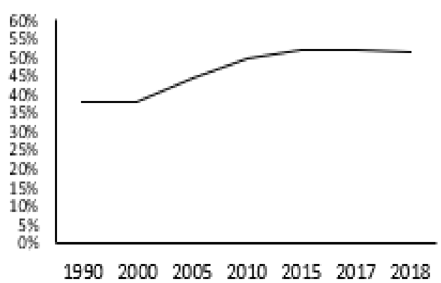
Fast-growing economies of East Asia Pacific and Latin American regions have achieved exceptionally high growth levels in past two decades. Global collaboration in manufactur-

[10] US was the largest emitter of GHGs but it was not part of the protocol at the time of its commencement

ing and industry, exploitation of natural resources, cheap energy as primary input, large market size, export, and investment-led growth has served these economies well. However, within small-time, these countries were one of the most significant contributors to carbon emissions. Major NIEs that experienced a transition in their economies include China, Brazil, Mexico, Russia, Malaysia, and Venezuela. Total carbon emission by these countries in 2018 alone comprises 37.9% of global carbon emissions[11].

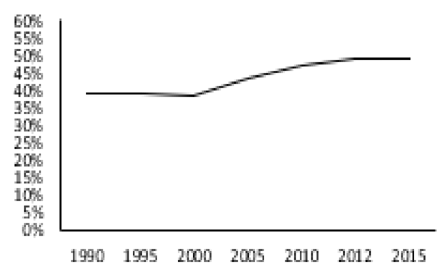
Initially, newly industrialized countries were not part of the Kyoto Protocol as IEs were considered responsible for past century industrial activity; thus, developed countries and EU were constrained to reduce their GHGs emissions levels. NIEs entered a carbon reduction mechanism in COP-21 later in 2015. This agreement was a hallmark for international collaboration on climate change reduction efforts. World's top GHGs emitters agreed to move forward in decelerating pace of global temperature and keeping it between 1.5 °C to 2°C as compared to pre-industrial levels. In early 1990s, NIEs contribution to global total carbon emission was around 37%, yet this share reached 51.6% in 2018, making NIEs the highest contributor among all country groups. Carbon emissions in NIEs show an increasing trend till 2010; after that, emission tends to be stable (See Figure: 6, Figure 7). Renewable energy resources are increasing more rapidly in NIEs than in IEs (See Figure 12).

Figure 6: The percentage share of NIEs in global total carbon emissions (Mton) 1990-2015.



Source: Global atmospheric research (EDGAR), EU

Figure 7: The percentage share of NIEs in global total GHGs emissions (Mton CO2eq)

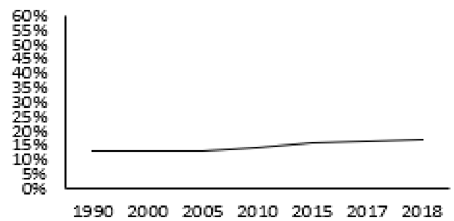


Source: Global atmospheric research (EDGAR), EU

Developing economies have a large population, rising demand for energy, transportation services, and rapidly growing urban areas. Industrial growth is driven by energy as primary source of input.Percentage share of global carbon and GHG emission in DEs (See Figure 8 and Figure 9) and LEs (See Figure 10 and Figure 11) is far less than IEs and NIEs but is increasing since 1990. Most of them are agriculture-based economies and are in their initial stages of development in which they use conventional cheap energy resources for production. Literature also suggests no causality between energy consumption and economic growth in low-income countries (Yasar, 2017).

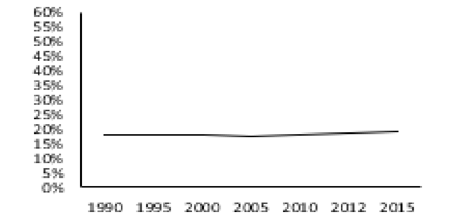
[11]China (29.7%) Brazil (1.32%), Mexico (1.31%), Russia (4.61%), Malaysia (0.68%) and Venezuela (0.32%) data is taken from https://ec.europa.eu/eurostat/data/database

Figure 8: The percentage share of DEs in global total carbon emissions (Mton) 1990-2018.



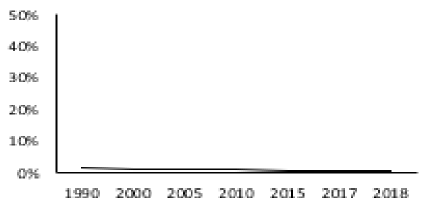
Source: Global atmospheric research (EDGAR), EU

Figure 9: The percentage share of DEs in global total GHGs emissions (Mton CO2eq) 1990-2015.



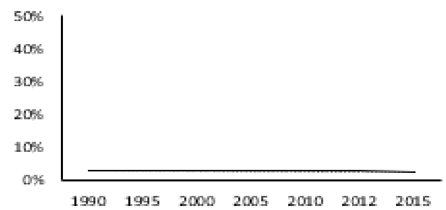
Source: Global atmospheric research (EDGAR), EU

Figure 10: The percentage share of LDEs in global total carbon emissions (Mton) 1990-2018.



Source: Global atmospheric research (EDGAR), EU

Figure 11: The percentage share of LDEs in global GHGs emissions (Mton) 1990-2018



Source: Global atmospheric research (EDGAR), EU

Figure 12: Renewable energy source calculated in (TWh) terawatt per hour. Source; BP review 2019

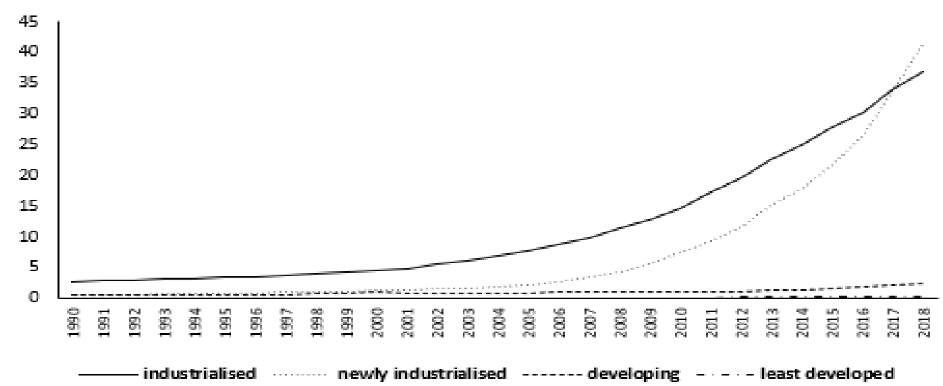


Figure 13a: Annual temperature anomaly (°C) 1990-1996

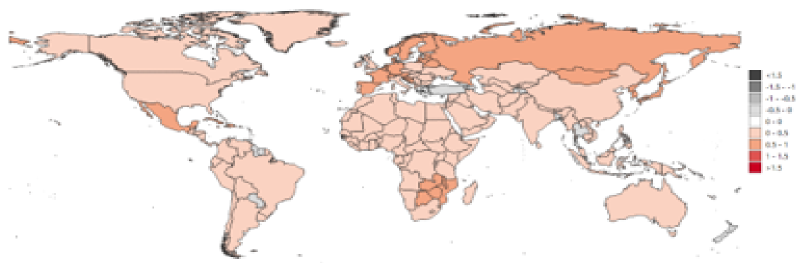


Figure 13b: Annual temperature anomaly (°C) 1997-2004

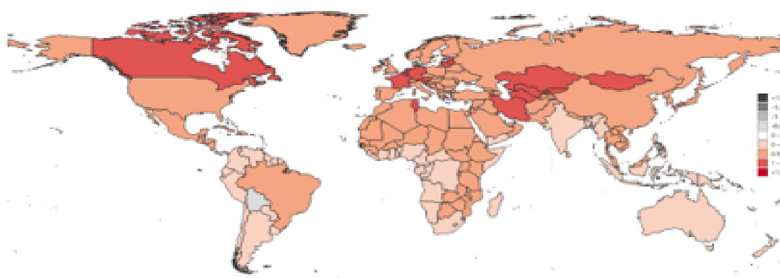


Figure 13c: Annual temperature anomaly (°C) 2005-2014

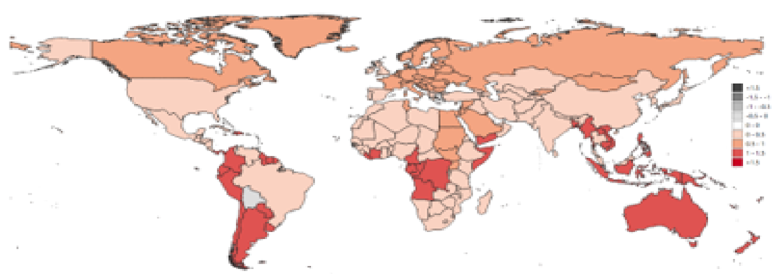


Figure 13d: Annual temperature anomaly (°C) 2015-2018

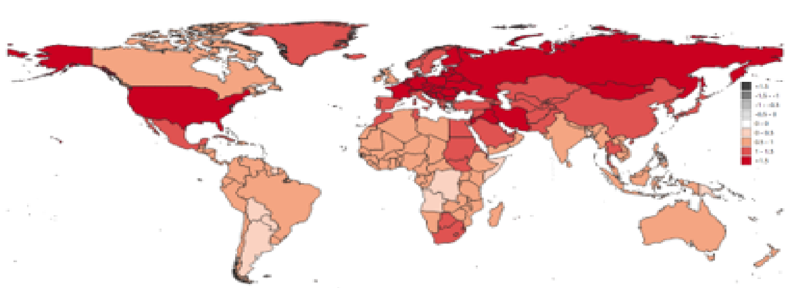


Figure 13e: Annual rainfall anomaly (mm) 1990-1996

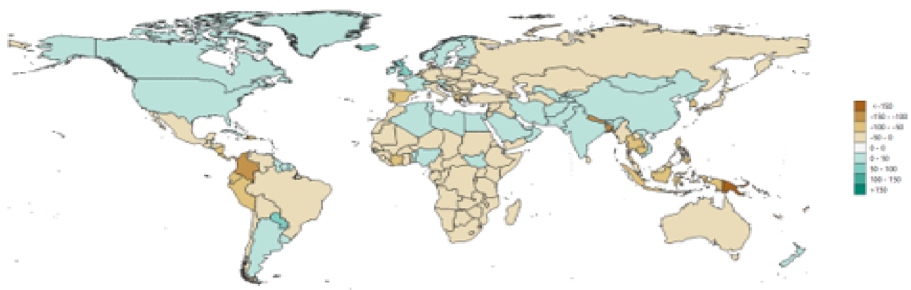


Figure 13f: Annual rainfall anomaly (mm) 1997-2004

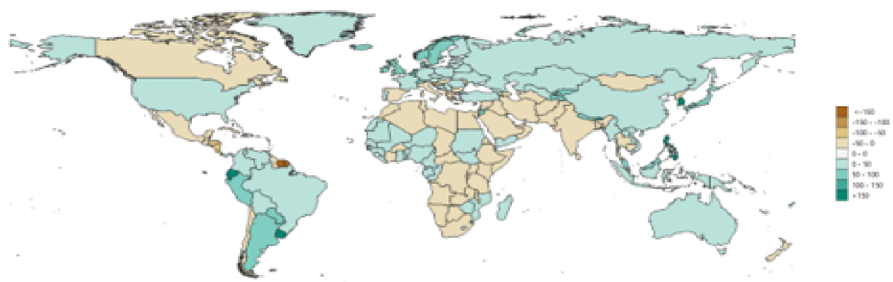


Figure 13g: Annual rainfall anomaly (mm) 2005-2014

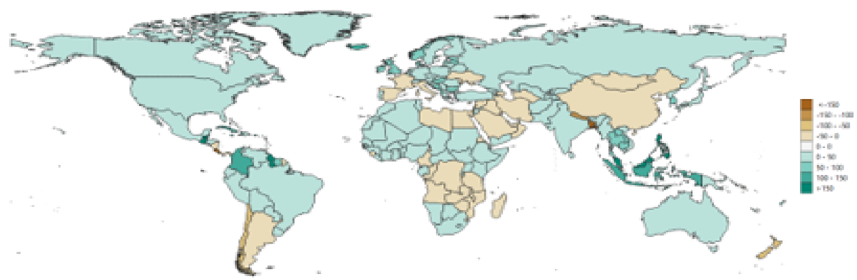
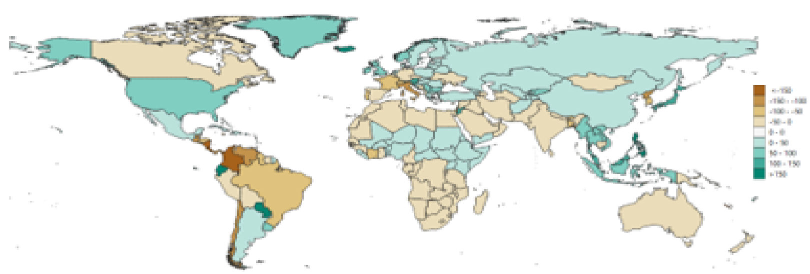


Figure 13h: Annual rainfall anomaly (mm) 2015-2018



5 Discussion and Conclusion

5.1 Discussion

Past century's unprecedented industrialization based on fossil fuel consumption has caused far-reaching consequences for the whole world. GHGs emissions are considered a key contributor to climate change. At same time, industrial activity is the primary source of emitting it. Sustainability holds a key position in policy formulation since climate change realization. Climate adaption and mitigation policies aim to move global economy to a sustainable path by managing driving sources such as industrial activity. International organizations have devised policies such as carbon emission restrictions to minimize vulnerabilities of climate change. The present study considers industrial activity along with carbon emission released at varying industrialization levels. Also, role of international organizations has been considered by analysing time before and after significant climate change agreements.

Interestingly, industrial levels are positively related to climate change; IEs have experienced more significant warming than NIEs, DEs, and LDEs. However, pace of warming and carbon emissions is higher in NIEs than in any other group. As far as international organizations are concerned, they have successfully decelerated path of carbon emissions and additional warming at all industrialization levels. Our results are in line with Ojeaga and Posu (2017) study that examined that industrial activity increases warming in developed and emerging economies. Mgbemene et al. (2016) study also show that industrial activity led by carbon emissions creates warming.

Most of IEs are high-income countries that are at well-established industrialization levels that employ an energy mix of renewable and non-renewable resources. This weakens the positive relationship between CO_2 emission and industrialization. The literature widely supports the fact that high-income countries will experience less damage from vulnerabilities of climate change because of their location, resources, and adaptive capacity (Dell et al., 2008; Gallup et al., 1999). Furthermore, their industrial structure is based on global value chains that transfer manufacturing hubs to developing and emerging economies. More than half of trade in IEs particularly in Western Europe, North America, and East Asia is carried out through GVCs. This mechanism also helps IEs to transfer manufacturing hubs to countries that have fewer environmental regulations (Opoku and Boachie, 2020). NIEs are home to international value chains with export and investment-led growth. Most of NIEs have experienced massive structural transformation. These economies are also production hubs for innovated value-added goods and are part of the global value chain (Sadorsky, 2014). Massive utilization of resources has threatened existence of natural resources that affect the ecosystem to maintain its balance. However, Appiah et al. (2019) revealed that employment of renewable energy resources leads to a better environment.

DEs and LDs industry and manufacturing sectors are backed by growth of foreign direct investment (FDI) in late 1980s and emergence of MNCs with mechanism of global value chain. Initially, DEs involved in trade of raw material and other low value-added products due to their natural resource and labour-intensive economies.

5.2 Conclusion

A constant warming trend is accompanied by a higher magnitude of warming with each additional year irrespective of industrialization. It is keeping in view the four policy regimes in the analysis. At all industrialization levels, countries experience more significant warming in regime two, which is period after the Kyoto protocol. In regime 3, pre-Paris agreement and Kyoto protocol enforcement period, additional warming increased but slower than other regimes. In regime 4, pace of warming increased, yet it is slower than warming in post-Kyoto protocol period. Overall, two significant climate change policy measures have deaccelerated pace of additional warming in the world.

Contrary to magnitude of warming (temperature anomaly), speed of change (percentage change of temperature anomaly) is different and is subject to industrialization level considered in the analysis. Level of industrialization is positively associated with magnitude of temperature anomaly. More industrialized countries have experienced more significant deviations from the reference period. Interestingly, speed with which this change has been registered is different. Considering industrialization, NIEs pace of additional warming is relatively faster than other IGs followed up by DEs, IEs, and LDs. DEs pace of additional warming is more than IEs. However, carbon emissions produced by them are far less than IEs and NIEs. The rainfall anomaly shows fluctuating trend in all income groups and industrialization groups with rise in rainfall from 2005 to 2014 followed by a decrease in rainfall from average in 2015 to 2018. Volatile behaviour of rainfall anomaly creates uncertainty and serves as a twin challenge to handle in presence of ever-increasing warming. All these regions are facing dual challenges of increased warming with a reduction in rainfall.

5.3 Implications

Distributional impacts across regions hold a crucial position for formulation of policy at regional and country levels. The present study creates a sense of urgency for international co-operation in industrial, renewable energy, and climate change policies as it enables sharing of goals, creating and adapting new innovative techniques that will help mitigate overall negative effects of climate change.Innovation-driven industry policy encourages sustainable industrialization hence research and development expenditure should be inclined towards energy-efficient and green technology projects. Cost of environmental degradation needs to internalise by applying carbon taxes stringently. An incentive structure can be built that encourages investors and entrepreneurs towards green technologies. Policies to transfer environmentally friendly technology across different levels of industrialised countries can be encouraged by applying low barriers to entry.

5.4 Limitations and Future Research Direction

Quantitative analysis of industrial sector is not included in the analysis as a major aim of study was to analyse spatial spread of a diverse set of IEs, NIEs, DEs, and LDs in their respective climate change.Therefore future research could be extended by incorporating the quantitative analysis.Different breakthroughs in industrial sectors such as emergence of multiple industrial revolutions (3.0 and 4.0 generation) and their impact on climate change can be analysed. Industrialization can mitigate negative impact of climate change. More cost-effective techniques can be explored by level of industrialization in countries. Industrial parks have proved to be cost-effective in many ways further research can be extended to gauge how they can help in limiting upward trajectory of consistent warming.

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