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THE IMPACT OF CLIMATE CHANGE: ON THE GLOBAL ECONOMY

L'IMPATTO DEL CAMBIAMENTO CLIMATICO SULL'ECONOMIA GLOBALE

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INTRODUCTION

Alongside the ongoing COVID-19 pandemic, global warming is the most threatening of all the problems the world is facing at the present time.

A growing number of scientific evidences suggests that the human activities have intensified the concentration of greenhouse gases in the atmosphere with a consequent increasing average temperature of the Earth. In its fifth assessment report (2013), the Intergovernmental Panel on Climate Change outlined that the Earth's surface was successively warmer in each of the last three decades than any previous decades since 1850 and the average global surface temperature has increased by 0.8 degrees in the last century above pre-industrial temperatures. Moreover, the projections for future are even more threatening since the Panel has predicted that by the end of 21st century the global surface temperature is likely to increase by 4 degrees or more above pre-industrial levels in business as usual scenario.

To prevent the climate induced global cataclysm, the consensus is that the global average temperature should not exceed by more than 2 degrees above pre-industrial temperatures and even if it seems difficult to peak below this limit, it does not mean that no action should be taken.

Assessing the impact of climate change is, at best, an extremely complex exercise with uncertainty about both the degree of future global warming and the subsequent impact on global activity. There are clearly some benefits as well as costs as the planet warms. There is also the unknown of how technological progress will respond and potentially alter the path of global warming.

The purpose of this thesis is to analyze which are climate change impacts on the global economy and which the potential pathways for climate change resilience. Governments have understood that the economic system needs to become sustainable in the long run and that the transition to a low-carbon and green economy may facilitate this change. Therefore, in order to reach this pathway, it is necessary a realignment of the business models with the Sustainable Development Goals (SDGs).

This thesis consists of four separate parts:

In Chapter 1, I give the basic information about climate change and science behind it. The historical overview let us understand how the phenomenon developed through the decades, what are the actual consequences on the environment and who is responsible for the extremely high carbon intensity.

Chapter 2 explores the political context highlighting the key environmental institutions and related responsibilities and subsequently, it draws attention on the goals of the few noteworthy international treaties.

The main part of the thesis resides in Chapter 3, the economic section, where firstly, I analyze the results obtained from scientists and economists' researches and secondly, perform a statistical analysis on the difference between developed and emerging countries.

Lastly, Chapter 4 describes a suitable path towards environmental sustainability, providing some examples of the feasibility of the so-called Green Economy.

Besides the economic purposes of this thesis, a particular attention is constantly given to necessity of increasing people awareness about the environmental issue. As far as I am concerned, awareness is even more important than economic aspects, because if we destroy the Earth there will be no planet to develop economy on.

"We are the first generation to feel the effect of climate change and the last generation who can do something about it."

Barack Obama, Former US President

CHAPTER 1
CLIMATE CHANGE: DEFINITION AND INSIGHTS

1.1 WHAT DO "CLIMATE CHANGE" AND "GLOBAL WARMING" MEAN?

In technical terms, *National Geographic* describes *climate change* as "the long-term alteration of temperature and normal weather patterns in a particular location or the planet as a whole."[1]

Climate change, also been defined as the 21st century biggest threat, is a serious and urgent issue because it is rapidly occurring, throughout the world as a result of global warming.

Global warming is the second fundamental term to explain in order to have a clear understanding of the whole situation.

Basically, it is an increase in the overall temperature of the Earth due to the burning of fossil fuels, such as natural gas, oil, and coal which releases significant amount of gases into the planet's atmosphere. Gases such *water vapor* (H_2O), *carbon dioxide* (CO_2), *methane* (CH_4) and *nitrous oxides* (N_2O) trap the warmth from the Sun's rays inside the atmosphere, causing planet's average temperature to increase, creating the so-called *greenhouse effect*.

Since the mid-20th century, many detailed observations have been elaborated by climate scientists, in which they investigate the link between different weather phenomena, such as temperatures, and related influences on climate, like ocean currents and the atmosphere's chemical composition.

Without any kind of doubt, the results of the researches indicate that Earth's climate has changed over almost every conceivable timescale since the beginning of geologic time and that the human species have played a central role in this scheme, at least, since the beginning of the Industrial Revolution.

[1] https://www.nationalgeographic.org/encyclopedia/climate-change/, seen August 20, 2019.

In fact, in 2018, the IPCC[2] reinforced this estimate further, clarifying that human beings and human activities have been responsible for a global average temperature rise of between 0.8 and 1.2°C global warming since preindustrial times.

The scientific report has also predicted that the global mean surface temperature is likely to increase between 3 and 4 °C by 2100 if average carbon emissions continue at the 1986–2005 rate.

The vast majority of the scientific community agree that significant societal, economic, and ecological damage would result if global average temperatures rose by more than 2 °C in such a short time. Such damage would have catastrophic consequences including increased extinction of many plant and animal species, shifts in patterns of agriculture, and rising sea levels due to the melting of the glaciers.

Fig. 1 Hieronymus Bosch, *The Garden of Earth Delights,* 1490-1510, in The Prado Museum (source: museodelprado.es)

"If you look at these panels long enough, they start to tell a story.

In the first panel you have Adam and Eve in the Garden of Eden, birds flying off into the distance, elephants and giraffe and a lot of religious iconography; The second panel is where it starts to become more interesting. The deadly sins start to infuse their way into the painting. There is overpopulation, there is debauchery and excess.

And the last panel, which is the most nightmarish one, is this twisted, decayed, burnt landscape. A paradise that had been degraded and destroyed"

Leonardo DiCaprio in documentary "Before the Flood"

[2] The Intergovernmental Panel on Climate Change (discussed in detail afterwards)

1.2 BASICS OF CLIMATE CHANGE SCIENCE

"Climate can be defined as the joint probability distribution describing the state of the atmosphere, ocean, and freshwater systems (including ice)"[3]. Each of these systems is itself an extraordinarily high-dimensional system, so it is interesting and needed to work with summary statistics such as *global mean surface temperature* closely linked to the fundamental physics of the Earth's energy balance that explain global warming.

1.2.1 PLANETARY ENERGY BALANCE AND GREENHOUSE EFFECT

Different from other planets, Earth's surface has a fairly temperate and stable temperatures due to its atmosphere, which is composed by many thin layers of gases that protect our planet.

Unfortunately, during the past centuries, human activities, such as burning fossil fuels, altered the delicate energy balance, including sunlight radiations system.

Sunlight[4] constantly penetrates Earth's atmosphere from space, and it is essential for the planet to maintain a balanced surface temperature[5], which means that incoming energy flows must be leveled by an amount of sunlight leaving the atmosphere.

According to NASA, around 30% of the radiation hitting the atmosphere is promptly mirrored back out to space by reflective surfaces such as clouds, ice, snow, sand and others.

On the other hand, the residual 70 percent of solar radiation is absorbed by the atmosphere, the land and the oceans, and heating up, they release warmth in the form of infrared thermal radiation, which breaks through the atmosphere and goes into the space.

This exchange between incoming and outgoing radiation that warms our planet has been stated as the *greenhouse effect* because of the similarity with the way in which a greenhouse works.

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[3] S. Hsiang and R. E. Kopp, *An Economist's Guide to Climate Change Science,* page 4.

[4] Sunlight reaching Earth's surface includes *visible light,* plus invisible light such as *ultraviolet* (UV) and *infrared radiation* (IR).
Ultraviolet light has a shorter wavelength and a higher energy level than visible light, while infrared radiation has a longer wavelength and a weaker energy level, and much of the energy from the Sun arrives on Earth in the form of infrared radiation.

[5] This equilibrium of incoming-outgoing radiation makes the Earth habitable, otherwise our planet would be as cold and lifeless as its moon, or as hot as Venus.

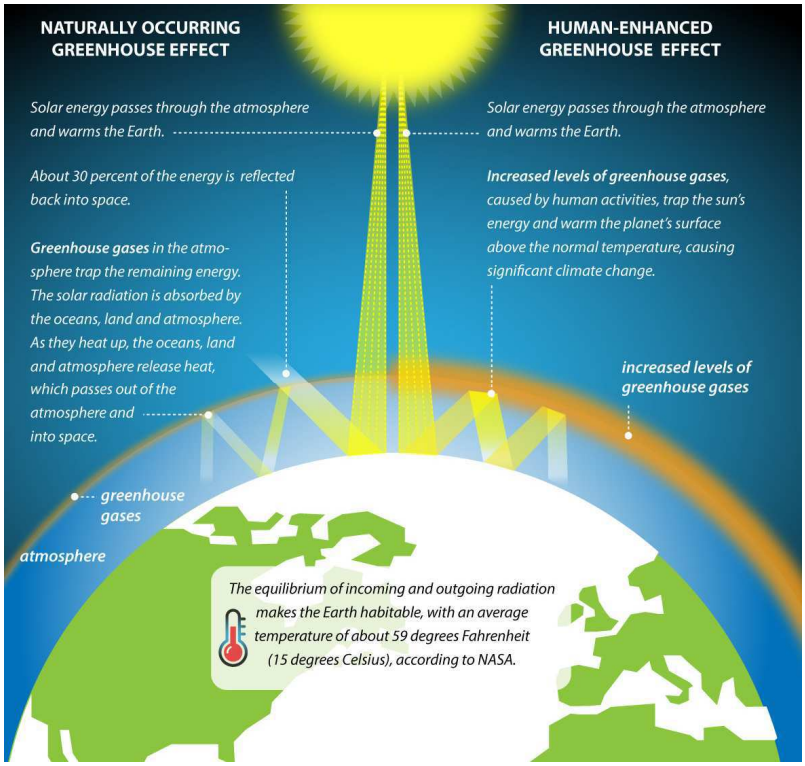


Fig. 2 *Greenhouse effect explanation* (source: ipcc.ch)

Ultraviolet radiations easily pass through the walls of a greenhouse and is absorbed by the plants and hard surfaces inside. In another way, infrared radiations, being weaker, have difficulty passing through the greenhouse walls and is trapped inside.

Greenhouse gases have a distort function over the Earth's energy balance because on the one hand they are transparent to incoming visible and ultraviolet sunlight while they absorb infrared radiation, obstructing the return flow of this energy from the planet's surface into space.

Scientifically, when infrared radiation headed from the surface to space crashes into a greenhouse gas molecule, the absorbed energy is re-emitted in all directions, sending some energy back down to the surface of the Earth, that might otherwise have escaped to space. This makes the surface and lower atmosphere to warm.

Important to mention is that the average height in the atmosphere from which infrared radiation can escape to space, contributing to balance the planet's energy budget, is at 5.5 kilometers altitude level from the planet's surface and it is known as the "*effective radiating level*."

The above-mentioned human attitudes increase emissions of carbon dioxide, methane and other gases

and when these greenhouse gases are added to the atmosphere, the first reaction is that the height of the effective radiating level moves upward. This heads to a decrease in the amount of radiation getting out from the Earth to space, which means higher conservation of energy warming up the Earth's surface and the lower atmosphere layer.

The net effect, already mentioned before, is the progressive heating of Earth's atmosphere and surface, known as global warming.

1.2.2 CLIMATE MODELS

Within climate science, "*paleoclimatology* is a well-developed subfield that focuses on the reconstruction of historical climates, thus setting a baseline for explaining climate changes."[6]

It utilizes a variety of proxy[7] methods from the planet and life sciences in order to obtain data antecedently preserved within rocks, sediments, ice sheets, tree rings, corals, shells, and microfossils. Paleo climatologists analyze these records to determine the past states of the Earth's various climate areas and its atmospheric system, what are the reflections on the current situation, with the ultimate aim of predicting the future outcomes.

In order to pursue the goal, they use mathematical representations of the climate system, also known as *climate models.* They are built on well-documented physical processes to simulate the transfer of energy and materials through the climate system, and through the use of the above-mentioned mathematical equations, they delineate how energy and matter engage in different parts of the atmosphere, ocean, and soil.

The climate model theory is easily understandable but, on the contrary, constructing and performing a model is a challenging and protracted process of identifying and quantifying Earth system processes, in which climate scientists have to set variables to describe the initial conditions and

[6] S. Hsiang and R. E. Kopp, *An Economist's Guide to Climate Change Science,* page 7.
[7] It is a data that paleo climatologists collect from natural recorders of climate variability.

following variations in climate forcing[8], and steadily solving the equations exploiting powerful supercomputers.

Through the *"hind-casting" method*, scientists can test the model accuracy once it has been set up. Firstly, this process executes the model from the present time backwards into the past, then the model results are compared with observed climatic and weather conditions to find out how well they match. The accuracy check allows climate scientists to re-examine their equations, if required.

Moreover, in order to obtain a more complete scientific instrument, teams around the world examine and compare their model achievements to outputs and results from other models.

Once a climate model can fulfil the hind-casting procedures, its results for reproducing future climate previsions are also assumed to be acceptable.

In order to translate climate into the future, the climate forcing is subject to changes in the possible future scenarios[9].

In fact, in 2000, the Intergovernmental Panel on Climate Change (IPCC) published the *Special Report on Emissions Scenarios* (SRES), in which they characterize 4 scenario families aimed to describe possible future conditions. Each scenario is described by letter-number combinations (A1, A2, B1, B2), and grounded on the relationship between the socioeconomic forces driving greenhouse gas, aerosol emissions and the status to which those emissions would ascend during the 21st century:

- "*The A1 storyline* and scenario family describes a future world of very rapid economic growth, global population that peaks in mid-century and declines thereafter, and the rapid introduction of new and more efficient technologies. Major underlying themes are convergence among regions, capacity building, and increased cultural and social interactions, with a substantial reduction in regional differences in per capita income. The A1 scenario family develops into three groups that describe alternative directions of technological change in the energy system.

[8] Climate forcing is the difference between incoming sunlights absorbed by the Earth and outgoing energy radiated back to space.

[9] Plausible stories about how quickly human population will grow, how land will be utilized, how economies will mature, and the atmospheric conditions that would result for each storyline.

The three A1 groups are distinguished by their technological emphasis: fossil intensive (A1FI), non-fossil energy sources (A1T), or a balance across all sources (A1B);

- *The A2 storyline* and scenario family describes a very heterogeneous world. The underlying theme is self-reliance and preservation of local identities. Fertility patterns across regions converge very slowly, which results in continuously increasing global population. Economic development is primarily regionally oriented and per capita economic growth and technological change are more fragmented and slower than in other storylines;
- *The B1 storyline* and scenario family describes a convergent world with the same global population that peaks in mid- century and declines thereafter, as in the A1 storyline, but with rapid changes in economic structures toward a service and information economy, with reductions in material intensity, and the introduction of clean and resource-efficient technologies. The emphasis is on global solutions to economic, social, and environmental sustainability, including improved equity, but without additional climate initiatives;
- *The B2 storyline* and scenario family describes a world in which the emphasis is on local solutions to economic, social, and environmental sustainability. It is a world with continuously increasing global population at a rate lower than A2, intermediate levels of economic development, and less rapid and more diverse technological change than in the B1 and A1 storylines. While the scenario is also oriented toward environmental protection and social equity, it focuses on local and regional levels."[10]

In a similar way, during 2013, climate scientists agreed upon a new set of provisional scenarios that concentrated on the level of greenhouse gas emissions in the atmosphere, which begin 2005 and finish in 2100. They have been defined as *Representative Concentration Pathways* (RCPs). Each of them indicates the quantity of climate forcing, expressed in watts per square meter, that would be present in the atmosphere in 2100:

[10] IPPC Special Report, *Emissions Scenario*, pages 4, 5. (source: http://greenswitching.pl/library_files/7_1_1270554574_IPCC_Emissions_Scenarios_IPCC-2000.pdf, seen August 22, 2019.)

- "RCP 8.5 (high emissions scenario) has the strongest forcing, with CO_2 emissions nearly doubling from their current levels by 2050 and continuing to rise thereafter;
- RCP 4.5 (moderate emissions scenario) has a moderate forcing, with CO_2 emissions stabilizing at close to their current levels through the middle of the century and declining thereafter, reaching about 40% of their current levels by 2080;
- RCP 2.6 (low emission scenario) has the weakest forcing, with CO_2 emissions declining immediately, to less than a third of the current levels by 2050 and becoming net-negative during the 2080s."[11]

1.3 HISTORICAL OVERVIEW

From another perspective, climate change can be also considered as the mix of various natural forces taking place over several timescales.

1.3.1 PRE-INDUSTRIAL PERIOD

As already stated, the human species has a massive influence on the climate.

Besides that, we also know that lots of other natural elements affect Earth's temperature, such as solar and volcanic activity, that obviously make trickier the determination of a precise pre-industrial baseline.

Climate scientists divide these natural forces into two categories: *internal* and *external forcings*.

Internal forcings move heat between different parts of the planet's climate system. For instance, the El Niño-Southern Oscillation[12] transfers warmth between the atmosphere and the ocean, causing variations in world average surface temperatures of about 0.2°C.

[11] S. Hsiang and R. E. Kopp, *An Economist's Guide to Climate Change Science,* page 13.

[12] It is an irregularly cyclical alteration in winds and sea surface temperatures over the tropical eastern Pacific Ocean, which influence the climate, happening on average every five years. It oscillates between three phases: Neutral, La Niña (cooling phase) and El Niño (warming phase).

By contrast, *external forcings*, which affect global temperature, originate from outside Earth's climate system. A clear example are volcanic eruptions, which emit particles into the upper atmosphere. This activity precludes energy from the Sun hitting the planet's surface, inevitably, leading to a transitory cooling.

An additional external influence is represented by the solar activity. It is a variable force, because the Sun's radiations are subject to multiple cycles, related to the quantity of sunspots. The more sunspots the higher temperatures, and vice versa.

Historically, our planet has experienced lots of timescales, ranging from the length of a human life span to billions of years. The technical term to define this variable in climate history is *epoch*.

For example, the *Pleistocene epoch* (about 2,600,000 to 11,700 years ago) was characterized by considerable changes in the worldwide size of glaciers and ice sheets. These fluctuations happened on time periods of tens to hundreds of millennia, due to variations in the solar activity across Earth's surface.

Important to mention is the most recent ice age, known as *Last Glacial Maximum,* which happened about 21,000 years ago. In the course of this period, ice sheets even reached regions of Europe and North America, where at the present-day London and New York City are located.

Average temperatures appeared to be around 4–5°C cooler than in the mid-20th century. This glacial period lasted till about 11,700 years ago and was followed by a relatively ice-free epoch known as the *Holocene*.

Even if the contemporary period is typically defined as residing within the Holocene, some climate scientists have claimed that the Holocene Epoch finished in the quite recent past and that nowadays, we are in new a climatic era, stated as *Anthropocene Epoch*, a period in which the human species has given proof of his massive capacity to influence the climate.

With the purpose of having a clear comparison, the graphics in figure 3 represents reconstructions of *atmospheric CO_2 concentrations*, *global mean surface temperature*, and *global mean sea level* over two separate time periods, which are 10,000 years ago and present-day.

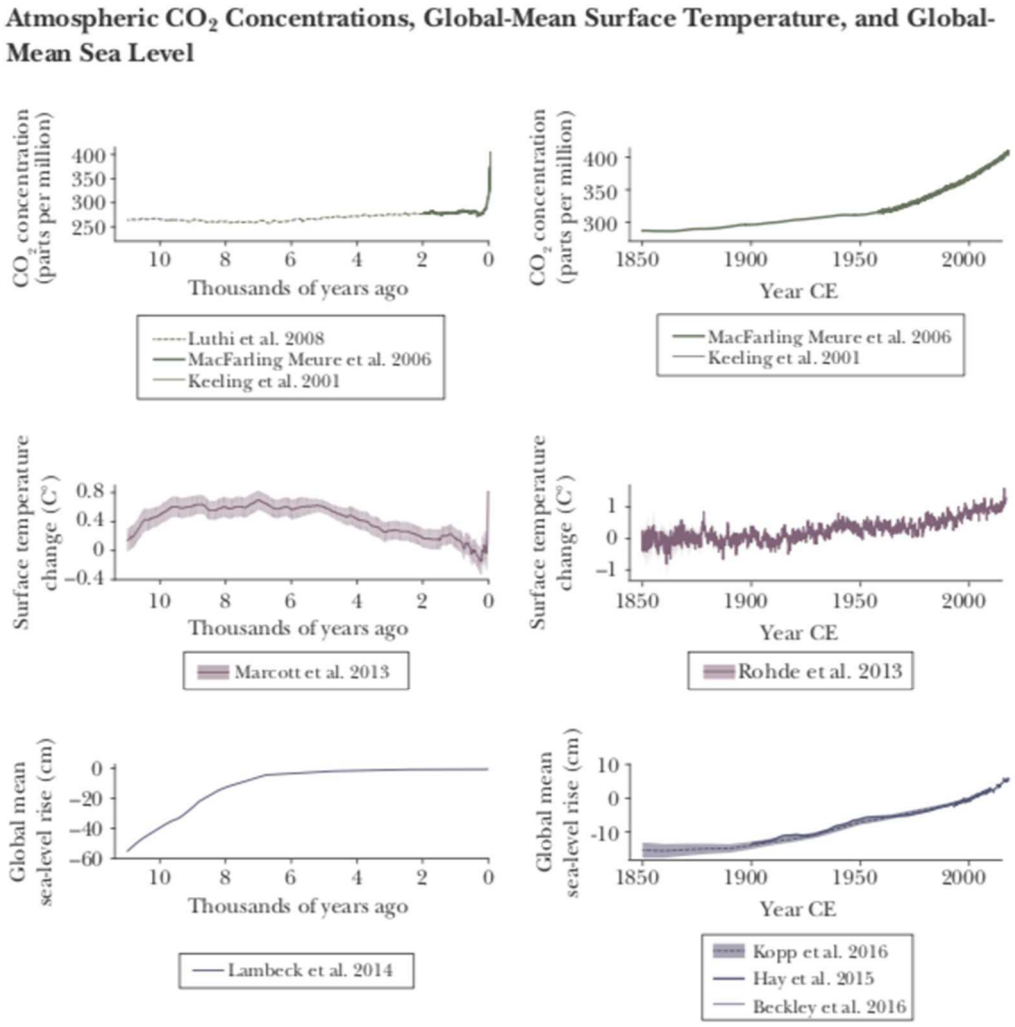


Fig. 3 (source: Journal of Economic Perspectives)

During the last 11,600 years, which means the above-mentioned Holocene Epoch, the marked rise in atmospheric CO_2 concentrations is very impressive and firmly justified by human activities. Despite the Holocene temperature record registered a long-term drop, owing to variations in Earth's orbit began more or less 5,500 years ago, the post-1850 trend exhibits that this fall was stopped in the course of the 20th century, collecting an average temperature increment of roughly 1.0°C between the late-19th and the early-21st century.

Unlike temperatures, the sea-level mean reacted more gradually to variations in climate forcing, because representing oceans and ice sheets major systems with a superior capacity to assimilate enormous quantities of warmth, the heating happens only moderately. However, the first half of the Holocene is affected by relatively quick sea-level rise, because of the vanishing of Laurentide Ice

Sheet, situated in North America, as a result to 5°C warming since the, already mentioned, 21,000 years ago ice age. The situation got worse during 20th, because the average sea-level rise was the fastest in at least 2,800 years, and the last quarter-century enhanced a rate about twice as rapid as the 20th century mean.

1.3.2 INDUSTRIAL PERIOD

Around 10,000 years ago, even if in a soft way, the human species started to alter the atmospheric composition through the use of new agriculture skills.

In contrast, the advent of Industrial Revolution[13] represented a radical change in the way of how natural resources were exploited.

This epoch has been stated as *Anthropocene*, formally began in 1784, which describes the human race capacity to affect the Earth's overall equilibrium systems, through activities such as fossil fuels burning and massive deforestation. In the initial days of the Revolution, no one would have thought that these human actions would have led to an almost imminent impact on the climate.

In fact, recent studies showed that heating in some Earth's areas actually emerged in the 1830s, much earlier than formerly thought. Moreover, they illustrated that warming evolves in different timescales across the planet: in the 1830s, the tropical oceans and the Arctic were the initial regions to start warming, followed by Europe, North America and Asia around two decades later; the southern hemisphere began heating up many years later, with Australasia and South America starting to warm from at the beginning of the 20th century.

This continental-scale time trend is still visible nowadays: while some Antarctic regions have begun to heat, an explicit warming signal over the whole continent is still not perceptible.

[13] Starting from Britain, the introduction of the steam engine gave birth to a period of development in the second half of the 18th century that transformed rural societies into urban-industrialized ones, in Europe and America.

By pointing out the date when the human being-initiated climate change, and through the climate models use[14], it can be possible to compute when the global warming trend gone beyond the thresholds of the climate's natural fluctuations.

The evidences claimed that all regions, except Antarctica[15], are currently fully acting in a greenhouse-influenced world.

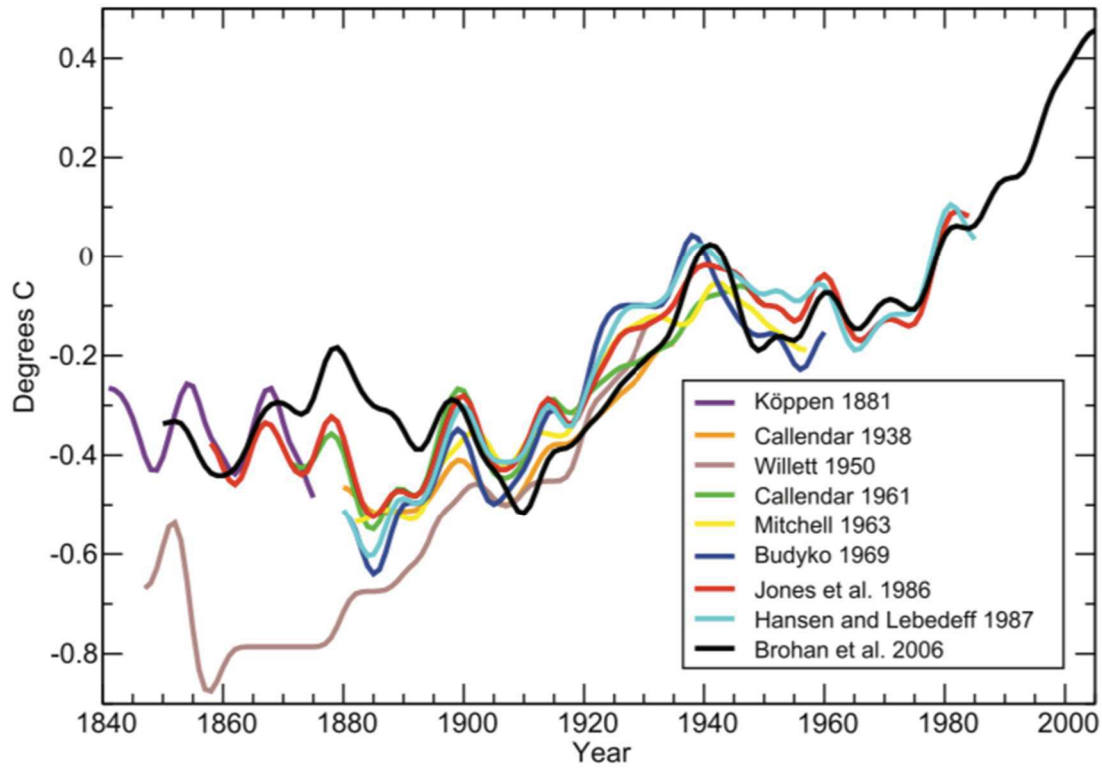


Fig. 4 *Published records of surface temperature change over large regions* (source: globalchange.gov)

[14] Built and implemented from unusual sources such as coral skeletons, ice cores, tree rings, cave deposits and ocean and lake sediment layers. These sources allow to an extended 500 years reconstruction, which provides a critical baseline for the Earth's past climate, much earlier than the Industrial Revolution.

[15] The Southern Ocean keeps apart the continent from the warming.

1.4 WHO IS POLLUTING THE MOST?

With the aim of having a well-defined picture, it is significant to establish who is responsible for greenhouse gas emissions, and in which degree countries and economic sectors affect global warming.

Nowadays, the situation is becoming more and more desperate, and it is crucial that these emissions are diminished so as to avoid the human species to perform terribly pressure on the planet.

The most polluting countries are aware they must cut their emissions, but, despite treaties and agreements such as the Kyoto Protocol, greenhouse gas emissions persist to increase.

To a larger or lower extent, almost all the nations are accountable for the elevated level of worldwide pollution, but data showed that five countries stand out from the rest:

1. China (28%), the Earth's most populated country, has seen its industry massive growth to become a severe danger to the planet. In fact, just the major five industrialized provinces emit more carbon dioxide than any other world's country;

2. United States (15%) is the world's main industrial and commercial power. Data analysis demonstrated that even though in the last years (Obama's government) serious actions have been taken to fight climate change, most of the which have been resulted to be inadequate, since pollution levels, earlier limited to big cities, now affect even many rural areas;

3. India (6%) is a developing country having law protecting air quality just since 1981. The fossil fuel burning boundaries have not been respected and, consequently, have grown remarkably. The World Health Organization report enhanced that 14 out of the world's 15 most polluted cities are located in India;

4. Russia (5%), the Earth's geographically largest country, emerges in this classification due to its high dependence on oil, coal, gas and fossil fuels, and also because of significant levels of deforestation and animal hunting.

5. Japan (4%) is the major consumer of fossil fuels and it has been ranked as the fifth main emitter of greenhouse gases. This considerable scenario is in consequence of its sharp level of urban development and nature careless industry.

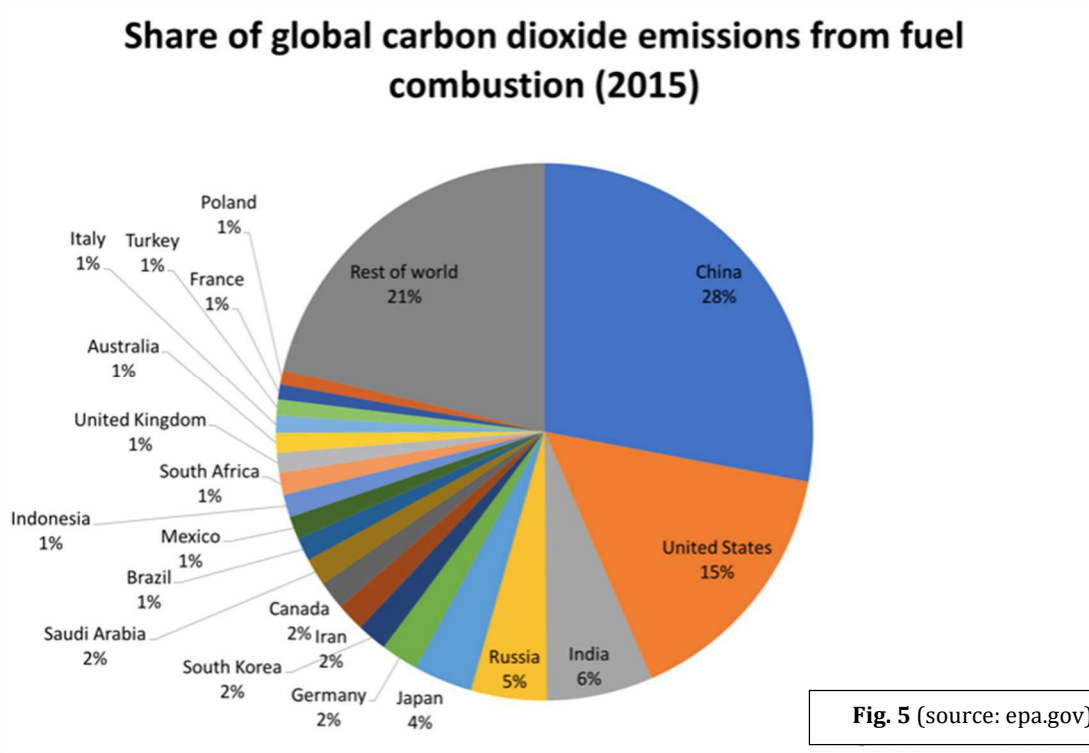


Fig. 5 (source: epa.gov)

From Figure 5 emerges the picture that, in general, developed countries and major emerging economy nations have a primary role in total carbon dioxide emissions, because developed nations usually have high CO_2 emissions per capita, while, typically, developing countries have higher growth rate of carbon dioxide emissions.

The graphic in figure 6 shows the total anthropogenic greenhouse gas emission per economic sectors, underlining the difference between direct and indirect emissions. The inner circle displays the direct impact of industry, transport, buildings, AFOLU[16] and electricity in 2010, while the right part of the picture indicates in which way indirect carbon dioxide emission shares are attributed to sectors of final energy use.

[16] Agriculture, forestry and other land use.

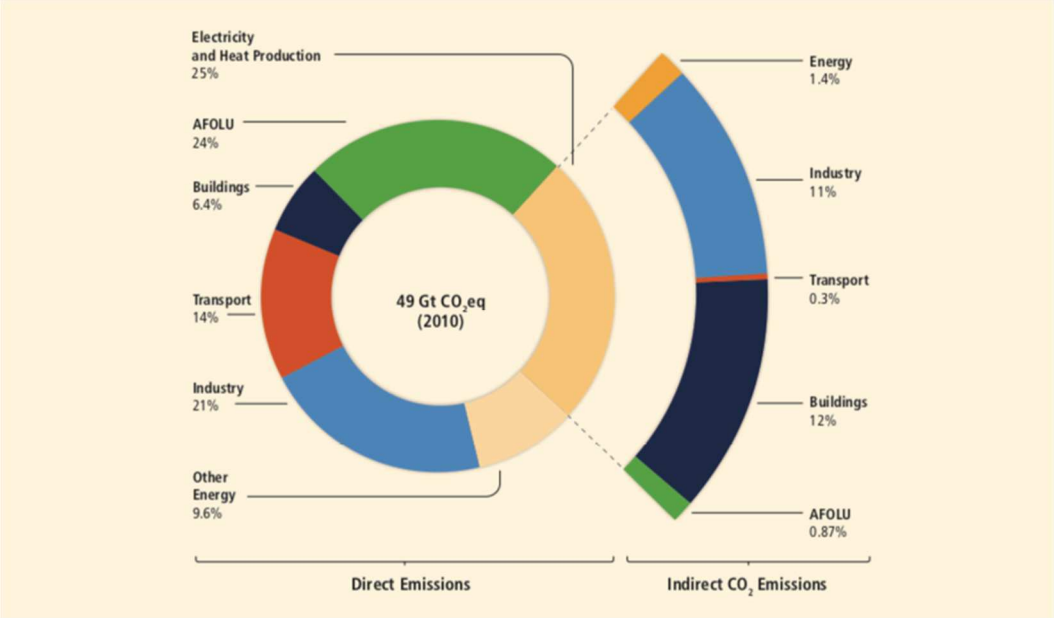


Fig. 6 (source: ipcc.ch)

More in detail, the *Environmental Protection Agency* published a paper in which they point out what are the most toxic industries in America. An analysis that can be largely applied to the rest of the world since U.S.A. is the economic worldwide landmark, as stated in the past lines.

The review includes 15 sectors:

1. *Metal mining* includes Teck American, Rio Tinto, and Newmont, the top three most polluting companies in America, and all of them are in the metal mining industry, with a sectorial release 1.52 billion pounds of toxins in 2016;
2. *Chemicals* is responsible of the 47% of total waste during its manufacturing process in 2016, with 515 million pounds of toxins released into the air;
3. *Electric utilities* allow too much grids across the country to burn oil and coal for electricity endowment. In fact, natural gases are still the biggest source for U.S. electricity, which discharge into the environment 368 million pounds of toxins;
4. *Primary metals,* which incorporates U.S. Steel and American Mining, have a total amount of 347 million pounds of toxins in 2016;

5. *Paper* making process release dioxin, nitrous oxide, sulfur oxide, and carbon monoxide into the atmosphere with an overall emissions volume around 170 million pounds of toxins. Similar to the chemical sector, it produces 10% of the total waste.
6. Enterprises operating in the *hazardous waste* sector bring medical waste, radioactive matter and not biodegradable materials in the safest resting place, with a 146 million pounds toxins discharge;
7. Beef production in the *food* sector has the major impact on the environment, because of the huge amount of methane issued by grazing cows. The industrial total amount is 137 million pounds of toxins in 2016;
8. *Petroleum* operations discharged 75.8 million pounds of toxins;
9. *Fabricated metal industry,* embracing cutlery and tools, is responsible for 46.4 million pounds of toxins into the atmosphere;
10. Even if *plastic and rubber* sectors showed an emission decrease in 2012, it remains remarkable for the 39.6 million pounds of toxins discharge;
11. *Transportation equipment* embodies automobile assembly, train production, aircraft manufacturing, and shipbuilding with a total release of 38.6 million pounds of toxins;
12. *Non-metallic minerals* such as stone and sand constitute a large portion of U.S. industry, with over 400,000 people employed. This sector discharges 29.6 million pound of toxins into the air;
13. *Computer and electronics* sectors are accountable of 12.2 million pounds of toxins.
14. *Wood* production includes logging, transportation, and heavy machine use. Each of them issues toxins into the ecosystem, which correspond to 9.8 million pounds;
15. *Machinery* industry is amendable for 6.6 million pounds of toxins in 2016.

However, a particular note is required for the companies operating in the *meat and dairy sectors*, because in accordance to a new released document, they are likely going to become the world's biggest contributors to climate change, outstanding even the mining and fossil fuel industries.

This outcome has been elaborated by the Institute for Agriculture and Trade Policy and GRAIN[17], which led a study on the planet's 35 most important meat and dairy corporations.

It has been found out that these companies were being confidential about their greenhouse gas emissions data and that just few of them, precisely 6, had set goals aimed to reduce their pollution observing international agreements.

According to the report's authors, if the majority of the above-mentioned enterprises will still follow the current path, it may be possible that the livestock sector could be accountable for 80% of the acceptable greenhouse gas budget by 2050.

1.5 ENVIRONMENTAL CONSEQUENCES

Climate change is having visible impacts evident around the entire planet, striking crucial sectors to society (on which next chapters will be focused) such as human health, transportation, water supply, energy, and agriculture.

At the same time, global warming affects the ecosystem in which we live, with an expected increasing trend of more severe weather events over this century, even with catastrophic impact on both flora and fauna.

A path that would likely diminish the security of the Earth's environment.

1.5.1 TEMPERATURE CHANGES

Starting from the last years of 19th century, Earth's mean surface temperature has augmented by about 1.0°C, with a faster trend after 1980.

It is normal to think that given the wide range of factors impacting the weather, the overall increment in temperatures has not been uniform over time and across space. In fact, among others, in the period

[17] Non-profit organizations supporting sustainable food, farm, and small farmers, both founded in the 80s.

1950s–1970s heating was tempered as a result of *aerosol emissions*[18], which mirrored sunlight away from the Earth's atmosphere, and also because of natural variability.

However, since the 80s the fastest heating has took place in the northern hemisphere, where due to the melting of highly reflective sea glaciers, the ocean's dark color quickly has risen the absorption of sunlights.

In accordance to the last IPCC assessment, as collected by projections, the future global mean surface temperature is likely to grow above preindustrial level by:

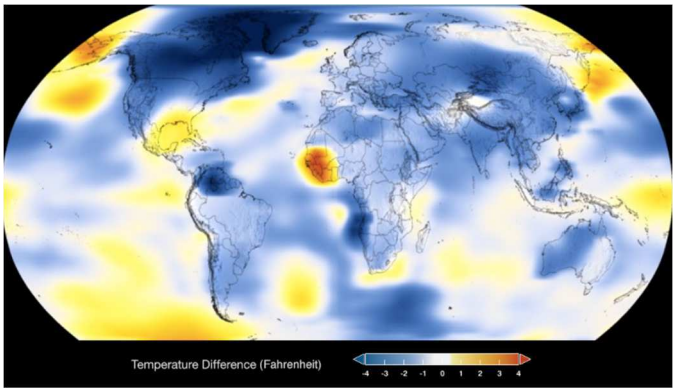
- 0.9–2.3°C under a low-emissions scenario;
- 1.7–3.3°C under a moderate-emissions scenario;
- 3.2–5.4°C under a high-emissions scenario.

by 2080–2100.

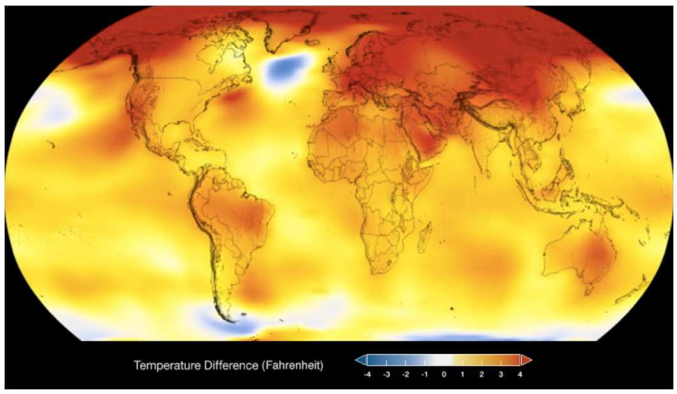
As already happened in the past and above explained, the heating will be faster over land in comparison to the oceans.

Even if climate is influenced by many endogenous and exogenous factors, NASA provides accurate images of global mean temperature changes, comparing the present-day to preindustrial age, as showed in the following figures:

Fig. 7 (source: climate.nasa.gov)



Panel A, 1884



Panel B, 2018

[18] Aerosol is a suspension of solid particles or liquid droplets into the air. It can have a natural (fog, dust, forest exudates and geyser steam) or anthropogenic (air pollutants and smoke) origin.

1.5.2 PRECIPITATION CHANGES

A heater atmosphere is able to assume more water vapor, driving to a rise in the total average precipitation, which includes rainfall and snowfall.

Precipitation records, in the mid-latitude Northern Hemisphere, has showed an increase since the 1950s, particularly in Europe and North America, where strong events have been registered.

Technically, due to the complexity of atmospheric dynamics that regulate rainfalls, precipitation variations are remarkably more difficult to model numerically compared to temperature alterations.

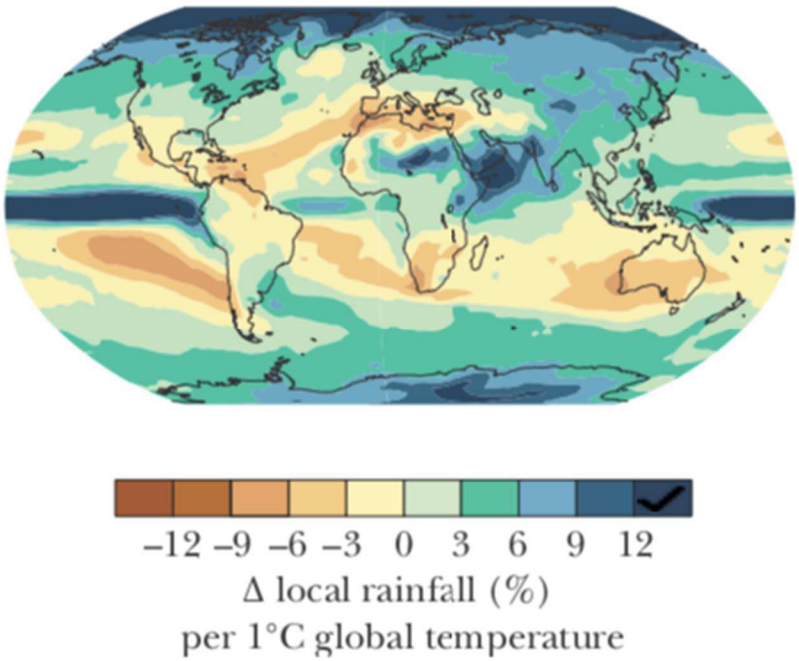


Fig. 8 (source: Journal of Economic Perspectives)

Figure 8 exhibits average changes in rainfall for each 1°C increase in planet's mean temperature. Explanatory statements like "dry regions are likely become generally drier and wet regions are likely to become generally wetter hold well over the ocean but are coarse descriptions of the complex precipitation changes that may occur over land (Greve et al. 2014)"[19].

[19] S. Hsiang and R. E. Kopp, *An Economist's Guide to Climate Change Science,* page 19.

1.5.3 HUMIDITY CHANGES

Humidity, the amount of water vapor in the atmosphere, grows exponentially as temperature rises, and since the 1970s, global mean humidity has augmented jointly with warming.

In human species life, humidity is particularly relevant owing to its influence over human health, because higher humidity levels make it more problematic for our body to freshen up in warm circumstances through sweating.

In addition, statistics showed that the frequency of warm and very humid days are projected to increase from 8 per year on average in the period 1981–2010 to:

- 17–28 days per year in 2040–2059 in a moderate emissions scenario;
- 40–70 days per year on average in 2080–2099 in a high emissions scenario.

1.5.4 TROPICAL CYCLONES

Tropical cyclones are phenomes "driven by the temperature difference between the warm ocean surface and cooler temperatures higher in the atmosphere. The warm ocean moistens overlying air, which rises and cools, releasing energy and rain. Thus, climate change is thought to have counter-vailing effects on storms: warming sea surface temperatures fuel storms but warming temperatures higher in the atmosphere may suppress them."[20]

However, in addition to inferences difficult due to discrepant historical data, the storms creation and trajectory depend on many other determinants that make projections even more complicated. For instance, wind patterns.

Despite these issues, in the Atlantic zone, there are proofs that the periodicity and the strength of the cyclones have been growing since the 1970s, with some indications of human activities contribution to this increasing variation.

[20] S. Hsiang and R. E. Kopp, *An Economist's Guide to Climate Change Science,* pages 19-20.

Climate models justify the above-mentioned theory, illustrating that the frequency of severe tropical cyclones, alongside with the severity of their associated rainfall, is likely to increase with global heating.

1.5.5 SEA-LEVEL RISE

Physically, the increase of sea-level is propelled by two expansive processes: an increment in the mass of water in the ocean, mostly due to the dissolution of ice lands, and the volume growth of the water currently in the ocean, which happens when the water warms and expands.

During the 20th century, global mean sea level has risen by around 18–21 centimeters, with a doubled, almost tripled, growing rate rise since 1990, substantially imputable to human actions.

Differently, regional sea-level changes can essentially diverge from the global path, because of the divergent influences of winds, Earth's gravitational field, height of land and many other elements.

Owing to the slow reaction time of glaciers and oceans to global warming, sea-level growth is quite insensible to greenhouse gas emissions and climate change, but climate researches show forecasts of future global mean sea-level rise of 20–30 centimeters during the periods 2000–2050. Obviously, the further we go the more uncertain projections become, because of unreliable human activities and the unsure response of ice sheets.

Nevertheless, estimations for the current century, 2000-2100, vary depending on the different emissions picture, with a rise from 40–80 centimeters for a low-emissions scenario to 70–150 centimeters for the high one[21].

Possible consequences can be constituted by tropical cyclones growing rate and coastal areas constantly inundated, which will make some low-lying island cities uninhabitable, as supposed by the following up-to-date satellite observations provided by NASA, where due to a possible larger slimming of an area of the Greenland ice sheet would lead to a 1-meter sea-level increase. While if it

[21] Historically, the last time temperatures were as warm as they presently are, around 125,000 years ago, global mean sea-level was about 6–9 meters superior.

melts entirely, the frozen water contained in the Greenland ice sheet will represent a sea level growth of 5-7 meters.

Fig. 9 (source: climate.nasa.gov)

Panel A

Panel B

1.5.6 DROUGHTS AND FLOODS

Extreme weather events, such as floods and droughts, are direct results of changing temperature and precipitation schemes that modify their regularity and energy, with a growing awareness of imputing these severe intensifications to human behavior.

The drought probabilities depend on the geographic area and its features with an increasing trend in the Mediterranean and West Africa and a reduced one in central North America and Australia; In climate model forecasts, the periodicity of droughts is likely to grow especially in dry zones, where hot and waterless periods are expected to become essentially more recurrent.

In areas with a high vegetation degree, intensifying fluctuations between heavy rainfall and drought increase the chances of wildfires due to quick vegetative fuel rise during rainy times that becomes highly flammable during dry periods.

Concerning flood, the increasing trend of strong precipitation implies that climate change makes increase the likelihood of rain-driven flood damages. Moreover, the above-mentioned sea-level rise intensify the frequency of coastal and inland flooding.[22]

Essential to clarify is the peculiar socio-economic importance of flood risk, as this catastrophic climate event is recognized as one of the most expensive worldwide disaster.

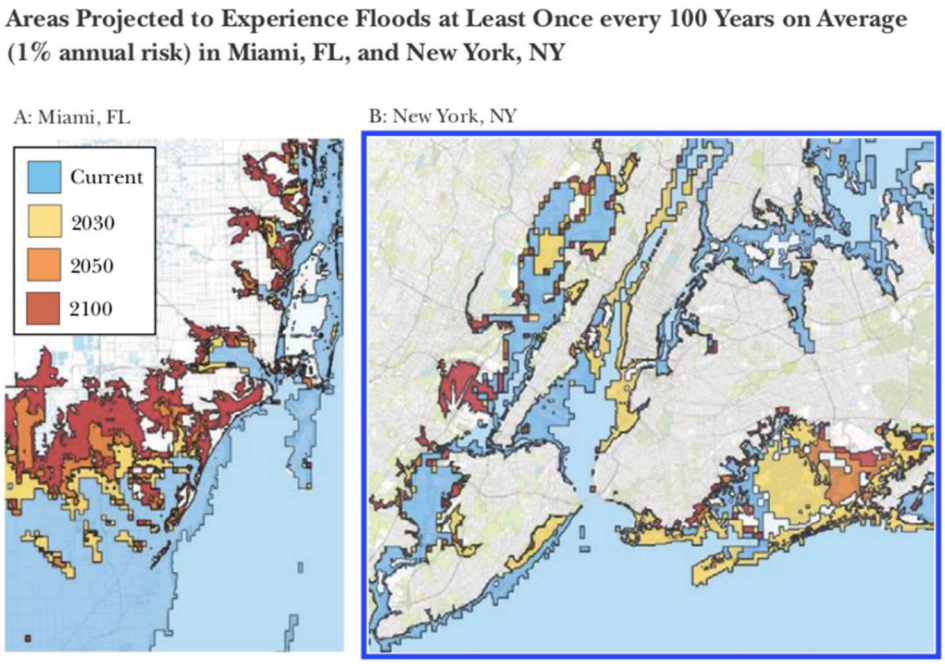


Fig. 10 (source: Journal of Economic Perspectives)

Figure 10 shows forecasts of sea-level rise-tropical cyclone activity joint effects on the flood risk of U.S. cities Miami and New York.

The projections have been made, supposing a high-emission scenario, with the extent of zones expected to flood with a 1 percent annual probability rises, after 2050 concerning Miami but sooner for many New York regions.

[22] It is important to say that, in many cases, the key drivers of risen flood damages are linked to the number of people and extent of development affected, rather than the real physical size of the flood.

1.5.7 CLOUDS

Comprehension of clouds system is physically intricate, owing to the many dynamics taking place in the Earth's climate, which make doubtful forecasts in cloud cover for lot of area across the world.

Scientifically, on one side, the mirroring effect on visible light, makes low-altitude clouds cover increase the reflected incoming sunlight portion before reaching and heating the planet's surface, while, at the same time, outgoing infrared radiations are absorbed by clouds, making it contribute to greenhouse effect and global warming.

In general, global-scale changes in cloudiness data continue to be affected by uncertainty, with a widely spread belief suggesting low-latitude cloudiness decrease can lead to a sensibility rise of temperature to CO_2 forcing.

With a view to the present-future, geoengineering is trying to understand how make clouds counterbalance greenhouse gas emissions impact. The most concrete proposal is known as *solar radiation management*. It aims to augment the reflectivity of the Earth's atmosphere in order to shade and cool the surface, through spraying aerosol into the upper atmosphere, simulating the volcanic eruptions mechanism that historically refrigerated the surface.

1.5.8 OCEAN ACIDIFICATION

Water chemical composition increase in acidity when carbon dioxide dissolves into the oceans. So as a consequence, the higher CO_2 level in the atmosphere is, the more quantity of CO_2 will disperse into the water, generating carbonic acid and increasing ocean acidity.

The rate of acidification differs from area to area because it depends on local chemistry, temperature, circulation patterns, and freshwater inputs.

At the present-day, the oceans approximately absorb one-quarter of the overall carbon dioxide emissions, with forecasts in a high-emissions scenario projecting ocean acidity to rise by 100–150%. The effects of this share water acidification is planned to drastically alter marine ecosystems, mining clams and corals survival.

1.5.9 MELTING GLACIERS

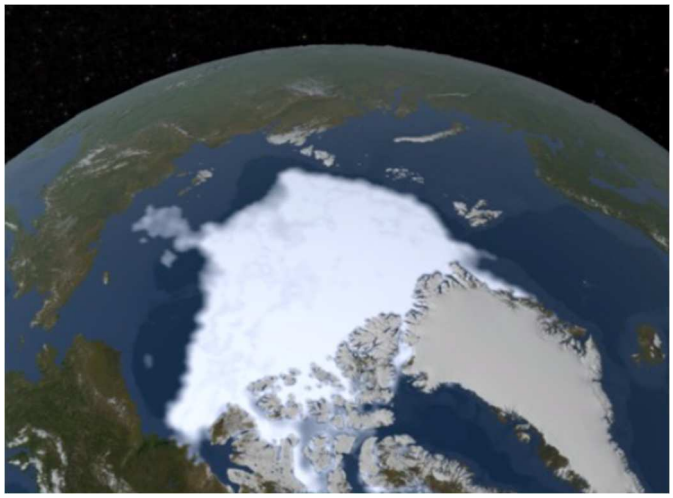
Ice sheets composition is changing all over the world, from Kilimanjaro[23] to Himalaya, where in India, forecasts following the current scenario projected a complete ice disappearance by 2035.

During the second half of the 20th century, arctic sea ice suffered a sizeable shrunk, with an additional 10% decline in its extent during the last 30 years, as illustrated in NASA's figure 11.

In the Northern hemisphere, the impact is extremely significant because, as analysis results show, nowadays, spring freshwater ice breakup happens nine days before than it did 150 years ago, and in autumn freeze-up ten days after.

Fig. 11 (source: climate.nasa.gov)

Panel A, 1979



Panel B, 2018

When ice melts due to global warming, more water drifts to the seas, thus expanding in volume.

One of the main effects is the above-mentioned global sea-level rise, in paragraph 1.5.5, with a known capacity to generate dramatic changes in the Earth's shorelines, where saltwater would interfere with freshwater aquifers, threatening drinking sources of water and making crops farm tough.

However, that is not the only principal consequence.

[23] Data shows an 80% dissolution since 1912.

Quoting National Geographic: “oceans, in effect, mimic some functions of the human circulatory system. Just as arteries carry oxygenated blood from the heart to the extremities, and veins return blood to be replenished with oxygen, oceans provide life-sustaining circulation to the planet. Propelled mainly by prevailing winds and differences in water density, which changes with the temperature and salinity of the seawater, ocean currents are critical in cooling, warming, and watering the planet's terrestrial surfaces and in transferring heat from the Equator to the Poles.”[24]

Ocean currents dictate the Earth’s climate, and the temperate climate we live in is due to a delicate equilibrium in the *thermohaline circulation*[25], a hot, saline water flow from the North-Atlantic tropical to the Pole, in surface currents like the well-known *Gulf Stream*[26].

Obviously, depending on the magnitude of climate change, variations in water temperature and salinity could have significant effects on planet’s life, as already happened in the past.

The equilibrium is obtained by warm water (low density) rising to the surface, and cold water (high density) going down to the bottom, both of them, influenced by the amount of salt in the water.

Being polar ice sheets made up by fresh water, the dissolution releases more fresh water into the sea, violating the equilibrium, and at some point, stopping the Gulf Stream.

It would represent the beginning of a new cataclysmic Ice Age.

[24] https://www.nationalgeographic.com/environment/global-warming/big-thaw/, seen September 2, 2019.
[25] Composed word by "thermo" for heat and "haline" for salt.
[26] This current carry brings seawater all around the Earth, from the Gulf of Mexico to the eastern coastlines of the USA, then across the Atlantic Ocean, where divided in two crosses to Northern Europe and recirculates off West Africa.
It’s what makes winters on the west coast of Europe so mild, keeping winter temperatures hotter and summer temperatures colder.

CHAPTER 2
POLITICAL CONTEXT: LEGISLATION AND GOALS

2.1 KEY INSTITUTIONS

The climate change threat is analyzed and managed by worldwide institutions such as the *Intergovernmental Panel on Climate Change*, the *United Nation Framework Convention on Climate Change* and the *Climate and Clean Air Coalition*.

In general, these organizations are accountable for elaborating report and for making countries governments ratify instructions emerged from summits. Countries taking part in these conferences, commit themselves to respect the objectives established in the general agreement, representing the first step towards a general pollution level reduction.

2.1.1 INTERGOVERNMENTAL PANEL ON CLIMATE CHANGE (IPCC)

"The *Intergovernmental Panel Climate Change* provides regular assessments of the scientific basis of climate change, its impacts and future risks, and options for adaptation and mitigation."[1]

This organization was instituted by a cooperation between the *United Nations Environment Programme* and the *World Meteorological Organization*, in 1988. Nowadays, the IPCC includes government members of the United Nations, which counts 195 components.

The regular scientific reports provision, as stated before, is the main purpose of this entity, and they represent the key inputs into international climate change dialogues.

For the assessment reports realization, hundreds of people from all over the world, in addition to IPCC scientists, volunteer their time to elaborate the plenty of technical documents published each year, in order to offer a more accurate extract of what is known about climate change causes, its effects and future risks, and how governments can mitigate these threats.

[1] https://www.ipcc.ch/about/, seen October 21, 2019.

One of the crucial parts of the IPCC procedure is the clear review made by specialists and countries cabinets, with the aim to guarantee a complete assessment agreed upon by heterogeneous range of opinions and expertise. The IPCC reports also point out where extra researches are required.

2.1.1.1 STRUCTURE

As illustrated in Figure 1, the IPCC is composed by several bodies: plenary, bureau, committee, secretariat, working groups, task forces, authors, contributors and reviewers, each of them with different tasks.

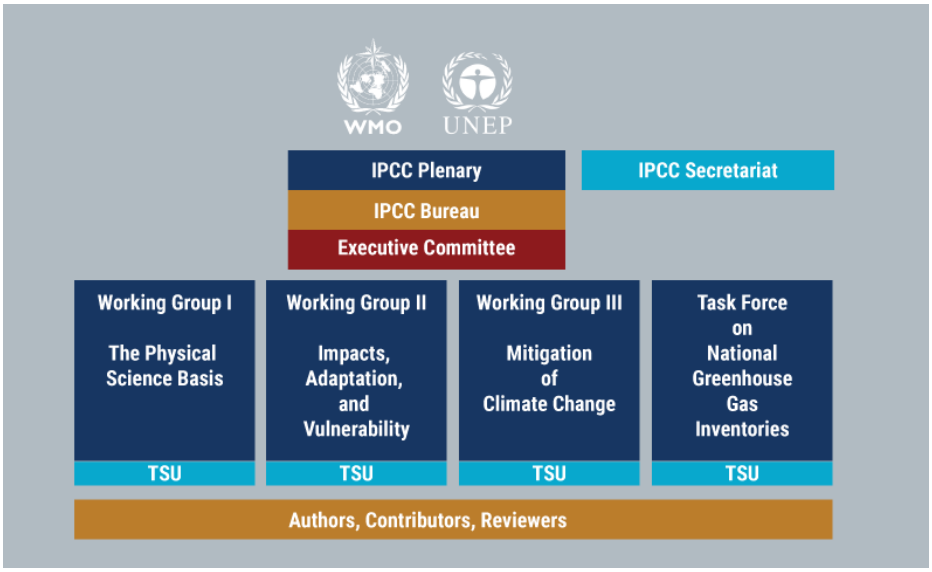


Fig. 1 (source: ipcc.ch)

- *The Panel and the Plenary Sessions* are performed, at least once a year, by an appointed representative per state member, called National Focal Point[2], by Observer Organizations[3] and by a considerable number of experts from ministries, agencies and research organizations from member nations. Decisions concerning the organization's budget, work programme, reports framework, procedures issues, Working Groups and Task Forces assignment, are its

[2] The Ministry of Foreign Affairs substitutes the National Focal Point in case the government has not nominated one.
[3] Any non-profit, national or international, governmental or intergovernmental, entity competent in issues covered by the IPCC may be admitted in the Sessions.

main duties, and they are taken by consensus. In addition, the Panel elects Chair, Bureau and Task Force members.

- *The Bureau* is designated to offer scientific and specialized counseling to the Panel, instructing on strategic issues and taking decisions on specific subjects within its mandate. The Bureau members, which currently are 34[4], remain in charge just for the duration of an assessment cycle and their selection must be geographically balanced, with due consideration for scientific and technical requirements.
- *The Executive Committee*, constituted by the Working Groups and the Task Force Chairs, Vice-Chairs, and the Co-Chairs and headed by the IPCC Chair, meets ordinarily. It aims to consolidate and to speed up the IPCC work programme realization taking into account the IPCC's Principles and Procedures, the Panel's decisions, and the counselling from the Bureau.
- *The Secretariat*, based in Geneva, supports the IPCC job arranging all the Plenary, Bureau and Executive Committee rendezvous and offering bureaucratic assistance[5]. When necessary, it also provides sustenance in activities coordination to the Working Groups and Task Forces. Furthermore, the Secretariat is responsible of operations related to the IPCC Trust Fund such as budgeting, contributions, management of expenditure, auditing and reporting.
- The technical roles are processed by *Working Group* I, II, and III that respectively take care of the *Physical Science Basis of Climate Change*, the *Climate Change Impacts, Adaptation and Vulnerability* and the *Mitigation of Climate Change*, and by the *Task Force on National Greenhouse Gas Inventories*, which aims to elaborate and implement a technique for the national greenhouse gas emissions estimation[6].
- By its very nature, *Technical Support Units (TSU)* assist every Working Group and Task Force through scientific, specialized and institutional information supply and provide help in

[4] The Bureau components are divided in IPCC Chair, IPCC Vice-Chairs, the Co-Chairs and Vice-Chairs of the three Working Groups and the Co-Chairs of the Task Force on National Greenhouse Gas Inventories.
[5] Arrangement and monitoring of paperwork, literature and reports.
[6] The Panel has the power to appoint other specific-topic Task Groups for a set time period. For instance, in Paris 2018 IPCC Session, a Task Group to improve gender balance within the IPCC.

all the significant IPCC products development, including the *IPCC Protocol for addressing errors*, the *IPCC Communication Strategy* and the *Conflict of Interest Policy*. The TSUs chiefs also take part in the Executive Committee as Advisory Members.

- Hundreds of volunteers, defined as *Authors and Contributors,* work alongside IPCC bodies for the report's arrangement. They are chosen on the basis of governments references, which, in the first place, take into account expertise and detailed CVs, and then also consider the variety of scientific, technical and socio-economic backgrounds, territorial and gender balance[7].
- Since the IPCC aspires to the reports' scientific excellence, each document must be subject to two review periods, an Expert Review of the First Order Draft, and a Government and Expert Review of the Second Order Draft. These procedures include a broad *Expert Reviewers* participation, in which they analyse the report's accuracy and reliability enclosed in the drafts, with the chance to make comments on one section of the report, on an entire chapter or on the full report.

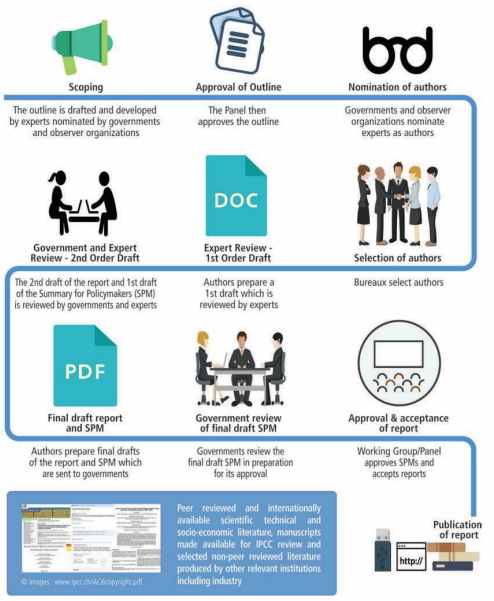


Fig. 2 Report's preparation
(source: ipcc.ch)

[7] These principles aim to guarantee a good team assortment of experts with and without previous IPCC experience, and to avoid distort papers towards the perspective of any one region. If required, teams might include specialists, for example from industry or from non-governmental institutions, who add precious points of view to the final evaluation.

2.1.2 UNITED NATIONS CLIMATE CHANGE

The *UNFCCC secretariat*, based in Bonn (Germany) and also known as UN Climate Change, was founded in 1992 when the *United Nations Framework Convention on Climate Change*[8] (UNFCCC) was broadly promulgated by UN member states.

Later on, due to the ratification of the Kyoto Protocol in 1997 and the Paris Agreement in 2015, the secretariat's position, as the United Nations institution appointed to face the climate change threat, have been remarkably confirmed.

Currently, the Executive Secretary is the Mexican Patricia Espinosa and more than 450 people, representing over 100 different nations, are employed at UN Climate Change. Alongside the UNFCCC, further organizations such as the *United Nations Environment Programme* [9] (UNEP) and *World Meteorological Organization*[10] (WMO) have a central role in dealing with climate change threat.

2.1.2.1 MISSION

The UNFCCC secretariat main objective consists in "facilitating the intergovernmental climate change negotiations and supporting a complex architecture of bodies that serve to advance the implementation of the Convention, the Kyoto Protocol and the Paris Agreement."[11]

It additionally offers technical knowledge, providing support in the examination of climate change reported data and in the Kyoto processes implementation, and also holds the Nationally Determined Contributions[12] records.

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[8] It will be discussed in more detail in the next paragraphs.

[9] It arranges the international environmental agenda and encourages the sustainable development implementation among the UN member countries. Its mission is "to provide leadership and encourage partnership in caring for the environment by inspiring, informing, and enabling nations and peoples to improve their quality of life without compromising that of future generations" (source: https://www.unenvironment.org/about-un-environment, seen November 6, 2019).

[10] The mission of this intergovernmental organization composed by 193 states is to "provide world leadership and expertise in international cooperation in the delivery and use of high-quality, authoritative weather, climate, hydrological and related environmental services by its Members, for the improvement of the well-being of societies of all nations." (source: https://public.wmo.int/en/about-us/vision-and-mission, seen November 6, 2019).

[11] https://unfccc.int/about-us/about-the-secretariat, seen November 4, 2019.

[12] They represent the key point of the 2015 Paris Agreement, in which the countries committed themselves to respect the agreed guidelines, reducing national greenhouse gas emissions.

The secretariat arranges from two to four dialogue sessions per year. The largest and most significant is represented by the so-called *Conference of the Parties*, which takes place on a yearly basis in different places around the planet, usually attended by approximately 25,000 members. Along with this main summit, seasonal seminars and workshops of the subsidiary bodies are held throughout the year.

Lastly, the secretariat publishes the *Annual Report,* in which the UNFCCC achieved outcomes and next goals are illustrated in detail.

2.1.3 CLIMATE AND CLEAN AIR COALITION (CCAC)

In 2011, a technical report published by UN branches assessed that actions targeting *short-lived climate pollutants*[13] could lead to extreme positive results for the environment, air goodness, and human wealth over a relatively short timescale. For that reason, in 2012, administrations from the United States, Canada, Bangladesh, Sweden, Ghana and Mexico, side by side with the UNEP, constituted the *Climate & Clean Air Coalition,* aimed to boost effective common measures to handle the above-mentioned polluting emissions.

By definition, the *Climate and Clean Air Coalition* is a "voluntary partnership of governments, intergovernmental organizations, businesses, scientific institutions and civil society organizations committed to improving air quality and protecting the climate through actions to reduce short-lived climate pollutants."[14], that nowadays counts more than 120 heterogenous members. In fact, it embraces states and non-state partners, countless of regional players and plenty of skilled and influential worldwide stakeholders that carry on activities in both the public and private sector.

However, with the intention of guaranteeing a common direction in the performed measures, this coalition accomplishes its duties following four *core values*, illustrated in figure 3.

[13] Represented by black carbon, methane, tropospheric ozone, and hydrofluorocarbons and regularly related to refrigerants, diesel-fueled machines, and solid-fuel cooking fires, these polluters, according to their appellation, remain for a short period (about two weeks) in the atmosphere.

[14] https://www.ccacoalition.org/en/content/who-we-are, seen November 6, 2019.

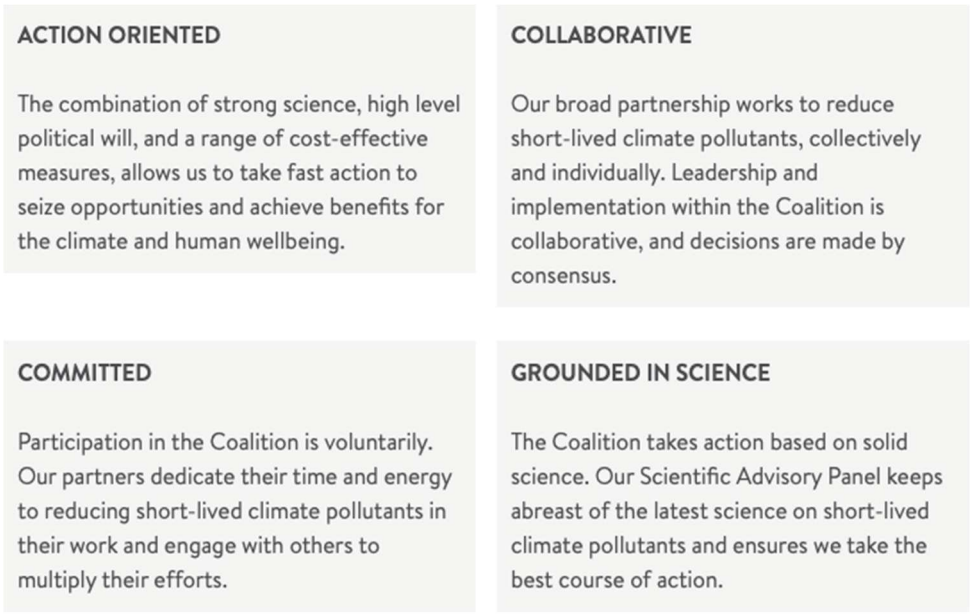


Fig. 3 (source: https://www.ccacoalition.org/en/content/who-we-are)

2.1.3.1 GOVERNANCE

The CCAC governance system is made up of several bodies, which reflects the heterogeneity of the member parties, and also includes a high cooperation level among the states, in which tasks and responsibilities are shared.

- The *High-Level Assembly*, constituted by the countries' state member ministers and the chiefs of non-state partners, rendezvous no less than once per year and imparts the strategic instructions to the coalition.
- The entity which takes decisions on functional matters such as new members entry, initiative proposals approval and funding is the *Working Group,* which annually meets at least two times and supervises the CCAC's actions.
- Also, the *Steering Committee* constantly oversees the coalition's measures and additionally makes recommendations to the Working Group concerning work programs, budgeting, and financial motions.

- The technical segments are managed by the *Scientific Advisory Panel*, in which worldwide esteemed men of science elaborate proper ways to mitigate the short-lived climate pollutants.
- Lastly, the *Secretariat* stands by the CCAC managing the Trust Fund, facilitating the initiatives, taking care of the meetings and informing about the progress made.

2.1.3.2 STRATEGIES

With the already discussed aim of having emissions reduced in the incoming years, the CCAC converges its actions in four *main strategies*:

1. "*Enable transformative action* by providing knowledge, resources, and technical and institutional capacity to act and supporting the sharing of information, experience, and expertise;

2. *Mobilize support* for action to put short-lived climate pollutants on the policy map through advocacy at all levels of government and in the private sector and civil society;

3. *Increase the availability of and access to financial resources* to support the successful implementation of scalable, transformational action;

4. *Enhance scientific knowledge* to help decision-makers scale up action and promote the multiple benefits of action on short-lived climate pollutants."[15]

Through the above-described strategies implementation and initiatives pursuit, which involve, for instance, awareness raising campaigns and assistance in laws' development, this organization expects the positive results illustrated in Figure 4, if only fast actions are performed on both short and long-lived climate pollutants.

[15] https://www.ccacoalition.org/en/content/what-we-do, seen November 8, 2019.

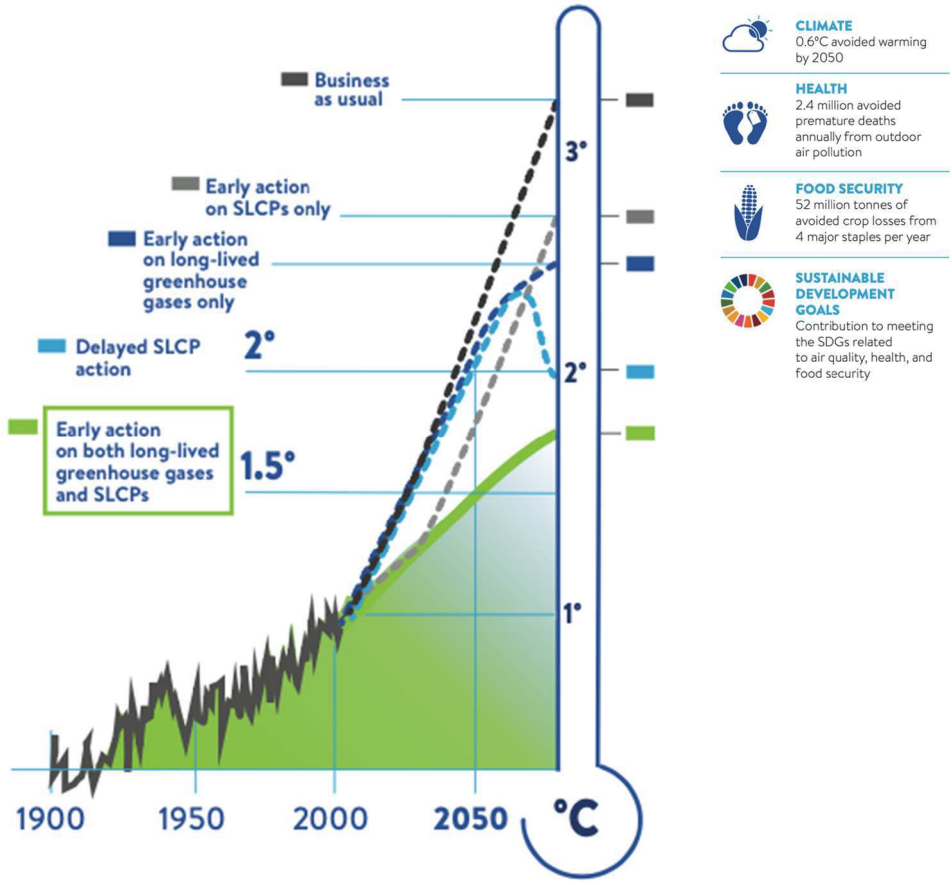


Fig. 4 (source: About the CCAC: 2018 info sheet)

The 8th United Nations Secretary-General, Ban Ki-Moon, in charge during the decade 2007-2016, has stated his appreciation to the CCAC saying: *"The coalition you have built among the private sector, finance, civil society, research and other institutions can help to build a new world of collaboration and high standards. The results of your actions can have an immediate impact: cleaner industries; cleaner engines and oil and gas production; cleaner recycling and waste processing; cleaner brick kilns and cookstoves; and cleaner urban air".*

2.2 MILESTONES OF INTERNATIONAL CLIMATE POLICY

The *United Nations Climate Change Conferences* are annual meetings for transnational dialogue regarding global warming issues.

These summits, which remarkably grew in volume over the previous two decades[16], take place in a different country every year and they serve as official rendezvous of the *Conference of the Parties (COP)*, the *Conference of the Parties serving as the meeting of the Parties to the Kyoto Protocol (CMP)* and the *Conference of the Parties serving as the meeting of the Parties to the Paris Agreement (CMA)*.

The Conference of the Parties, gathering as COP, CMP and CMA, tend towards two central goals, which are the constant revision of the UNFCCC, the Kyoto Protocol and the Paris Agreement and the decisions' ratification aimed to the further enforce these three treatys.

2.2.1 1992: UNITED NATIONS FRAMEWORK CONVENTION ON CLIMATE CHANGE

The *United Nations Framework Convention on Climate Change (UNFCCC)* is a global environmental agreement, also known as *"Rio Convention"*, since it has been adopted during the 1992 *"Rio Earth Summit"*.

It became formally effective on 21 March 1994, after a satisfactory group of nations ratification, and nowadays, it has near-worldwide participation, with the above-mentioned Parties to the Convention counting 197 countries.

Its general purpose is the greenhouse gas emissions stabilization to a stage that would preclude precarious anthropogenic interference in the climate mechanism, but more in detail it:

I. for its time, notably *recognized that there was a problem*, since when the agreement came into force, there was less accurate scientific proofs than there is today;

[16] Involving an ever-growing number of worldwide representatives from governments, civil community and mass media, the state-to-state consultations have become more and more challenging.

II. *sets an elevated but explicit objective*. In fact, the above-mentioned GHG stabilization must be reached in accordance with an adequate period of time, which can naturally enable the environment adaptation to the climate shifts, in order to guarantee a safe food production and a sustainable economic growth;

III. *binds the industrialized countries to open up the way.* Given that they represent the cause of most previous and present pollution, developed nations must do the most to reduce home ground emissions;

IV. *implements a new system of finance concessions to climate change activities*. In fact, developed nations, in addition to technology sharing, agreed in granting loans to developing countries;

V. *supervises on the issue,* since countries, which took part in the agreement, must consistently declare their climate change approach and strategies, and additionally submit a year-to-year record of their GHG emissions;

VI. *takes into account the economic progress of the poorer countries,* accepting the fact that the GHG emission portions generated by such nations will likely increase in the years ahead. Despite that, always pursuing its main objective, the agreement helps these countries to confine polluting emissions to a degree that will not obstruct their economic development;

VII. makes Parties endorse the establishment of financial means for adaptation rather than mitigation.

2.2.2 1997: COP3, KYOTO

Promulgated in Kyoto (Japan) on 11 December 1997 and became operative on 16 February 2005[17], "*The Kyoto Protocol* is an international agreement linked to the United Nations Framework

[17] Protocol's article n°25 determines that it formally goes into effect "on the ninetieth day after the date on which not less than 55 Parties to the Convention, accounted in total for at least 55% of the total carbon dioxide emissions for 1990 have deposited their instruments of ratification, acceptance, approval or accession".
In 2002, Iceland satisfied the first condition becoming the 55th members, while in November 2004, the Russian ratification met the remaining "55% clause", bringing the agreement into force three months later.

Convention on Climate Change, which commits its 192 Parties by setting internationally binding emission reduction targets."[18]

It recognizes that the present-day large amount of GHG that have been released into the atmosphere are mostly due to the massive industrial activities of developed nations. For this reason, following the *"common but differentiated responsibilities"* principle, it sets an accentuated burden on such countries according to the fact that each of them, as a result of economic development, has different competences in facing climate change.

The Protocol has been developed in commitment periods. During the first one, dated 2008-2012, even if almost all of the 36 developed participating nations satisfied the Protocol's goals and former Soviet Union countries significantly reduced emissions, the global trend augmented by 32% from 1990 to 2010. The second commitment term, approved in 2012 *Doha Amendment to the Kyoto Protocol*, requires the approval of 144 countries. Nowadays, it counts 37 binding commitments, of which 7 have been ratified, and notable steps back from Japan, New Zealand and Russia that took part in the first round, not taking into account the Canada withdrawal from the Kyoto Protocol in 2012, and the total ratification failure of the United States.

Countries which took part in the Protocol must not exceed their *Party's assigned amount* [19] and have to pursue the goals mainly through domestic measures. As a matter of fact, the nations that meet the so-called *eligibility requirements*[20] are provided of *three market-based mechanisms,* which basically aim to reduce the overall price of accomplishing the emissions targets:

- *Clean development mechanism (CDM)*: allows a developed country to perform an emission-reduction plan in developing countries with the purpose of promoting a clean economic

[18] https://unfccc.int/kyoto_protocol, seen December 10, 2019.
[19] Allowable emissions level.
[20] They must have:
  - ratified the Kyoto Protocol;
  - calculated their assigned amount in terms of tonnes of CO2-equivalent emissions;
  - in place a national system for estimating emissions and removals of greenhouse gases within their territory.
  - in place a national registry to record and track the creation and movement of ERUs, CERs, AAUs and RMUs and must annually report such information to the secretariat.
  - annually reported information on emissions and removals to the secretariat.

progress in such areas (e.g. rural electrification project using solar panels). It simultaneously encourages sustainable development and emission reductions in less industrialized regions and allows some versatility in how developed nations comply their emission cut targets;

- *Joint implementation (JI):* empowers any developed nation to make investments in a GHG reduction project in another industrialized country. By doing so, the Protocol goals can be met by investing where bringing down pollution rate might be cheaper. This instrument offers a responsive and cost-efficient solution to the country that finances the project and the opportunity to benefit of the technology transfer to the host state;
- *Emission trading (ET):* authorizes the countries that have AAUs[21] in excess to sell this surplus to those nations that, on the contrary, exceeded their limit. It basically gave birth to a new commodity market, the so-called *carbon market.*

The Kyoto Protocol is considered as the first serious step towards a worldwide emission slowdown and as the guideline instrument to the subsequent international dialogues on climate change.

2.2.3 2005: COP11-CMP1, MONTREAL

In 2005, from November 28 to December 9, Montreal greeted an historic rendezvous, in which the 11th *UNFCCC* (COP) was parallelly held to the first ever *Conference of the Parties serving as the Meeting of the Parties to the Kyoto Protocol* (CMP).

With more than 10,000 delegates, it represented the biggest climate meeting since '97 Kyoto.

Its key goals are the Kyoto Protocol time extension above its 2012 natural termination and a more effective negotiation for improved GHG reductions.

The final conclusion, known as the *Montreal Action Plan* (MAP), refers to Kyoto and embraces four main tracks:

[21] The targets set by the Kyoto Protocol are expressed as levels of allowed emissions, also known as a*ssigned amount units* (AAUs).

i. Based on 3.9 Kyoto Protocol section, it has been concluded that developed nations, starting dialogues in 2006, have to update their binding environmental goals before the second commitment begins, in order to assure the carbon market sustainability;

ii. Anchored to Kyoto paragraph 9, track number 2 enhances the necessity of industrialized countries improved efforts, providing cooperation to developing nations in order to have joint commitments and extended involvement of the major emerging economies;

iii. It concentrates on lowering the deforestation-caused emission in less industrialized regions;

iv. The last element established a *"Dialogue on Long-term Cooperative Action"* from 2006. It incorporates four workshops that pay attention to pioneering concepts aimed to enforce decarbonization solutions in developing countries.

In addition, the Montreal agreement reinforces the above-discussed *Clean Development Mechanism*, upgrading and strengthening its management rules. In fact, the purpose points towards additional financial support and to an augmented number of accepted projects, despite the initial criticism concerning the discussion of the *CDM* into the Montreal summit, mostly due to the lack of efficiency for projects to start performing.

2.2.4 2009: COP15-CMP5, COPENHAGEN

The 2009 *Copenhagen Summit*, which occurred between December 7-18, was full of high expectations and optimism, as the United States, after quite a time, would have participated as an active player, and also because an enhanced attention would have been paid to emerging economies such as China and India.

According to the *Bali Road Map*[22], the more than 40,000 participants were supposed to find a post-Kyoto global agreement on climate issue to go into effect in 2013.

[22] Outcome of the climate conference held in Bali during December 2009.

In greater detail, this meeting brought to the *Copenhagen Accord*, and even if governments had converging ideas on few points, it:

- pushed forward negotiations on the required facilities for a successful international climate change teamwork;
- demonstrated a political desire to face off with climate change, in either the short and long period. In fact, industrialized nations, allocating 30US$ billion for the 2010-2012 interval and a supplementary annual 100US$ billion until 2020, committed to support activities mitigating GHG emissions and to comply with the necessities of emerging countries;
- set the long-run target at a global average temperature rise not higher than 2 degrees Celsius above pre-industrial standards;
- established the assessment, communication and verification procedures of developing nation efforts.

However, on the closing day of the meeting, mass media defined the agreement as a "weak political statement", imputable to the fact that and it was not approved unanimously and because, above all, since it was just "taken note of" and not "adopted", the accord was not officially binding.

2.2.5 2015: COP21-CMP11, PARIS

The Paris Agreement represents a turning point that strengthens the required measures and contributions towards a sustainable low carbon scenario.

Drawing upon the 1992 UNFCCC, for the first time ever, it brought all countries into a widespread cause to carry out audacious efforts to mitigate climate change and comply with its consequences.

The Agreement became effective on 4 November 2016, after the double threshold[23] had been met. From that time, as shown in Figure 5, more nations have endorsed it, with an amount of 187 Parties

[23] 55 nations, representing at least 55% of global emission must ratify the agreement.

in 2020. Unfortunately, on June 2017, Us President Donald Trump announced that the country would withdraw from the Agreement.

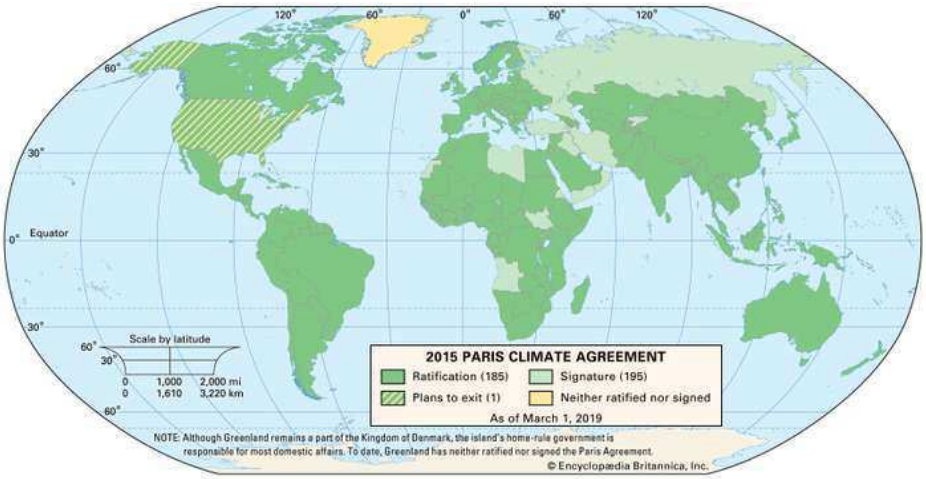


Fig. 5 (source: britannica.com)

Its primary objective is "to strengthen the global response to the threat of climate change by keeping a global temperature rise this century well below 2 degrees Celsius above pre-industrial levels and to pursue efforts to limit the temperature increase even further to 1.5 degrees Celsius."[24] Moreover, the treaty intends to intensify the countries'capabilities to cope with global warming effects the impacts, and to expand financial investments towards low greenhouses gas emissions.

With the aim of achieving these goals, opportune economic resources and an up-to-date technology framework must be introduced, following the stipulated requirements, in which all Parties, in addition to report regularly and transparently on their GHG, commit to raise their efforts through "*nationally determined contributions* (NDCs)"[25] in the years to come.

Accurately, the main points of the Paris Agreement are:

1. *Long-term temperature goal*, reasserting the aim to confine worldwide temperature raise to well below 2 degrees Celsius, at the same time trying to limit it to 1.5 degrees;

[24] https://unfccc.int/process-and-meetings/the-paris-agreement/what-is-the-paris-agreement, seen January 28, 2020.
[25] The NDCs, representing the key point of the meeting, are each country's post-2020 strategies mitigating climate change. As established in the Paris Agreement they must be disclosed.

2. *Global peaking*, which aims to reach an explicit maximum emission level by 2020 before declining afterwards and *climate neutrality* which, by definition, implies that every ton of anthropogenic CO_2 issued must be balanced with an equal amount of CO_2 removed;
3. *Mitigation* includes binding obligations by all countries to implement a nationally determined contribution (NDC) and to perform transparent domestic measures to accomplish them;
4. Stimulation of all the Parties to preserve properly *sinks and reservoirs* such as forests;
5. *Voluntary cooperation* among nations with the purpose of setting higher objectives;
6. Global goal on *adaptation* that deepens resilience and diminishes exposure to climate change issues;
7. Reinforcement of *finance, technology and capacity-building support* from industrialized countries to developing ones, with the purpose to help them in building clean;
8. Development of *climate change education, training, public awareness, public participation and public access to information*;
9. T*ransparency, implementation and compliance* of the Parties, that in addition to reporting data on mitigation, adaptation and support, must submit their actions to an international scientific expert evaluation;
10. *Global Stocktake,* which from 2023 onwards, every 5 years, will measure the shared progress toward reaching the purpose of the Paris Agreement. The assessments will be based on the best accessible science instruments.

2.3 SUSTAINABLE DEVELOPMENT

A guaranteed bright future to the next generations is the crucial aspect of *sustainable development*, that in technical terms can also be defined as "the kind of development that meets the needs of the present without compromising the ability of future generations to meet their own needs."[26]

[26] https://www.iisd.org/topic/sustainable-development, seen January 29, 2020.

With the purpose of performing this mission, in 2015, during the *United Nations Conference on Sustainable Development* in Brazil, the *UN General Assembly*[27] set a group of worldwide interconnected objectives, better known as *Sustainable Development Goals (SDGs)*, to accomplish in critical areas, such as environment, economy and politics.

These goals, replacing the Millennium Development Goals[28], represent a brave commitment to reverse our planet onto a more sustainable and equal direction.

2.3.1 APPOINTED ORGANIZATIONS

Actions pursuing the above-mentioned goals are performed by *the United Nations Development Programme (UNDP)* and the *United Nations Department of Economic and Social Affairs (UNDESA)*.

The UNDP, which is financially supported by voluntary donations, is the UN's general development network working in 177 countries. It cooperates with local governments offering integrated solutions that support nations in improving their local capacity and in general, facilitates the SDGs achievement.

Besides promoting sustainable change and countries' connection, it assists least developed nations offering technical cooperation and expert guidance.

Simultaneously, the second above-mentioned organization, the UNDESA, is the UN's body in charge of the conferences supervise. It accomplishes its tasks assisting countries in calendar-setting and economic, social and environmental policymaking.

Moreover, furnishing a wide selection of analytical items and technical assistance, UNDESA strongly stimulates sustainable development converting worldwide commitments into national legislations and on the ground activities.

[27] One of the six main organs of the United Nations.

[28] Established in 2000, they led to important results such as lifting out of severe poverty more than a billion people and more than 50% drop of children mortality.

2.3.2 SUSTAINABLE DEVELOPMENT GOALS (SDGs)

"The Sustainable Development Goals are the blueprint to achieve a better and more sustainable future for all. They address the global challenges we face, including those related to poverty, inequality, climate change, environmental degradation, peace and justice."[29]

A landmark in the sustainable development vision is that 17 interconnected SDGs listed below must be all achieved by 2030:

1. *"No Poverty*: end poverty in all its forms everywhere;
2. *Zero Hunger*: end hunger, achieve food security and improved nutrition and promote sustainable agriculture;
3. *Good Health and Well-being*: ensure healthy lives and promote well-being for all at all ages;
4. *Quality Education*: ensure inclusive and equitable quality education and promote lifelong learning opportunities for all;
5. *Gender Equality*: achieve gender equality and empower all women and girls;
6. *Clean Water and Sanitation*: ensure availability and sustainable management of water and sanitation for all;
7. *Affordable and Clean Energy*: ensure access to affordable, reliable, sustainable and modern energy for all;
8. *Decent Work and Economic Growth*: promote sustained, inclusive and sustainable economic growth, full and productive employment and decent work for all;
9. *Industry, Innovation, and Infrastructure*: build resilient infrastructure, promote inclusive and sustainable industrialization and foster innovation;
10. *Reducing Inequality*: reduce inequality within and among countries;
11. *Sustainable Cities and Communities*: make cities and human settlements inclusive, safe, resilient and sustainable;

[29] https://www.un.org/sustainabledevelopment/sustainable-development-goals/, seen January 29, 2020.

12. *Responsible Consumption and Production*: ensure sustainable consumption and production patterns;
13. *Climate Action*: take urgent action to combat climate change and its impacts;
14. *Life Below Water*: conserve and sustainably use the oceans, seas and marine resources for sustainable development;
15. *Life on Land*: protect, restore and promote sustainable use of terrestrial ecosystems, sustainably manage forests, combat desertification, and halt and reverse land degradation and halt biodiversity loss;
16. *Peace, Justice, and Strong Institutions*: promote peaceful and inclusive societies for sustainable development, provide access to justice for all and build effective, accountable and inclusive institutions at all levels;
17. *Partnerships for the Goals*: strengthen the means of implementation and revitalize the global partnership for sustainable development."[30]

By nature, countries' development degree results in different paths towards sustainability, because, as illustrated in the next figure, there are nations that are closer to meet SDGs (marked in dark blue) and other ones that will need years to fill the gap (marked in light blue):

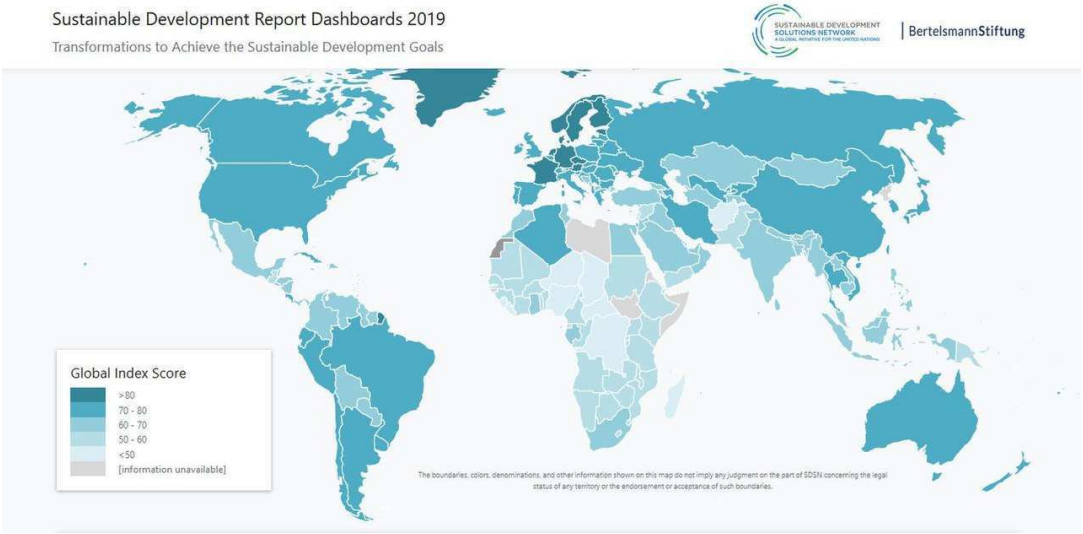


Fig. 6 (source: BertelsmannStiftung)

[30] https://sustainabledevelopment.un.org/?menu=1300, seen January 29, 2020.

2.3.3 FOCUS ON CLIMATE ACTION

Studies demonstrate that warmer climate is projected to affect the global accessibility to essential needs such as freshwater, food security, and energy. In particular, low-income and less developed countries, due to their social and economic inefficiency to cope with the above-cited issues, will be among those most negatively damaged.

That is the reason why 2015 Sustainable Development Goals, coinciding with Paris Climate Agreement, elaborated a set of accessible objectives to mitigate GHG emissions, building a solid link between climate change and sustainable development.

The global political response to climate change, started in 1992 at the Rio Convention and progressed with the Paris Agreement and sustainable development implementation in 2015, in SDG number 13 "focuses on the integration of climate change measures into national policies, the improvement of education, awareness-raising and institutional capacity on climate change mitigation, adaptation, impact reduction and early warnings."[31]

Analyzing the goal 13's advancement, it is possible to notice both positive and negative outcomes, with increasing CO_2 emissions in the one hand, and improved climate finance flows and contributions in the other side.

As a matter of fact, statistics show:

- rising GHG emissions, with new peak reached in 2017;
- economic damages from environmental calamities estimated around $3 trillion and 1.3 million lives;
- 17% global finance flow growth in 2015–2016 compared to 2013–2014;
- 28 new countries joined the Green Climate Fund in May 2019, with a total of 75 nations requesting assistance for national adaptation programmes.

[31] https://sustainabledevelopment.un.org/topics/climatechange, seen January 31, 2020.

However, much more aggressive and rapid plans are required on mitigation and adaptation. In fact, access to finance and reinforced capacities must be intensified at a much faster rate, especially for developing and least developed countries.

2.4 PUBLIC OPINION: SKEPTICISM AND AWARENESS

Climate change skepticism is a major issue to take into consideration.

Figure 7, complying with the thesis of mankind influence on the environment, compares global surface temperature variations and the solar irradiation received by our planet since 1880.

In fact, several lines of evidence disagree with skeptics that suppose that current warming climate is explained by alterations in energy released from the Sun.

First of all, since 1750, the average incoming solar energy has been constant or has poorly risen, while global temperature has increased remarkably. Secondly, if the heating were caused by a stronger solar activity, scientists would expect to notice hotter temperatures in all atmosphere layers and not just in the lower parts, where GHG trap heat.

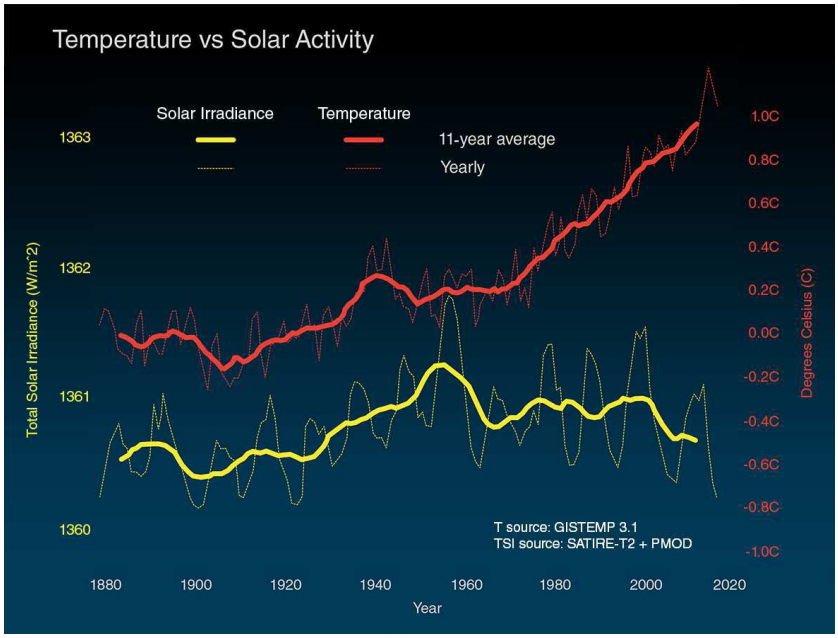


Fig. 7 (source: nasa.com)

Data show that 97% of scientific community agrees on the fact that global warming is due to fossil fuels burn and human activity, while the rest 3% denies it, saying that the mankind is not able to affect the environment.

In fact, "a colorful cast of scientists has made a living out of denying the science of climate change. These so-called "experts" launch into a series of carefully rehearsed talking points meant to confuse the public on the climate change issue. Many of them are well-paid operatives of organizations like The Heartland Institute, CFACT, and Americans for Prosperity, which take contributions from fossil fuel corporations — including ExxonMobil, the Koch Brothersand — who seek to delay or block any substantial government policy initiatives meant to curb fossil fuel emissions or hasten the rapid growth of cheaper, cleaner sources of energy like wind and solar power."[32]

This massive disinformation campaign is meant to divide and confuse the public.

US senators and congressmen such as James Inhofe[33] and Marc Morano, even if reportedly paid by institutions managed by big fossil fuel corporations, are the environmental committee chairmen in charge of climate policies.

But they are not the unique example, because even the US President Donald Trump during his election campaign stated: "It is supposed to be 17 degrees today. It is freezing here. Speaking of global warming, where is it? We need some global warming".

Not by chance, statistics show that, nowadays, fossil fuel sector almost completely favors Republicans in campaign contributions[34] and furthermore indicated that 2017 Trump's election had concurred with a considerable concern increase among environmental experts, since he has been planning to withdraw from the Paris Agreement, considered too risky for the US economy.

[32] https://www.beforetheflood.com/explore/the-deniers/top-10-climate-deniers/, seen February 11, 2020.

[33] He equalized the Environmental Protection Agency to the Gestapo, and also brought a snowball onto the Senate room to 'disprove' global warming.

[34] OpenSecrets released data show that contributions from oil and gas industry were relatively split among democrats and republicans until the 2000s, while by the 2018 election cycle, 87% of industry donations went to the Republican Party, with forecasts indicating an increase to 89% in the next cycle.

Historically, the two major US political parties supported the same ideas on climate policies during the 70s and 80s but started to differ in the 1990s.

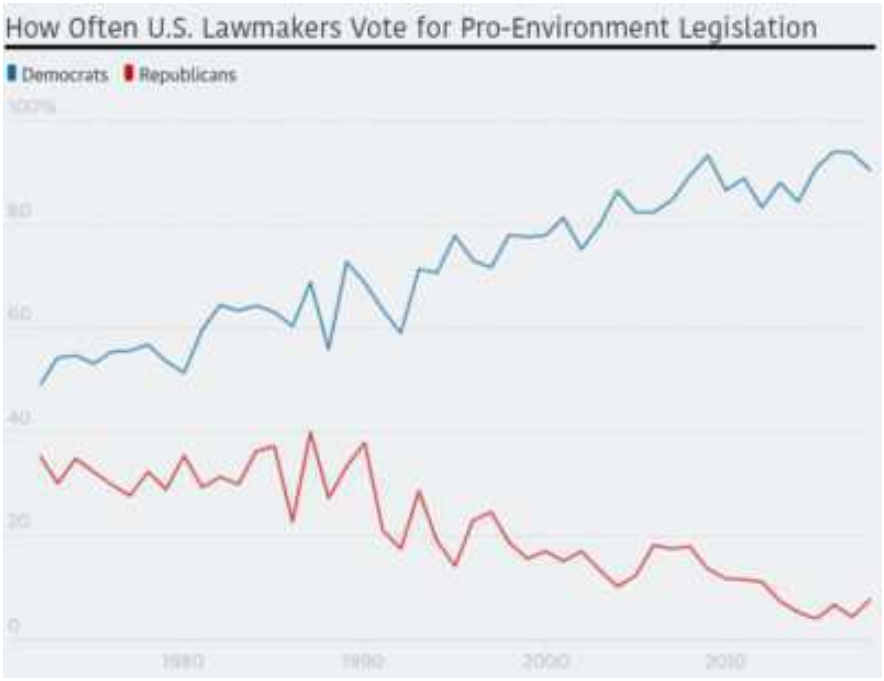


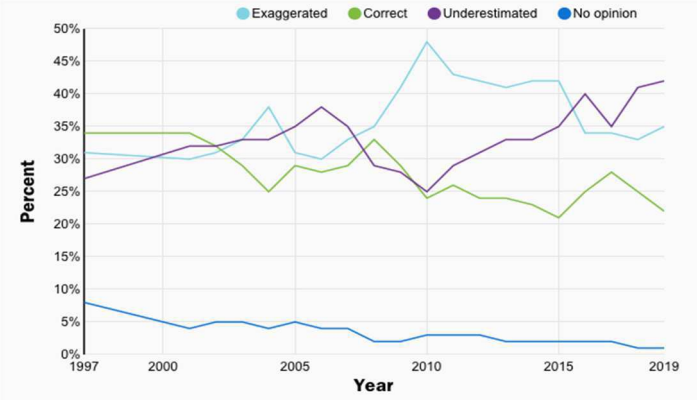
Fig. 8 (source: League of Conservation Voters)

As the graph illustrates, the actual trends occupy opposite ends of the spectrum.

These conflicting attitudes make US and worldwide citizens divided and resistant to decisive and wide actions preserving the environment.

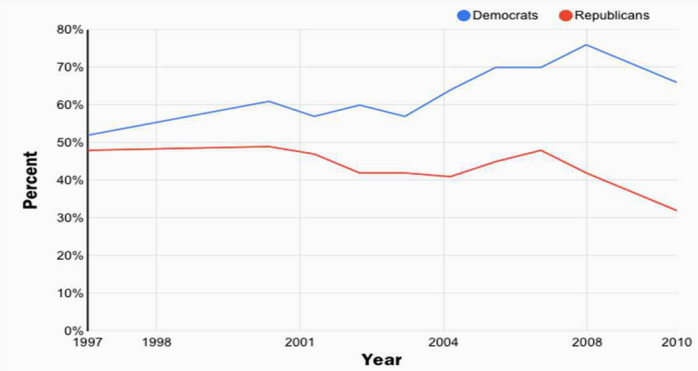
For that matter, only about half to two-thirds of Americans believe that climate change is caused by humans especially and as shown in Figure 9 panel a) the percentage of voters who were "very concerned" about climate change stayed within the 40% range, while about a third to almost half of the public believes that the seriousness of global warming is generally exaggerated. Moreover, the political different ideals are naturally reflected on the public, with a general discrepancy between democrats and republicans' voters, as panel b) exhibits.

Fig. 9



Source: Gallup. Note: In 1997, this was asked of a half sample.

Panel a)



Source: Elke U. Weber and Paul C. Stern, "Public Understanding of Climate Change in the United States," American Psychologist, May-June 2011.

Panel b)

In order to combat climate change and have a significant carbon footprint reduction, awareness is the key weapon. But how to increase awareness among people?

As explained by the climate scientist Katharine Hayhoe, if you want to persuade someone skeptic about climate threat, it is important to lead with values and not with facts because "in such conversations, it may be important to remember how your interlocutor's values differ from your own. For example, research has found that conservatives are more likely to support a pro-environmental agenda when presented with messages containing themes of patriotism and defending the purity of nature."[35]

[35] https://www.nytimes.com/2020/01/02/opinion/climate-change-deniers.html, seen February 11, 2020.

Moreover, enhancing the large number of possible damages of unmitigated climate change is likely to be ineffective. Alternatively, explaining the potential gains of mitigation can be more profitable. At the same time, the messenger matters, because people are more likely to pay attention to an information when it derives from someone they trust, a family member or an appreciated celebrity such as Leonardo Di Caprio, Greta Thunberg and Jane Fonda.

"Climate change is real, it is happening right now. It is the most urgent threat facing our entire species, and we need to work collectively together and stop procrastinating. We need to support leaders around the world who do not speak for the big polluters, but who speak for all of humanity, for the indigenous people of the world, for the billions and billions of underprivileged people out there who would be most affected by this. For our children's children, and for those people out there whose voices have been drowned out by the politics of greed. Let us not take this planet for granted"

-Leonardo Di Caprio- *Oscar Awards, February 29th, 2016*

CHAPTER 3
THE IMPACT ON THE ECONOMY

3.1 BASIC ECONOMIC INFORMATION

Nearly two centuries ago, the political economist David Ricardo elaborated the theory that is still the basis of the present economic theory of trade, known as the *Theory of Comparative Advantage.*

It affirms that, through specializing in efficiently in-home produced goods, both trading sides reach a comparative advantage[1], making international trade profitable. The overall welfare progress results in all participants', both importer and exporter, economic growth.

If in the one hand, this improvement empowers the states to increase resources in various sectors, that may also include environmental expansive policies or eco-friendly technology implementation, in the other side, Ricardo's theory does not take into account the environmental externalities related to the global trade boost.

In fact, if the above-mentioned externalities are considered in the equation, there is no guarantee that free trade will lead to a net positive advantage, with the total outcome depending on the type and volume of the environmental loss and the mitigation policies to absorb these external costs.

Thus, a precise comprehension of the climatic agents' impact on major topics such as agricultural output and economic growth may be crucial to the successful realization of economic intervention. What's more, with global temperatures awaited to increase over the future decades, understanding these correlations become always more and more important for assessing the "damage function", key element in estimating the likely effects of climate change on the economy.

[1] The ability to find out which good can be produced at a relatively lower cost than other commodities.

3.1.1 METHODS AND DATA

To understand the implications of climate events on the economy, it would be necessary to establish the functional relationship:

$$\mathbf{y} = f(\mathbf{C}, \mathbf{X}) \qquad [1]$$

which relates series of climatic variables (C) and other parameters (X) to outcomes y. C can involve temperature, precipitation, and radical weather phenomenon, X includes any features connected to C that also impact y and, as outcomes of interest, the dependent variable y may embody national income, energy consumption, agricultural or industrial output, migration and so on.

With the intention of separating the impact of the above-cited climatic variables apart from the other many elements that had an effect over the long run, the *longitudinal approach*[2], arisen in latest years, should be employed.

Using standard panel methods, the regression models in this literature typically take variations of the form

$$y_{it} = \beta \mathbf{C}_{it} + \gamma \mathbf{Z}_{it} + \mu_i + \theta_{rt} + \varepsilon_{it} \qquad [2]$$

where t denotes time and i different geographic zones. C_{it} stands for weather variables, Z_{it} for time-varying observables and ε_{it} represents the error term. The fixed effects for the spatial areas, μi, absorb fixed spatial features, while θ_{rt} embodies time-fixed effects.

Many researches use weather variation as a tool to analyse non-climatic relationships like the connection between poverty and civil war, while the reduced-form analysis in [2] simply determines the net effect of the weather event on the dependent variable, such as the rainfall impact on a conflict).

A fundamental point in every kind of study is constituted by the data collection and in an econometric analysis, weather data can be separated in four major types:

[2] Also known as *panel study*, the longitudinal approach is an observational study where researchers collect information without manipulating the study environment. It involves repeated observations of the same variables over a short or long period of time, allowing the researchers to detect developments or changes in the behaviors of the target population.

- The most basic kind is represented by *ground stations data*, which directly observe temperature and other weather parameters like precipitations, wind speed and humidity. Even if it normally provides a very accurate measurement of the area's climate in which the stations are located, there are some themes that should be taken into consideration. In fact, particularly in poor country with more financial constraints, the common entry and exit of weather stations can possibly concern the estimations of [2], increasing the likelihood of measurement errors;
- In order to cope with the ground stations changes over time, researchers can employ *gridded data* to offer a more complete coverage thanks to the interpolation of station information over a grid. The result is a balanced panel of climatic data for every point on a grid, representing a good source of temperature data for economic analysis. However, the use of different interpolation schemes can produce disparate estimates, especially for precipitation, since they display a higher spatial variation than temperature, especially in rugged regions, making the interpolation more challenging;
- If information is only needed since the 2000s, *satellite data* allow remarkably higher resolution to be completed, even if they do not extend back as much as other datasets. Moreover, satellite data have lower accuracy than ground stations, considering that satellites do not directly measure climate parameters, but rather perform inferences from electromagnetic reflectivity in diverse wavelength bands;
- *Reanalysis data* build a gridded weather dataset merging information from ground stations, satellites, and other sources. The main difference with gridded data is that, instead of using a statistical method to interpolate between observations, a climate model is used. In fact, even if reanalysis can offer some progresses in areas with sparse data, it does not represent an obvious better solution than interpolated gridded data, since the climate models, by definition, are simplifications of the climate reality.

Once weather data have been collected, they are required to be aggregated to an economically purposeful level. The first method, represented by a spatial scheme that employs a simple area-

weighted average of weather parameters, leads vast regions with little economic activity and sparse demography such as deserts and tropical forests to outplay the climate averages of large spatial units like U.S. and India. On the other hand, a second approach is the aggregation performed by using a fixed set of population weights.

The method's choice depends on the analysis framework because for instance, area weights may be more suitable for agriculture studies, while for researches on the impact over labour force productivity, a fixed set of population weights can be more desirable.

3.2 ECONOMIC CONSEQUNCES

Studies demonstrated that temperature, precipitation, and severe climatic events have economically and statistically relevant effects on plenty of outcomes such as aggregate output, agriculture, and labour productivity among others. These results exhibit the multiple nature of the weather–economy linkage, with several applications to comprehend past, present, and future economic consequences and potential responses, because for instance, the impact of climatic parameters on energy demand or agricultural productivity may instruct policy-makers on energy and agricultural investment rates and policy implementation.

Furthemore, these researches release information about the economic costs of future climate change.

3.2.1 AGGREGATE OUTPUT

In order to have a bigger picture of the whole topic, it is important to have a basic knowledge of the past literature and theories that stimulated the newest analyses. In fact, from *The Spirit of Laws*[3] to more recent works like 1999 *Gallup, Sachs, and Mellinger'*s study, the exhibited theory is that high temperatures bring down labor productivity, also showing a severe negative relationship between warm climates and income per person. One of the many examples is illustrated in the above-

[3] Montesquieu's treatise on political theory and comparative law published in 1748.

mentioned Gallup, Sachs, and Mellinger's work, where a 50 percent difference in income per capita were showed between countries located in the tropical regions and the other ones.

Other researches pointed out that the 20 percent income divergence between the African continent and the wealthiest countries in the world may be also due to discrepancies in geographic characteristics like altitude and land quality in addition to different precipitations and temperatures. On average, the per capita income results show a reduction from 8.5 percent, across countries, to 1-2 percent within, per 1°C increase.

Now, taking into consideration recent panel-based estimates:

- *Dell, Jones, and Olken's* study (2012), which focuses in a global sample from 1950 to 2003, analyzed how yearly fluctuation in temperature and precipitation impacts per capita income. In a given year, the final assessment expresses a 1.4 percent fall in per capita income per 1°C increase in poor countries. Furthermore, they stated that not just income volume is touched, but also growth rates, as the effect is not inverted once the temperature shock is done. And being growth rates a significant indicator of a nation's wealth over the long term, it represents a central issue in which develop further researches;
- Similarly, *Hsiang* (2010) demonstrates a 2.5 percent domestic output drop per 1°C warming in a cluster of twenty-eight Caribbean countries over the 1970–2006 interval;
- *Barrios, Bertinelli, and Strobl*'s 2010 study concentrates on the 1960–1990 period, operating on a sample of twenty-two African and thirty-eight non-African nations. The researchers assess that larger amount of rainfall is related to quicker growth in the sub-Saharan African countries. In addition, they indicate that since the 1960s, the aggravated rainfall conditions may partly justify the 15-40 percent gap in per person income between sub-Saharan Africa and the other the developing countries;
- In studying forty-one African nations during the 1981-1999 period, *Miguel, Satyanath, and Sergenti* (2004) illustrate that annual income per capita growth is positively influenced by rainfall growth.

Additionally, to the abovesaid studies taking into account temperature and precipitation, other researches consider the effects of severe weather events, such as windstorms and droughts:

- *Hsiang and Narita* (2012), exploiting a meticulous global body of data, examine the impact of windstorms across 233 nations in the 1950–2008 period. The disclosed result is that higher wind speeds lead to higher economic losses, in the same way illustrated by 2010 *Nordhaus*'s analysis. It indicated that is U.S., from 1950 to 2008, the annual hurricane costs equal, on average, to 0.007 of GDP;
- In the 2010 research, although *Hsiang* did not find significant cyclones' effect on income in a group of twenty-eight Caribbean regions, the assessment shows positive influence on construction sector;
- The net impact of cyclones on growth rates, studied by *Hsiang and Jina* (2013), amounts to 1.3 percent world GDP decrease in the period 1970-2008;
- *Deryugina* (2011) performing a study within U.S., showed that there are no effects on counties after a period of ten years from the hurricane. This assessment is influenced by the considerable amount of government transfers into the impacted areas after the extreme climatic event, suggesting that there may be an important loss in locally produced income, which is in any case balanced by the transfers.

"Integrating across the weather studies above, it appears that an unusually hot year is associated with substantially lower income growth in poor countries. This finding is consistent with the strong negative cross-sectional relationship between temperature and per capita income. The studies also show that unusually low precipitation has had negative impacts on income per capita in Africa, with less clear effects elsewhere. Studies find large effects of windstorms on local income but generally smaller effects on national income, although damages from windstorms are highly convex in wind speed."[4]

[4] M. Dell, B.F. Jones and B.A. Olken, *Journal of Economic Literature 2014,* page 755.

3.2.2 AGRICULTURE

Considering temperature and water as fundamental inputs into the natural process of crop growth, the relationship between weather and agricultural productivity has been the core of many of the published research listed below:

- In a research dated 2007, *Deschênes and Greenstone*, using a year-to-year within-county variation in temperature and precipitation, tried to detect the influence of a warmer or wetter year on agricultural incomes. The final assessment showed no statistically significant linkage between climate and U.S. agricultural earnings, further declaring that if in the short-term, oscillations have no effect, then in the long period, with possibility of adaptation, climate change is likely to display a small impact or could even be profitable. These results have been considerably questioned by *Fisher et al.* in 2012, when data errors have been highlighted. Once corrected, the research exhibits a damaging impact of weather fluctuations on U.S. agriculture;
- As demonstrated by *Schlenker and Lobell* (2010) for sub-Saharan regions, by *Guiteras* (2009) for India and by *Feng, Krueger, and Oppenheimer* (2010) for Mexico, weather variations and warmer temperatures tend to reduce crops' yields;
- Focusing on rice lands in different Asian countries, in 2010, *Welch et al.* estimated that higher minimum temperature lowers agricultural outcome and higher maximum temperature raises yields, with a net decline under an acceptable warming scenario;
- In 2009, *Schlenker and Roberts* reviewed a panel model of U.S. agricultural yields using day-to-day data. Basing their work on a range between 29-32°C and on the basis of the crop, temperature results being slightly beneficial at temperatures inferior than the threshold and considerably destructive above;
- *Jayachandran* (2006), concentrating on labor supply's determining factors in Indian regions, indicated that recurrent rainfall results in higher crop yields and improved farmers' wages.

Other researchers focused on key issues that may be valuable for assessing possible effects of climate change:

a) Historical researches have underlined the farmers' ability to efficiently adapt to new climates, sometimes even by moving elsewhere in reply to the negative environmental events. Estimates from short-term climatic oscillations may shed some light on the long run needed adaptation. However, *Hornbeck* (2012) and *Burke and Emerick* (2013) found small evidence for adaptation. Differently, in 2011, *Fishman*, analyzing the ability of irrigation as mitigating system for climate change in India, stated that irrigation just partly balances the impact of warmer and rainless days;

b) The connection with migration phenomenon has been studied by *Munshi* in 2003. Given a Mexican group of people, the researcher pointed out that lower rainfall pushes more migrants in the U.S.

   Similarly, *Feng, Krueger, and Oppenheimer* (2010) exposed that inferior crop yields positively influence emigration, particularly for young adults;

c) Studies examining the link between forestry and global warming have been performed in the extent that forests play a fundamental function in the carbon balance and biodiversity preservation. *Van Mantgem et al.* (2009) highlighted a considerable rise in tree mortality connected to warming and precipitation declines in the western U.S. regions, as well as in the Iberian Peninsula region. In the same way, *Westerling et al.* (2006) illustrated that wildfire boost in western U.S. is closely linked to variations in local temperature and precipitation that resulted in earlier, longer and drier summer seasons.

"In summary, panel estimates tend to predict economically and statistically significant negative impacts of hotter temperatures on agricultural output. These impacts are pronounced when temperatures increase beyond a crop-specific threshold. They appear in rich countries such as the United States, particularly in the rain-fed eastern part of the country, and are also important in poor countries, where agriculture is a large share of aggregate output. Evidence also suggests that rainfall

and droughts impact agricultural output, although these effects can be complicated to disentangle and may be mitigated in the presence of large-scale irrigation systems. The negative effects of low rainfall on agriculture in developing counties appear consistently in those countries, perhaps due to lower levels of irrigation. Outmigration appears to be a common response to declines in local agricultural productivity."[5]

3.2.3 LABOR PRODUCTIVITY

Starting at least from the Ancient Greeks, there is the belief that temperature affects labor productivity and cognitive performance. More recently, precisely in 1915, the geographer Ellsworth Huntington, in his *Civilization and Climate,* explained that productivity is superior in spring and autumn, when temperatures are mild, and poorer in summer and winter, when weather conditions are more radical. With the purpose of investigating the weather's implication on productivity, modern laboratories have performed up-to-date experiments, in which subjects are asked to accomplish cognitive and physical assignments in rooms where temperature is varying:

- In 2003, *Seppanen, Fisk and Faulkner* stated that per 1°C increase for temperatures over 25°C there is a 2 percent productivity loss in several cognitive tasks. Similar assessment has been carried out by *Seppanen, Fisk, and Lei* (2006), as their research exhibited a 9 percent productivity reduction for increasing temperature from 23 to 30°C;
- In examining the efficiency of call center employees in different surrounding temperatures, changing due to both outdoor and indoor parameters, *Niemelä et al.* (2002) arrived at the result that, within the 22-29°C range, each additional °C means a diminution around 1.8 percent in labor productivity;

[5] M. Dell, B.F. Jones and B.A. Olken, *Journal of Economic Literature 2014,* page 759.

- *Wargocki and Wyon* (2007) conducted a test considering a sample of 10 to 12 years old children in a classroom context. In randomly varying the classroom temperature between 25°C and 20-21°C, the researchers noticed diverse tasks' improvements in the cooler settings;
- Taking under exam Japanese bank employees, *Lee, Gino, and Staats* (2012) displayed that productivity occurs to be superior in days where outdoor weather is less appealing for entertainment activities, considering nice weather as a distraction. To confirm this trend, *Connolly* (2008) says that, on average, in U.S., workers are likely to substitute about thirty minutes per day from leisure activities to work when it rains.

With reference to the economy, *Graff Zivin and Neidell* demonstrate that weather oscillations result in significant changes in labor supply. In fact, examining the U.S. case, they show that warm days remarkably bring down the labor supply in sectors susceptible to outdoor temperature, such as agriculture, mining and construction.

3.2.4 INDUSTRIAL AND SERVICES OUTPUT

Even if elevated temperatures per se appear to hit labor productivity, given factors like heating, air conditioning and mechanization, the consequences on indoor activities such as industry and services may not be the same as the ones over outdoor sectors.

Recent studies, all investigating using panel specifications as in equation [2], indicate that there are relevant effects on industrial and services output caused by weather shocks:

- In 2012, *Hsiang*, considering a sample of twenty-eight Caribbean regions over the 1970-2006 time interval, conducted a study on the effects of temperature and cyclones. He ascertains that exceptional warm periods have considerable negative influence for the majority of nonagricultural sectors, with output falling by 2.4 percent per 1°C. More peculiar is the cyclones' impact, since it is negative on mining and utilities sectors and positive for constructions, with a no resulting net effect;

- In examining the annual industrial value-added output in a 125 countries sample over the interval 1950-2003, *Dell, Jones, and Olken* (2012) showed that just poor countries face industrial losses amounting to 2 percent per 1°C increase;
- *Jones and Olken* (2010) focused on global industrial losses in terms of trade. The conclusive assessment displays an average 2.4 percent fall per 1°C warming in poor countries' exports, including key products such as wood, metal, and rubber manufactures;
- Concentrating on the plant level of U.S automobiles sector, *Cachon, Gallino, and Olivares* (2012) analyzed the climate's impact on the 1994-2004 interval. They determined a remarkable output decrease due to warmer days. In fact, in a week with at least six days above 90°F (32°C), the weekly production lowers by about 8 percent. In addition, employees' absenteeism is an important parameter, since the research finds massive output losses due to severe windstorms. On average, such of event occurs 2.5 times per year, with a consequent output fall of 26 percent per windstorm day.

3.2.5 HEALTH AND MORTALITY

Newest papers using the panel method investigate the impact of climate change on mortality, both in developed and in developing areas:

- In the United States*, Deschênes, and Greenstone* (2011) and *Barreca* (2012) working on death's datasets, respectively stated that each additional day exceeding 32°C raises mortality by about 0.11 and by about 0.2 deaths per thousand;
- Similar but even more severe effects are proven in developing countries. In India, *Burgess et al.* (2011) display an annual mortality rate increase of 0.75 per additional day exceeding 36°C.

The Indian mortality rate is around seven times higher than the one displayed by United States. "Interestingly, the mortality impacts of temperature in the United States in the 1920s and 1930s were also six times larger than the estimated impacts in the United States during more recent periods, as shown by (Barreca et al. 2013), who further find that the adoption of residential air-conditioning may

explain this decline. These findings suggest that, should countries like India develop and gain widespread access to adaptation technologies."[6]

The effects of weather on health detected by the literature have shown a direct impact when radical temperatures affect especially people with preexisting respiratory or cardiovascular diseases and a collateral impact, when temperatures influence pollution levels, the rate of food spoilage and vector-borne disease particularly in those low refrigeration regions.

Mostly focusing on infant health, different researchers worked on these topics:

- *Deschênes, Greenstone, and Guryan* (2009) paper on U.S. case illustrates that birth weight lowers between 0.003 and 0.009 percent per each day warmer than 30°C during pregnancy;
- Analyzing Texas' data, *Currie and Rossin-Slater* (2013) assessed that exposure to hurricanes during pregnancy raise the likelihood of infants with abnormal conditions or diseases. Same result exhibited by *Anttila-Hughes and Hsiang* (2011) that show typhoons trigger a considerable growth in infant mortality in developing countries, precisely in the Philippines;
- Selecting a sample of twenty-eight African countries, *Kudamatsu, Persson, and Strömberg* (2012) investigated the influence of prenatal weather events on following outcomes. Firstly, they indicate that the more are the days climatically associated with the flourishing of malaria[7] during pregnancy the higher is infant mortality, with an increasing risk by about three per thousand. Additionally, the authors display that droughts result in higher infant mortality due to maternal malnutrition;
- In a long run setting, *Maccini and Yang* (2009) analyze the health consequences of poor rainfall for Indonesian adults born between 1953 and 1974. The final result shows that women who experienced stronger rainfall as infant girls are, as adults, taller, richer, and have better

[6] M. Dell, B.F. Jones and B.A. Olken, *Journal of Economic Literature 2014,* page 762.

[7] It is a mosquito-borne infectious disease that affects humans and other animals. Malaria causes symptoms that usually include fever, tiredness, vomiting, and headaches that sometimes can lead to coma, or death. It is positively influenced by modest rainfall, no very cold temperatures, and warm temperatures.

health. This suggest that weather-induced scarce nutrition as infants may have long-lasting effects.

3.2.6 ENERGY

In light of climate change, paperwork vastly examines how climatic parameters, in particular temperature, affect energy demand. This bond is crucial for the design of electricity networks since energy demand adapts to weather fluctuations. At the same time, energy consumption effects greenhouse gas emissions, which conversely influences upcoming energy demand.

The majority of researches concentrates on residential electricity demand, where consumers' behavior is heterogeneous and where, by nature, they necessitate heat when temperatures are cold and cooling air when temperatures are hot. In this way, depending on the season or location, the occurrence of an "unusually warm day" may either lower or augment the demand of energy.

Always focusing on panel model approaches, researchers use temperature bins, in which they make a distinction between "heating degree days" (HDD) and "cooling degree days" (CDD) that allow to determine the amount of days below and above a threshold temperature:

- Studying annual observations of residential energy consumption from 1968-2002 across U.S., *Deschênes and Greenstone* (2011) find serious increases at the extremes of the temperature distribution that point out an explicit U-shape relationship between energy demand and temperature. The assessment displays that an extra day below 10°F (-12°C) or above 90°F (32°C) increase annual energy consumption by 0.3-0.4 percent;
- The study conducted by *Auffhammer and Aroonruengsawat* in 2011 investigating the household-level energy consumption statistics in California during the 2003-2006 time interval, largely confirmed the U-shape relationship. Furthermore, as a result of climate change models that indicate a likely increase of very warm days, the authors stated that the net impact of global warming over the 21st century has high chances to significantly boost energy demand, ceteris paribus, by 3 percent;

- *Bhattacharya et al.* (2003) expressed that higher electricity costs affect other aspects of household budgets. In fact, a consumer expenditure survey indicated that for poor households, low temperatures result in a heavier impact of fuel expenditures on the total budget with negative consequences on food consumption;
- Taking into account a sample of thirty-one European nations over a ten-years period observation, *Eskeland, and Mideksa* (2010) assessed that a unit increment in "cooling degree days" results in a energy consumption growth four times bigger than the impact of a one unit increase in "hot degree days".

"Such studies appear important for understanding global energy demand responses, especially given that the penetration of heating and cooling technologies in poor countries is low.

To the extent that cooling appliances attenuate other climatic effects, including effects on labor productivity, industrial output, and health, the biggest question here may be less about the costs of increased energy demand and more about the adaptive benefits such energy appliances may provide. Integrating across the studies above, one (speculative) description of mechanisms may note that in rich countries, high heat raises energy demand but does not reduce GDP, while in poor countries, GDP and sectoral losses appear large. To the extent that cooling technologies decouple heat from productivity in many sectors, energy demand increases may signal important adaptive responses—but ones that are largely unavailable in much of the world. Increased energy demand may, meanwhile, further exacerbate climate change."[8]

3.2.7 CONFLICT AND POLITICAL STABILITY

Over the past decades, the linkage between climatic events and conflict/political stability has been deeply examined:

[8] M. Dell, B.F. Jones and B.A. Olken, *Journal of Economic Literature 2014,* page 765.

- In 2004, focusing on forty-one sub-Saharan African regions, *Miguel, Satyanath, and Sergenti* analyzed the bond between rainfall fluctuations and civil conflict in the 1981-1999 period. They pointed out a process in which low rainfall triggers negative economic shock, which consequently stimulates wars;
- The trend is confirmed by *Burke et al.* (2009), since their final assessment sees that warmer temperatures lead to higher conflict frequency in Africa, with a growing tendency of 4.5 percentage per 1°C increase;
- Political stability has been highlighted as weather shocks' consequence by *Burke and Leigh* (2010) and *Bruckner and Ciccone* (2011) since their papers demonstrate how extreme climate events appear to result in democratization. Similarly, *Dell, Jones, and Olken* (2012) indicate that harmful temperature shocks raise the likelihood of irregular leader transitions.

Although the number of researches finding significant connections between climate and conflict/ political stability is considerable, panel studies have not been fully unambiguous. In fact, severe weather events do not result in civil wars in wealthy, stable nations, and in the world as a whole, climatic shocks are not deeply related to national conflict. In order to have a better understanding of this issue, *Hsiang, Burke, and Miguel* (2013) performed a reanalysis of all empirical works concerning the weather's impact on civil conflict. The final assessment says: "All twenty-one estimates of temperature in the reanalysis are positive. While not all estimates are statistically significant, they argue that these coefficients would be very unlikely to arise by chance if the true impact of temperature on conflict were zero or negative."[9]

3.2.8 CRIME AND AGGRESSION

As for labor productivity, the perception that weather events directly impact the tendency for aggression and criminal activities is also dating back to the Ancient Greeks. Relationship that has

[9] M. Dell, B.F. Jones and B.A. Olken, *Journal of Economic Literature 2014,* page 767.

been confirmed by U.S. statistics during 1960s, when government officers noticed that riots were more likely to take place in warmer temperature, and also by future analysis:

- In 1986 *Kenrick and MacFarlane* and 1994 *Vrij, Van der Steen, and* Koppelaar's papers, empirical evidences have respectively related warm temperature to a greater extent of horn honking and aggression by police officers, with a substantial weaker connection in areas that are likely to be air conditioned (*Rotton and Cohn* 2004);
- In a given week, *Jacob, Lefgren, and Moretti* (2007) find that in U.S. territory warmer temperatures raise both violent and property crime during, while stronger precipitation lowers violent crime with no particular impact on property crime. In the same way, *Ranson* (2012), focusing on a fifty-year panel crime and weather dataset of 3,000 American counties, similarly points out that the warmer temperatures the higher criminal activity;
- Climate might also affect criminality through its influence on income. In fact, *Miguel* (2005) highlighted that, in Tanzania, severe precipitations augment the assassination of old women, assuming that rainfall-induced negative income shocks lead households to eliminate unproductive family components. In addition, focusing on the Indian regions, *Sekhri and Storeygard* (2011) show an increasing trend of murders of women failing to bring adequate dowry in last years during periods of poor rainfall.

Alongside the aforementioned studies suggesting a direct relationship between and criminal activity, "some researchers have argued for a biological pathway through which temperature affects serotonin neurotransmission in the brain, influencing impulsivity and aggression but this hypothesis remains controversial. Whether the temperature-aggression nexus occurs via neurological or social-psychological channels remains an important area of research in criminology, and studying potential linkages between aggression mechanisms and broader social conflict is an interesting subject for further research."[10]

[10] [10] M. Dell, B.F. Jones and B.A. Olken, *Journal of Economic Literature 2014,* page 768, 769.

3.2.9 OTHER CHANNELS

Two more variables such as international trade and innovation may have significant implications in the climate–economy interface.

By assumption, market integration has the ability to impact weather-shock sensitivity. Trade can moderate or intensify the local effects of productivity damages due to climatic events by granting the access to foreign markets that in the one hand facilitate local consumers but that conversely hurt local producers, with similar but opposite effect on foreign consumers and producers:

- Examining annual data for 125 Indian areas, *Burgess and Donaldson* (2010) demonstrate that low rainfall-induced famine is basically eradicated in those districts that had access to railroads, showing that market integration may signficantly dampens the negative local effects of weather shocks;
- As *Jones and Olken* (2010) explained, climate shocks may result in a considerable agricultural and industrial exports' reductions in poor countries, with local producers facing important losses and foreign consumers small negative effects, mostly thanks to the wide range of substitute providers;
- Innovation represents a major adaptation mechanism. Analyzing patenting in response to climatic disasters over a twenty-five years period and concentrating on a sample of thirty countries, *Miao and Popp* (2013) illustrate that, among others, an additional $1 billion in economic damages caused by drought, augmented drought-resistant crops patent applications by 20 percent. Similarly important consequences have been found for earthquakes and floods.

Even if the efficacy of these patents is not well defined, paperwork suggests that R&D innovative activities are strictly tied to climate.

3.3 POLICY RESPONSES

By 2050, about the 25% of the present greenhouse gas emissions must be cut. Anything lower would essentially results in very harmful environmental effects and anything higher, even if extremely unrealistic, would impose very large adjustment costs in the short term.

Determining and comparing the estimated strength and limitations of policies can provide guidance in establishing how much to do and how quickly.

Policies should be more ambitious and challenging, because the more communities dislike bearing risks, the more they worry about global warming hitting poorer people heavier, the more positive they are about technology opportunities, and the less they ignore next generations' well-being simply because they live later.

The first milestone of climate change policy is *carbon pricing*. Since greenhouse gases are considered as an externality, those who discharge polluting emissions and do not fully cope with the negative impact of the social costs of their actions, must restore the equilibrium through the payment of a marginal cost of emissions that reflects the damage they cause. This will hopefully lead emitters to move investments away from high-carbon goods and services to low-carbon business opportunities.

Nevertheless, the existence of a range of other market failures and barriers makes carbon pricing alone not good enough.

In fact, *technology policy*, the second component of a global warming mitigation plan, is considered necessary to push forward the variety of low-carbon and high-efficiency technologies aimed to reduce emissions. Research and development expenditure and market support policies may aid to drive innovation and motivate a rapid response by the private sector.

Furthermore, since windows for cost-effective mitigation solutions are not always opened because of information scarcity, complexity or initial financial constraints, strategic politics on knowledge, financing and regulation aiming to eliminate behavioral barriers and promote discussion, education and persuasion are perceived as third essential element.

3.3.1 CARBON PRICING

In the conventional theory of externalities, there are four methods in which a negative externality can be addressed:

a) Introduction of a *tax* in a way that emitters face the entire social cost of their polluting actions, establishing a carbon price that reflects the damage induced by emissions;
b) Definition of *restrictions* that can limit the emissions' magnitude emissions;
c) Allocation of property rights[11], defined as *quotas* or *licenses*, among those institutions causing the negative impact and/or those affected;
d) Establishment of a single *organisation* including those triggering the externality and all those impacted.

By assumption, requiring businesses to pay for the right to emit GHG result in both carbon taxes and tradable quotas improving public revenues. In the one hand, through the direct transfer of funds from polluting companies to government, taxes automatically strengthen the public balance sheet. Then, these financial resources can be used to:

- expand the revenue base;
- ease the overall tax burden on the impacted sectors through revenue recycling[12] with the purpose of enabling society to switch its habits in sustainable behavior, technology, systems, and infrastructure;
- cut taxes elsewhere in the economy[13].

Differently, a tradable quota system will not automatically lead to a revenue raise unless firms purchase the licenses directly from the government through a sale or auction. In fact, if quotas are

[11] They represent the right to emit a certain volume of greenhouse gases. The allocation to businesses can be performed by the government for free or through the purchase, and afterwards they can be traded between companies.
[12] Revenue recycling, which include, among others, clean energy investments and supports to industry, may stimulate polluters to lower GHG emissions. The benefit of this approach is represented by the attenuation of the initial impact of the scheme for those companies facing the highest increase in costs. Over time, however, this recycling process may discourage the necessary exit of businesses from the polluting fields after the wide competitors' reduction.
[13] In such circumstances, because of both negative externality reduction and revenues increase, carbon taxation is sometimes argued to result in a "double dividend".

assigned for free, the asset will be hold by the private sector with the benefits ultimately fall on the hands of the involved firms.

Along with the tax approach, the most common practice, known as *cap-and-trade systems*, tend to mix elements of the second and third method, as explained in the above 2.2.2 paragraph on Kyoto Protocol. The major example of a cap-and-trade scheme for greenhouse gas emissions is the *EU's Emissions Trading Scheme*[14], the first emissions trading programme involving several countries. More in detail, this system sets a uniform price of carbon across European countries for polluting emissions from heavy industry sectors. Then, through the National Allocation Plans, which must be approved by the European Commission, member states establish the total amount of allowances within their nation, and how these are allocated amongst firms.

As a rule, the carbon market aims to diminish the emission of greenhouse gases and it is functioning correctly if two conditions are respected:

- The mitigation should take place up to the point where the utility of additional emission reductions is balanced by the costs, in other terms, where the marginal social cost of carbon intersects the marginal cost of abatement. This is the necessary condition to set the proper level of emissions, and as a consequence, to define the long-term stabilisation strategy;
- At a given moment, in order to achieve emissions' cut at least cost, a common price signal is needed across countries and industries of their economies.

With the optimal market conditions of perfect information, certainty and no transaction costs ensured by the perfect competition, both taxes and restrictions approaches, if successfully designed, can satisfy these criteria, and be utilized to identify the above-mentioned common price.

However, considerable uncertainty exists, especially around the timing and size of impacts, just as much as the costs of abatement. In such a case, in order to implement an efficient policy, instruments must be carefully selected.

[14] It started on January 1st, 2005 with Phase 1, continued with Phase 2 in the period 2008-12, and with further phases beyond 2012.

To have a better comprehension of what is the most efficient policy to reduce emissions and how carbon market works, the understanding of 1974 *Weitzman*[15] paper is crucial.

In fact, taking into account the inclination of the curves in different situations from equal slopes for marginal damage and marginal abatement cost, in which loss of efficiency is the same for both policies, the general rules are:

- Prices, here taxes, are more suitable than licenses where the benefits of making additional reductions in pollution change less with the level of pollution than do the costs of delivering these reductions. For instance, when the marginal damage curve is substantially flat, compared with the marginal abatement cost curve, as pollution increases;

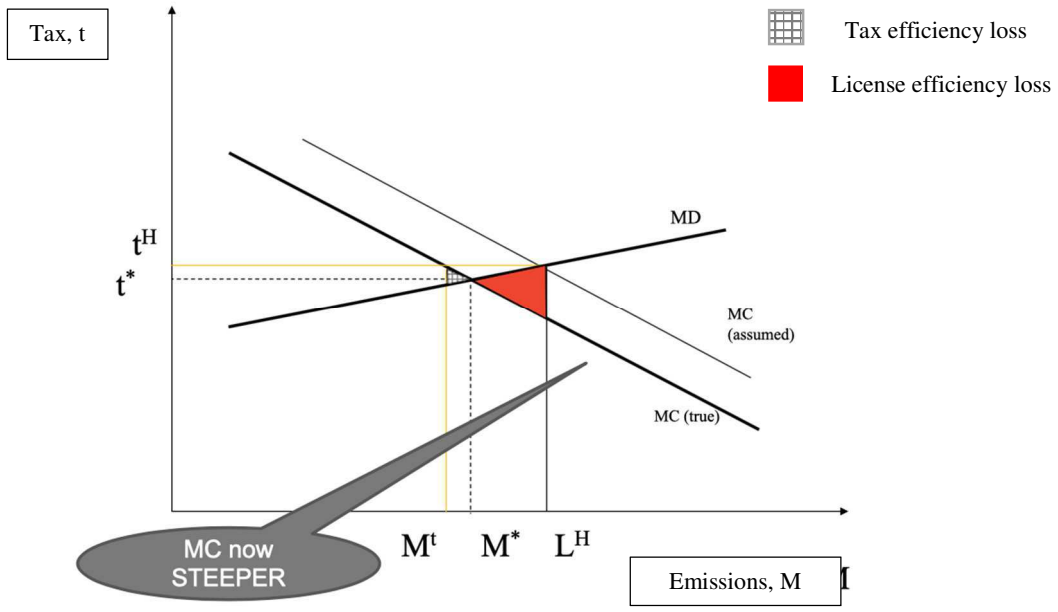


Fig. 1 (source: *Prices vs. Quantities,* M.Weitzman)

[15] In his *Prices vs. Quantities*, Martin L. Weitzman analyzed how price or quantity-control mechanisms, in this case respectively represented by tax and quota, compare where there is uncertainty about the costs and benefits of action, and how this influences the comparative efficiency of the two instruments.

- Quantity controls, here defined as quotas or licenses, are preferable where the benefits of more reductions rise more with the level of pollution than do the costs of delivering these reductions, when for example, the marginal damage curve is steeper with respect to the marginal abatement cost curve.

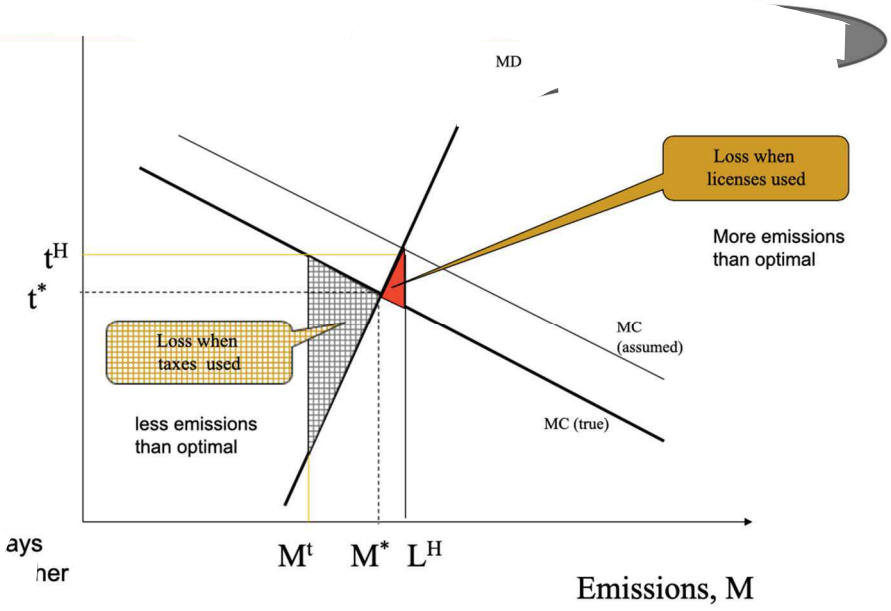


Fig. 2 (source: *Prices vs. Quantities,* M.Weitzman)

As much as curves' inclinations, the short and the long period may present diverse policy scenarios. Analyzing the short period in Figure 3, "the expected marginal benefits of abatement are flat or gently decreasing as the quantity of emission reduction increases. This reflects the fact that variations in emissions in any single year are unlikely to have a significant effect on the ultimate stock of greenhouse gases. The expected marginal costs of abatement (MAC_E), however, are steeply increasing as abatement activity intensifies; firms find it progressively more difficult to reduce emissions, unless they can adjust their capital stock and choice of technology (assumed by definition to be impossible in the short term).

If it were known with certainty that the marginal costs of abatement were given by the schedule MAC_E, the policy-maker should set the rate of the emission tax to equal T_E, given by the intersection of the schedule with the marginal benefits of abatement, also assumed to be known. The optimal quantity of emission quotas or allowances allocated (Q_E) would also be given by this intersection,

giving rise to an equilibrium price in a perfectly competitive allowance market of PE. The choice of quota or tax would not matter in this case.

However, the real marginal costs of abatement in the period are not known with certainty in advance and turn out to be higher at every point, as represented by the curve MAC_{REAL}, and that the policy-maker cannot adjust the policy instrument in anticipation. In this case, the optimal quantity of allowances to be allocated would in fact turn out to have been Q_{REAL}. In the figure, the efficiency loss caused by issuing Q_E instead of Q_{REAL} allowances is given by the large blue triangle. If instead a tax had been set at T_E, the efficiency loss resulting from having set a slightly lower tax rate than turns out to have been warranted is given by the small red triangle. Thus, it is often argued that a tax is superior to a quota as an instrument of climate-change policy in the short run."[16]

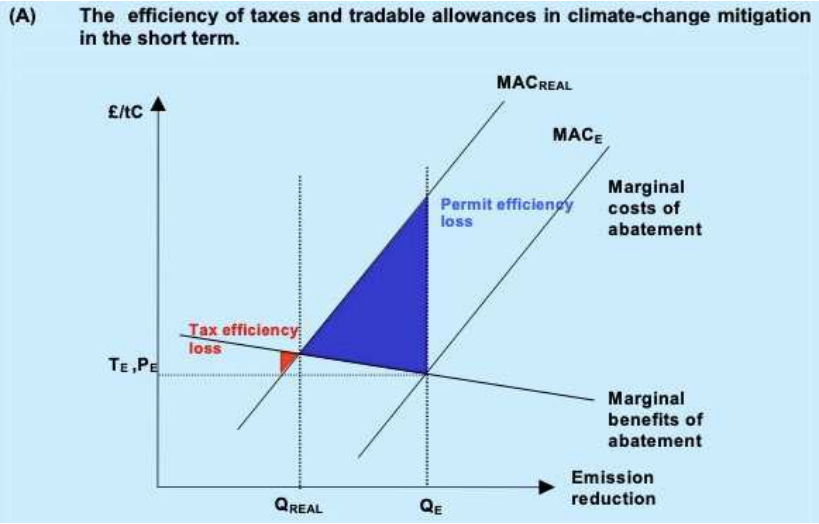


Fig. 3 (source: *The Economics of Climate Change*)

"Figure 4 illustrates the situation in the long term, with the cumulative emissions reductions required to reach the ultimate stabilisation target. The curve representing the marginal benefits of abatement is steeply decreasing, as more and more abatement effort is put in. But the marginal costs of abatement are only gently increasing as a function of abatement effort, since in the long run there is more flexibility. In the certainty case with MAC_E as the true cost of abatement curve, Q_E is the appropriate

[16] Nicholas Stern, *The Economics of Climate Change: The Stern Review,* page 312.

cumulative quota, while T_E is the equivalent tax. But if MAC_E represents the expected costs of abatement and MAC_{REAL} the higher ex post actual costs, the efficiency loss implied by setting the tax at T_E (the blue triangle) is now much larger than that implied by setting the quantity of tradable allowances at Q_E."[17]

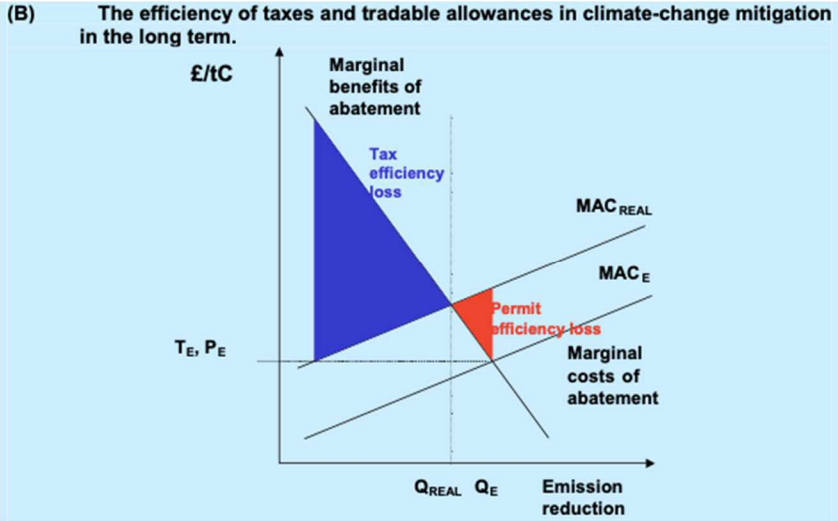


Fig. 4 (source: *The Economics of Climate Change*)

This divergence between short and long period marginal cost and marginal benefit curves raises the dilemma of how to connect a tax-like regime in the short-run with a quantitative limitation in the long term. In general, a long-term stabilization target should be utilized to set a quantity ceiling to limit the stock of carbon and reduce the risk of catastrophic damage over the years. Consequently, short-term policies instruments such as tax or trading scheme must be consistent with the long-term stabilization objective, without defining too rigid constraints that will result in extremely high abatement costs. For that matter, in order to reduce the costs of meeting these goals, it is crucial to embody flexibility in when, where and how reductions are made. Policies should be tailored to evolving situations as the costs and benefits of climate change become more transparent over years. This implies a constant reassessment of the short-term policies to integrate more recent information, as and when it comes, so as to carry on actions towards meeting the long-term objectives.

[17] Nicholas Stern, *The Economics of Climate Change: The Stern Review,* page 313.

To be defined successful and effective, a carbon pricing policy must be built on a structure that enables shareholders to have confidence that the carbon strategy will be maintained over the future years and that at the same time must display key elements such as credibility, predictability and the before-mentioned flexibility.

Having a long-term view on the carbon market is considerably important for businesses and their investments in long-lived assets that last for several decades like power stations and industrial plant, because if there is the belief that carbon taxes are likely to increase in the long run to match the damage costs of polluting emissions, with the purpose of remaining competitive, companies have to switch from high-carbon to low-carbon assets.

Obviously, the sectors' environmental response varies widely in accordance with transaction costs, carbon leakage[18], distributional impacts and existing frameworks. In fact, heavy industry[19], due to its high carbon intensity, is highly sensitive to carbon pricing since future policies' directions are critical to drive investments in long-lived capital infrastructure.

3.3.1.1 A PRACTICAL EXAMPLE: NORWAY

In the early 1990s, many Scandinavian regions, including Norway, introduced a carbon tax with the purpose of complying with environmental goals. Taxation, meant to be an effective instrument providing large price predictability, embraced the majority of the heavy industry[20] as well as the transport sector and was designed for a massive shift in fiscal policy as Norway intended to use the environmental tax revenues to lower the distorting labour impositions.

The assessment indicated that the revenues from carbon policy represented the 0.7 percent of total revenue in 1993 and the 1.7 percent in 2001, with estimated CO_2 reduction of approximately 2.3% in

[18] It refers to the scenario that may take place if, for cost-related reasons, companies were to move production to different countries with less strict emission constraints. This action may lead to an increase in the overall GHG emissions.

[19] For example, it includes sectors like iron and steel, cement, aluminum, paper, chemical and petrochemical.

[20] At first, the carbon tax covered 60 percent of all Norwegian energy related CO_2 emissions, with plenty of exemptions for cement, foreign shipping, fisheries, domestic aviation, pulp and paper sectors. Similarly, also natural gas and electricity production were exempt, although all Norway's electricity output is substantially from carbon-free hydroelectric power.

1990-1999 period. Moreover, in the same period, the Norwegian GDP increased by almost 23 percent with emissions growing by roughly 4, implying a decoupling of emissions growth from economic growth.

Remarkably, evidences showed that environmental policies stimulated technological innovation. For instance, taking account of the Sleipner case, one of the largest gas fields in the Norwegian sector of the North Sea. Its gas incorporates a higher CO_2 amount than is needed for the gas to burn properly and with the introduction of the carbon tax, the Statoil's[21] annual tax bill amounted to more or less $50 million. For this reason, Statoil researchers have been encouraged to study the storing of excess carbon dioxide in a nearby geological formation and after several years of study, a commercial plant was placed on the Sleipner platform. Ultimately, the research led to a significant contribution to the understanding of carbon capture and storage technology.

However, some difficulties in the implementation of the tax such as competitiveness concerns, taxation level for different sectors and approach harmonization within the Scandinavian area underlined the complexity of proper policy design and international coordination.

3.3.2 TECHNOLOGY POLICIES

Mitigation of greenhouse gas emissions will require the massive deployment of low-carbon and high-efficiency technologies on a worldwide scale. Even if plenty of technologies are already available, often the issue is represented by the superior costs of low-carbon solutions compared to fossil-fuel-based options.

A universal shift to sustainable technology is needed, especially in cardinal sectors such as power generation, transport, energy use and agriculture and even if a stronger partnership between governments and industry increases the likelihood of more effective actions, the private sector plays the major role in technology spreading and in R&D activities.

[21] The Norwegian state oil company.

Alongside private activities, governments, in addition to carbon pricing, should support the emission cut on the scale and pace required through:

- Improving the assistance for R&D and demonstration projects, both in public and private organizations;
- Expressing support for early phase commercialisation investments.

At the same time, profit-maximising companies would react to the establishment of the path of carbon prices by adapting their research and development strategies in order to reduce the costs of technologies and collect returns in the future. The understanding of this process is needed for the implementation of policies aimed to stimulate firms' investments.

Innovation, essential in lowering the financial efforts of new technologies, is meant as the successful development of new ideas and four types of them can be detected in relation to technological change:

1. *Incremental innovations* embody the constant improvements of existing products through upgraded quality, design and performance, as happened with car engines;
2. *Radical innovations* are brand new creations that give rise to a substantial change from previous production methods, such as hybrid cars;
3. *Changes in the technological systems* take place at the system level when several radical innovations impact on more branches, as would occur in a transition to a low-emission economy;
4. *Changes of techno-economic paradigm* happen when technology alteration affects every sector of the economy, the internet is an example.

The stages of the innovation process detected by Schumpeter[22] are three and are refer to the first practical demonstration of the new idea, the commercial implementation and the diffusion throughout the market. The typical diffusion trend of the new technology is outlined by an S-shaped curve, in

[22] Joseph Alois Schumpeter (1883-1950) was an Austrian political economist, amongst the most influential of the 20th century.

which the spreading begins slowly, then takes off achieving a phase of rapid diffusion and ultimately decelerates progressively as saturation levels are reached.[23]

More in detail, as exhibited below, experience curves say that new technologies may not become cost-effective until significant investment has been performed and experience gained, with the majority of firms waiting for the innovator to proof the innovation's profitability to enter the market.

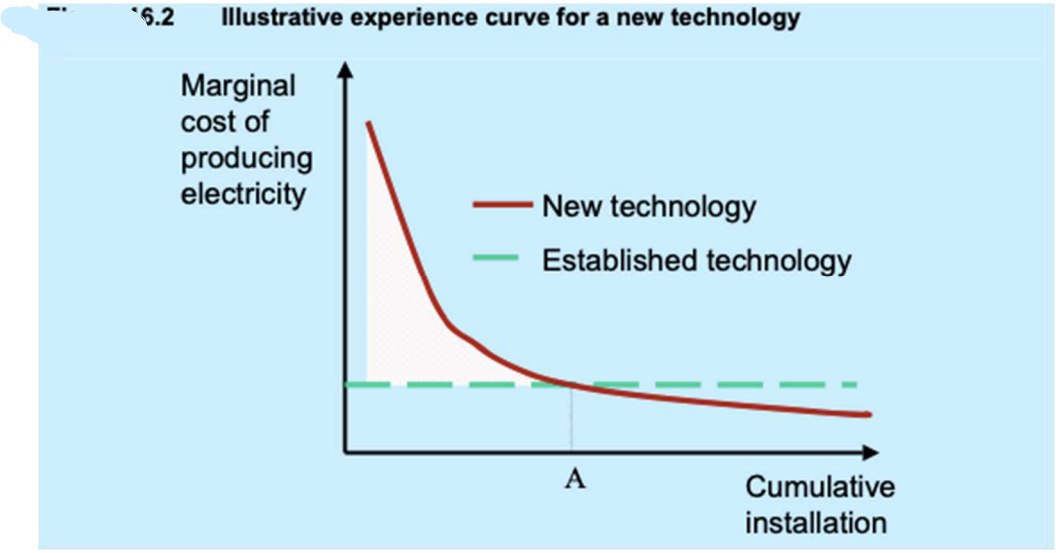


Fig. 5 (source: *The Economics of Climate Change*)

In this diagram, the market dominant technology that has already been through a process of learning is delineated by the green line, the red line describes the innovation's trend and the white area represents the learning cost of the new technology, which is how much more the innovation costs than the established technology. As production augments the new technology expense decrease because of dynamic increasing returns, with the innovation ultimately becoming cheaper than the old technology below point A. However, as occur in some sectors, the time before the innovation turns competitive might be decades with consequent high learning costs. In such a case, additionally to uncertainty over the future pricing of the carbon, businesses operating in the private sector and

[23] The theory is valuable as simplification of the development stages model, but it fails to catch many issues of the innovation process, since many products fail at each phase and the transition between the stages is not automatic.

financial institutions may be unwilling to make investments, which will result in no technology development, especially if there is a likely free-rider problem.

The latter issue may result in a significant investment aversion since information is a public good. In fact, once a new information has been released and it is practically costless to pass on, the firm that generated the intellectual property in the first place may be unable to fully benefit of its investment in R&D. The direct response to this problem is the application of private property rights through patenting, but that in turn may delay the innovation path by preventing companies from building on each other's progress, particularly if patenting is rigid.

Focusing on environmental innovations[24] in two major industries like power generation and transports, the matter is whether there are reasons to expect higher barriers than in other fields.

3.3.2.1 POWER GENERATION

Market failures and barriers slow down research and development in the power generation industry, which is one of the key sectors to decarbonise by at least 60% by 2050 to keep on track the greenhouse gas mitigation trajectories outlined by the Paris Agreement.

Statistics display a sector characterised by low levels of R&D investments and taking U.S. as an example, even if the public R&D represented around two thirds of the total R&D expenditure, the intensity[25] of the power sector was just 0.5% compared to the other main fields like car industry (3.3%), electronics industry (8%) and pharmaceutical sector (15%).

As a result, data on energy research and development expenditure exhibit a downward trend in both the public and private sector in the past decades:

[24] Defined as low-carbon technology innovations that either control pollutant emissions or improve the production processes aimed to lower or prevent emissions. Their main purpose consists in maintaining the 'public good' of a clean environment.

[25] R&D as a share of total turnover.

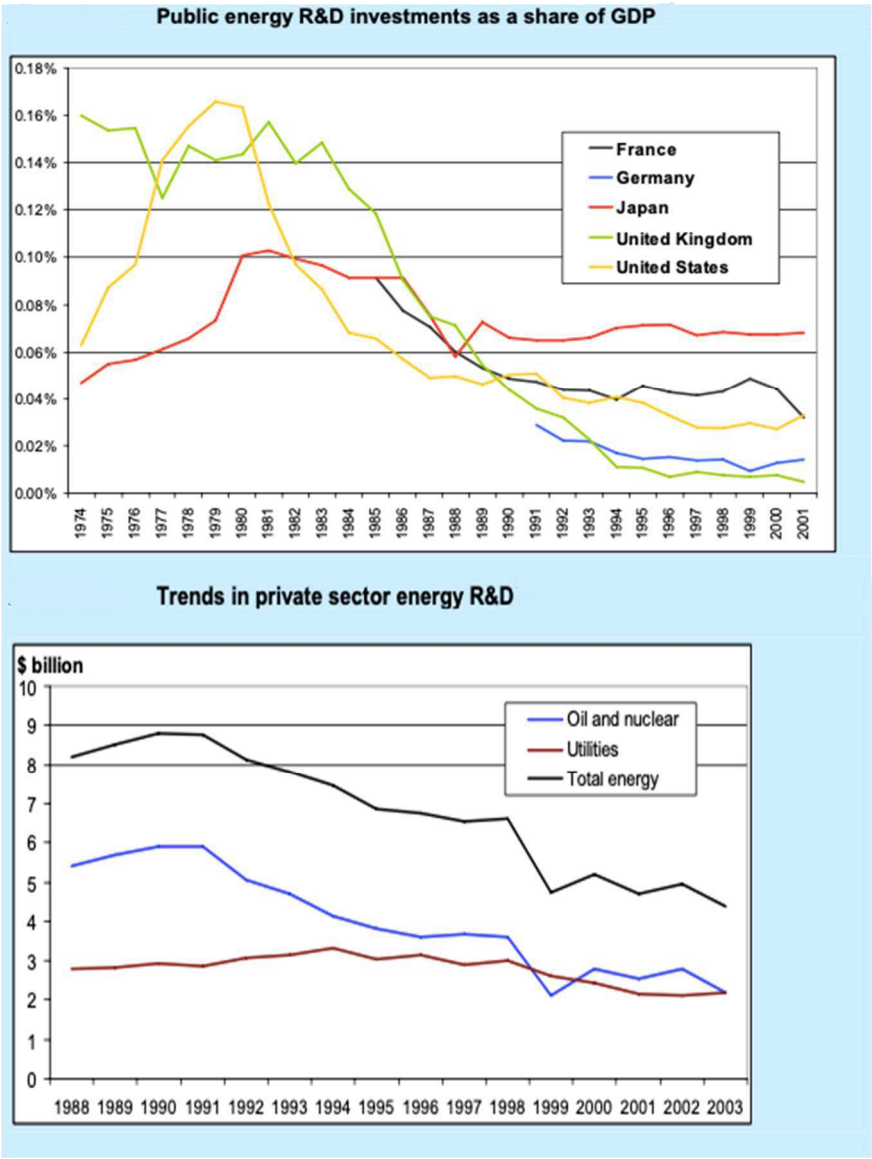


Fig. 6 (source: *The Economics of Climate Change*)

Three major elements negatively outlined the decline in public and private R&D expenditure:

- In 1970s, energy R&D budgets, considerably expanded in response to the oil price crisis, aimed to look for alternative solutions to imported oil. Then, with the oil price drop in the 80s and the low prices during 90s, concerns about energy security decreased with a consequent relaxation of the R&D effort;

- As result of the energy market liberalisation in the 1990s, businesses reversed the focus from long-term strategies such as R&D into the exploitation of already existing plant and less risky well-developed technologies;
- After the experience of many countries with cost over-runs, concerns about reactor safety and nuclear waste disposal, a significant decline have been experienced by R&D expenditures on nuclear.

Even if these statistics can be read in different ways, the overall assessment suggests that private returns to R&D are relatively low in the power generation sector. Firstly, it is due to the nature of the learning process. In fact, historical evidences say that the learning process commonly takes several decades before they become commercially profitable. The second issue concerns infrastructure because national networks are typically adapted towards the operation of centralised power plants, consequently favouring their performance. Innovations that do not easily fit into these networks may have problems to enter the market, even if the technology itself is commercially competitive. Similarly, many structural policies distort the market in favour of existing fossil fuel solutions. Last but not least, the nature of competition within the energy markets with a limited number of operating firms, sometimes only one, may not stimulate new firms to compete. And no competition usually results in less innovation as there is no concern to stay ahead of competitors.

All these factors may not only discourage the process of developing new technologies but also negatively impact the effectiveness of policies to control the carbon externality.

3.3.2.2 TRANSPORT

As 2010, the transport industry, being the largest growing source of emissions because of constant increase of car transport and rapid growth of air transport, constituted 14% of global pollution. The steady progress in the combustion engine from a century of learning by doing, the proficiency of fossil fuel as an energy source and the availability of an oil distribution network culminated in consumers' confinement in existing high-carbon technologies.

Alternative solutions such as electricity or hydrogen may require plenty of time and a massive structural change, the cost of which is unlikely affordable without incentives provided by governments since just a small number of big corporations have the financial capacity to make serious R&D investments for sustainability. Highly efficient and almost silent in operation, electricity and hydrogen solutions for transport may provide the total diversification away from fossil fuel, producing as little as 5% of the emissions from conventional high carbon sources.[26]

Obviously, the environmental outcome of alternative transports will rely on how production is organized because if electricity and hydrogen is generated from high carbon sources the benefit would not be sufficient. In addition, the improvements in sustainable technologies in the road transport sector are preparatory for emissions' stabilisation in other key transport solutions such as aviation, railway and maritime industries with differences in capital stock and adaptation. In fact, since ships, planes and trains last many times longer than automobiles and weight and safety are major concerns, an early commercialisation in these industries is unlikely and is highly dependent on advancements in other areas first.

Substantial behavioural changes should be encouraged, for example, by pricing congestion, intelligent infrastructure and high fuel taxes. This may lead to higher incentives for the implementation of more efficient transport solutions and to an important positive trend of consumers pleased to pay a premium for an eco-friendly and more fuel-efficient good.

[26] Many global hydrogen projects took place and are projected to occur:

- plans for a 580km hydrogen corridor between Oslo and Stavanger in a joint project between the private sector, local government and non-government organizations. The first hydrogen station opened in August 2006 (Norway);
- first hydrogen fueling station in April 2003 and it is proposed that Iceland could be a hydrogen economy by 2030 (Iceland);
- trial of hydrogen buses (Europe);
- hydrogen buses used at the Beijing Olympics in 2008 (China);
- plans to introduce hydrogen in 21 interstate highway filling stations (California).

3.3.2.3 GOVERNMENT INTERVENTION

Innovations are unpredictable. Some of them will prosper and other ones will crash. By its very nature, the market usually tends to push forward the least-cost short-term solution, sometimes ignoring technologies that could ultimately provide enormous cost savings in the long term.

The most effective remedy to uncertainty experienced in many others investment areas, that also drives short and long period decisions, is the design of a technology portfolio enforced by government interventions such as carbon pricing and R&D incentives aiming to bring low-emission solutions to commercial viability. For reasons of individual technologies' constraints, a portfolio is required for the emissions reduction in key sectors and at the right magnitude, but as a countereffect, with the development of the portfolio arises high learning cost for more technologies.

The role of the public institutions here is to offer a reliable and transparent policy framework to positively drive the investments of the private sector also through the realization of an effective deployment strategy that delivers a competitive market in which firms are stimulated to innovate.

Deployment support is necessary to soften capital market failures and imprisonment in high emission technologies that typically preclude the development of potentially low-cost alternatives. The mechanism of deployment incentives, without which the market may never adopt the cheapest and more efficient innovations, exists throughout the World[27] and takes different forms:

- *Fiscal incentives* including grant[28], energy production payment[29], rebate[30] and tax reduction applicable to the purchase or production of renewable technologies;
- *Public finance* embracing investment[31], guarantee[32], loan and public procurement[33];

[27] For instance, in recent years, China and India have both fostered wide-scale renewable deployment and now have respectively the largest and fifth largest renewable energy capacity worldwide.
[28] Monetary assistance, conditional upon certain requirements, that does not have to be repaid to the public authority.
[29] Direct payment provided by the government per unit of renewable energy produced.
[30] One-time direct payment granted to a private institution to cover a percentage of the investment in renewable energy system.
[31] Financial support provided in return for an equity ownership interest in a renewable energy company or project. Typically delivered as a government-managed fund that directly invests equity in projects and companies.
[32] Risk-sharing system aimed at stimulating domestic lending from commercial banks for renewable energy companies and projects that have high perceived credit risk. It usually covers 50-80% of the loan.
[33] The purchase of renewable energy services and equipment is carried out by public entities.

- *Regulations* such *as* quantity-driven renewable portfolio standard[34] and tendering[35], quality-driven green labelling[36] and price-driven fixed payment feed-in tariff (FIT)[37].

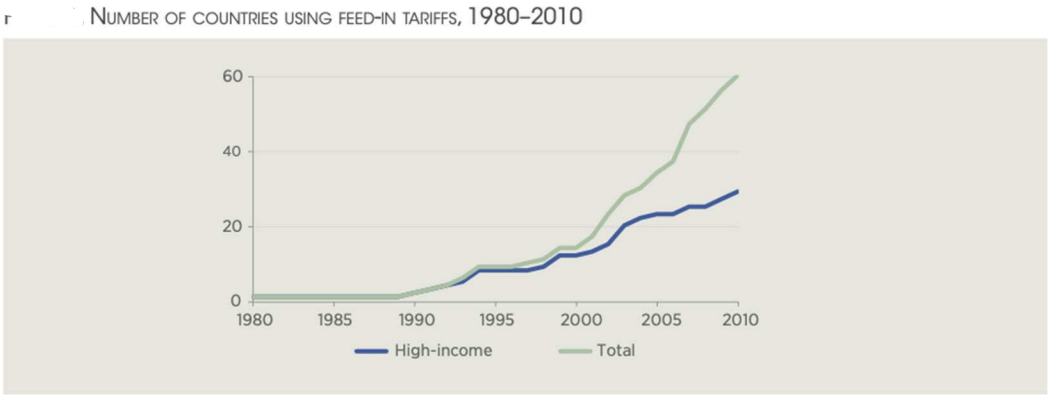


Fig. 7 (source: *REN21, 2012*)

As displayed by the graphic, the amount of countries using FIT is constantly increasing. Germany is one of those countries and decided to promote the deployment of wind, biomass, hydropower, geothermal and solar photovoltaic to meet, by 2020, a 20% renewable energy use over the gross electricity consumption. The level of support for deployment amounts to €2.4 billion and differ depending on size and technology type with solar energy receiving between €0.457 to 0.624 per kWh and wind €0.055 to 0.091 per kWh. Once the technology is developed the price rate is guaranteed for 20 years;

- *Access policies* including priority access to network that provides renewable energy supplies with unrestricted access to established energy networks.

Even if are the consumers the ones who generally pay for the cost of deployment policies in the form of higher prices, strengthening existing deployment incentives is crucial for the private sector to build and distribute low-carbon technologies with consequent overall cost reductions in the forthcoming years, both in terms of money and environment.

[34] Obligates involved parties to meet minimum renewable energy targets such as mandatory installation of a certain amount of sustainable heat or power technologies.
[35] Public entities organize tenders for given quota of renewable energy supplies or supply capacities and remunerate winning bids at prices mostly above standard market levels.
[36] Government-sponsored labelling aimed to guarantee that energy products meet certain sustainability criteria to facilitate voluntary green energy purchasing.
[37] Ensures renewable energy supplies with priority access and dispatch with a fixed price varying by technology per unit delivered during a specified amount of years.

Even more importantly, the government has the crucial role in funding education, skills, basic knowledge creation and training of scientists and engineers with new generations requested to work on energy-technology research and development during at least the next 40-50 years to stabilise GHG emissions and also in inspiring young people to develop a deeper interest in science. In some countries, financial support has experienced a "roller-coaster" trend and to permit the research base to flourish, the funding of these activities should avoid volatility. In fact, evidences show that high variability between years has made it harder for laboratories to attract, educate, and maintain human capital and that has reduced investors' confidence in the potential returns of private R&D. In avoiding volatility, public institutions should allocate public R&D funds relying on the precious peer review process and this should incorporate post-project assessments and review to take full advantage of the research.

3.3.3 REMOVING BARRIERS

As we said, effective carbon markets and technological R&D support and spreading are essential in providing incentives to firms and in strengthening their mitigation activities. Nevertheless, even if they are performed, barriers and market imperfections may still prevent the achievement of the necessary size of investment and behavioral responses.

It is important to understand that behavior is driven by many factors and not just by financial costs and benefits, in fact, consumers and businesses repeatedly do not make investments that appear rational and cost-effective, explaining sometimes the weak take up of efficient energy solutions. This implies the presence of, at least, three more potentially larger set of costs, barriers and market failures that obstruct rational decisions and behavior:

- Alongside financial reasons, there are *hidden costs and benefits* such as the cost of the time required to design new investment strategies compensated by benefits such as lower risk exposure to energy price volatility or reputational gains from displaying environmental responsibility;

- Reliable, reachable and understandable information is crucial in enabling businesses and consumers to make conscious economic decisions. Hence, *lack of information* is a threat. That is the case of people not investing in more energy efficient technologies because have higher initial costs but that result much cheaper in the long-term;
- *Behavioural and motivational factors* affect individuals and firms, especially those ones that are not able to make decisions involving elaborated and uncertain outcomes such as determining the value of energy savings over the long period. As a result, they typically make decisions which simply meet their current needs rather than performing difficult analysis to establish the best possible decision. In such situations, social and institutional standards strongly influence the decision-making process, because people behave in response to social habits and expectations. This path dependency should be exploited by public policies conceived to raise efficiency and to stimulate fuel switching.

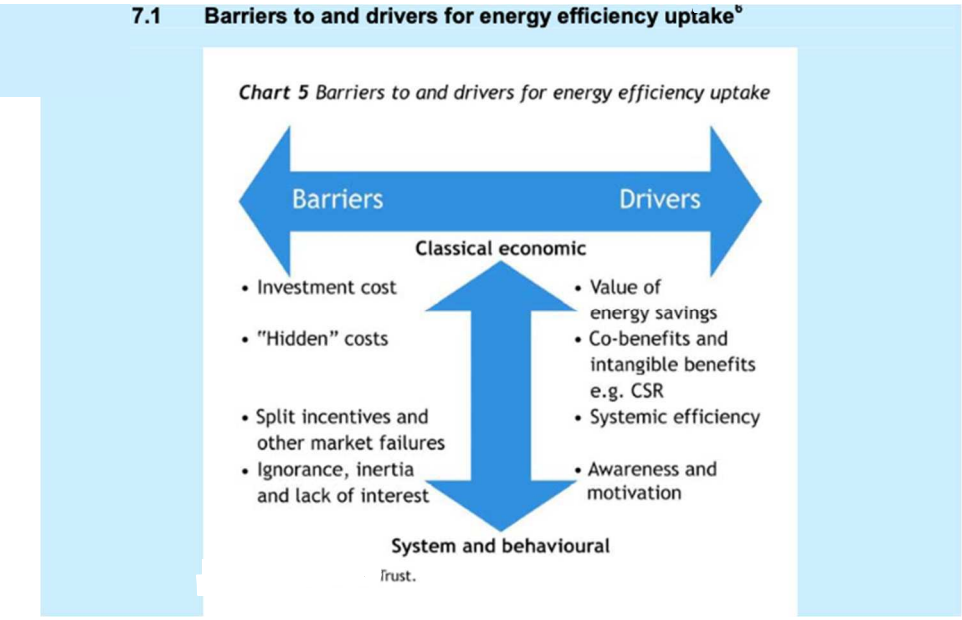


Fig. 8 (source: *The Carbon Trust*)

As will be explained in the next paragraphs, these market deficiencies resulting in substantial deterrent to the uptake of cost-effective innovation may be overcome by policy responses.

3.3.3.1 REGULATION

Regulatory measures have a significant role in constructing effective markets through disclosing policy objectives to the public, diminishing uncertainty, complexity and transaction costs and stimulating investments in innovation to avoid imprisonment in high emission technology. They may represent a successful response to inevitable market imperfections, sometimes complementary to tax or trading instruments, and other times even more effective and efficient, precisely when they:

- Lower the complexity faced by clients or companies removing inefficient or polluting technologies from the market supply;
- Reduce the investment-related transaction costs;
- Encourage competition and technological innovation by reporting policy intentions;
- Foster efficiency through strategic coordination of key sectors;
- Prevent capital stock lock-in, in particular in those industries like construction and power generation that are subject to lengthy capital replacement cycles.

Regulation determines a value on reducing pollution that can be computed by dividing the cost of the measure by the estimated savings in greenhouse gas emissions.

3.3.3.2 INFORMATION

Strategies aimed to spread information amongst individuals may achieve a number of purposes. Firstly, they offer people a fuller picture of the financial and environmental consequences of their choices, inviting them to take responsible actions. In the second place, through performance indicators and labels, information policies stimulate and deliver the framework for market innovation and competition in eco-friendly goods and services. Next, they may also reduce investment-related transaction costs by providing information on the energy use features of distinct products or processes.

Information policies can take three main forms on potential market applications:

1. *Labels, certificates and endorsements* increase the awareness of energy costs in investment choices and support sustainable procurement policies. Typically, the energy use, costs and environmental effects of purchasing decisions have low visibility, but where such labels exist, the impact on consumer behavior is considerable. In fact, especially in the energy sector, these instruments encourage more responsible purchasing choices, by enabling people to make comparisons between competing products on the basis of their environmental impact. As an example, the introduction of a European labelling scheme on refrigerators is calculated to have induced one-third of the 29% improvement in the energy efficiency of refrigeration goods between 1992 and 1999;
2. Periodic and accurate *energy billing*, as well as *displays* and *smart meters* are able to support conservation among energy users and cut the operating costs of utilities. More in detail, bills which show historical patterns of electricity consumption and hence allow the comparison with similar household or company, are potentially effective in boosting a response. Similarly, energy displays notify users on real time consumption levels and related expenses, while smart meters deliver sophisticated energy price and cost information. A deeper energy supervision, allow suppliers to apply a higher price for peak-time consumption that generally results in load shifting and reduced base load like exhibited by trials in California, where reductions in peak period energy use amounted between 8% and 17%;
3. *Best practice dissemination* inspires individuals and businesses to reach energy efficiency through benchmarking[38]. Considering the construction sector, a large amount of poor quality and inefficient buildings are built despite the availability of a wide range of cost-effective technologies and design methods, mostly because of high costs and coordination issues of several construction elements. Since the long-term environmentally efficiency of a building is considerably determined by choices made at the design stage, the UK Carbon Trust set an

[38] It is the practice of comparing a business processes and performance to the industry standards on dimensions such as quality, time and cost.

example. In fact, an independent but mainly publicly funded firm offers a range of advisory services to business of all dimensions, allowing every organizations to take advantage of up-to-date information with potential gains in terms of buildings cost-efficiency.

3.3.3.3 FINANCING

Successful financing policies addressing market barriers may intensify a wider adoption of energy-efficient technologies in both private and public sector.

Although is the private sector to play the major role in R&D investment aimed to increase efficiency, the governments have a limited but crucial function in supporting this, through the introduction of financial incentives such as loans, subsidies, and tax rebates, in particular where:

- *Capital market failure* forces households or companies to cope with an inadequate access to capital. This issue is particularly significant for poorer families and firms in developing countries and also for large private infrastructure investment;
- *Technology market failure* may lead firms to face high long run technology costs. To address this problem, for example again considering the construction industry, public policies can provide a direct support for next generation lighting technologies that reduce the overall polluting emissions of the buildings, with consequent possibilities for the sector to reach economies of scale markets;
- These financial supports can produce opportunities to *deliver wider climate-related or social policy objectives*. For instance, in supplying economic incentives on building insulation, it can also be possible deliver information on a larger range of innovations such as advanced window glazing or lighting control systems.

Examples in which such of financial incentives provided by public entities, non-governmental organizations or energy distributors have achieved significant energy savings is represented by US demand side management programmes that spared around $1.78 billions of energy in 2000 and the

British Carbon Trust that allows interest-free loans to small and medium companies to purchase energy efficient equipment.

Concerning investments in energetic efficiency, the public authority, as stated above, has a crucial function because it may both cut emissions and save public money. In fact, since public structures are usually the largest energy users within an economy, there is a massive opportunity for cost-effective energy conservation across public buildings and state-owned industrial facilities. For instance, the public industry releases more or less 11% of the UK's total carbon emissions, and it is calculated that more than 13% of this could be saved in a cost-effective way. However, even if increasing the public energy efficiency is an important concern, many of the barriers outlined above for the private sector are faced also by the public sector.

3.3.3.4 RESPONSIBLE BEHAVIOR

It is crucial to understand that individual choices represent a particularly important in environmental issues with extreme climatic events that cannot be avoided solely through high level international agreements.

Evidence, education, persuasion and discussion are important tools in promoting a shared awareness of the nature and consequences of climate change and its solutions. They are essential in both affecting individuals' behavior and preferences, especially in the perspective of their housing, transport and food consumption choices, and in strengthening national and international political action and engagement.

In particular, governments should mostly concentrate on encouraging responsible behavior and on promoting the willingness to cooperate as a community, respectively providing policies towards pensions, smoking and recycling, and sustaining neighborhood watch schemes on crime and community services. However, the acceptability of persuasion needs a shared public discussion, as crude attempts by public authorities to tell people what's best for them are likely to be rejected, and in any case bring up ethical issues. This required dialogue may involve many actors such as public

sector, communities and individuals, non-governmental organizations, mass media and companies, and must bring to public attention the concerns of those parties that are usually ignored, such as future generations and citizens of poorer regions.

Anyway, as suggested by evidences, a significant percentage of people defines the climate change topic as confusing, and to address this issue, an effective dialogue creates the conditions for more responsible behaviors by underlining the potential for action using simple, positive messages, by targeting groups that share values and by involving individuals and community leaders to spread key messages that can engage people.

In order to grow into a mass phenomenon, schools play a key role in educating individuals from an early age about how our decisions impact the environment. In such sensible life moments, responsible behavior may be boosted through creative and practical activities that may help children to translate the understanding of climate change into actions in their quotidian lives.

3.4 CLIMATE JUSTICE

Climate change is the biggest negative externality produced and never addressed by the humankind that is leading to dissimilar effect not uniformly distributed across countries.

"Justice is generally understood to mean that which is right, fair, appropriate or deserved, with justice being achieved when an unjust act is redressed. Within the context of climate change this means that the poorest countries and people should be supported by those who have contributed most to climate change."[39] As a fairly recent notion, climate justice aims to connect human rights and development in carrying out a human-centered approach that defends the rights of the most exposed communities and shares the burdens and benefits of mitigation and adaptation to climate change in a fair way.

It takes just few seconds to understand that developing nations are more likely to disproportionally suffer the negative impact of global warming, not only because they typically face warmer climates

[39] https://www.mrfcj.org/pdf/Geography_of_Climate_Justice_Introductory_Resource.pdf, seen April 22, 2020.

than developed countries, but also because they deeply rely on climate sensitive industries such as agriculture, forestry and tourism, and as weather becomes warmer, areas such as Africa will experience lower crop yields and will firstly strive to provide enough food for domestic consumption, and then it will not be able to meet exports' demand.

Since underdeveloped countries are usually less likely to produce resistant harvests due to research funding constraints, the gap between the two groups will further increase if advanced countries are able to neutralize the fall in agricultural yields with new domestic sources.

Identifying climate change as a global phenomenon affecting economic, fiscal and external elements, Standard and Poor's performed a research in which the disproportional distribution of climate change effects has been underlined. Assessing the countries' vulnerability and ability to cope with adverse effects on three conditions[40], Figure 9 below exhibits the results on a world map, with many developing countries resulting to be more threatened by global warming.

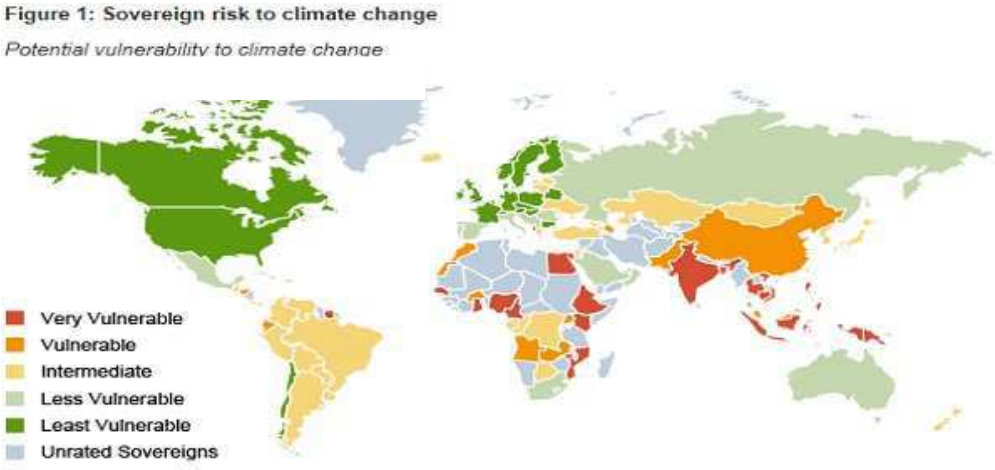


Fig. 9 (source: Standard and Poor's)

Poor communities, especially [illegible], are the most exposed to storms and extreme climatic events, with the outcomes of agricultural crops and fisheries expected to move toward the richer poles in the next decades. In addition, their buildings and infrastructures are generally weaker and they have less savings or insurance to turn back on when calamities strike.

[40] A) Share of the population living in coastal areas below five meters of altitude; B) Share of agriculture in national GDP; C) Score from the "vulnerability index" delivered by the Notre Dame University Global Adaption Index.

Even if subject to a physiological uncertainty, mostly due to the extent of adaptation policies, estimates show that underdeveloped nations got hit with 78 percent of the cost of climate change in 2015, with a projected 87 percent by 2035.

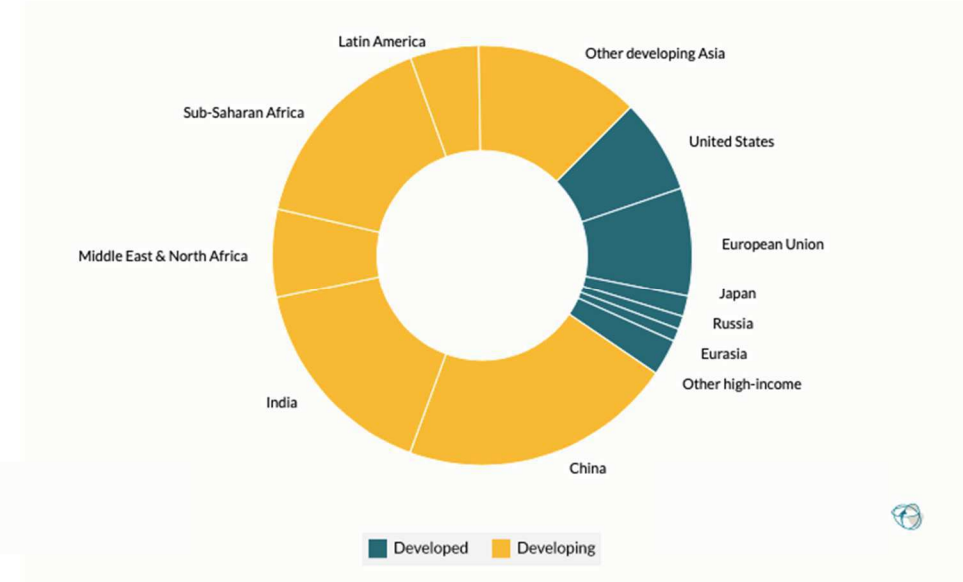


Fig. 10 Who's hurt by climate change?
(source: cgdev.org)

Historically, increasing wealth has been strictly tied to growing industry, energy usage, and CO_2 emissions. This correlation may only now be gradually starting to decouple. For instance, in 2014, the UK's emissions declined by 8.4 percent while its economy grew by 2.6 percent and on average, the global economy augmented by 3 percent while GHG emissions flatlined. Nevertheless, as illustrated by Figure 11, developed countries are recognized to be responsible for having generated 79 percent of the emissions from 1850 to 2011, with this unbalanced historical concentration of emissions representing the major issue of current international climate negotiations. In fact, the Kyoto Protocol required just to industrialized nations to cut emissions and the exclusion from this constraint of rapidly growing countries like China and India resulted in the U.S. missing ratification, more concerned about the economic leadership rather than the environment. The truth is that in recent years, while advanced nations still produce a massive amount of emissions, developing countries are increasingly doing so as well.

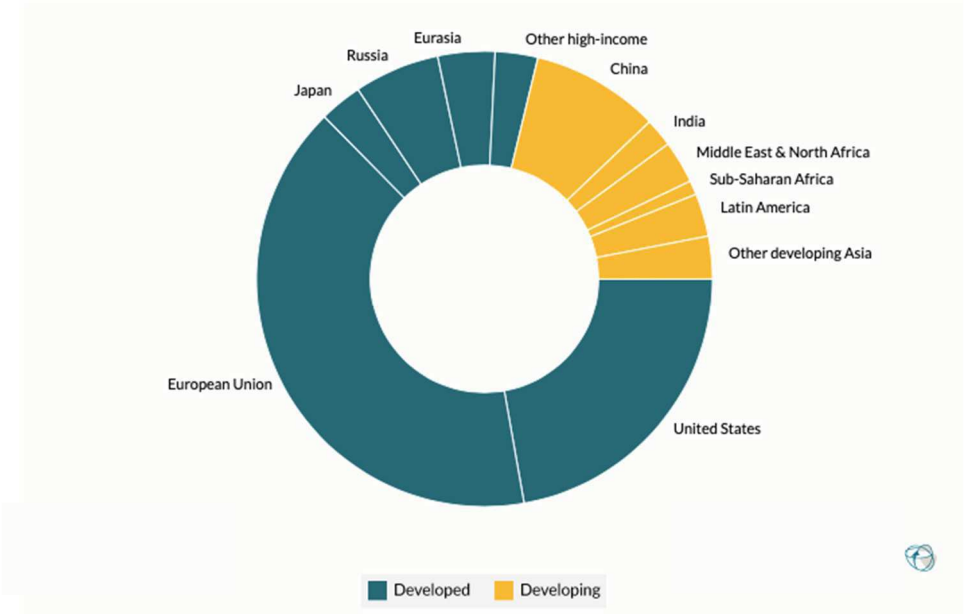


Fig. 11 Who caused climate change historically? (source: cgdev.org)

Nowadays, 63 percent of yearly emissions are generated by emerging countries. In fact, if in the one hand, the industry, energy, and wealth are gradually improving in the developing world, the side effect is represented by the amount of carbon emissions produced[41].

This balancing of the emissions bases ironically raised the likelihood for international cooperation, because the more countries are polluting, the more countries contribute in looking for cost-effective and politically satisfactory agreements.

[41] Differently from industrialized nations, a much bigger share of emissions in developing countries comes from deforestation, more than 1/5 of emissions from Latin America in 2011, nearly 1/3 of emissions from sub-Saharan Africa, and 2/5 of emissions from Southeast Asia.

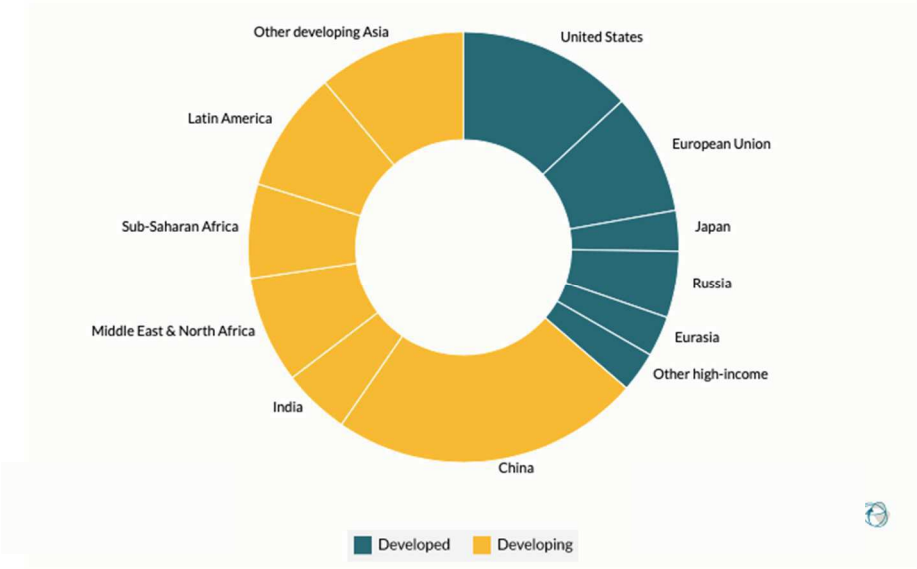


Fig. 12 Who's causing climate change now?
(source: cgdev.org)

As stated above, the U.S. complained about the unfairness of the required emissions reductions outlined by the Kyoto Protocol, but at the same time "forgot" to mention that the emerging countries are not the ones who have polluted for the past 150 years and that they, as much as other developed countries, accepted the UNFCCC principle "common but differentiated responsibilities".

It is therefore unreasonable to expect the developing countries to make radical reductions, especially if considering that their growth and consumption is generally for basic needs, while for advanced ones, it often concerns unnecessary and luxury lifestyle. In accordance with a 1999 NGO's review, since the early 1900s, it has been estimated that every living American citizen is accountable for more than 1,050 tonnes of CO_2, while a Chinese and an Indian respectively for 68 and 25 tonnes, with an important share of emissions said to be from underdeveloped countries, when the reality is that there are plenty of foreign corporations out-sourcing the production to these low-wages countries, and then globally export the products.

Martin Khor[42], in a technical review on historical emissions accountability, assumed by 2050 600 gigatons of polluting emissions as the limit that should not be exceeded so to avoid irrecoverable

[42] Martin Khor Kok Peng (November 9, 1951-April 1, 2020) was an important UN Secretariat member since 1997, and executive director of the South Centre, an intergovernmental organization of developing nations, from 2009 to 2018.

environmental effects. Highlighting that developed nations have already had their opportunity to develop and emitted more than how much was fair, he defined an equal allocation of emissions built on per capita emissions, considering the historical emissions background of both industrialized and underdeveloped countries. Substantially, a fairer distribution, characterized by the emerging countries' growth, is possible just if rich nations take significant steps back.

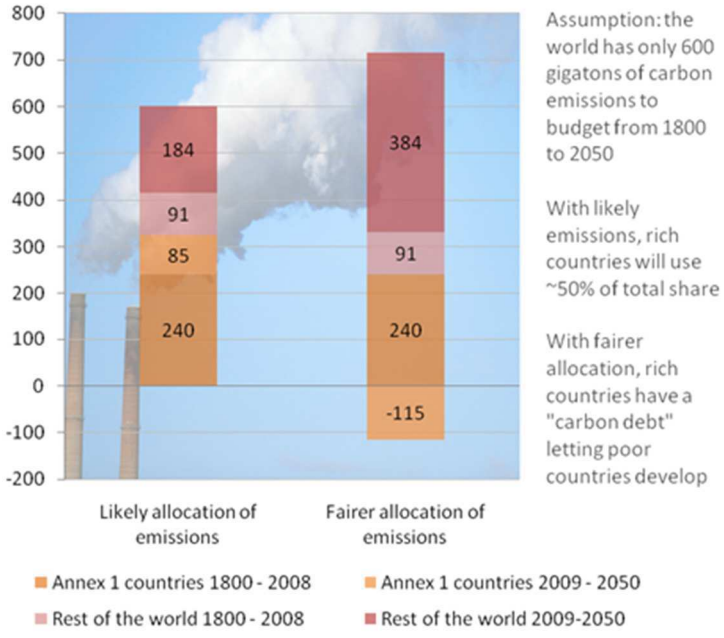


Fig. 13 Breakdown of carbon emissions allocation, 1800-2050
(source: Martin Khor, South Centre, June 2009)

Even if the main issue remains the willingness to seriously commit, climate justice may be delivered through:

1. *Procedural justice,* which stands for the involvement in the decision-making process of all those communities who have been victims and that are particularly vulnerable to global warming;
2. *Distributional justice,* that aims to guarantee a fair distribution of costs and benefits of addressing the challenge of climate change according to different responsibilities and abilities;
3. *Sustainability*, taking into consideration the needs of the next generations and non-human beings, basically all those who do not have a voice in the current decisions;

4. *Human rights reinforcement*. It is obvious that climate change is a threat to human rights, but the problem is represented by whether courts can apply existing law and legal precedent to address these violations. Governments, politicians, lawyers and the international community are the ones appointed to improve the situation;
5. *Corporations' accountability*. As said above, through subsidiaries and foreign suppliers, MNEs often evade carbon responsibility in the same way as they have always escaped human rights violations. To combat the problem, pollutant emissions should be traced right along the international supply chain, from sourcing to production to distribution to sale;
6. *A greener trade system*. It is crucial to ensure that trade regulations do not penalise climate actions such as low carbon trade policies in favor to high carbon technologies.

All these valuable theories to make a change will be always easily vanished as long as our thought will be: "Just between you and me, shouldn't the World Bank be encouraging more migration of dirty industries to the Less Developed Countries? The economic logic behind dumping a load of toxic waste in the lowest wage country is impeccable, and we should face up to that. Under-populated countries in Africa are vastly under-polluted; their air quality is probably vastly inefficiently low compared to Los Angeles or Mexico City. The concern over an agent that causes a one in a million change in the odds of prostate cancer is obviously going to be much higher in a country where people survive to get prostate cancer than in a country where under-five mortality is 200 per thousand."[43]

Until we have such greedy thoughts climate injustice will prosper with plenty of painful stories of lives destroyed, extreme droughts, floods and typhoons, and families and whole peoples ripped away. *"Climate justice will never come from corporations or from schemes based on the market, because the market is what got us into this crisis in the first place."*[44], and it our moral duty to support those politicians and institutions who do not speak just for the big corporations but also for the underprivileged communities.

[43] Leaked internal memo written by Lawrence "Larry" Summers in 1991, as Chief Economist for the World Bank. He also was the US Treasury Secretary in the Clinton Administration.
[44] https://globaljusticeecology.org/climate-justice/, seen April 23, 2020.

3.4.1 ADVANCED AND EMERGING COUNTRIES: A STATISTICAL ANALYSIS

The International Monetary Fund formally separates the countries in two major groups, *advanced economies* and *emerging market and developing economies*, following key indicators of their relative dimension such as GDP valued by purchasing power parity, total exports of products, and population. The Advanced Economies amount to 39 countries and can be divided in the subgroups: Major Advanced Economies (G7), Euro Area and Other Advanced Economies.

At the same time, the category Emerging Market and Developing Economies embraces all those countries that are not ranked as advanced economies, and can be subsequently grouped in Emerging and Developing Asia, Emerging and Developing Europe, ASEAN-5, Latin America and the Caribbean, Middle East and Central Asia, and ultimately in sub-Saharan Africa.

This global classification is useful to comprehend what are the different characteristics of the two main groups and how they behave in the contribution to the climate change topic.

The main purpose of the following statistical analysis is to have a clearer understanding of the relationship between the greenhouse gas emissions and some of the variables considered in the past paragraphs of the thesis, so to establish the strength of the bonds, how it evolved through the years and how it may be possible to link the analytical results to the explained policies.

In order to perform a significant analysis that may answer more questions, I selected two samples of countries based on the data accuracy and availability (World Bank database), one for the advanced economies (34) and one for the emerging ones (32), and per each sample collected the data for 8 different variables in a 20-year interval 1996-2015, then performing a regression analysis for the two extremity years.

The chosen variables are:

1. *Total Greenhouse Gas Emission (in kiloton)* is the dependent variable of the study. This indicator displays trends in man-made emissions of the “Kyoto basket” of greenhouse gases including carbon dioxide, methane, nitrous oxide, and the so-called F-gases;

2. *Gross Domestic Product (in US $)* is defined as the market value of all the finished goods and services produced within a nation's borders in a specific time interval (independent variable);
3. *Population Density (per km^2)* is a measurement of a population per unit area given by dividing the total number of people by the country's area, in this case calculated in square kilometres (independent variable);
4. *Energy Use (kg per capita)* refers to the energy consumed by every person to perform an action, manufacture something or simply inhabit a building (independent variable);
5. *Renewable Energy Consumption (kg per capita)* is the per person energy used coming from sources that do not deplete or can be replenished within a human's lifetime such as solar, wind or hydropower (independent variable);
6. *Government Expenditure on Education (in US $)* refers to the total public funds invested in the whole sector embracing primary, secondary and tertiary education (independent variable);
7. *Research and Development Expenditure (in US $)* is the amount of public finances used for innovative technologies and developing services (independent variable);
8. *Environmental Tax Revenues (in US $)* are those taxes applied to activities that have a negative impact on the environment (independent variable).

Performing the analysis using Microsoft Excel, the regression function

$$\text{Total\_GHG\_emissions} = \beta 0 + \beta 1\text{GDP\_} + \beta 2\text{Population\_density} + \beta 3\text{Energy\_use} + \beta 4\text{Renewable\_energy\_consumption} + \beta 5\text{Government\_expenditure\_on\_education} + \beta 6\text{R\&D\_expenditure} + \beta 7\text{Environmental\_tax\_revenues} + \varepsilon$$

led to the following four results:

1) ADVANCED ECONOMIES – 1996

SUMMARY OUTPUT								
Regression Statistics								
Multiple R	0,995704911							
R Square	0,99142827							
Adjusted R Square	0,989120496							
Standard Error	118694,3317							
Observations	34							
ANOVA								
	df	*SS*	*MS*	*F*	*Significance F*			
Regression	7	4,23668E+13	6,05241E+12	429,603805	3,31532E-25			
Residual	26	3,66297E+11	14088344374					
Total	33	4,27331E+13						
	Coefficients	*Standard Error*	*t Stat*	*P-value*	*Lower 95%*	*Upper 95%*	*Lower 95,0%*	*Upper 95,0%*
Intercept	-80022,00707	59512,10054	-1,344634223	0,190357434	-202350,8817	42306,86755	-202350,8817	42306,86755
GDP (current US$)	1,56616E-06	2,88054E-07	5,437023175	1,06452E-05	9,74054E-07	2,15826E-06	9,74054E-07	2,15826E-06
Population Density (per km2)	-32,19586446	25,19341806	-1,277947454	0,212560262	-83,98167694	19,58994802	-83,98167694	19,58994802
Energy use (kg per capita)	33,79062496	15,9028312	2,124818188	0,043269693	1,101887281	66,47936265	1,101887281	66,47936265
Renewable energy consumption (kg per capita)	-48,54693697	29,52411668	-1,644314629	0,112150239	-109,234628	12,14075401	-109,234628	12,14075401
Government expenditure on education (current US$)	1,11773E-05	2,67723E-06	4,17494365	0,000295863	5,67416E-06	1,66804E-05	5,67416E-06	1,66804E-05
Research and development expenditure (current US$)	-3,73813E-05	6,54573E-06	-5,710801068	5,20772E-06	-5,08363E-05	-2,39264E-05	-5,08363E-05	-2,39264E-05
Environmental tax revenue (current US$)	-3,79315E-05	3,43396E-06	-11,04599338	2,56859E-11	-4,49901E-05	-3,08729E-05	-4,49901E-05	-3,08729E-05

The "goodness of fit" of the model can be assessed through the review of the index *Adjusted R Square*, while the significance of the model through the *F---statistics*.

The analysis presents an *Adjusted R Square* equal to 0,989120496, meaning that the model has an extremely accuracy.

Using the *F---statistics*, it is possible to check whether the overall model is significant at a level of confidence=5%, and in this case, having F=429,603805, far greater than $F_{k,n-k-1,0.05}=F_{7,26,0.05}=2,39$ means that the whole model is significant.

Moving the attention to the single parameters, in this model just two variables, *Population Density* and *Renewable Energy Consumption*, are not significant at level of confidence=5% while the other ones display a p-value lower than 0,05:

- *Gross Domestic Product*: a 1 US $ increment of the independent variable leads to an intensification of *Total Greenhouse Gas Emissions* by 0,0000015 kiloton, ceteris paribus;
- *Energy Use*: a 1-kilogram per capita increment of the independent variable leads to an intensification of *Total Greenhouse Gas Emissions* by 33,79062496 kiloton, ceteris paribus;
- *Government Expenditure on Education*: a 1 US $ increment of the independent variable leads to an intensification of *Total Greenhouse Gas Emissions* by 0,00001117 kiloton, ceteris paribus;

- *Research and Development Expenditure*: a 1 US $ increment of the independent variable leads to a reduction of *Total Greenhouse Gas Emissions* by 0,0000373 kiloton, ceteris paribus;
- *Environmental Tax Revenues*: a 1 US $ increment of the independent variable leads to a reduction of *Total Greenhouse Gas Emissions* by 0,0000379 kiloton, ceteris paribus.

2) *ADVANCED ECONOMIES – 2015*

SUMMARY OUTPUT

Regression Statistics	
Multiple R	0,995863753
R Square	0,991744614
Adjusted R Square	0,98952201
Standard Error	112998,2524
Observations	34

ANOVA

	df	*SS*	*MS*	*F*	*Significance F*
Regression	7	3,98822E+13	5,69746E+12	446,2084394	2,03489E-25
Residual	26	3,31984E+11	12768605037		
Total	33	4,02142E+13			

	Coefficients	*Standard Error*	*t Stat*	*P-value*	*Lower 95%*	*Upper 95%*	*Lower 95,0%*	*Upper 95,0%*
Intercept	-144223,153	54101,35769	-2,665795443	0,013028548	-255430,0862	-33016,2194	-255430,0862	-33016,2194
GDP (current US$)	6,4823E-07	1,50456E-07	4,308423923	0,000208377	3,38962E-07	9,57498E-07	3,38962E-07	9,57498E-07
Population Density (per km2)	-41,0048683	16,32788732	-2,511339494	0,018574192	-74,56732136	-7,44241522	-74,56732136	-7,44241522
Energy use (kg per capita)	74,18389289	17,13633316	4,329041237	0,000197377	38,95965562	109,4081302	38,95965562	109,4081302
Renewable energy consumption (kg per capita)	-84,6352101	20,86036722	-4,057225324	0,000402637	-127,514309	-41,7561112	-127,514309	-41,7561112
Government expenditure on education (current US$)	-4,2282E-06	2,01438E-06	-2,099001991	0,045676533	-8,3688E-06	-8,757E-08	-8,3688E-06	-8,757E-08
Research and development expenditure (current US$)	-2,1663E-06	2,37906E-06	-0,910589259	0,370877052	-7,05658E-06	2,72388E-06	-7,05658E-06	2,72388E-06
Environmental tax revenue (current US$)	-6,3671E-06	1,57391E-06	-4,045386511	0,000415284	-9,60232E-06	-3,1319E-06	-9,60232E-06	-3,1319E-06

This second regression analysis, as much as the 1996 case, displays a high *Adjusted R Square* equal to 0,98952201, meaning an excellent model's accuracy.

The whole model is significant, as the *F---statistics*=446,2084394 is greater than $F_{k,n-k-1,0.05}=F_{7,26,0.05}=2,39$.

In this occasion, just the parameter *Research and Development Expenditure* is not significant at level of confidence=5% while the other ones display a p-value lower than 0,05:

- *Gross Domestic Product*: a 1 US $ increment of the independent variable leads to an intensification of *Total Greenhouse Gas Emissions* by 0,000000648 kiloton, ceteris paribus;
- *Population Density*: a 1-unit increment of the independent variable leads to a reduction of *Total Greenhouse Gas Emissions* by 41,0048683 kiloton, ceteris paribus;

- *Energy Use*: a 1-kilogram per capita increment of the independent variable leads to an intensification of *Total Greenhouse Gas Emissions* by 74,18389289 kiloton, ceteris paribus;
- *Renewable Energy Consumption*: a 1 US $ increment of the independent variable leads to a reduction of *Total Greenhouse Gas Emissions* by 84,63521013 kiloton, ceteris paribus;
- *Government Expenditure on Education*: a 1 US $ increment of the independent variable leads to a reduction of *Total Greenhouse Gas Emissions* by 0,000004228 kiloton, ceteris paribus;
- *Environmental Tax Revenues*: a 1 US $ increment of the independent variable leads to a reduction of *Total Greenhouse Gas Emissions* by 0,000006367 kiloton, ceteris paribus.

3) *EMERGING AND DEVELOPING ECONOMIES – 1996*

SUMMARY OUTPUT

Regression Statistics	
Multiple R	0,954856025
R Square	0,911750028
Adjusted R Square	0,886010453
Standard Error	324485,5126
Observations	32

ANOVA

	df	*SS*	*MS*	*F*	*Significance F*
Regression	7	2,61074E+13	3,72962E+12	35,42210859	3,79559E-11
Residual	24	2,52698E+12	1,05291E+11		
Total	31	2,86343E+13			

	Coefficients	*Standard Error*	*t Stat*	*P-value*	*Lower 95%*	*Upper 95%*	*Lower 95,0%*	*Upper 95,0%*
Intercept	-91690,9111	179496,5064	-0,510822818	0,614142165	-462153,4925	278771,6702	-462153,492	278771,6702
GDP (current US$)	7,17382E-06	9,07249E-07	7,907222641	3,87734E-08	5,30135E-06	9,04629E-06	5,30135E-06	9,04629E-06
Population Density (per km2)	998,4689777	825,2874495	1,209843889	0,238121115	-704,8406022	2701,778558	-704,840602	2701,778558
Energy use (kg per capita)	22,78837448	54,15228783	0,420820161	0,677630898	-88,97645448	134,5532034	-88,9764545	134,5532034
Renewable energy consumption (kg per capita)	14,65717193	434,0862663	0,033765574	0,973343345	-881,2528487	910,5671925	-881,252849	910,5671925
Government expenditure on education (current US$)	-0,00012751	2,55249E-05	-4,995512213	4,2044E-05	-0,000180191	-7,48291E-05	-0,00018019	-7,48291E-05
Research and development expenditure (current US$)	0,000149142	0,000150209	0,992898533	0,330665161	-0,000160874	0,000459158	-0,00016087	0,000459158
Environmental tax revenue (current US$)	-7,7513E-05	7,04849E-05	-1,09971423	0,282365718	-0,000222987	6,79604E-05	-0,00022299	6,79604E-05

The first regression analysis focusing on emerging and developing countries shows an *Adjusted R Square* equal to 0,886010453, resulting in a very good model's accuracy.

The *F---statistics*, scrutinizing the significance, amounts to 35,42210859 and it is greater than $F_{k,n-k-1,0.05}=F_{7,23,0.05}=2,44$.

In this analysis the majority of the parameters, precisely five, are not significant at level of confidence=5% while the other two display a p-value lower than 0,05:

- *Gross Domestic Product*: a 1 US $ increment of the independent variable leads to an intensification of *Total Greenhouse Gas Emissions* by 0,00000717 kiloton, ceteris paribus;
- *Government Expenditure on Education*: a 1 US $ increment of the independent variable leads to a reduction of *Total Greenhouse Gas Emissions* by 0,00012751 kiloton, ceteris paribus.

4) <u>EMERGING AND DEVELOPING ECONOMIES – 2015</u>

SUMMARY OUTPUT

Regression Statistics	
Multiple R	0,99778073
R Square	0,995566386
Adjusted R Square	0,994273249
Standard Error	170481,8077
Observations	32

ANOVA

	df	*SS*	*MS*	*F*	*Significance F*
Regression	7	1,56632E+14	2,2376E+13	769,8844465	1,20106E-26
Residual	24	6,97537E+11	29064046742		
Total	31	1,57329E+14			

	Coefficients	*Standard Error*	*t Stat*	*P-value*	*Lower 95%*	*Upper 95%*	*Lower 95,0%*	*Upper 95,0%*
Intercept	-54022,82493	89556,50727	-0,60322613	0,552016979	-238858,3715	130812,7216	-238858,3715	130812,7216
GDP (current US$)	-9,1726E-07	3,43909E-07	-2,66716128	0,013482379	-1,62705E-06	-2,07467E-07	-1,62705E-06	-2,07467E-07
Population Density (per km2)	516,8385408	410,109395	1,260245552	0,219696975	-329,5856496	1363,262731	-329,5856496	1363,262731
Energy use (kg per capita)	-4,969835057	13,48556798	-0,3685299	0,715709042	-32,80267941	22,8630093	-32,80267941	22,8630093
Renewable energy consumption (kg per capita)	43,27435196	196,5687019	0,22014874	0,827617203	-362,4235092	448,9722131	-362,4235092	448,9722131
Government expenditure on education (current US$)	2,01691E-05	3,56481E-06	5,657834038	7,94806E-06	1,28117E-05	2,75265E-05	1,28117E-05	2,75265E-05
Research and development expenditure (current US$)	6,74475E-05	1,22131E-05	5,522552909	1,11415E-05	4,22409E-05	9,26542E-05	4,22409E-05	9,26542E-05
Environmental tax revenue (current US$)	3,99602E-05	7,3368E-06	5,446549388	1,3478E-05	2,48178E-05	5,51027E-05	2,48178E-05	5,51027E-05

This last regression analysis exhibits an *Adjusted R Square* equal to 0,994273249, which means a superb model's accuracy.

The model is significant since the *F---statistics* increase drastically to 769,8844465, resulting greater than $F_{k,n-k-1,0.05}=F_{7,23,0.05}=2,44$.

In this case the significant variables at level of confidence=5% are four, precisely:

- *Gross Domestic Product*: a 1 US $ increment of the independent variable leads to a reduction of *Total Greenhouse Gas Emissions* by 0,000000917 kiloton, ceteris paribus;
- *Government Expenditure on Education*: a 1 US $ increment of the independent variable leads to an intensification of *Total Greenhouse Gas Emissions* by 0,0000201 kiloton, ceteris paribus;

- *Research and Development Expenditure*: a 1 US $ increment of the independent variable leads to an intensification of *Total Greenhouse Gas Emissions* by 0,0000674 kiloton, ceteris paribus;
- *Environmental Tax Revenues*: a 1 US $ increment of the independent variable leads to an intensification of *Total Greenhouse Gas Emissions* by 0,0000399 kiloton, ceteris paribus.

STATISTICAL ANALYSIS: CONCLUSIONS

In performing the analysis I may define two different set of conclusions, one more intuitive from the scrutiny of the considered database and one more exhaustive from the regression analysis' results.

Focusing on the data:

- There is a large lack of data availability and accuracy, especially for underdeveloped countries that face budget constraints. It makes more complex the analysis of their impact on the environment and consequently reduces the likelihood to deal with the issues;
- Petrol biggest exporters such as Russia, Saudi Arabia and Qatar do not deliver significant environmental taxation, often equal to 0%;
- In absolute terms, advanced economies display a higher amount of renewable energy consumption, but taking into account the two samples, the average percentage of the green consumption on the total energy use is higher in developing countries, with peak of 86,40% in Mozambique;
- Research and Development expenditure is quite higher in developed countries with an average 2,05% of the Gross Domestic Product, against the 0,61% of the developing ones.

Focusing on the regression analysis:

- In both advanced and emerging countries, the number of the significant variables increases from 1996 to 2015 respectively by one and two units. This may imply a growing correlation between the dependent and independent parameters;

- Differently from developing countries, the renewable energy consumption becomes significant in the developed nations, probably meaning a more effective use of these resources;
- Inverse path for the two samples concerning R&D expenditure. In the case of advanced countries, the variable becomes non-significant through the decades, while it evolves into significant for emerging ones;
- Along with R&D expenditure, the underdeveloped nations see their environmental taxation parameter becoming significant;
- Even if there are some exceptions, variables such as GDP and Energy Consumption generally positively influence Total GHG Emissions, while Renewable Energy Consumption and Environmental Tax display a negative impact on the dependent variable;
- Unfortunately, the Energy Use coefficient more than doubled from 33,79 to 74,18 with extremely negative effects on the environment;
- Focusing on the 2015 emerging countries analysis, the positive influence on the Total GHG Emissions expressed by Government Expenditure on Education, R&D expenditure and Environmental Tax Revenues may suggest that these countries are investing more on the easier and faster high-carbon development path, in the case of the taxation perhaps preferring to pay the fine, instead of investing in green technology that can lead to a cleaner but slower progress.

Some exceptions that do not have a clear and intuitive meaning:

- The negative correlation between the dependent variable and the Population Density in the 2015 Advanced countries case, because usually the higher the population the higher the polluting emissions;
- In the case of 2015 developing countries analysis, the negative influence of the GDP on the dependent variable, because the general assumption is that the higher GDP the higher GHG emissions;

- The positive impact of the Environmental Tax Revenues on the Total GHG Emissions illustrated by the emerging countries in 2015, because usually this kind of taxation discourages pollution.

CHAPTER 4
THE PATH TOWARDS SUSTAINABILITY

4.1 POTENTIAL SCENARIOS

In addition to IPCC' report on emission scenarios and to Representative Concentration Pathways explained in Chapter 1, the 2019 more recent *"World Energy Outlook* series is a leading source of strategic insight on the future of energy and energy-related emissions, providing detailed scenarios that map out the consequences of different energy policy and investment choices."[1]

In the worst case, taking into account that global demand for energy still heavily relies on fossil fuels, if environmental effective policies are not implemented, the first scenario expects a one-fourth increase in greenhouse gas emissions and an annual increase of 1.3% in energy demand until 2040.

Then, the second case, formally known as Stated Policies Scenario, delivers a meticulous sense of the direction in which present policy frameworks and ambitions would affect the energy sector till 2040. In the event that the planned strategies are accomplished, the demand for energy grows by 1% per year until 2040 and low carbon sources such as photovoltaics satisfy half of this growth and another third is granted by natural gas. The demand for oil flattens out and coal follows a short distance away. Unfortunately, the document pictures a scenario in which greenhouse gas emissions will not begin to decrease before 2040, in which hundreds of millions of people will remain without electricity, in which premature deaths caused by pollution will remain high, and, finally, where the greenhouse gases emitted will cause irreversible climate change damages.

Even if countries are not on track to meet environmental goals, the third and more desirable Sustainable Development Scenario delineates a substantial transformation of the global energy structure, showing how the world can switch course and reach at the same time the three major

[1] https://www.iea.org/reports/world-energy-outlook-2019, seen April 30, 2020.

energy-related Sustainable Development Goals.[2] This scenario is fully aligned with the Paris Agreement, which has the goal of "holding the increase in the global average temperature to well below 2 °C above pre-industrial levels and pursuing efforts to limit the temperature increase to 1.5 °C above pre-industrial levels". According to the Paris Agreement, the ambition is to reach the emissions climax as soon as possible and decrease rapidly thereafter, leading to a net-zero carbon emissions in the second half of the century. In fact, these circumstances are all considered in this third scenario, with a 66% probability that the temperature increment will stay below 1.8 °C and global greenhouse gas emissions decreasing from 33 billion tonnes in 2018 to less than 10 billion by 2050 and to a net zero by 2070.

The comparison between advantages and disadvantages of action distinctly displays that the benefits of intense, early action on climate change surpass the costs, while ignoring climate change will eventually result in economic damages in the long period. The actual costs of carrying out effective environmental actions will depend on many elements, especially on bringing down the costs of technologies that will not be evenly felt amongst sectors, because some industries will suffer while other ones will seize the opportunities.

As we already know, fossil fuel emissions can be reduced through lowering the demand for high-carbon products, raising the energy efficiency, and switching to low-carbon solutions. The theory is extremely simple because if prices of carbon-intensive items start to reflect the full costs of production, including the negative environmental externality, clients and companies will shift their consumption to relatively cheaper low-carbon products. The problem is that, at least for now, the actual price of eco-friendly products is quite higher. It is also important to lower non-fossil fuel emissions, particularly concerning deforestation, because the cost of cutting emissions from this sector may be relatively low, if proper incentive structures are introduced and countries facing this challenge obtain adequate support, such in the Brazilian Amazon case, where other countries can

[2] Part of SDG n°3 aims to reduce the severe health impacts of air pollution, SDG n°7 aspires to achieve universal access to energy and SDG n°13 intends to tackle climate change.

remunerate Brazil for providing "oxygen", offering a chance to progress in a clean way, not forcing the country to deforest and follow the high-carbon development path.

The transition to a low-emissions global scenario will unlock a myriad of new business and employment opportunities across the whole economy. In fact, such kind of markets offering clean products are projected to be worth at least $500 billions per year by 2050. Studies exhibit that business opportunities for low-carbon energy sources are expanding rapidly, thanks to a combination of relative higher fossil fuel prices and strengthened public incentives on climate change and renewable energy. In 2005, the whole low-emission sector registered an average 25% increase, with some sectors growing at an even more rapid rate like in the cases of solar photovoltaic (55%) and wind power (50%).

According to estimates from *International Energy Agency*[3], the growth rates in these markets will persist. It reports a $13 trillion aggregate investment in these low-carbon technologies accounting for over 60% of all power generation by 2050, complemented by a change in employment patterns, that is projected to face a rise from the present level of 1,7 million to more than 25 million employed by the same date.

There are many examples of future-oriented firms and countries, innovative high-technology start-ups and world's biggest corporations, among others, that are currently positioning themselves to take advantage of these growing opportunities. In particular, those regions that for historical or geographical reasons present flexible markets, attractive conditions for investments and techno-scientific endowment are likely to win significant shares of the expanding clean energy market. For instance, *Hanemann et. al.* (2006) studied the economic consequences of California opening the way in the adoption of policies mitigating greenhouse gas emissions. They assessed that early actions may result in California gaining a competitive advantage and representing a leader in the new technology

[3] It was founded in 1974 during the oil crises to ensure the security of oil supplies. The IEA has evolved through the decades. Energy security remains a core mission, but it is also focusing on issues ranging from electricity security to investments, climate change and air pollution, energy access and efficiency. Today IEA is the heart of international dialogue providing statistics and analysis.

sectors, with projections that see a $60 billion increase in Gross State Product and a 20.000 jobs boost by 2020.

A practical example of the way in which environmental policies can clear up market energy inefficiencies is represented by the Indian case.

“India’s economic growth is constrained by an inadequate power supply that results in frequent blackouts and poor reliability. Subsidized tariffs to residential and agricultural consumers, low investment in transmission and distribution systems, inadequate maintenance, and high levels of distribution losses, theft and uncollected bills place the State Electricity Boards, which form the basis of India’s power system, under severe financial difficulties. These losses and subsidies are a significant drain on budgets and can result in public spending on vital areas such as health and education being crowded out. Annual power sector losses associated with inefficiencies and theft are estimated at over $5 billion more than it would cost to support India’s primary health care system. The demand shortages facing India, 56% of Indian households have no electricity supply, create incentives for getting generation plants in line as rapidly as possible. These priorities in turn favor reliable, conventional, coal-fired units. The use of coal for the bulk of electricity generation presents particular challenges. Coal mining is dangerous, and its transportation creates environmental problems of its own. Coal also produces pollutants such as sulphur dioxide that damage local air quality, causing further problems for human health and the environment. These issues are exacerbated by the low energy efficiency of India’s coal-fired power plants, combined with India’s policies of high import tariffs on high-quality coal and subsidies on low-quality domestic coal. The use of *Carbon Capture and Storage technology* will be an important way to reconcile the cost and convenience advantages of coal with environmental goals. The government of India has set out an energy policy to help address these constraints and concerns. The broad objective of this policy is to reliably meet the demand for energy services of all sectors at competitive prices, through safe, clean and convenient forms of energy at the least-cost in a technically efficient, economically viable and environmentally sustainable manner.

With sufficient effort made in improving energy efficiency and conservation, for example, the government of India has stated that it would be possible to reduce the country's energy intensity by up to 25% from current levels. Progress in achieving the goals and objectives of their energy policy, ranging from improving energy efficiency to promoting the use of renewables, will also make a significant contribution to reducing future GHG emissions from India."[4]

Financial institutions will play a key role in granting and allocating the trillions of dollars required to support investment in low-carbon solutions. New business occasions for start-up, small and medium firms and large multinationals focusing on clean energy goods and services will rise, switching clean technology investment from representing a niche investment activity into the mainstream. Alongside the already mentioned employment pattern change, with a demand increase for financial intermediaries, such as brokers, carbon asset managers[5], and legal and registry services, new and different trading and financial instruments such as carbon trading, financing clean energy, greater energy efficiency, and insurance will have a significant role in the market.

It is the case of the so-called *Green Bonds,* a recent financial service introduced in 2014, that work in a very similar way to the ordinary bonds, with the difference that the liquidity obtained by the issuer company must be invested in projects with a positive environmental impact. According to the statistics exhibited by a non-governmental organization on behalf of the London bank HSBC, the increase in green bonds from 2016 to 2017 amounted to $201 billions with an overall climate-related bonds calculated around $895 billions. The study takes into consideration six macro-areas: transport, energy, construction and industry, water, waste and pollution, agriculture and forests, and shows that the main issuers of these bonds are public companies or state subsidiaries. The topic of Green Bonds initially only concerned international financial institutions such as the World Bank and the European Investment Bank, later it entered the corporate universe thanks also to the support of Paris Agreement. Investor confidence in the marked growth of the green bond market is mostly because of two factors.

[4] Nicholas Stern, *The Economics of Climate Change: The Stern Review,* page 279.

[5] Since reducing carbon may imply difficult and interrelated processes and ways of working at a company level, new opportunities will arise for consultancy services to help companies manage these processes.

On the one hand, the policy of emerging countries, especially China and India, willing to take on a predominant role in the sustainability industry, and on the other hand, the increased attention to environmental issues of international institutions, such as the European Bank of Reconstruction and Development, European Investment Bank, International Finance Corporation. The relevance assumed by Green Bonds can be found in the public policies implemented by many governments, such as Poland and France. The first, in December 2016, issued 5-year bonds with a value of 750 million euros. Similarly, France released Green Bonds expiring in 2032, with a total value of 7,5 billion euros and with a rate of return slightly higher than the usual rate of common bonds. However, it is the Asian continent the leader of this market as, in 2016, China, in addition to Indian, Japanese and Korean policies, issued Green Bonds for $11,2 billions, equal to one-third of the total green bonds worldwide, with the addition of further investments for 300 billion dollars for the realization of environmental objectives in the five-year plan which will expire at the end of 2020.

It is crucial to understand that whilst climate change includes severe challenges and high costs to the global economy, it also offers opportunities. As well as supporting to eradicate negative environmental externalities and market inefficiencies, climate change policy should also help to reach other policies and goals, especially around energy strategy and sustainable development.

4.2 THE GREEN ECONOMY

"An inclusive green economy is one that improves human well-being and builds social equity while reducing environmental risks and ecological scarcities."[6]

In a green economy, the progress in employment and income are conducted by public and private investments in lots of economic activities that enable resource efficiency and prevent the loss of biodiversity.

[6] https://www.unenvironment.org, seen May 7, 2020.

Over the last ten years, the vision of the green economy has arisen as a priority for many countries. In fact, 65 countries, supported by the UN Environment Programme, have entered the path towards a sustainable economy that sees the natural capital as a vital economic asset and a source of common benefits, with the necessity to be endorsed by proper public expenditure, taxation and policy reforms.

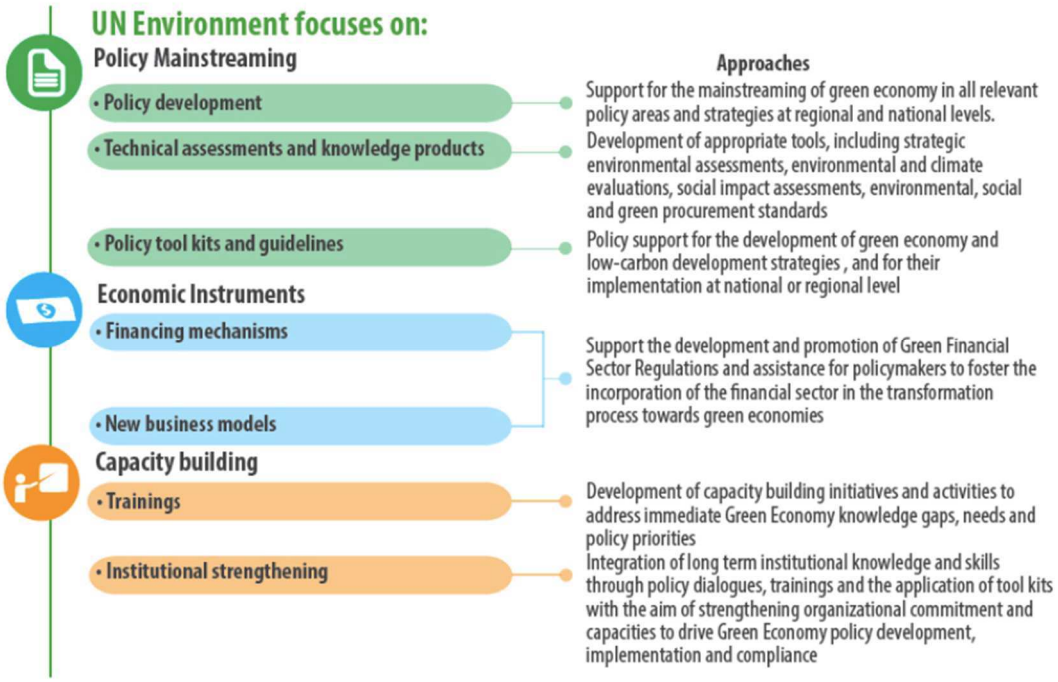


Fig. 1 (source: unenvironment.org)

An inclusive green economy is the ideal-proposed solution to the current economic model, which unfortunately accentuates inequalities, waste, resource scarcities, and also threats the environment and the human health.

It is the designed pathway towards realizing the 2030 Sustainable Development Goals, which may be pursued in multiple ways and lead to several economic, health, security, social and environmental benefits. As a matter of fact, there are two major purposes for nations to speed up the structural changes, that can be easily guessed and synthesized as the “dual challenge”. First, the challenge of generating wealth, especially in those developing countries where poverty is prevalent and second, the urgency to decouple economic growth and human well-being from resource wastage, basically reverting the present trend, because if governments usually place economic development above the

planet's capacity, in the other hand, environmentalists tend to put conservation first and understate the challenge of increasing wealth for billions of people who hope for a more desirable material life. It is critical to understand that, in the long term, there is no trade-off amongst social, economic and environmental targets, because there is no human development or economic growth on an uninhabitable earth, and that the shift to greener economies carry out many benefits even from a purely economic point of view. Countries need to seek the fine balance between environmental goals and competitiveness even when some components of the transformation meet the solid resistance from interest groups. That is the reason why governments, in implementing effective industrial policies that promote an economic restructuration towards a greener and better societal outcome, should observe three basic principles such as embeddedness, discipline and accountability, since they are asked to hold intimate relationships with the private sector to get a wide understanding of how specific economic sectors work while preserving full autonomy in decision-making and legitimization of adequate industrial policies, without being colluded and captured by private interests.

4.2.1 ECONOMIC AND SOCIAL CO-BENEFITS

Besides the environmental advancement that can be gained through the adoption of green industrial policies, there is a range of promising co-benefits for less developed regions in terms of welfare improvement and socio-economic growth.

As we are currently experiencing, the concept of growing first and cleaning up later is not a sustainable approach, in particular for those developing countries that face pressing issues perceived as more urgent than greening their economies. In fact, many policy measures are cost-effective and offer notable co-benefits in association with moving to a green economic system. Governments should investigate the feasible synergies between socio-economic enhancement and environmental protection that would ease their shift to a sustainable development route. Twelve positive reasons for

the implementation of green industrial policies are outlined by the 2017 UN Environment's report *Green Industrial Policy: Concept, Policies, Country Experiences*:

1. Environmental improvement lead to high quality environmental products and better human health;
2. Deterioration of environmental resources threatens the potential for future growth of developing countries;
3. Environmental goods can be considered common-pool resources[7]. Measures to avoid the overuse of common-pool resources will raise resource productivity, because since many low-income people rely on these shared resources, an accurate management would reverse their degeneration and strengthen their economic productivity. The introduction of property rights and economic incentives may help to set the value of the resource and its scarcity. An example is given by the payment for environmental services that in the one hand can reverse the degradation of ecosystem services and also help to alleviate poverty;
4. Measures to boost resource efficiency usually pay for themselves. In several industrial sectors, existing technologies could lower energy consumption resulting in net economic benefits rapidly, besides the positive environmental impact. This represents a particularly powerful point for developing countries because of their initial phase of industrialization;
5. Once locked into resource-intense, polluting energy and unsustainable urban infrastructure development, countries will find it difficult to switch to green pathways in the future;
6. Reducing environmentally harmful incentives, which typically are maintained because of the pressure of special groups of interest, can improve the environment and offer positive economic effects. Besides their direct damage, energy subsidies lock countries into inefficient technologies that will be more complicated and costly to replace in the next years;

[7] Defined as limited resources that are shared, with no clear owners and no management system restricting the use of the resources in the form of fisheries, forests or pasturelands.

7. Low-income countries can leverage new competitive advantages in environmental goods and technologies by adapting and offering eco-friendly products. Many of them display extremely rich natural endowments, such as solar energy in North Africa, that could stimulate the development and export of green products;
8. Since low-income nations may not be in the position to invest in pioneering green R&D due to their resource constraints, to make their own industry more competitive at the international level, developing countries can significantly profit from the deployment of already proven green technologies;
9. Green energy policies boost energy security, lowering the vulnerability of countries to oil price shocks and dependence on fuel imports;
10. Positive employment effects due to green sectors and technology installation and servicing may produce more decent jobs and provide a possible double dividend, switching from taxing labor to taxing environmental damages. This approach should lead to environmental and labor demand benefits as result of environmental fiscal reforms that make labor cheaper relative to energy;
11. Not participating in international environmental agreements and following the high-pollution development path could undermine the long-term potential for exports and industrial development of developing countries;
12. International environmental agreements can also include financing possibilities and technology transfers for underdeveloped nations.

4.2.1.1 FOCUS ON THE FIRM LEVEL

A prevailing opinion concerning environmental safeguard is that it adds new expenses to firms' balance sheet. In fact, according to this point of view, the abatement of the pollution from production processes requires that companies substitute dirty inputs with cleaner but costlier ones or may imply

a conversion to more expensive technologies and significant investments in activities aimed to cut or mitigate pollutant emissions, handle their waste, or boost energy efficiency.

However, such additional green expenses may turn out to be remunerative in the long term and lead to a sustainable competitive advantage for businesses, with both sectorial competitiveness and environmental quality improved. This win-win situation should follow three paths.

First, green standards and certifications facilitate companies to differentiate their products from competition. As a matter of fact, by going beyond obligatory standards, for example using fewer pollutant inputs, increasing their percentage of renewable sources, or recycling their products, hence raising their expenses, firms place themselves at an adverse position compared to competitors. But supplying sustainable quality products represents a vertical differentiation strategy which focuses on a niche of consumers and private companies that are willing to pay more for environmental quality and that may enable businesses to regain the higher production costs. Common consumers can recognize green quality products through eco-labels and in order to be effective, the label should be readable, easily identifiable, reliable, advertised in a comprehensible way for non-experts and the certification system should be immune to bribery and manipulation.

Second, firms can earn considerable capitals by selling and adopting green technology since resolving environmental issues has become a market opportunity for firms offering pollution-control technologies. Moreover, governments with the purpose of stimulating businesses to adopt greener but costlier technologies can provide subsidies to offset additional expenses of higher environmental standards. The most common economic incentive, presented in more than 50 countries, is the feed-in tariff for renewable energy sources. By issuing a feed-in tariff, governments commit to purchase, from private firms, electricity generated by sustainable sources such as wind and solar power at a fixed price, which is much greater than the wholesale market price.

Third, green policies can boost competitiveness due to knowledge spillovers and produce positive externalities amongst companies in the R&D process. The economy and the society in its entirety profit from spillovers of new technologies, because by its very nature, knowledge is a public good,

and when passed to production processes, new technologies become public. That is why companies typically do not get the full return on their innovation investments and why they are often discouraged from sinking money in breakthrough technologies. Public authorities should soften this market failure for a general benefit while guaranteeing a fair level of investments in R&D activities, safeguarding firms' inventions with effective patents, consolidating the property rights, granting them more easily and with lower application costs. *Dechezleprêtre et al.* (2014) outline that knowledge spillovers have considerable positive impacts on green innovation. The report, focusing on spillovers in clean and dirty technologies of four fields[8], analyzes patent citations in which innovators applying for a patent must quote all previous innovations on which the new technology is based. The final assessment displays that clean patents get an average of 43 per cent more citations than the dirty ones and happened to be mentioned by more remarkable patents.

4.2.1.2 EMPLOYMENT BENEFITS

The global economic system will have to go through a process of structural change with considerable consequences on labour markets and incomes, especially in the environmental-related sectors, because if in the one hand green transition constitute challenges for certain pollutant industries and correlated jobs, it also offers opportunities for new jobs in other sectors.

Employment aspects should not only concern the quantity of jobs produced or lost, but also their quality, safety, social dialogue and skills development, among others, as described by the afore-mentioned Sustainable Development Goal 8.

The first task to accomplish in understanding the impact of green industrial measures on the labour market is to detect those sectors that deeply affect the environment, because they will be the ones that will have to face the largest adjustments in employment. It involves industries with activities directly designed for the preservation or rehabilitation of the natural habitat like recycling, eco-tourism, or

[8] Fuel, automobiles, energy production and lighting.

renewable energy and sectors actively depending on the exploitation of natural resources such as heavy industries and fossil fuel-based businesses. People employed in these industries will have to adapt, develop new skills and methods, switch enterprise or move to the upcoming greener sectors. Even if it is impossible to quantify the exact overall employment consequences of greening, estimates provided by Eurostat displays that within the European Union the share of Environmental Goods and Services Sectors (EGGS) in total value added augmented by more than 50 per cent with full-time employed people increasing from 2.785 million to 4.1 million over the 2000-2012 time interval. The major part of these new jobs, defined as green jobs[9], were established in energy resource management, especially in the production of energy from wind and solar power, and installations of energy savings equipment. Figure 2 illustrates the latest available (2014) employment shares of the EGSS on the total employment ranging from around 0.9 per cent in Ireland up to 4 per cent in Austria and Luxembourg.

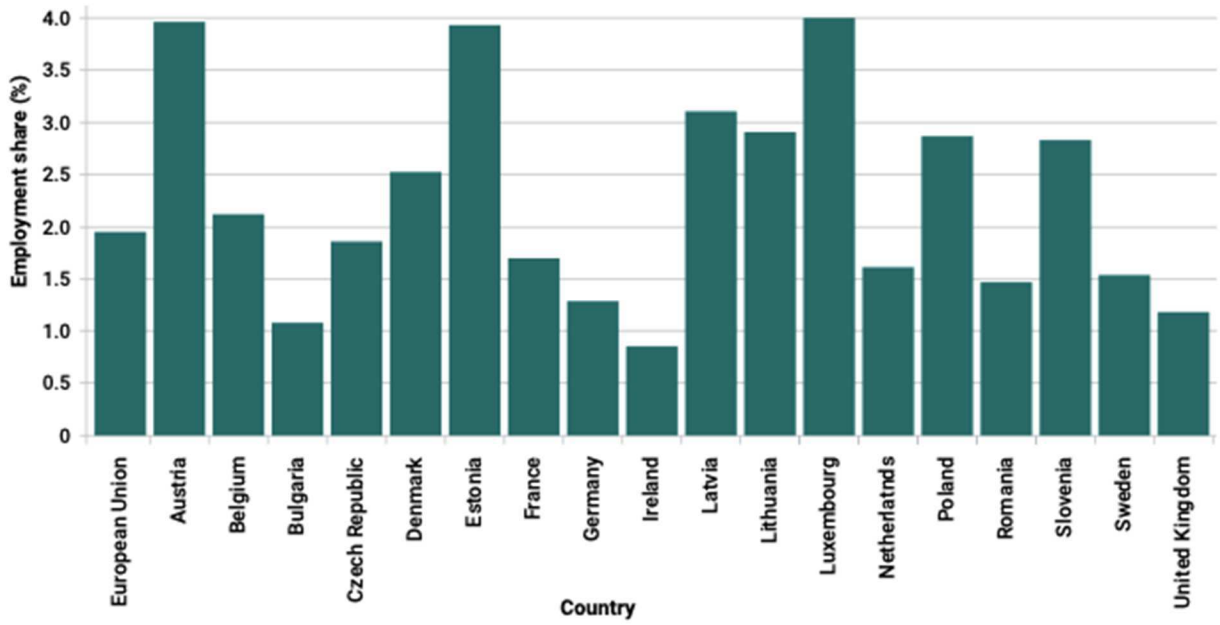


Fig. 2 (source: Eurostat)

[9] Jobs in sectors that produce green goods and services as well as occupations in green processes that are environmentally favourable (ILO 2012).

In the United States:

- In 2007, the *Department of Commerce* assessed the number of green jobs in the private sector amounting to 2.4 million, corresponding to 2 per cent of total private employment in that year;
- *BLS* calculated around 3.4 million green jobs in 2011 divided and amounting to 2.3 per cent of private sector, and 4.2 per cent of public sector;
- *Pollin et al.* (2008) approximated the employment consequences of a proposed 10-year green recovery strategy for six areas[10], including for example cap-and-trade policies and technology-specific programmes. The analysis exhibits a creation of 935,200 direct jobs, 586,000 indirect jobs and 496,000 induced jobs, reporting that a $100 billion investment in the green recovery programme, rather than in fossil fuel-based industries, would result in a greater total employment impact and in higher household incomes;
- *Morgenstern et al.* (2002) also focus on the US, investigating the effects of environmental policies for four industries: pulp and paper mills, plastic manufacturers, petroleum refiners, and iron and steel mills sectors. On average, a US$ 1 million increase in environmental spending would produce 2 to 3 additional jobs across the four industries;
- In 2013, *Belova et al.* assessed that for 6 out of 10 scrutinized industries, per every US$ 1 million spent in environmental abatement the number of people employed increase from 10 to 30;
- *Kato et al.* (2012) review the short-term consequences of an environmental tax applied on carbon-intensive goods in nine high-income countries. If the tax is enforced by a subsidy paid on products achieved by low carbon-intensive sectors, the total employment effect is assessed to be positive at around 0.5 per cent, while in the case of no subsidy the carbon tax would lead to a decrease in employment of 0.4 per cent.

[10] Retrofitting buildings, mass transit, smart grid, wind power, solar power and advanced biofuels.

According to the International Labour Organization (ILO), the top 15 carbon-intensive industries in advanced countries employ a relatively modest percentage of workers, with the majority operating not in the high-carbon sectors and 22 per cent works in a carbon-intensive industry that is already influenced by green transformation.

By contrast, as exhibited in Figure 3, by virtue of the large employment shares in the agricultural, forestry and fishing industries in developing countries, nonrenewable sectors are the greatest provider of occupation in Asia and the Pacific, with 53 per cent of the total employees in the sample, which points out the significant challenges faced by these regions in the field of employment.

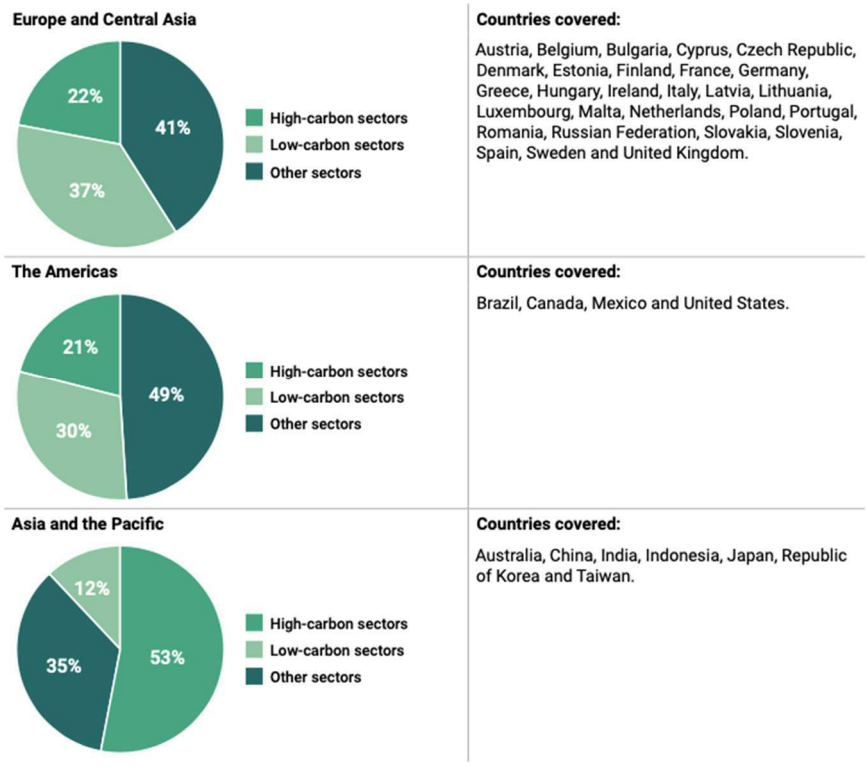


Fig. 3 Employment shares in GHG emitting industrial sectors by region
(source: International Labour Organization - ILO)

As a consequence, differently from industrialised regions, emerging countries will see a much larger amount of the workforce affected by greening changes. That is the reason why green policies are required to help workers relocating from the polluting fields to non-resource-intensive productive sectors and granting a decent job from the new positions.

Since workers may also have to change jobs, within the same organization, leaving the firm but staying in the same sector, or even may have to move to different industrial fields, people need to be encouraged, assisted and given concrete assurances about the transition. To ease this process, companies should be supported in defining training systems that ensure an effective skills upgrade of both employed and unemployed workers. Moreover, significant reform of education systems may also be inevitable, especially because green transformation will not necessarily be conducted by large, existing businesses, as start-ups developing new ideas may play an important role. In this regard, employment measures should not only focus on employees but also on the promotion of self-employment and entrepreneurship, strengthening the access to credit.

4.2.2 ACCELERATING CHANGE

Green industrial policy is defined as: "comprising any government measure aimed to accelerate the structural transformation towards a low-carbon, resource-efficient economy in ways that also enable productivity enhancements in the economy"[11].

By far, during the past years, the preponderance of green industrial policy targeted the advancement of low-carbon energy systems such as solar photovoltaics and wind turbines, but it actually goes beyond renewable sources covering a multitude of industrial sectors. It also analyses the methods in which governments can promote green industrial progress by primarily negative policies, which means implementing solutions aiming to weaken the role of specific environmentally harmful sectors, phasing them out, thus granting space for green firms to compete.

Lütkenhorst et al. (2014) and *Altenburg and Pegels* (2012) define this style of green industrial policy strategy as "*pathway disruption*". It involves the dismantling of undesirable key polluting industries of the economy, such as oil and gas, to provide opportunities for greener alternatives to grow.

[11] Altenburg & Rodrik, *Green Industrial Policy: Concept, Policies, Country Experiences,* UN Environment 2017.

Obviously, the eventual dissolving of such important industrial sectors requires the proper management of the subsequent significant transition costs faced by the whole economy.

Tools employed in the pursuit of phasing out targeted sectors may take different forms:

- *Environmental taxes, charges, levies, fees* or any other kind of financial burden will diminish the competitiveness of the designed sectors in comparison to the other stakeholders in the economy;
- *Elimination of incentives* guaranteed in the past that may include cash grants, low-interest loans, tax breaks, or support to R&D investments, among others. Dismissing fossil fuel subsidies will make sustainable alternatives more competitive and leads consumers toward consumption of less pollutant final products;
- *Mandated phase out*, the most powerful and extreme strategy, involves a mandatory decision to end a specific sector's operations through legal bans or limitation on sales.

There are soft policies, like the well-known carbon tax, that just aim to diminish the functions of polluting industries, that would be anyway beneficial for a broad variety of green companies, but which do not set specific targets for phase out, and strong disruptive measures, that join together deliberate phasing out of target sectors with purposeful cultivation of clear alternative solutions. An example is given by the dismantling of coal-fired electricity generation and the parallel development of domestic renewable energy sectors in Ontario (Canada). The key ingredient of the strategy's political feasibility was represented by the promise of jobs from green industrial development maintained within the province. Moreover, the programme included a generous 20-year feed-in tariff contract for renewable power, the streamlining of the approval processes for renewable energy projects, a rapid residential uptake of renewable energy and the wind, solar and bioenergy capacity to be added by 2021.

Total Installed Capacity (MW)			
	Aug 2010	May 2016	% change
Nuclear	11,446	12,978	13%
Hydroelectric	7,903	8,432	7%
Coal	6,434	0	-100%
Oil / Gas	8,792	9,942	13%
Wind	1,084	3,823	253%
Biomass / Landfill Gas	122	495	306%
Solar	0	280	-
Total	35,781	35,950	0.5%

Fig. 4 Ontario's electrical generating capacity 2010-2016
(source: IESO 2010-2016)

Industries to phase out should be harmful for the natural habitat and also must present very little opportunities for improvement, because if there are practicable prospects for reducing the induced environmental damages, then it might be possible to invest in the green conversion.

It is a key point important to understand, because phasing out a sector is filled with issues, especially if it delivers a considerable contribution to the national or regional economy. In such a case, public support for vulnerable parts of the society and underprivileged people is vital. Governments should raise awareness about the nature and size of the problem and the benefits of the projected transformation, because people must understand that the status quo is unsustainable and that the plan is going to work, respecting the promise of prosperity and the concept of short-term pain from adjustment counterbalanced by a long-term gain.

4.2.2.1 PHASING-IN

The implementation and phase-in of green technologies display significant challenges for both industrialised and developing countries. In fact, market failures such as poor information on products, confusion about benefits and unclear incentives prevent investments in green innovations. As a consequence of these market failures and of persistent investments in high-carbon technologies that

further strengthen the current lock-in, product development and consumer choices still mainly converge on nonrenewable technologies.

Typically, innovative techniques initially generate low payoffs because they have not yet leveraged from the dynamic scale and learning effects that often lead to cost reductions per unit of output produced. Moreover, they are particularly challenging in those emerging countries where policymakers are less experienced, have financial constraints and fewer institutional and professional resources, with some exceptions where the techno-institutional growth is just at the beginning characterized by a lock-in effect still weak. In these regions, phasing in green alternatives is less about discovering new technological niches and more about identifying which already-available opportunities are best suited to the development goals of the country.

Public authority, in this case also defined as transition management, seek to remedy a situation of lock-in and market failure by gradually implementing policies with clear objectives aimed to attract private investors for sectorial or systemic structural innovation. The development of a long-term vision is coupled to a mechanism of policy learning formed by interim transition goals and diverse steps, because the design of policies and connected goals does not require that all errors must be avoided in the first place, but what is required instead is a set of regulations that identifies its mistakes and re-examines policies accordingly. Furthermore, there is a need for embedded autonomy, which is the involvement of welfare-oriented government delegates in business networks to acquire valuable information and capabilities to elaborate plausible economic goals without falling in political capture[12].

Regardless of the technology and policy area, the pashing-in process in emerging countries involves seven key elements that boost the likelihood for a successful green transition:

1. Governments, as first step, should accurately define the long-term vision and its roadmap with interim goals and steps;

[12] Corruption from important interest groups and influence of lobbying pressure, patronage, populism or party politics.

2. Both the vision and roadmap should be early and clearly disclosed to stakeholders to detect innovations and to prepare producers and customers, in line with the above-mentioned embedded autonomy principle;
3. The choice of options and forms for support should be implemented carefully with the assistance of independent experts;
4. A sequential approach, that consists in gradual tightening of controls and execution of pilot projects before spreading, works well in these situations;
5. Inclusion of policy learning to carry out a socially and economically successful realization of the phase-in process.
6. Design of a strategy package embracing instruments such as policy-push, market-pull policies, R&D investments, institutional capacity and skill and job creation programmes;
7. Implementation of proper control mechanisms in the form of building and financing testing facilities.

These seven characteristics of transition management offer significant suggestions for developing countries keen on green innovations. Even if they provide no guarantee for the successful phase-in process in each and every case, other elements such as foreign direct investments or coupling phase-in with phase-out increase remarkably the chances to succeed.

The Chinese case provides an example of improved industrial energy efficiency:

"A decade ago, the Chinese industry appeared to be locked into an unsustainable, fossil fuel-based path. Industrial energy consumption increased significantly in China: from 34 per cent in 1990 to approximately 70 per cent of total national energy consumption in 2009. This decreased to 50 per cent in 2015, but 65 per cent of all electricity was still produced from coal in 2016.

The government developed a comprehensive package of mandatory and voluntary policies and measures aimed at advancing energy efficiency and energy saving, the Medium and Long Term Energy Conservation Plan was published in 2004. In the 11th Five Year Plan (2006–2010), command-and-control regulations were combined in:

- *Sticks*: The Pricing Policy for industries consists of four categories with different surcharges that increase with consumption. More efficient enterprises thus pay less. To phase-out inefficient enterprises, the surcharge in this category was increased by a factor of four over time;
- *Carrots*: Companies can receive a reward of 250 Yuan per ton of coal equivalent saved through technical upgrading and engineering projects;
- *Sermons*: In 2012, the programme became mandatory and was expanded to the Top 10,000. It requires companies to annually send their energy use statistics to government and to meet national and inter- national standards. The Top 10,000 programme and its combination with energy management systems helped to raise awareness among provincial authorities and top-level management;
- *Prohibitions*: sets targets for the closure and phase-out of small and inefficient production facilities.

China's approach to industrial energy efficiency did produce the envisioned reduction in energy intensity of 20 per cent by 2010, but progress since has been rather slow. The government is struggling to achieve structural change that actually replaces less energy-efficient firms and technologies with more efficient ones across all sectors. The market for energy efficiency consultants and energy service companies has been developing since 2006. From 2010 to 2015, this market grew by 31.9 per cent annually, employing 654,000 people in approximately 2,600 companies by 2015. In spite of these numbers, energy efficiency consultants and energy service companies have been criticised for not working effectively enough due to imperfect business models, asymmetric information, high transaction costs, lack of ability to build a relation of trust to customers and lack of skills especially in new energy industry services. While the market is developing well, it is far from having reached its full potential. Strategies are adjusted over time if they do not bring the desired results."[13]

[13] Altenburg & Rodrik, *Green Industrial Policy: Concept, Policies, Country Experiences,* UN Environment 2017, pages 93,94.

4.2.3 CIRCULAR ECONOMY

In 2019, the Earth Overshoot Day, the date which points out when human demand for environmental resources rises above what the natural habitat can regenerate within the calendar year, fell on July 29, the earliest date since measurements began in 1970. It means that the resources of not one, but 1.7 Earths would be required to meet the humankind's global demand. This is the obvious result of the so-called linear model of resource consumption in which new resources are constantly extracted, utilized as inputs for manufacturing processes and then thrown away.

To remain within the Earth's boundaries, economic growth must be decoupled from resource use and environmental deterioration, because it is possible to lower unsustainable exploitation of natural resources while raising human and economic prosperity. It may become achievable if we all face a transition from the current linear model to a system in which resources are efficiently managed, inputs be reused or recycled within the production and consumption schemes, and waste and extractions kept to a minimum. It is known as circular economy.

It builds on reduce, reuse, recycle, the 3Rs scheme that constitutes a framework for managing a product in a different and sustainable way, throughout its whole life cycle. In fact, manufactured products should be designed for long-term use and reuse, promoting repair and refurbishment, and when the product's lifetime is over, the input should be recycled and returned to the manufacturing process. This system, in addition to induced energy powering coming from renewable sources, enables waste in production, supply, use and disposal to be minimised.

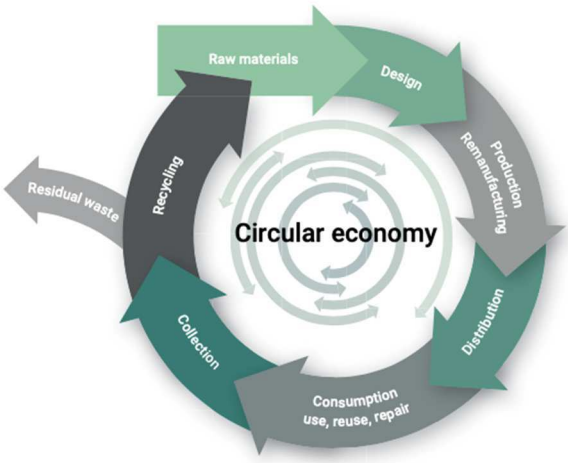


Fig. 5 Conceptual diagram of a circular economy
(source: European Commission, 2014)

As illustrated by Figure 5, circular economy takes the full lifespan of a product into consideration, but since some small quantity of residual waste is impossible to avoid, at some point new resources should be re-introduced to the production process. The key point of circular economy is to keep this amount of residual waste at the minimum and to rely on recycled resources for the largest share of the economic process. It goes beyond "simple" efficiency increments at the industry level, because it must be supported by changes in consumer behaviour at the societal extent.

However, until now, no country has made much progress towards implementing a circular economy. Yet, quite an amount of local experimental tests has been performed in line with the so-called industrial symbiosis, which outlines networks of businesses sharing nontoxic by-products as resources to collectively gain eco-innovative benefits while improving the environmental impact. In fact, since individual companies are rarely diversified enough to reuse the totality of their outputs within the firm, organizations can cluster in geographic proximity to make the exchange of inputs more efficient. In such system, one firm is able to exploit an output of another company that would otherwise have been thrown away.

The Turkish and South Korean examples are tangible cases of industrial symbiosis and increased awareness:

- Turkey

The Iskenderun Bay Industrial Symbiosis Programme (2011-2014) established an industrial symbiosis network in the Iskenderun Bay region of Turkey and aims at increasing collaboration between regional companies to achieve environmental and economic improvements.

Within the industrial symbiosis network, 51 member companies from 28 different sectors work together to benefit from synergies. An orange juice producer uses the waste heat of a lime producer to dry orange juice waste. As a result, 12,000 tons of waste pulp no longer go to landfills, but are turned into 1,400 tons of animal feed for reselling instead. A cooperation project of seven companies discovered that lint, a waste product from cottonseed production, could be used for the bioremediation of petroleum-polluted soils.

The estimated reduction in CO2 emission of 36,700 tons annually and the redirection of 327,250 tons of solid waste from landfills to various forms of reuse. In financial terms, annual savings of US$ 6.37 million balance against total programme investments of nearly US$ 7 million, meaning the programme will pay off in just over a year. The success of the Iskenderun Bay Symbiosis Programme has led to the integration of Industrial Symbiosis into the 2014 to 2023 plans of 19 regional development agencies.

- South Korea:

To tackle a significant food waste problem in South Korea, several government ministries put in place a coordinated and comprehensive policy mix to change food culture among the population, reduce waste and improve recycling.

For example, restaurants started offering eco-friendly menus and cut down the number of available small side-dishes. Cafeterias in public institutions organized a no-leftover-day once a week.

Another interesting approach was the introduction of a volume-based food waste fee system. It requires households to pay a fee based on the amount of food waste they generate measured on a scale at the bottom of the waste bin. To promote recycling, the government has financed the development of public recycling facilities. This mix of food waste reduction measures has had a great impact on raising consumer awareness and on the environment.

The recycling rate of food waste has risen from 2 per cent in 1995 to 95 per cent in 2009. Remaining food waste is now being turned into compost and live-stock feed, as well as biomass and biofuels."[14]

4.2.3.1 CO-BENEFITS OF GOING CIRCULAR

Apart from environmental benefits, circular economy may lead to positive social and economic consequences in the employment and macro-economic area.

[14] Altenburg & Rodrik, Green Industrial Policy: Concept, Policies, Country Experiences, UN Environment 2017, pages 123, 124 and 125.

Concerning employment, in 2013, the Ellen MacArthur Foundation[15] approximated that in the European manufacturing industry alone, the circular approach could save net material costs up to US$ 630 billion per year and generate an additional 310,000 to 320,000 jobs.

Waste collection and recycling provide a source of income for unskilled workers, who usually look for recyclables in cities and landfills that they can repair and resell. Only in Latin America between 500,000 and 4 million people operate in this informal sector, selling mainly to formal companies and demonstrating that there is an actual demand for recycled products. Governments, in implementing improved recycling systems, should consider the livelihood, workers' rights, health and safety of the informal waste picker group with inclusive public policies that expressly and formally define their role and contribution like what happened in Buenos Aires, where waste pickers were given certificates and recognised as qualified waste management service providers.

Focusing on the macro-economic area, investments in circular economies may lower the import bill of resource-importing nations and alleviate price shocks since natural resources have been frequently characterized by high volatility and raised their vulnerability. In these countries, natural resources such as refined oil and coal account for a massive share of their imports and cutting their domestic consumption would consequently free up significant financial resources.

Obviously, the reduction of fossil fuel imports will have negative repercussions on resource-exporting countries. These consequences can be limited to the short period if exporters design mitigation programmes and diversify their economic systems away from resource extraction and export.

4.2.3.2 OVERCOME BARRIERS AND PROMOTE CIRCULAR ECONOMIES

Unfortunately, although there are several potential benefits in achieving full circularity, diverse barriers are holding the circular economy back. This paragraph analyses these barriers and suggest what governments can do to overcome them.

[15] Charity organization launched in 2010 to boost the transition towards a circular economy.

To obtain circular economies at an economy-wide scale, policymakers should recognize the path towards circularity as a fundamental principle of the green industrial programme and coordinate actions and goal across all the stakeholders, from various levels of government to different players of the private sector such as investors, social entrepreneurs and marginalized communities.

The European Union, for example, in highlighting the relevance of a multi-stakeholder approach that involve both private and public sectors, has designed an action plan that is supported by a concrete set of measures, portioned in stages according to product life cycle. Then, within the stages are disposed sub-strategies for the different fields and stakeholders influenced by the transition.

Furthermore, in order to accelerate circularity, producers should be incentivized by an extended producer responsibility. Founding its origins in the 1992 German legislation and adopted by EU in 2008, extended producer responsibility implies that the costs of disposal and recovery at the end of a product's lifetime should be accounted to the producer himself, with the chance to either take products back or being charged of the cost of recycling or waste management. This would result in higher incentives to improve a product design, because if firms purchase a more resistant, reliable and durable goods, the disposal fees would be lower. Public authorities can strengthen this process providing a more transparent market, requesting to producers the disclosure of information relative to repair and maintenance. Competition would be stimulated, repair prices lowered, companies' disposal fees cut and environmental impact mitigated. For instance, French producers of vacuum cleaners with toxic flame-retardant plastics are charged with a fee 20 per cent higher than for vacuum cleaners exploiting non-hazardous materials and, in the U.S., a US$ 10 deposit-refund system for lead-acid batteries culminated in a recycling rate of 97 per cent.

Besides national regulations, international ones are also important, because resources and waste are commonly traded illegally across borders. In fact, taking into account the electronic waste alone, the estimates show that between 60 and 90 per cent are handled informally and unsafely with an annual worth around US$ 19 billion. International agreements aimed to restrict the export of toxic waste, such as the Basel Convention, offer some exemptions that enable the abuse of bypassing regulation.

In order to limit this excess, national regulations should complement international treaties, like happened in Africa, where 20 countries, in reinforcing the Basel Convention, agreed on the management and treatment of the cross-border movements of electronic waste.

The achievement of an efficient circular economy considerably depends on the conversion of those business models that still ground their sales system on increasing the quantity of products sold, regardless of the inputs used in the production process.

It is challenging to encourage businesses to change their way of dumping waste, especially when the costs of sending waste directly to landfills are incredibly low. In this case, economic incentives may attribute value to recycled products and stimulate organizations, particularly recyclers, to build facilities for proper recycling and to create a worthy business.

In offering incentives, policymakers should guarantee that all players in the value chain benefit from them. The life cycle approach, which analyses the design, repair, remanufacture, resources extraction, transport and infrastructure requirements of a product, enables governments to detect where the main economic opportunities reside. In addition, entrepreneurs should be informed about potential investors willing to cooperate and credit lines should be granted more easily, especially for those business models that need technology investments.

In practice, two emerging trends exhibit how business models can move towards circularity:

- *Reverse logistics* aims to maximise the recovery of inputs used in production. It promotes the opposite flow of products at the edge of their lifetime from consumers back to the industry, where materials can be repaired or remanufactured to be sold in second markets or re-entered the first market;
- *Product sharing* has the goal to lower the volume of goods that have to be manufactured, encouraging sharing over buying brand new products. Insights from South Korea show that public support is fundamental in the initial phases of a sharing economy. The 2012 Seoul's Metropolitan Government initiatives provide online platforms through which citizens, especially those economically and socially disadvantaged can access to services such as cars,

books, music, tools, knowledge and skills, education, lodging and meeting facilities. To set off the diffusion and raise the number of members, Seoul allocated subsidies for US$ 500,000.

Environmental taxes and fees can be exploited to promote regional coordination and spatial clustering with the purpose to establish eco-industrial parks and industrial symbiosis networks. A high level of cooperation is required to ensure synergies in which firm throughout the supply chain get a constant flow of materials. The issue concerning the secrecy of companies' policies can be solved by the employment of specific committees aimed to oversee the management of eco-industrial parks, providing recommendations on how inputs flows amongst tenants can be streamlined and which organizations could be added to complement the cluster while assuring the integrity of environmental infrastructures.

As every aspect previously mentioned, civil society must be involved in the process, because recycling and waste reduction begin in houses and in schools, as does education about sustainable development. Consumer preferences play a pivotal role in the circular economy, because they define the quality and quantity of the products available on the market, and many citizens may be persuaded by significant information instruments such as awareness campaigns and corporate sustainability reports on the origins and sustainability of the purchased products that combined with educational initiatives is likely to result in better consumption choices.

In this direction, Italy delivered an excellent example, as underline by the November 6, 2019 CNN's article:

"From next year, Italian school students in every grade will be required to study climate change and sustainability, in an attempt to position the country as a world leader in environmental education. Education Minister Lorenzo Fioramonti said all public schools will include about 33 hours a year in their curricula to study issues linked to climate change. The lessons will be built into existing civics classes, which will have an environmentalist footprint from September 2020. The idea is that the citizens of the future need to be ready for the climate emergency.

In addition, sustainable development will appear in more traditional subjects, such as geography, maths and physics. There will be more attention to climate change when teaching those traditional subjects.

I want to make the Italian education system the first education system that puts the environment and society at the core of everything we learn in school, he said.

A panel of scientific experts, including Jeffrey D. Sachs, director of Columbia University's Center for Sustainable Development, and American economic and social theorist Jeremy Rifkin, will help the ministry redevelop the national curriculum to pay more attention to climate change and sustainability.

Since becoming minister, Fioramonti has been criticized by right-wing opposition parties for supporting striking students protesting climate change and backing taxes on plastic and sugary drinks.

Even consumers with pro-environment attitudes do not always engage in behaviour that is environmentally responsible. The reason for this gap is that consumer behaviour can be influenced by rather irrational tendencies, such as cognitive biases and force of habit. Increasing numbers of people, as citizens and consumers, are aware of the benefits of closed cycle, circular economies. Green consumerism organizations are emerging in many countries and communities demanding more durable, well-designed, sustainable products and processes. Policymakers can support such movements as important drivers of change towards circular economies."[16]

4.3 NOTEWORTHY GREEN BUSINESSES

Human beings can enormously reduce the environmental footprint through simple actions. Eventually, the variables to consider are awareness and willingness, because we can easily avoid to utilize "throw away" goods like paper plates, plastic straws and cups, we can dry clothes naturally, save water through turning off the tap when we are brushing our teeth or taking a shower, use organic

[16] G. Mezzofiore (CNN), *Italy to become first country to make learning about climate change compulsory for school*, November 6, 2019.

ad eco-friendly fertilizers instead of chemicals, bring our own reusable bags to groceries, use public transport, cycle or walk instead of driving a car and so on. But most of all, we all should spread knowledge amongst our acquaintances, encourage them to do the same with other people and also support those green companies that, alongside profits, give a remarkable importance to the environment.

Green strategies look different within every firm. From carbon offset programmes to sustainable inputs to water and energy preservation, there are several ways to redesign a company's structure, as well as its company vision, and make them friendlier towards the Earth's natural habitat. While some businesses are doing more than their fair share to lower their environmental footprint, others are gradually initiating to follow the lead. When well-aware consumers see the good a firm is doing in the world, an emotional connection is likely to be built, so that, the increasing demand for greener and sustainable products is slowly transforming the way companies are run.

In the upcoming paragraphs, let's take a look at some interesting eco-friendly brands that are positively affecting the planet, in a way or another, that got my attention.

4.3.1 TESLA

In 2019, the American electric vehicle and clean energy firm published its first-ever environmental impact report, underlining the good changes the organization has made towards sustainability. In fact, according to its records, over 550,000 electric vehicles were sold. On aggregate, estimations say that for 10 billion miles only 282,000 metric tons of CO_2 have been released into the atmosphere, which compared to other traditional automakers that emit millions of carbon dioxide metric tons, lead to astonishing perspectives.

Based in Palo Alto (California, U.S.), Tesla Inc. was incorporated in 2003 by a group of engineers who wanted to demonstrate that people did not have to compromise in driving electric cars with regard to quality, safety and speed. Nowadays, with the purpose to build an entire sustainable energy

ecosystem, the company manufactures not only all-electric automobiles but also clean energy generation and storage products that enable households and businesses to save important resources.

In line with its mission to speed up the world's transition towards a zero-emission scenario offering always more and more affordable electric vehicles and energy products, Tesla shares the idea that the sooner we stop relying on fossil fuels moving towards, the better.

The production process is developed in different factories, known as Gigafactories. In practice, a gigafactory is a building with a massive extension[17], totally covered by photovoltaic panels, which make the facility self-sufficient in terms of energy. Additionally, the in-house cell production allowed Tesla to manufacture batteries at the volumes needed to meet production goals (500,000 vehicles per year), while generating thousands of jobs.

With the Gigafactory intensifying the production, the cost of battery cells will considerably fall through economies of scale and the products will be available to more and more people at an affordable price, providing the chance to make the biggest potential impact on switching the world to sustainable energy.

4.3.2 PATAGONIA

Patagonia Inc. is an American clothing company founded in 1973, one of the world's most successful activewear retailers.

Being an activist and environmental-conscious firm, it takes part in corporate social responsibility in several ways, such as profit donations, internal sustainability and awareness increase. In this context, the mission is *"At Patagonia, we appreciate that all life on earth is under threat of extinction. We aim to use the resources we have—our business, our investments, our voice and our imaginations—to do something about it."*

[17] Gigafactory 1, based in Nevada, covers an area of about 1200 hectares, which amounts to 3 times the extent of Central Park in NY. The company's CEO, Elon Musk, confidently argues that with the construction of 100 gigafactories the global demand for electricity would be sustainably fulfilled.
Tesla has the objective to build at least other 10 gigafactories in the upcoming years.

It published advertisements on the importance of support to eco-friendly politicians, additionally encouraging people to not purchase things they don't need, even Patagonia's own goods, and designed a strategy to repair their products rather than replace. The firm's sustainable dedication is not just in messaging and marketing, as it also resides within its products. Initiating from its production line, Patagonia is set on battles against the negative consequences of fast fashion by offering durable, reparable and reusable products. For instance, natural rubber is the input material of wetsuits and plastic bottles are converted into parkas.

Going forward, the company's vision embraces partnerships with organizations relying on renewable power infrastructure, regenerative organic agriculture, water preservation and sustainable inputs usage, among others.

However, Patagonia is not perfect, because some divisions of the business contribute to climate change, hence require improvement. The firm's commitment to changing and improving those procedures sets the goal in achieving an entirely carbon-neutral supply chain by 2025.

4.3.3 IKEA

The Swedish company commits to sustainability throughout its entire business activities. It begins with the supply chain, where Ikea acquires around 50 per cent of its wood from sustainable foresters and the entirety of its cotton from farmers that comply with sustainable practices.

The commitment to sustainability is also visible in the stores, where more than 700,000 solar panels are the energetic source, new products that reduce consumers' electricity and water use are available and single-use plastic products are completely pashed-out, among others.

Ikea declared its objectives to be powered by 100 percent renewable sources, also raising the stakes to become also a net energy exporter, and to recycle 91% of stores' waste by 2020. Furthermore, at the end of 2019, it invested US$ 220 million in green energy, reforestation and forest protection programmes.

4.3.4 DYECOO

Thanks to re-commerce and clothing rental that encourage take-back products, the apparel sector is increasingly becoming a leader in environmental sustainability. However, not all circular methods in this industry are seen by the customer, because plenty of activities are behind the scenes.

That is the case of DyeCoo, a Dutch company that implemented the first commercially available textile dyeing machine that totally eliminates the necessity for water and chemicals in the dyeing system.

The Ellen MacArthur Foundation's New Textiles Economy report estimated that while conventional textile dyeing requires from 95 to 150 liters of water for every two pounds (0,90 kilograms) of textile with a global amount of 92.96 trillion liters per year, a single DyeCoo machinery saves 32 million liters and around 176 tons of chemicals during the same time period.

The technical process functions by pressurizing and heating carbon dioxide to above 31.1° Celsius, at which it turns into supercritical, in a phase between liquid and gas. This enables dyes to simpler dissolve and to infiltrate deeply into fibers without the need of water or diverse chemicals. Consequently, the CO_2 is cleaned, and 95 percent is recycled back into the machinery to be exploited again. The innovative technology does not just prevent the use of water and chemicals, because being DyeCoo's strategy waterless, textiles do not have to be dried, and as a consequence, the dyeing process is accelerated by 40 percent which reduced the energy use by 60 percent.

The profitability and accountability of DyeCoo is guaranteed by the fact that one of the afore-mentioned companies, Ikea, is both investor and partner of the Dutch company since 2013.

4.3.5 STARBUCKS

The well-known American multinational chain of coffeehouses is currently implementing an environmentally-friend container to duplicate the cups' recycled content and reusability by the end of the year.

Starbucks is also committed to purchase 100% ethically-sourced coffee and to provide 100 million coffee trees to farmhouse by 2025 with the purpose to make coffee the first sustainable agricultural good. In addition, it aims to build 10,000 energy-efficient retail stores by the same date.

By operating in sustainable stores, the organization is able to reduce operating costs as well as diminish the influence of business practices on the environment.

4.3.6 BEYOND MEAT

In accordance to what has been illustrated in chapter 1, the meat industry is one of the biggest contributors to global warming with no rationale denying that the meat production is having important adverse consequences on the environment.

That is where Beyond Meat comes in.

This company is shaking up the food industry by offering on the market plant-based "meat" products that comply more with human health, environment and animals. Obviously, since these products are meatless, there is skepticism about the "meat" taste, but people who tasted Beyond Meat burgers assure they are as good as any burger they have ever eaten.

All of the firm's branding focuses on the good they are delivering to the natural habitat and to their customers since it is frequently displayed that plant-based "meat" produces 90% fewer GHG emissions, needs 46% less energy, and has 99% lower impact on water scarcity and 93% less impact on land use.

Marco Springmann, a senior environmental researcher at the University of Oxford, said: "It makes sense to develop alternatives to beef, because we have to change our eating habits to more plant-based diets if we want to limit global warming to under 2 degrees Celsius. Beyond Meats taps into this market. However, while their processed products have about half the carbon footprint that chicken does, they also have 5 times more of a footprint than a bean patty. So companies like Beyond Meat go somewhere towards reducing your carbon footprint, but saying it's the most climate friendly thing to do it is a false promise."

4.3.7 CHR. HANSEN HOLDING

Ranked by Forbes in the first position amongst the 100 most sustainable companies in the world in 2019, Chr. Hansen Holding is a Danish bioscience company that obtains over 80% of its revenues elaborating natural solutions for foods preservation, which safeguard crops through the use of natural bacteria instead of pesticides, and providing alternatives to antibiotics for animals.

More in details, the firm produces enzymes, probiotics and natural colors for a wide range of foods, candies, drinks, dietary supplements as well as animal feed and plant preservation. Thanks to more than 30,000 microbial strains, also known as good bacteria, food manufacturers are able to produce more with less, while cutting the use of pollutant chemicals and synthetic additives, contributing to a more sustainable agriculture, human and animal welfare growth and food waste reduction.

In a recent 10-year agreement, Chr. Hansen Denmark obtained green electricity from two brand new solar parks and it is not just about lowering environmental footprint, because significant internal policies enabled a 30%-board made up of women, and CEO wage about 24 times those of an normal employee, a relatively low ratio compared to other organizations.

4.3.8 ECOSIA

Ecosia is a search engine company built on a simple vision: making the Earth a greener place, one search at a time. Generating its income through search ads submitted on its website, the earmings are then used to plant trees all around the world. The company claims that on average, every search produces 0,20€ and for every 45 searches a tree is planted. As June 27, 2020 Ecosia has planted over 98 million trees. However, its mission goes beyond tree-planting. In fact, the company is also focused on building communities across the planet by helping local farmers, safeguarding wildlife, restoring biodiversity and its operations come all from its very own solar energy plant, 100% sustainable.

4.3.9 ESG INVESTMENTS

Global warming, climate change and environmental pollution are issues that are having an increasingly pervasive impact in conducting the choices and decisions of national and international institutions, outlining what will be the next drivers for industrial systems around the world.

This approach is part of a broader trend in which not only governments participate but also, and above all, small savers, who more and more opt for sustainable investment strategies in those assets that comply with *Environmental, Social and Governance (ESG) criteria*.

Environmental implies the reduction of CO_2 emissions, air or water pollution, deforestation and, in general terms, everything related to climate change, increased biodiversity, food safety and population growth. *Social* embraces gender policies, human rights, working conditions and relations with the civil community, child labor and equality. *Governance practices* include all corporate remuneration policies, the composition of the board of directors, internal control and compliance with regulations, shareholder rights or the presence of corruption.

This direction was also dictated by the United Nations, which in 2006 drafted the *Principles for Responsible Investment (PRI)*, a set of guidelines, signed by more than a thousand financial companies, with the purpose to raise awareness investors.

According to *BlackRock*[18] CEO and co-founder Larry Fink, the future of financial markets will be in eco-sustainability and firms that ignore this aspect will be increasingly disadvantaged in the medium and long-term compared to those ones taking into account environmental elements.

It will not be possible to avoid supplying climate change economically, neither for companies, nor for governments nor for shareholders. BlackRock observes that there has long been a growing tendency to favor the purchase of shares of companies that implement policies for environmental sustainability, and in accordance with Fink's estimations, with the new generations, the trend will be destined to grow almost exponentially.

[18] Headquartered in New York and founded in 1988, BlackRock Inc. is the world's largest asset manager (US$ 7.4 trillion as of the end of 2019) guiding individuals, financial professionals and institutions in building better financial futures.

In evaluating a company, considering the amount of earnings it produces is as important as the way it is produced and studies displayed a correlation between respect for ESG criteria and company quality. Companies that follow these principles generally have a stronger orientation towards the future, gain investor confidence in choosing greater sustainability and achieve better results, as demonstrated in 2005 by a *Journal of Sustainable Finance & Investment*'s study, from which emerged that compliance with ESG criteria is often associated with greater profitability.

However, even if the relevance of these principles is spreading rapidly, the road ahead is still quite long.

"If you think you're too small to make a difference, try sleeping in a room with a mosquito."

-African Proverb

CONCLUSION

Studies demonstrated that temperature, precipitation, and severe climatic events have economically and statistically relevant effects on plenty of outcomes such as aggregate output, agriculture, and labour productivity among others. These results exhibit the multiple nature of the weather–economy linkage, with several applications to comprehend past, present, and future economic consequences and potential responses, because for instance, the impact of climatic parameters on energy demand or agricultural productivity may instruct policy-makers on energy and agricultural investment rates and policy implementation.

In fact, integrating across the weather studies above, it appears that an unusually hot year is associated with substantially lower income growth in poor countries and considering temperature and water as fundamental inputs into the natural process of crop growth, the relationship between weather and agricultural productivity exhibits a damaging impact of weather fluctuations on agriculture. Moreover, negative effects of global warming on labor productivity have been proved, with papers illustrating that productivity is superior in spring and autumn, when temperatures are mild, and poorer in summer and winter, when weather conditions are more radical, especially in susceptible outdoor sectors such as agriculture, mining and construction. Another crucial bond is given by "energy demand-climate change". In fact, in light of the current environmental issues, paperwork vastly examines how climatic parameters, in particular temperature, affect energy demand. Energy consumption adapts to weather fluctuations, a higher energy demand increases greenhouse gas emissions, which conversely influences upcoming energy demand. One of the above-described research, studying annual observations of residential energy consumption from 1968-2002 across U.S., assessed that an extra day below 10°F (-12°C) or above 90°F (32°C) increase annual energy consumption by 0.3-0.4 percent.

The policy response and the proposed tools to mitigate global warming are diverse (e.g. carbon pricing, technology policies), but until now, the results seem to very poor. Unfortunately, the role of international organizations looking out for the natural habitat are underestimated. Most of the

countries act just thinking at their own national interests and when massive polluters like U.S and Brazil display no interest in changing direction, the already difficult path towards sustainability becomes even harder.

As we are experiencing, climate change is the biggest negative externality produced and never addressed by the humankind that is leading to dissimilar effect not uniformly distributed across countries. It takes just few seconds to understand that developing nations are more likely to disproportionally suffer the negative impact of global warming, hence climate justice is the topic analyzed in the statistical analysis, aimed to look at the differences between developed and emerging countries in a 20-years time interval (1996-2015), performed in Chapter 3.

The analysis' results enhance a limited improvement of the general situation, since both advanced and emerging countries display a higher number of significant variables from 1996 to 2015, which implies a growing correlation between the dependent and independent parameters. However, like any other research, this study also suffers from limitations. The main limitations of the work are that, focusing on the broad picture to see if there exists any dominant pattern, one cannot go in to great detail about any single country, and secondly, I went through a large lack of data availability and accuracy, especially for underdeveloped countries that face budget constraints. It makes more complex the analysis of their impact on the environment and consequently reduces the likelihood to deal with the issues.

Even if the entire scenario may look discouraging, the example set by innovative eco-friendly companies analyzed in Chapter 4 can lead to the a decisive step towards a green and sustainable economy.

During the Covid-19 lockdown, a question came to my mind: "Why for a pandemic, although extremely destructive and globally distributed, a significant common economic effort can be made (e.g. Recovery Fund) and for the environmental issue no remarkable and tangible action has been realized?"

The answer is that we probably do not perceive climate change as urgent and threatening as the Covid-19 pandemic and for this reason we think we can procrastinate. But we cannot.

We must start from the bottom of the society, from the newborn generations through education and awareness, because the later we educate to sustainability the more severe the consequences will be.

Change is up to responsible and well-aware people. They must enlarge the share of responsible citizens, and from there, this responsible base will be able to choose responsible governments, because the change that matters will not come from positions of privilege.

As human beings, everyone must play his part.

I will feel satisfied if through my thesis I will change the behavior of few people, which in turn may influence other ones' habits and so on.

This is the objective of my thesis, apart from the economic perspective.

REFERENCES

- N. STERN, *The Economics of Climate Change: The Stern Review,* Cambridge University Press, Cambridge, 2007
- S. HIANG-R.E. KOPP, *Journal of Economic Perspectives: An Economist's Guide to Climate Change Science,* American Economic Association, Nashville, 2018
- M. DELL-B.F. JONES-B.A. OLKEN, *Journal of Economic Literature: What Do We Learn from the Weather? The New Climate-Economy Literature,* American Economic Association, Nashville, 2014
- CLIMATE AND CLEAN AIR COALITION, *Annual Report 2018-2019: Fast Action, Quick Results, Multiple Benefits,* CCAC, Paris, 2019
- T. ALTENBURG- C. ASSMANN, *Green Industrial Policy. Concept, Policies, Country Experiences*, UN Environment, Geneva-Bonn, 2017
- P.J. CRUTZEN, *Benvenuti nell'Antropocene*, Mondadori, Milano, 2007
- M. GAROZZO, *Energie Pulite*, Le Scienze S.p.A., Roma, 1997
- M. GAROZZO, *La Sfida del Clima*, Le Scienze S.p.A., Roma, 2004
- RINALDI-M. VINCENZI, *Il Pianeta Impazzito*, La Repubblica, Roma, 2007

CHAPTER 1

- https://www.nationalgeographic.org/encyclopedia/climate-change/
- https://www.reuters.com/article/us-global-climatechange-health/climate-change-biggest-global-health-threat-of-century-doctors-warn-idUSKCN1NX2ZX
- https://www.britannica.com/science/global-warming/Climatic-variation-since-the-last-glaciation
- https://climate.nasa.gov
- https://www.ipcc.ch/documentation/

- https://www.ipcc.ch/site/assets/uploads/2018/02/ipcc_wg3_ar5_summary-for-policymakers.pdf
- https://www.britannica.com/science/global-warming/Land-use-change
- https://www.reuters.com/article/us-global-climatechange-health/climate-change-biggest-global-health-threat-of-century-doctors-warn-idUSKCN1NX2ZX
- https://www.iberdrola.com/environment/greenhouse-effects-consequences-and-impacts
- https://time.com/5496630/pollution-manufacturing-buildings-2018-study/
- https://www.epa.gov/ghgemissions/sources-greenhouse-gas-emissions
- https://www.globalchange.gov/climate-change/impacts-society
- https://www.nationalgeographic.org/encyclopedia/climate-refugees/

CHAPTER 2

- https://unfccc.int/about-us/about-the-secretariat
- https://www.ipcc.ch
- https://www.un.org/en/climatechange/un-climate-summit-2019.shtml
- https://www.ipcc.ch/site/assets/uploads/2018/02/ipcc_wg3_ar5_chapter15.pdf
- https://www.brookings.edu/research/how-the-geography-of-climate-damage-could-make-the-politics-less-polarizing/
- https://ccacoalition.org/en
- https://www.minambiente.it/pagina/climate-and-clean-air-coalition-initiative-ccac
- https://writingexplained.org/analyse-or-analyze-difference
- https://www.ecowatch.com/leonardo-dicaprio-before-the-flood-2057070140.html
- https://ec.europa.eu/clima/citizens/eu_it
- https://www.eea.europa.eu/it/themes/climate/policy-context
- https://gep-guide.net/climate/institutions.html

CHAPTER 3

- https://globaljusticeecology.org/climate-justice/
- https://www.theguardian.com/sustainable-business/2015/jan/12/achieve-climate-justice-human-rights
- https://www.un.org/sustainabledevelopment/blog/2019/05/climate-justice/

CHAPTER 4

- https://www.iea.org/reports/world-energy-outlook-2019
- https://www.iea.org
- https://www.iberdrola.com/environment/circular-economy-3-rs
- https://www.unenvironment.org
- http://wedocs.unep.org/bitstream/handle/20.500.11822/22277/Green_industrial_policy.pdf?sequence=1&isAllowed=y
- https://edition.cnn.com/2019/11/06/europe/italy-climate-change-school-intl-scli-scn/index.html
- http://www.dyecoo.com
- https://www.startingfinance.com
- https://www.tesla.com
- https://www.forbes.com/sites/karstenstrauss/2019/01/22/the-most-sustainable-companies-in-2019/#4ccf1aae6d7d
- https://stories.starbucks.com/stories/sustainability/
- https://www.patagonia.com/home/

APPENDIX

List of Advanced Economies and Emerging Countries (*source: International Monetary Fund*)

Table A6. Advanced Economies: Consumer Prices[1]
(Annual percent change)

	Average									Projections			End of Period[2]	Projections	
	2001–10	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020	2024	2018	2019	2020
Advanced Economies	**2.0**	**2.7**	**2.0**	**1.4**	**1.4**	**0.3**	**0.8**	**1.7**	**2.0**	**1.5**	**1.8**	**2.0**	**1.6**	**1.7**	**1.7**
United States	2.4	3.1	2.1	1.5	1.6	0.1	1.3	2.1	2.4	1.8	2.3	2.3	1.9	2.2	2.4
Euro Area[3]	2.1	2.7	2.5	1.3	0.4	0.2	0.2	1.5	1.8	1.2	1.4	1.8	1.5	1.3	1.3
Germany	1.6	2.5	2.2	1.6	0.8	0.7	0.4	1.7	1.9	1.5	1.7	2.1	1.8	1.8	1.7
France	1.9	2.3	2.2	1.0	0.6	0.1	0.3	1.2	2.1	1.2	1.3	1.7	2.0	1.0	1.4
Italy	2.2	2.9	3.3	1.2	0.2	0.1	–0.1	1.3	1.2	0.7	1.0	1.5	1.2	0.7	1.0
Spain	2.8	3.2	2.4	1.4	–0.2	–0.5	–0.2	2.0	1.7	0.7	1.0	1.8	1.2	0.7	1.1
Netherlands	2.1	2.5	2.8	2.6	0.3	0.2	0.1	1.3	1.6	2.5	1.6	2.0	1.8	2.1	1.7
Belgium	2.1	3.4	2.6	1.2	0.5	0.6	1.8	2.2	2.3	1.5	1.3	1.8	2.2	1.1	1.3
Austria	1.9	3.5	2.6	2.1	1.5	0.8	1.0	2.2	2.1	1.5	1.9	2.0	1.7	1.6	1.9
Ireland	2.2	1.2	1.9	0.5	0.3	0.0	–0.2	0.3	0.7	1.2	1.5	2.0	0.8	1.4	1.5
Portugal	2.5	3.6	2.8	0.4	–0.2	0.5	0.6	1.6	1.2	0.9	1.2	1.7	0.6	4.3	–3.1
Greece	3.4	3.1	1.0	–0.9	–1.4	–1.1	0.0	1.1	0.8	0.6	0.9	1.8	0.6	0.9	0.9
Finland	1.7	3.3	3.2	2.2	1.2	–0.2	0.4	0.8	1.2	1.2	1.3	1.8	1.3	1.1	1.3
Slovak Republic	4.1	4.1	3.7	1.5	–0.1	–0.3	–0.5	1.4	2.5	2.6	2.1	2.0	1.9	2.4	2.0
Lithuania	3.0	4.1	3.2	1.2	0.2	–0.7	0.7	3.7	2.5	2.3	2.2	2.2	1.8	2.4	2.2
Slovenia	4.2	1.8	2.6	1.8	0.2	–0.5	–0.1	1.4	1.7	1.8	1.9	2.0	1.4	2.2	1.9
Luxembourg	2.6	3.7	2.9	1.7	0.7	0.1	0.0	2.1	2.0	1.7	1.7	1.9	1.9	2.0	1.6
Latvia	5.4	4.2	2.3	0.0	0.7	0.2	0.1	2.9	2.6	3.0	2.6	2.2	2.5	2.1	2.3
Estonia	4.2	5.1	4.2	3.2	0.5	0.1	0.8	3.7	3.4	2.5	2.4	2.1	3.3	2.5	2.4
Cyprus	2.4	3.5	3.1	0.4	–0.3	–1.5	–1.2	0.7	0.8	0.7	1.6	2.0	1.1	1.2	1.3
Malta	2.4	2.5	3.2	1.0	0.8	1.2	0.9	1.3	1.7	1.7	1.8	2.0	1.2	2.0	1.9
Japan	–0.3	–0.3	–0.1	0.3	2.8	0.8	–0.1	0.5	1.0	1.0	1.3	1.3	0.8	1.6	0.2
United Kingdom	2.1	4.5	2.8	2.6	1.5	0.0	0.7	2.7	2.5	1.8	1.9	2.0	2.3	1.6	2.1
Korea	3.2	4.0	2.2	1.3	1.3	0.7	1.0	1.9	1.5	0.5	0.9	2.0	1.3	0.7	0.9
Canada	2.0	2.9	1.5	0.9	1.9	1.1	1.4	1.6	2.2	2.0	2.0	2.0	2.1	2.2	1.9
Australia	3.0	3.4	1.7	2.5	2.5	1.5	1.3	2.0	2.0	1.6	1.8	2.5	1.8	1.8	1.7
Taiwan Province of China	0.9	1.4	1.6	1.0	1.3	–0.6	1.0	1.1	1.5	0.8	1.1	1.4	–0.1	0.8	1.1
Singapore	1.6	5.2	4.6	2.4	1.0	–0.5	–0.5	0.6	0.4	0.7	1.0	1.5	0.5	0.7	1.1
Switzerland	0.9	0.2	–0.7	–0.2	0.0	–1.1	–0.4	0.5	0.9	0.6	0.6	1.0	0.7	0.3	0.9
Sweden	1.9	1.4	0.9	0.4	0.2	0.7	1.1	1.9	2.0	1.7	1.5	1.9	2.2	1.6	1.4
Hong Kong SAR	0.4	5.3	4.1	4.3	4.4	3.0	2.4	1.5	2.4	3.0	2.6	2.5	2.4	3.0	2.6
Czech Republic	2.5	1.9	3.3	1.4	0.4	0.3	0.7	2.5	2.2	2.6	2.3	2.0	2.0	2.3	2.0
Norway	2.0	1.3	0.7	2.1	2.0	2.2	3.6	1.9	2.8	2.3	1.9	2.0	3.5	1.9	1.9
Israel	2.1	3.5	1.7	1.5	0.5	–0.6	–0.5	0.2	0.8	1.0	1.3	2.0	0.8	1.1	1.8
Denmark	2.0	2.7	2.4	0.5	0.4	0.2	0.0	1.1	0.7	1.3	1.5	2.0	0.7	1.2	1.4
New Zealand	2.6	4.1	1.0	1.1	1.2	0.3	0.6	1.9	1.6	1.4	1.9	2.0	1.9	1.5	2.0
Puerto Rico	2.7	2.9	1.3	1.1	0.6	–0.8	–0.3	1.8	1.3	–0.1	1.0	1.2	0.6	–0.1	1.0
Macao SAR	. . .	5.8	6.1	5.5	6.0	4.6	2.4	1.2	3.0	2.4	2.7	3.0	2.9	2.4	2.7
Iceland	6.2	4.0	5.2	3.9	2.0	1.6	1.7	1.8	2.7	2.8	2.5	2.5	3.7	2.6	2.6
San Marino	. . .	2.0	2.8	1.6	1.1	0.1	0.6	1.0	1.5	1.3	1.5	1.7	1.5	1.3	1.5
Memorandum															
Major Advanced Economies	1.8	2.6	1.9	1.3	1.5	0.3	0.8	1.8	2.1	1.6	1.9	2.0	1.7	1.8	1.8

[1]Movements in consumer prices are shown as annual averages.
[2]Monthly year-over-year changes and, for several countries, on a quarterly basis.
[3]Based on Eurostat's harmonized index of consumer prices.

Table A7. Emerging Market and Developing Economies: Consumer Prices[1]

(Annual percent change)

	Average									Projections			End of Period[2]	Projections	
	2001–10	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020	2024	2018	2019	2020
Emerging and Developing Asia	**4.3**	**6.5**	**4.6**	**4.6**	**3.4**	**2.7**	**2.8**	**2.4**	**2.6**	**2.7**	**3.0**	**3.3**	**2.3**	**2.8**	**3.0**
Bangladesh	6.3	11.5	6.2	7.5	7.0	6.2	5.7	5.6	5.6	5.5	5.5	5.5	5.5	5.5	5.5
Bhutan	4.6	7.3	9.3	11.3	9.5	7.6	7.6	5.5	3.5	3.6	4.2	4.5	3.2	3.1	3.9
Brunei Darussalam	0.5	0.1	0.1	0.4	–0.2	–0.4	–0.7	–0.2	0.1	0.1	0.2	0.2	0.0	0.1	0.2
Cambodia	5.1	5.5	2.9	3.0	3.9	1.2	3.0	2.9	2.4	2.2	2.5	3.0	1.6	2.3	2.5
China	2.1	5.4	2.6	2.6	2.0	1.4	2.0	1.6	2.1	2.3	2.4	3.0	1.9	2.2	2.4
Fiji	3.7	7.3	3.4	2.9	0.5	1.4	3.9	3.4	4.1	3.5	3.0	3.0	4.9	3.5	3.0
India	6.5	9.5	10.0	9.4	5.8	4.9	4.5	3.6	3.4	3.4	4.1	4.0	2.5	3.9	4.1
Indonesia	8.6	5.3	4.0	6.4	6.4	6.4	3.5	3.8	3.2	3.2	3.3	3.0	3.1	3.4	3.1
Kiribati	3.1	1.5	–3.0	–1.5	2.1	0.6	1.9	0.4	1.9	1.7	2.4	2.6	1.4	1.7	2.2
Lao P.D.R.	7.6	7.6	4.3	6.4	4.1	1.3	1.8	0.7	2.0	3.1	3.3	3.1	1.5	2.9	3.1
Malaysia	2.2	3.2	1.7	2.1	3.1	2.1	2.1	3.8	1.0	1.0	2.1	2.3	0.2	1.9	2.1
Maldives	4.0	11.3	10.9	3.8	2.1	1.9	0.8	2.3	1.4	1.5	2.3	2.0	0.5	2.1	2.4
Marshall Islands	. . .	5.4	4.3	1.9	1.1	–2.2	–1.5	0.0	0.8	0.6	1.8	2.1	0.8	0.6	1.8
Micronesia	3.2	4.1	6.3	2.3	0.7	0.0	–0.9	0.1	1.5	1.8	2.0	2.0	1.5	1.8	2.0
Mongolia	8.8	7.7	15.0	8.6	12.9	5.9	0.5	4.6	7.6	9.0	8.3	7.1	9.7	8.4	8.1
Myanmar	19.5	6.8	0.4	5.8	5.1	7.3	9.1	4.6	5.9	7.8	6.7	5.5	8.6	7.2	6.8
Nauru	. . .	–3.4	0.3	–1.1	0.3	9.8	8.2	5.1	0.5	2.5	2.3	2.0	3.4	1.5	2.2
Nepal	6.1	9.6	8.3	9.9	9.0	7.2	9.9	4.5	4.2	4.5	6.1	5.3	4.6	6.2	6.0
Palau	2.6	2.6	5.4	2.8	4.0	2.2	–1.3	0.9	1.6	2.2	2.0	2.0	1.4	2.2	2.0
Papua New Guinea	6.5	4.4	4.5	5.0	5.2	6.0	6.7	4.9	5.2	3.9	4.4	4.8	4.8	3.5	4.8
Philippines	5.2	4.8	3.0	2.6	3.6	0.7	1.3	2.9	5.2	2.5	2.3	3.0	5.1	1.6	3.0
Samoa	5.7	2.9	6.2	–0.2	–1.2	1.9	0.1	1.3	3.7	2.9	2.7	2.8	5.8	4.0	2.9
Solomon Islands	8.5	7.4	5.9	5.4	5.2	–0.6	0.5	0.5	2.7	0.4	2.2	4.3	3.2	3.2	3.5
Sri Lanka	9.7	6.7	7.5	6.9	2.8	2.2	4.0	6.6	4.3	4.1	4.5	5.0	2.8	4.2	4.6
Thailand	2.6	3.8	3.0	2.2	1.9	–0.9	0.2	0.7	1.1	0.9	0.9	2.0	0.4	1.3	1.2
Timor-Leste	4.5	13.2	10.9	9.5	0.8	0.6	–1.5	0.5	2.3	2.5	3.1	4.0	2.1	2.8	3.5
Tonga	7.7	6.3	1.1	2.1	1.2	–1.1	2.6	7.4	2.9	3.8	3.9	2.5	4.8	2.8	4.9
Tuvalu	2.9	0.5	1.4	2.0	1.1	3.1	3.5	4.1	2.1	2.1	3.2	2.0	2.3	2.1	3.2
Vanuatu	2.9	0.9	1.3	1.5	0.8	2.5	0.8	3.1	2.9	2.0	2.2	2.6	2.6	2.6	2.2
Vietnam	7.7	18.7	9.1	6.6	4.1	0.6	2.7	3.5	3.5	3.6	3.7	4.0	3.0	3.7	3.8
Emerging and Developing Europe	**11.5**	**7.9**	**6.2**	**5.6**	**6.5**	**10.5**	**5.5**	**5.4**	**6.2**	**6.8**	**5.6**	**5.3**	**7.4**	**6.0**	**5.5**
Albania	3.0	3.4	2.0	1.9	1.6	1.9	1.3	2.0	2.0	1.8	2.0	3.0	1.8	1.8	2.2
Belarus	20.1	53.2	59.2	18.3	18.1	13.5	11.8	6.0	4.9	5.4	4.8	4.0	5.6	5.0	4.5
Bosnia and Herzegovina	2.8	4.0	2.1	–0.1	–0.9	–1.0	–1.6	0.8	1.4	1.1	1.4	1.9	1.6	1.2	1.4
Bulgaria[3]	6.0	3.4	2.4	0.4	–1.6	–1.1	–1.3	1.2	2.6	2.5	2.3	2.2	2.3	2.5	2.2
Croatia	2.8	2.3	3.4	2.2	–0.2	–0.5	–1.1	1.1	1.5	1.0	1.2	1.5	0.9	1.2	1.3
Hungary	5.6	3.9	5.7	1.7	–0.2	–0.1	0.4	2.4	2.8	3.4	3.4	3.0	2.7	3.2	3.4
Kosovo	2.8	7.3	2.5	1.8	0.4	–0.5	0.3	1.5	1.1	2.8	1.5	2.0	2.9	1.6	1.7
Moldova	9.5	7.6	4.6	4.6	5.1	9.6	6.4	6.6	3.1	4.9	5.7	5.0	0.9	7.5	5.0
Montenegro	7.3	3.5	4.1	2.2	–0.7	1.5	–0.3	2.4	2.6	1.1	1.9	1.9	1.7	2.3	1.6
North Macedonia	2.1	3.9	3.3	2.8	–0.3	–0.3	–0.2	1.4	1.5	1.3	1.7	2.2	0.8	1.4	1.8
Poland	2.8	4.3	3.7	0.9	0.0	–0.9	–0.6	2.0	1.6	2.4	3.5	2.8	1.1	3.3	3.5
Romania	12.1	5.8	3.3	4.0	1.1	–0.6	–1.6	1.3	4.6	4.2	3.3	2.5	3.3	4.5	3.5
Russia	12.5	8.4	5.1	6.8	7.8	15.5	7.0	3.7	2.9	4.7	3.5	4.0	4.3	3.8	3.7
Serbia	14.7	11.1	7.3	7.7	2.1	1.4	1.1	3.1	2.0	2.2	1.9	3.0	2.0	2.0	2.2
Turkey	17.5	6.5	8.9	7.5	8.9	7.7	7.8	11.1	16.3	15.7	12.6	11.0	20.3	13.5	12.0
Ukraine[4]	11.1	8.0	0.6	–0.3	12.1	48.7	13.9	14.4	10.9	8.7	5.9	5.0	9.8	7.0	5.6
Latin America and the Caribbean[5]	**5.8**	**5.2**	**4.6**	**4.6**	**4.9**	**5.5**	**5.6**	**6.0**	**6.2**	**7.2**	**6.7**	**4.3**	**7.1**	**7.3**	**6.0**
Antigua and Barbuda	2.2	3.5	3.4	1.1	1.1	1.0	–0.5	2.4	1.2	1.6	2.0	2.0	1.7	2.0	2.0
Argentina[4]	9.5	9.8	10.0	10.6	. . .	. . .	. . .	25.7	34.3	54.4	51.0	17.0	47.6	57.3	39.2
Aruba	3.3	4.4	0.6	–2.4	0.4	0.5	–0.9	–0.5	3.6	3.0	2.0	2.2	4.6	1.8	2.7
The Bahamas	2.3	3.1	1.9	0.4	1.2	1.9	–0.3	1.6	2.2	1.8	2.6	2.2	2.0	2.8	2.4
Barbados	4.1	9.4	4.5	1.8	1.8	–1.1	1.5	4.4	3.7	1.9	1.8	2.3	0.6	1.4	2.3
Belize	2.5	1.7	1.2	0.5	1.2	–0.9	0.7	1.1	0.3	1.2	1.6	2.0	–0.1	2.4	0.8
Bolivia	4.6	9.9	4.5	5.7	5.8	4.1	3.6	2.8	2.3	1.7	3.1	5.0	1.5	2.3	4.0
Brazil	6.6	6.6	5.4	6.2	6.3	9.0	8.7	3.4	3.7	3.8	3.5	3.5	3.7	3.6	3.9
Chile	3.2	3.3	3.0	1.8	4.7	4.3	3.8	2.2	2.3	2.2	2.8	3.0	2.1	2.6	2.9
Colombia	5.6	3.4	3.2	2.0	2.9	5.0	7.5	4.3	3.2	3.6	3.7	3.0	3.2	3.9	3.1

Table A7. Emerging Market and Developing Economies: Consumer Prices[1] *(continued)*

(Annual percent change)

	Average									Projections			End of Period[2]	Projections	
	2001–10	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020	2024	2018	2019	2020
Latin America and the Caribbean (continued)[5]	**5.8**	**5.2**	**4.6**	**4.6**	**4.9**	**5.5**	**5.6**	**6.0**	**6.2**	**7.2**	**6.7**	**4.3**	**7.1**	**7.3**	**6.0**
Costa Rica	10.3	4.9	4.5	5.2	4.5	0.8	0.0	1.6	2.2	2.7	3.1	3.0	2.0	3.2	3.0
Dominica	2.2	1.1	1.4	0.0	0.8	–0.9	0.0	0.6	1.4	1.6	1.8	2.0	1.4	1.8	1.8
Dominican Republic	12.1	8.5	3.7	4.8	3.0	0.8	1.6	3.3	3.6	1.8	4.1	4.0	1.2	3.0	4.0
Ecuador	8.1	4.5	5.1	2.7	3.6	4.0	1.7	0.4	–0.2	0.4	1.2	1.1	0.3	0.5	1.1
El Salvador	3.4	5.1	1.7	0.8	1.1	–0.7	0.6	1.0	1.1	0.9	1.1	1.0	0.4	1.4	1.2
Grenada	3.0	3.0	2.4	0.0	–1.0	–0.6	1.7	0.9	0.8	1.0	1.6	1.9	1.4	1.0	1.9
Guatemala	6.8	6.2	3.8	4.3	3.4	2.4	4.4	4.4	3.8	4.2	4.2	4.3	2.3	3.8	3.9
Guyana	5.9	4.4	2.4	1.9	0.7	–0.9	0.8	1.9	1.3	2.1	3.3	2.8	1.6	2.7	3.5
Haiti	14.0	7.4	6.8	6.8	3.9	7.5	13.4	14.7	12.9	17.6	17.1	5.9	13.3	19.7	15.0
Honduras	7.6	6.8	5.2	5.2	6.1	3.2	2.7	3.9	4.3	4.4	4.2	4.0	4.2	4.4	4.2
Jamaica	11.8	7.5	6.9	9.4	8.3	3.7	2.3	4.4	3.7	3.6	4.6	5.0	2.4	4.7	4.5
Mexico	4.7	3.4	4.1	3.8	4.0	2.7	2.8	6.0	4.9	3.8	3.1	3.0	4.8	3.2	3.0
Nicaragua	8.3	8.1	7.2	7.1	6.0	4.0	3.5	3.9	5.0	5.6	4.2	5.0	3.9	7.0	4.2
Panama	2.6	5.9	5.7	4.0	2.6	0.1	0.7	0.9	0.8	0.0	1.5	2.0	0.2	0.8	1.8
Paraguay	7.8	8.3	3.7	2.7	5.0	3.1	4.1	3.6	4.0	3.5	3.7	3.7	3.2	3.7	3.7
Peru	2.4	3.4	3.7	2.8	3.2	3.5	3.6	2.8	1.3	2.2	1.9	2.0	2.2	1.9	2.0
St. Kitts and Nevis	3.3	5.8	0.8	1.1	0.2	–2.3	–0.3	0.0	–0.2	0.6	2.0	2.0	–0.7	2.0	2.0
St. Lucia	2.6	2.8	4.2	1.5	3.5	–1.0	–3.1	0.1	2.0	2.1	2.3	2.0	2.2	2.1	2.2
St. Vincent and the Grenadines	2.9	3.2	2.6	0.8	0.2	–1.7	–0.2	2.2	2.3	1.4	2.0	2.0	1.4	2.0	2.0
Suriname	13.1	17.7	5.0	1.9	3.4	6.9	55.5	22.0	6.9	5.5	5.8	4.8	5.4	7.1	4.8
Trinidad and Tobago	7.0	5.1	9.3	5.2	5.7	4.7	3.1	1.9	1.0	0.9	1.5	2.6	1.0	0.9	1.5
Uruguay	8.7	8.1	8.1	8.6	8.9	8.7	9.6	6.2	7.6	7.6	7.2	7.0	8.0	7.5	7.0
Venezuela[4]	22.0	26.1	21.1	40.6	62.2	121.7	254.9	438.1	65,374.1	200,000	500,000	. . .	130,060.2	200,000	500,000
Middle East and Central Asia	**7.2**	**9.2**	**9.4**	**8.8**	**6.6**	**5.5**	**5.5**	**6.7**	**9.9**	**8.2**	**9.1**	**7.1**	**11.1**	**7.9**	**8.9**
Afghanistan	. . .	11.8	6.4	7.4	4.7	–0.7	4.4	5.0	0.6	2.6	4.5	5.0	0.8	4.5	4.5
Algeria	3.6	4.5	8.9	3.3	2.9	4.8	6.4	5.6	4.3	2.0	4.1	8.7	2.7	3.9	3.2
Armenia	4.4	7.7	2.5	5.8	3.0	3.7	–1.4	1.0	2.5	1.7	2.5	4.1	1.9	1.5	3.3
Azerbaijan	7.4	7.8	1.0	2.4	1.4	4.0	12.4	12.8	2.3	2.8	3.0	3.5	2.3	2.8	3.0
Bahrain	1.8	–0.4	2.8	3.3	2.7	1.8	2.8	1.4	2.1	1.4	2.8	2.2	1.9	2.0	2.8
Djibouti	3.7	5.2	4.2	1.1	1.3	–0.8	2.7	0.6	0.1	2.2	2.0	2.0	2.0	2.0	2.0
Egypt	7.9	11.1	8.6	6.9	10.1	11.0	10.2	23.5	20.9	13.9	10.0	7.1	14.4	9.4	8.7
Georgia	6.6	8.5	–0.9	–0.5	3.1	4.0	2.1	6.0	2.6	4.2	3.8	3.0	1.5	5.4	3.0
Iran	14.7	21.5	30.6	34.7	15.6	11.9	9.1	9.6	30.5	35.7	31.0	25.0	47.5	31.1	30.0
Iraq	. . .	5.6	6.1	1.9	2.2	1.4	0.5	0.1	0.4	–0.3	1.0	2.0	–0.1	0.3	1.2
Jordan	4.0	4.2	4.5	4.8	2.9	–0.9	–0.8	3.3	4.5	2.0	2.5	2.5	3.6	2.5	2.5
Kazakhstan	8.6	8.4	5.1	5.8	6.7	6.7	14.6	7.4	6.0	5.3	5.2	4.0	5.3	5.7	4.7
Kuwait	3.2	4.9	3.2	2.7	3.1	3.7	3.5	1.5	0.6	1.5	2.2	2.5	0.4	1.8	3.0
Kyrgyz Republic	7.4	16.6	2.8	6.6	7.5	6.5	0.4	3.2	1.5	1.3	5.0	5.0	0.5	4.0	5.1
Lebanon	2.6	5.0	6.6	4.8	1.8	–3.7	–0.8	4.5	6.1	3.1	2.6	2.4	4.0	3.4	2.4
Libya[4]	0.4	15.9	6.1	2.6	2.4	9.8	25.9	28.5	9.3	4.2	8.9	6.5	–4.5	12.0	6.5
Mauritania	6.5	5.7	4.9	4.1	3.8	0.5	1.5	2.3	3.1	3.0	3.4	4.0	3.2	2.8	4.0
Morocco	1.8	0.9	1.3	1.9	0.4	1.5	1.6	0.8	1.9	0.6	1.1	2.0	0.1	0.6	1.1
Oman	2.9	4.0	2.9	1.2	1.0	0.1	1.1	1.6	0.9	0.8	1.8	2.5	0.9	0.8	1.8
Pakistan	8.1	13.7	11.0	7.4	8.6	4.5	2.9	4.1	3.9	7.3	13.0	5.0	5.2	8.9	11.8
Qatar	5.1	2.0	1.8	3.2	3.4	1.8	2.7	0.4	0.2	–0.4	2.2	2.0	. . .	. . .	. . .
Saudi Arabia	2.1	3.8	2.9	3.5	2.2	1.3	2.0	–0.9	2.5	–1.1	2.2	2.1	2.3	–1.1	2.2
Somalia	. . .	. . .	. . .	. . .	. . .	. . .	. . .	. . .	. . .	. . .	. . .	. . .	3.2	4.0	3.0
Sudan[6]	10.8	18.1	35.6	36.5	36.9	16.9	17.8	32.4	63.3	50.4	62.1	74.7	72.9	56.9	66.9
Syria[7]	5.7	. . .	. . .	. . .	. . .	. . .	. . .	. . .	. . .	. . .	. . .	. . .	. . .	. . .	. . .
Tajikistan	13.5	12.4	5.8	5.0	6.1	5.8	5.9	7.3	3.8	7.4	7.1	6.5	5.4	7.0	6.8
Tunisia	3.3	3.2	4.6	5.3	4.6	4.4	3.6	5.3	7.3	6.6	5.4	4.0	7.5	5.9	5.5
Turkmenistan	7.2	5.3	5.3	6.8	6.0	7.4	3.6	8.0	13.2	13.4	13.0	6.0	7.2	9.0	8.0
United Arab Emirates	5.5	0.9	0.7	1.1	2.3	4.1	1.6	2.0	3.1	–1.5	1.2	2.1	3.1	–1.5	1.2
Uzbekistan	14.5	12.4	11.9	11.7	9.1	8.5	8.8	13.9	17.5	14.7	14.1	7.6	14.3	15.6	12.4
Yemen	10.9	19.5	9.9	11.0	8.2	22.0	21.3	30.4	27.6	14.7	35.5	5.0	14.3	15.0	36.3

Table A7. Emerging Market and Developing Economies: Consumer Prices[1] *(continued)*

(Annual percent change)

	Average									Projections			End of Period[2]		
	2001–10	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020	2024	2018	Projections 2019	2020
Sub-Saharan Africa	**9.9**	**9.3**	**9.2**	**6.5**	**6.4**	**6.9**	**10.8**	**10.9**	**8.5**	**8.4**	**8.0**	**6.6**	**7.9**	**9.0**	**7.4**
Angola	42.4	13.5	10.3	8.8	7.3	9.2	30.7	29.8	19.6	17.2	15.0	6.0	18.6	17.0	12.0
Benin	3.1	2.7	6.7	1.0	–1.1	0.2	–0.8	1.8	0.8	–0.3	1.0	2.0	–0.1	0.5	1.1
Botswana	8.6	8.5	7.5	5.9	4.4	3.1	2.8	3.3	3.2	3.0	3.5	4.0	3.5	2.7	3.5
Burkina Faso	2.8	2.8	3.8	0.5	–0.3	0.9	–0.2	0.4	2.0	1.1	1.4	2.0	0.3	2.0	2.0
Burundi	8.9	9.6	18.2	7.9	4.4	5.6	5.5	16.6	1.2	7.3	9.0	9.0	5.3	9.0	9.0
Cabo Verde	2.4	4.5	2.5	1.5	–0.2	0.1	–1.4	0.8	1.3	1.2	1.6	1.8	1.0	1.0	1.6
Cameroon	2.6	2.9	2.4	2.1	1.9	2.7	0.9	0.6	1.1	2.1	2.2	2.0	2.0	2.3	2.2
Central African Republic	3.3	1.2	5.9	6.6	11.6	4.5	4.6	4.5	1.6	3.0	2.6	2.5	4.6	3.0	2.5
Chad	3.2	2.0	7.5	0.2	1.7	4.8	–1.6	–0.9	4.0	3.0	3.0	4.2	4.4	9.1	–6.4
Comoros	4.2	2.2	5.9	0.4	0.0	0.9	0.8	0.1	1.7	3.2	1.4	1.9	0.9	4.8	0.6
Democratic Republic of the Congo	36.8	14.9	0.9	0.9	1.2	0.7	3.2	35.8	29.3	5.5	5.0	5.0	7.2	5.5	5.0
Republic of Congo	2.9	1.8	5.0	4.6	0.9	3.2	3.2	0.4	1.2	1.5	1.8	3.0	0.9	1.9	2.5
Côte d'Ivoire	2.9	4.9	1.3	2.6	0.4	1.2	0.7	0.7	0.4	1.0	2.0	2.0	1.1	1.0	2.0
Equatorial Guinea	5.6	4.8	3.4	3.2	4.3	1.7	1.4	0.7	1.3	0.9	1.7	2.0	2.6	1.6	1.7
Eritrea	18.0	5.9	4.8	5.9	10.0	28.5	–5.6	–13.3	–14.4	–27.6	0.0	2.0	–29.3	–0.1	0.0
Eswatini	7.1	6.1	8.9	5.6	5.7	5.0	7.8	6.2	4.8	2.8	4.0	7.0	5.3	2.3	4.4
Ethiopia	11.1	33.2	24.1	8.1	7.4	9.6	6.6	10.7	13.8	14.6	12.7	8.0	10.6	14.5	10.0
Gabon	1.2	1.3	2.7	0.5	4.5	–0.1	2.1	2.7	4.8	3.0	3.0	2.5	6.3	3.0	3.0
The Gambia	7.0	4.8	4.6	5.2	6.3	6.8	7.2	8.0	6.5	6.9	6.5	5.0	6.4	7.0	6.0
Ghana	15.9	7.7	7.1	11.7	15.5	17.2	17.5	12.4	9.8	9.3	9.2	8.0	9.4	9.3	9.0
Guinea	16.0	21.4	15.2	11.9	9.7	8.2	8.2	8.9	9.8	8.9	8.3	7.8	9.9	8.6	8.1
Guinea-Bissau	2.3	5.1	2.1	0.8	–1.0	1.5	1.5	1.1	1.4	–2.6	1.3	2.5	5.9	1.5	–1.4
Kenya	7.0	14.0	9.4	5.7	6.9	6.6	6.3	8.0	4.7	5.6	5.3	5.0	5.7	6.2	6.2
Lesotho	7.0	6.0	5.5	5.0	4.6	4.3	6.2	4.5	4.7	5.9	5.7	5.5	5.2	6.0	5.3
Liberia	10.0	8.5	6.8	7.6	9.9	7.7	8.8	12.4	23.5	22.2	20.5	13.5	28.5	20.6	19.0
Madagascar	10.2	9.5	5.7	5.8	6.1	7.4	6.7	8.3	7.3	6.7	6.3	5.0	6.1	6.4	6.0
Malawi	8.1	7.6	21.3	28.3	23.8	21.9	21.7	11.5	9.2	8.8	8.4	5.0	9.9	8.6	7.8
Mali	2.7	3.1	5.3	–2.4	2.7	1.4	–1.8	1.8	1.7	0.2	1.3	1.9	1.0	1.0	1.5
Mauritius	5.7	6.5	3.9	3.5	3.2	1.3	1.0	3.7	3.2	0.9	2.3	3.3	1.8	2.0	2.7
Mozambique	11.0	11.2	2.6	4.3	2.6	3.6	19.9	15.1	3.9	5.6	7.6	5.5	3.5	8.5	6.5
Namibia	7.1	5.0	6.7	5.6	5.3	3.4	6.7	6.1	4.3	4.8	5.5	5.5	5.1	4.8	5.5
Niger	2.5	2.9	0.5	2.3	–0.9	1.0	0.2	0.2	2.7	–1.3	2.2	2.0	1.6	0.4	2.0
Nigeria	12.9	10.8	12.2	8.5	8.0	9.0	15.7	16.5	12.1	11.3	11.7	11.0	11.4	11.7	11.7
Rwanda	7.9	5.7	6.3	4.2	1.8	2.5	5.7	4.8	1.4	3.5	5.0	5.0	1.1	5.0	5.0
São Tomé and Príncipe	16.2	14.3	10.6	8.1	7.0	5.2	5.4	5.7	7.9	8.8	8.9	3.0	9.0	7.8	10.0
Senegal	2.1	3.4	1.4	0.7	–1.1	0.1	0.8	1.3	0.5	1.0	1.5	1.5	1.3	2.0	1.5
Seychelles	7.6	2.6	7.1	4.3	1.4	4.0	–1.0	2.9	3.7	2.0	1.8	3.0	3.4	2.3	1.9
Sierra Leone	8.3	6.8	6.6	5.5	4.6	6.7	10.9	18.2	16.9	15.7	13.0	8.3	17.5	14.0	12.0
South Africa	5.9	5.0	5.6	5.8	6.1	4.6	6.3	5.3	4.6	4.4	5.2	5.3	4.9	4.7	5.3
South Sudan	. . .	. . .	45.1	0.0	1.7	52.8	379.8	187.9	83.5	24.5	16.9	8.0	40.1	35.9	10.8
Tanzania	6.6	12.7	16.0	7.9	6.1	5.6	5.2	5.3	3.5	3.6	4.2	5.0	3.3	4.1	4.3
Togo	2.6	3.6	2.6	1.8	0.2	1.8	0.9	–0.2	0.9	1.4	2.0	2.0	2.0	1.7	2.2
Uganda	6.4	15.0	12.7	4.9	3.1	5.4	5.5	5.6	2.6	3.2	3.8	5.0	2.2	3.5	3.9
Zambia	15.4	8.7	6.6	7.0	7.8	10.1	17.9	6.6	7.0	9.9	10.0	8.0	7.9	12.0	8.0
Zimbabwe[8]	–5.6	3.5	3.7	1.6	–0.2	–2.4	–1.6	0.9	10.6	161.8	49.7	3.0	42.1	182.9	9.4

[1]Movements in consumer prices are shown as annual averages.
[2]Monthly year-over-year changes and, for several countries, on a quarterly basis.
[3]Based on Eurostat's harmonized index of consumer prices.
[4]See country-specific notes for Argentina, Libya, Ukraine, and Venezuela in the "Country Notes" section of the Statistical Appendix.
[5]Excludes Venezuela but includes Argentina from 2017 onward. See country-specific notes for Venezuela and Argentina in the "Country Notes" section of the Statistical Appendix.
[6]Data for 2011 exclude South Sudan after July 9. Data for 2012 and onward pertain to the current Sudan.
[7]Data for Syria are excluded for 2011 onward owing to the uncertain political situation.
[8]The Zimbabwe dollar ceased circulating in early 2009. Data are based on IMF staff estimates of price and exchange rate developments in US dollars. IMF staff estimates of US dollar values may differ from authorities' estimates.

ABSTRACT (ITALIAN)

Oltre all'attuale pandemia COVID-19, il riscaldamento globale è il più minaccioso di tutti i problemi che il mondo sta affrontando al giorno d'oggi.

Un numero crescente di evidenze scientifiche suggerisce che le attività umane hanno intensificato la concentrazione di gas serra nell'atmosfera con un conseguente aumento della temperatura media della Terra. Nel suo quinto rapporto di valutazione risalente al 2013, l'Intergovernmental Panel on Climate Change ha sottolineato che la superficie terrestre è stata progressivamente sempre più calda in ciascuno degli ultimi tre decenni e che la temperatura media della superficie globale è aumentata di 0,8 gradi nell'ultimo secolo rispetto alle temperature preindustriali. Inoltre, le proiezioni per il futuro sono ancora più preoccupanti poiché il gruppo di esperti scientifici ha previsto che entro la fine del corrente secolo, la temperatura superficiale globale aumenterà probabilmente di 4 gradi o più rispetto ai livelli preindustriali se le cose non dovessero cambiare in breve tempo.

Per evitare il cataclisma globale indotto dal clima, la temperatura media globale non dovrebbe aumentare di 2 gradi sopra i livelli preindustriali e anche se sembra quasi utopico non eccedere questo limite, non significa che nessuna azione dovrebbe essere presa.

La valutazione dell'impatto del cambiamento climatico è un esercizio estremamente complesso con incertezza sia sul grado del futuro riscaldamento globale che sul conseguente impatto sull'attività globale. Ci sono chiaramente alcuni vantaggi e costi quando il pianeta si riscalda. C'è anche l'incognita di come il progresso tecnologico risponderà e potenzialmente altererà il percorso del riscaldamento globale.

Lo scopo di questa tesi è analizzare quali sono gli impatti dei cambiamenti climatici sull'economia globale e quali i conseguenti potenziali percorsi per la resilienza. I governi hanno capito che il sistema economico deve diventare sostenibile nel lungo periodo e che la transizione verso un'economia verde a basse emissioni di carbonio può facilitare questo cambiamento. Pertanto, per raggiungere questo percorso, è necessario un riallineamento dei modelli di business con i Sustainable Development Goals (SDGs).

La tesi si compone di quattro parti:

Nel Capitolo 1, fornisco le informazioni di base sul cambiamento climatico e la scienza che lo caratterizza. La panoramica storica ci fa capire come si è sviluppato il fenomeno nel corso dei decenni, quali sono le effettive conseguenze sull'ambiente e chi è responsabile dell'altissima intensità di carbonio nell'atmosfera.

Il capitolo 2 esplora il contesto politico evidenziando le principali istituzioni ambientali e le relative responsabilità e, successivamente, richiama l'attenzione sugli obiettivi dei trattati internazionali degni di nota.

La parte principale della tesi risiede nel Capitolo 3, la parte economica, dove in primo luogo, analizzo i risultati ottenuti dalle ricerche di scienziati ed economisti e, in secondo luogo, effettuo un'analisi statistica sulla differenza tra paesi sviluppati ed emergenti.

Infine, il Capitolo 4 descrive un adeguato percorso verso la sostenibilità ambientale, fornendo alcuni esempi di fattibilità della cosiddetta Green Economy.

Oltre alle finalità economiche di questa tesi, una particolare attenzione viene costantemente data alla necessità di aumentare la consapevolezza delle persone sul tema ambientale. Per quanto mi riguarda, la consapevolezza è ancora più importante degli aspetti economici, perché se portiamo la Terra ad un livello di inabitabilità, non ci sarà nessun pianeta su cui sviluppare l'economia.

Gli studi analizzati nella tesi hanno dimostrato che la temperatura, le precipitazioni e i gravi eventi climatici hanno effetti economicamente e statisticamente rilevanti su molti aspetti come PIL, agricoltura e produttività del lavoro, per citarne alcuni. Questi risultati mostrano la natura multipla del link clima-economia, con diverse applicazioni per comprendere le conseguenze economiche passate, presenti e future e le potenziali risposte, perché ad esempio, l'impatto dei parametri climatici sulla domanda di energia o sulla produttività agricola può istruire le istituzioni sui tassi di investimento nel settore energetico e agricolo e sull'attuazione delle manovre economico-politico.

Per fare qualche esempio concreto, integrando gli studi meteorologici di cui sopra, sembra che un anno insolitamente caldo sia associato a una crescita del reddito sostanzialmente inferiore nei paesi

poveri e considerando la temperatura e l'acqua come input fondamentali nel processo naturale di crescita delle colture, il rapporto tra clima e produttività agricola mostra un impatto dannoso delle fluttuazioni meteorologiche sull'agricoltura. Inoltre, sono stati dimostrati gli effetti negativi del riscaldamento globale sulla produttività del lavoro, con documenti che dimostrano che la produttività è superiore in primavera e in autunno, quando le temperature sono miti, e più povere in estate e in inverno, quando le condizioni meteorologiche sono più radicali, soprattutto nei settori più sensibili alle variazioni climatiche come l'agricoltura, l'estrazione mineraria e l'edilizia. Un altro legame cruciale è quello con la domanda energetica. Infatti, alla luce delle attuali problematiche ambientali, gli studi evidenziano come la temperatura influenza la domanda di energia: partendo dal presupposto che il consumo energetico si adatta alle fluttuazioni meteorologiche, una maggiore domanda di energia aumenta le emissioni di gas serra, che a sua volta influenza la domanda di energia, come un cane che si morde la coda. Infatti, una delle ricerche sopra descritte, osservando parametri annuali del consumo di energia residenziale dal 1968 al 2002 negli Stati Uniti, ha valutato che un giorno in più al di sotto di 10 ° F (-12 ° C) o al di sopra di 90 ° F (32 ° C) aumenta l'energia annuale consumo dello 0,3-0,4 per cento.

Le proposte politiche e le relative soluzioni ideate per mitigare il riscaldamento globale sono molteplici (es: carbon pricing, politiche tecnologiche), ma fino ad ora i risultati sembrano scarsi. Purtroppo, il ruolo delle organizzazioni internazionali che hanno come obiettivo quello di tutelare dell'habitat naturale è sottovalutato. La maggior parte dei paesi agisce solo pensando ai propri interessi e quando nazioni inquinanti come Stati Uniti e Brasile non mostrano alcun interesse a cambiare direzione, il già difficile percorso verso la sostenibilità diventa ancora più tortuoso.

Il cambiamento climatico è la più grande esternalità negativa prodotta e mai affrontata dal genere umano che sta portando a effetti dissimili non distribuiti uniformemente tra i paesi. Bastano pochi secondi per capire che le nazioni in via di sviluppo hanno maggiori probabilità di subire in modo sproporzionato l'impatto negativo del riscaldamento globale, quindi la giustizia climatica è l'argomento che emerge nell'analisi statistica, volta a guardare le differenze tra paesi sviluppati ed

emergenti in un intervallo temporale di 20 anni (1996-2015), in cui possiamo capire come i due gruppi di paesi si sono comportati negli ultimi due decenni e quali sono le variabili economiche che influenzano maggiormente la questione ambientale.

I risultati dell'analisi vedono un miglioramento, anche se limitato, della situazione generale, poiché sia i paesi avanzati che quelli in via di sviluppo mostrano un numero maggiore di variabili significative dal 1996 al 2015, il che implica una correlazione crescente tra i parametri dipendenti e indipendenti. Tuttavia, come qualsiasi altra ricerca, anche questo studio ha dei limiti. Infatti, con l'obiettivo di concentrarsi sul quadro generale per vedere se esiste uno schema dominante, non si può entrare nel dettaglio di ogni singolo paese e, in secondo luogo, si riscontra una grande mancanza di disponibilità e accuratezza dei dati, soprattutto per i paesi sottosviluppati che devono far fronte a dei vincoli di bilancio. Quest'aspetto, oltre a far intuire una scarsa passata attenzione ai fattori economici-ambientali, rende più complessa l'analisi dell'effettivo impatto ambientale e di conseguenza riduce la probabilità di trovare soluzioni efficienti.

Tuttavia, anche se l'intero scenario può sembrare scoraggiante, l'esempio dato dalle aziende innovative eco-sostenibili analizzate nel Capitolo 4 può portare a un passo decisivo verso la Green Economy.

Durante il periodo di lockdown dovuto al Covid-19, mi è sorta il seguente dubbio: "Perché per una pandemia, sebbene estremamente distruttiva e distribuita globalmente, può essere fatto uno sforzo economico comune significativo (es. Recovery Fund) e per la questione ambientale nessuna azione notevole e tangibile è stato messa in atto?"

La risposta è che probabilmente non percepiamo il cambiamento climatico tanto urgente e minaccioso quanto la pandemia di Covid-19 e per questo motivo pensiamo di poter procrastinare. Ma non possiamo.

Dobbiamo partire dalle radici della società, dalle generazioni neonate attraverso l'educazione e la consapevolezza, perché più tardi educheremo alla sostenibilità più gravi saranno le conseguenze.

Il cambiamento è in mano a persone responsabili e consapevoli. Abbiamo il dovere di allargare la quota di cittadini responsabili e da lì, questa base responsabile potrà scegliere governi responsabili, perché il cambiamento che conta non verrà da posizioni di privilegio.

In quanto esseri umani, ognuno deve fare la sua parte.

Mi sentirò soddisfatto se attraverso la mia tesi cambierò il modo di fare di alcune persone, che a sua volta potranno influenzare le abitudini di altri e così via.

Questo è l'obiettivo della mia tesi, aldilà della prospettiva economica.