Economics of Zero Carbon Society:

*Investing in Carbon Reduction Technologies*

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## 1. The Economic Impacts of Carbon

Climate change is not a fairytale; evidence suggests that human activities are having an increasingly larger effect on global warming, mainly due to industrial GHG (Greenhouse Gas) emissions. It is expected that global temperature will rise 2 degrees Celsius compared to the pre-industrial era by 2050 without active carbon reduction efforts.[1] However, it is difficult to push low carbon energy projects or endorse carbon capture & storage technologies due to their costly nature. Despite the evolution of renewable energy, current infrastructure will not support full transition towards 100% carbon free energy due to massive capital expenditures required for energy storage systems. Switching to 100% carbon free energy is also not enough to eradicate the human impact on climate change, as manufacture of steel, cement, plastics, and even semiconductors that are essential in today's technology driven world, result in an extraordinary amount of carbon emissions.

To prove that technologies that reduce the emission of greenhouse gases are economically sensible, which often requires massive upfront capital expenditures, calculating and comparing the cost of environmental damages if the world decides to not change its course of action and the savings (returns) we can retrieve from our low carbon technologies is imperative to convince the public and the policy makers to make them financially sound business opportunities for corporations around the world.

In order to achieve that, I am going to discuss ***1.1 Earth Environment without Intervention****, and* ***1.2 Economic Impacts of Climate Change*** in the first chapter.

### *1.1 Earth Environment without Intervention*

It is unanimously expected that the global surface temperature will rise continuously, if we assume the current energy demand growth is sustained and there is no meaningful difference in our energy mix and therefore the subsequent emission of GHGs. Climate scientists attribute the warming of mean surface temperature over the past 50 years as a consequence of human activities.[2]

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[1] Schleussner et al., "Differential Climate Impacts for Policy-Relevant Limits to Global Warming."

[2] Masson-Delmotte, V., P. Zhai, A. Pirani, S.L. Connors, C. Péan, S. Berger, N. Caud, Y. Chen, L. Goldfarb, M.I. Gomis, M. Huang, K. Leitzell, E. Lonnoy, J.B.R. Matthews, T.K. Maycock, T. Waterfield, O. Yelekçi, R. Yu, and B. Zhou (eds.),

In most cases, climate scientists expect the global mean temperature to rise 2 degrees Celsius or more compared to the pre-industrial revolution levels, while it is assumed that it can heat up to 4.4 degrees Celsius by the end of this century.[2]

What matters most is not the rising temperature itself, but the impact on the environment it will have. While it is difficult to estimate the global impact of temperature increase, geo-specific climate incidents including extreme weather events will become more intense and prevalent as evidenced in the last two decades. Such events are determined based on commonly accepted weather protocols such as intensity of hot extremes (TXx), warm spell duration indicator (WSDI), dry spell length consecutive dry days (CDD), and heavy precipitation intensity or maximum accumulated 5-day precipitation (RX5day).[1] According to predictions made based on above measures, extreme weather events such as heat extremes, extreme precipitation and dry spells were considerably more likely if the mean temperature increase was 2 degrees Celsius above pre-industrial revolution era, with the impact especially higher in tropical regions including Amazonia, East and West Africa and South-East Asia which are expected to have a median WSDI of up to 3 months with a 50% chance of permanently moving into a novel heat regime by the year 2030.[3]

Extreme weather is not the only impact that humanity faces amid almost inevitable rise in global mean temperature. As more GHGs are released into the atmosphere, the Earth is expected to get hotter which results in melting icebergs. It is projected that mean sea level rise will be 0.27 meters by the end of the 21st century, with regional discrepancies.[4] If Greenland or West Ice Sheets start to melt irreversibly, sea level rise between 5-12 meters is also believed to be possible over the course of the next few centuries.[5] Because the sea level dictates the habitability of coastal regions, many areas that are adjacent to the sea are expected to be unhabitable by 2050, including some parts of Florida, Texas, California, New York, and Maine. It is also predicted that 4 million $Km^2$ of habitable of land will be rendered useless due to sea level rise, which 5% of the world's population resides currently.[5]

"IPCC, 2021: Climate Change 2021: The Physical Science Basis. Contribution of Working Group I to the Sixth Assessment Report of the Intergovernmental Panel on Climate Change."

[3] Diffenbaugh and Scherer, "Observational and Model Evidence of Global Emergence of Permanent, Unprecedented Heat in the 20th and 21st Centuries."

[4] Mori et al., "Multi-Model Climate Projections of Ocean Surface Variables under Different Climate Scenarios—Future Change of Waves, Sea Level and Wind."

[5] Stern, *The Economics of Climate Change*.

Another phenomenon related to habitability caused by climate change is desertification, a process where fertile land becomes desert usually due to draught or deforestation. The expansion of the deserts is global and ongoing problem, which also negatively influences crop yields.

Overall, if the current pace of GHG emissions stay consistent, continuous climate change involving mean surface temperature rise between 4 to 5 degrees Celsius by the end of the 21st century, along with serious problems such as frequent extreme weather events, loss of habitable and cultivable land, health problems related to heat, and food and water scarcity are projected to emerge.

### *1.2 Economic Impacts of Climate Change*

It is clear that climate change due to GHG emissions will have a profound impact on our lives, both physically and economically. Many living near the ocean will have to move due to rising sea levels or invest in expensive embankment to continue their lives. More will die of heat strokes, and demand for HVAC (Heating, ventilation, and air conditioning) equipment will surge to create a habitable indoor environment. Those living in relatively underdeveloped nations will bear the cost the most, as they lack the financial and technological resources necessary to adopt to changing climate.[6]

These tangible, highly likely scenarios are what frustrate the public and the policymakers around the world, pushing investment towards renewable energy and low carbon technologies. However, these investments often have high upfront costs, mainly due to heavy capex capital required in the beginning of an energy or transportation project. Accurately assessing potential economic damages due to climate change can help the public, who elects policymakers, understand why it could be economically beneficial to invest in such technologies, thus steering the society towards that direction.

One peered reviewed housing market research article from 2019 already determined that areas that are relatively more prone to flooding due to rising sea levels had lost $15.9 billion between 2005 to 2017 in relative property value.[7] However, what humanity experienced thus far as a consequence of GHGs induced climate change is fraction of what is to come. In 2019, International Labour Organization (ILO) claimed in its report that even if the rise in temperature

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[6] Hinkel et al., "The Ability of Societies to Adapt to Twenty-First-Century Sea-Level Rise."

[7] firststreet.org, "Property Value Loss from Sea Level Rise State by State Analysis - First Street Foundation."

is limited to 1.5 degrees Celsius by 2030, climate change will result losses of 2.2% in labor productivity, equivalent to 2.4 trillion dollars.[8]

It is estimated that the total cost of GHGs and its negative impact on the economy when our social costs are accounted for, amount from 5 to 20 percent of the value of global per-capita consumption over the next two centuries.[5] Because GHGs emitted today do not disappear next year, we have to treat them as a negative force on the economy that lingers even after its production, possibly compounding the effect of GHGs that were released prior to its production. Considering that the aggregate GDP for 2020 was $84.578 trillion dollars, potential damage of climate change amounts from $4.228 trillion to $16.916 trillion dollars in 2020-dollar terms.[9] Since the effect of GHGs compound over time as the concentration of $CO_2$ increases, it can also be said that the damage per metric ton of GHG will be increasingly higher over time, making an earlier investment to reduce GHG concentration in the air economical.

## 2. Returns on Low Carbon Technologies & Infrastructure Investment

Scientists' consensus is that climate change is the result of human activities and as its damage on humanity is being assessed via various economic models, it is imperative to determine the kind of low carbon technologies we should invest in, in order to maximize our benefit with the lowest investment possible, or simply put, increasing the ROI (Return on Investment).

First, the concept of carbon budget will be employed to address how much GHGs emissions we are allowed to make in an absolute basis, to limit the global warming beneath 1.5 degrees Celsius higher than pre-industrial revolution era, a number that is believed to limit further damage due to climate change before it becomes irreversible.[1] The carbon budget remaining is 460Gt $CO_2$ as of 2021, enough to last us about 11.5 years according to current carbon emission trends.

Second, technologies including renewable energy, nuclear energy, energy storage systems, carbon capture & storage systems will be discussed to effectively phase out GHG emission caused by human activities, with analyses using discounted cash flow model to calculate their benefit to cost ratio. It is important to note that carbon capture & storage

[8] Tord Kjellstrom, "Working on a Warmer Planet."
[9] World Bank

technology will be necessary in order to hit our emissions target, as some studies expect them to take half of world energy supply even with rapid expansion of renewable energy.[5]

The International Energy Agency (IEA) in 2014 has estimated that up to $53 trillion in investment is required to provide energy supply that resides within a credible emissions framework.[10] While extremely expensive, it is not costly when considering the yearly cost savings society can extract by reducing GHG emissions. As mentioned previously, the expected cost of climate change ranges from 4.2 to 16.9 trillion dollars in 2020 value, meaning that an investment of $53 trillion dollars now can yield at least 8 percent to almost 32 percent depending on how much damage climate change does to humanity. This is consistent with the findings of *The Stern Review*, a comprehensive report on the economics of climate change released for the government of United Kingdom, which predicted the cost of reducing GHG emissions to hold earth's surface temperature below 1.5 degrees Celsius above pre-industrial revolution era to be around 1% of the GDP each year, much lower than the expected cost of climate change.[5]

To calculate the effectiveness of investing in low carbon technologies, we have to think like economists or financiers and approximate the expected return on investment to determine whether investing in them is justified. Since GHGs incur social costs, I assumed that government entities around the world will be the mostly funding the capital investment required for low carbon technology transition. Governments being the main driver in the investment can be a significant advantage, as they are usually able to borrow money at the cheapest rate possible. As of November 2021, interest rate on 30-year U.S Treasury bonds stands at 2%, markedly lower than any other private entities around the world. Other assumptions include perpetual real GDP growth rate of 2.5% per year, potential costs of adopting low carbon technologies as a percentage of GDP, low and high end of loss aversion (as a percentage of GDP), and an interest rate of 2% or 5% to calculate the sensitivity towards higher interest rates.

[10] Hall, Foxon, and Bolton, "Investing in Low-Carbon Transitions."

| | | ($ in billions, %, % of GDP) |
|---|---|---|
| 2021 GDP | | $ 84,578 |
| Projection Period | | 2021-2075 |
| **Assumptions** | | |
| Perpetual GDP Growth Rate | | 2.5% |
| Interest Rate | | 2% |
| Low Carbon Project Costs | | 1% |
| Loss Aversion (Worst) | | 5% |
| Loss Aversion (Best) | | 20% |
| **Initial Capital Investment** | | $ 100,174 |
| | | **Net Benefits** |
| **ROI (Worst)** | 118% | $ 218,299 |
| **ROI (Best)** | 935% | $ 1,036,919 |

*Figure 1*

Although the IEA figure states that we may need up to $53 trillion in investment to provide energy within a credible emissions framework, I used the reference from the 'Stern Review: *Economics of Climate Change,'* which states that the cost of adopting low carbon technologies will be about 1% of the total GDP. This scenario was chosen because there should be a continued, long-term investment in low to zero carbon energy, transport, and manufacturing technologies to sustain economic growth without GHG emissions, not just for energy. For the 55 years of projection period between 2021 and 2075, the initial investment towards low carbon technologies and infrastructure was estimated to be around $100 trillion, far exceeding the IEA's figure of $53 trillion, partly due to longer time frame. The net benefits, which was calculated using the projected GDP loss aversion ranges between 5 to 20 percent, exceeded the initial investment by a wide margin, even when appropriately discounted by interest rate and time. In the worst-case scenario, the investment was expected to recoup 118% of its initial value and 935% in the best-case scenario. The numbers speak for themselves and seldom the best fund managers manage to make a return like the figures above.

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| Perpetual GDP Growth Rate | | 2.5% |
| Interest Rate | | 5% |
| Low Carbon Project Costs | | 1% |
| Loss Aversion (Worst) | | 5% |
| Loss Aversion (Best) | | 20% |
| **Initial Capital Investment** | | $ 100,174 |
| | | **Net Benefits** |
| **ROI (Worst)** | 7% | $ 106,945 |
| **ROI (Best)** | 407% | $ 507,989 |

*Figure 2*

While acknowledging that there could be a lot more variability in the calculation of benefit-cost ratio of low carbon technology and infrastructure investments, such as the damage of climate change having a lower or higher impact on a specific field of the economy (agriculture, real estate, productivity, etc.), those variables are represented accordingly in the best and worst loss aversion scenarios. One factor that heavily influences the end ROI (Return on Investment) is the interest rate, because significant initial capex investments are required for the transition towards renewable energy infrastructures and low carbon transportation that reduces the emission of GHGs. Despite higher interest rate assumption of 5%, the model suggests that the investment will be making a return in the worst ROI scenario, at 7%. In the best ROI scenario, the expected return jumps to 407%.

Another variable to consider is the assumption that all the capital investment will occur immediately in the present. It is difficult to discern the exact investment schedule towards low carbon infrastructure, but it is highly unlikely that all the required investment will occur immediately. No entity on Earth can borrow 100 trillion dollars in a matter of a year nor it makes sense to invest that money immediately in technologies and infrastructure that require time and human capital for development and manufacturing. For example, the amount of solar panel or energy storage systems that use battery that can be produced in a year is limited, despite continued capex investments in those sectors. If the investments are scheduled efficiently, the return will be far greater than what this model suggests as it heavily discounts future benefits for current investment.

Under the scenarios assumed in *Figure 1,* the investment is expected to breakeven on the 18th year at the worst, while it is expected to breakeven on the 5th year under the best scenario. Overall, this model is illustrative of how economically beneficial low carbon technologies are when society actually accounts for the damages induced by GHGs in the long run. In fact, even in the most harsh and unfavorable circumstances, the investment is highly likely to be a success and a win to humanity.

## 3. Carbon Emissions Market

While greenhouse gas emissions are concentrated in specific regions such as China, which accounted for 26.1% of total emission in 2018, the consequences of GHGs are applied to all of us due to its global commons characteristics.[11] To effectively fight against climate change, a global approach towards GHG reduction is therefore necessary.

One of the problems related to GHG emissions is the fact that profits are internalized fir corporations while the externalities are often unregulated on a globally agreed framework. Two factories operating within the same company which has the same equipment and manufacturing know-how but located in two different countries, the United States and China for example, can emit radically different GHG emissions per ton of goods made due to different standards in environmental regulation and the country's electricity generation mix.

Many developing nations offer cheap electricity often made with GHG intensive resources such as coal and relaxed environmental regulations to foreign companies seeking to maximize their profits, essentially by giving them a chance to externalize the societal costs. To address this issue, a global regulation on GHGs and creating a unified market for carbon could be suitable, as it can level the cost of emitting carbon regardless of geographical location, thus prohibiting corporations from externalizing the cost of climate change just by moving their factories around the world. A similar attempt has been made in the United States with sulfur dioxide ($SO_2$) cap-and-trade program, which cut emissions from power plants by more than 50%, while in the EU the European Union's Emission Trading Scheme (EU ETS) influenced by the U.S sulfur dioxide cap-and-trade program became the single largest cap-and-trade program for carbon emissions.[12] In 2021, China started a national carbon market set to become the world's

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[11] Center for Climate and Energy Solutions, "Global Emissions."
[12] Aldy and Stavins, "The Promise and Problems of Pricing Carbon."

largest emissions trading system. While selected 2200 companies in the power are initially participating in the system, the country has initiatives to expand it to other industries.[13]

Despite the establishment of the carbon market in China, a first for the nation, some worry that the officials will be lenient by providing large amount of free emission credits to bolster its world's largest manufacturing sector, thereby rendering the market system useless. This is in stark contrast to the EU ETS, where a lot of power suppliers had to invest more in renewables due to soaring prices for emission credits which made coal power plants economically unsustainable. By providing a marketplace for carbon emissions and thus financially incentivizing corporations with low-carbon technologies, the EU ETS is said to have had a positive and definitive impact on low-carbon patenting increase among participating firms.[14] However, the impact was not able to reach European firms outside the EU ETS system.

Overall, evidence seems to suggest that while carbon trading system is effective in reducing GHG emissions and increasing investments in technologies that reduce carbon emissions, it is likely that a standardized emissions market that works on a global scale is necessary to have a real-world impact, eliminating the dichotomy in each nation's own interpretation of benefit and cost of climate change.

[13] "China's Giant Carbon Market to Start Trading This Week."
[14] Calel and Dechezleprêtre, "Environmental Policy and Directed Technological Change."