A comprehensive look at the economic and environmental impact of decarbonization

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Most parts of the world still heavily rely on fossil fuels, such as coal, oil, and natural gas. Studies conducted over the years show that the use of these energy sources leads to a significant amount of carbon emission. A study conducted by the United States Environmental Protection Agency (EPA) reported that, since the 1970s, carbon emissions have gone up by 90% [1]. During that time, there has been a significant amount of uproar to limit the use of fossil fuels and decarbonize. From 2000-2004, carbon emissions increased by an average of 3.5%. Subsequently, from 2005-2015, the average emissions decreased by 1.8%, which later experienced a minor 0.2% increase in 2016 [2]. A recent study claims that to avoid extreme climate change, by 2050, carbon emissions should be reduced by 50-90% [3]. While we can all take such studies with a grain of salt, we can also agree that to contain the environmental impacts of carbon emissions, society needs to switch to sustainable energy sources, such as wind, solar, nuclear, and hydrogen. In order to ensure a quick and smooth transition to green energy, conducting a thorough economic analysis is critical. Many policymakers oppose decarbonization proposals solely because of the economic cost associated with the process. Figure 1 (Krishnan et al.) suggests that to ensure global decarbonization by 2050, approximately $275 trillion is needed to be spent on building new infrastructures to meet the zero-emission scenario, which is 7.5% of the GDP from 2021 to 2050 [4].

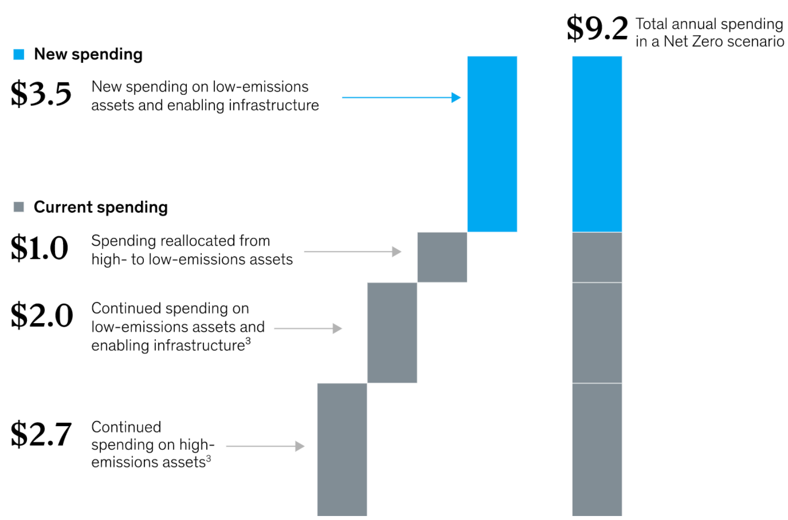


Figure 1: Approximate annual spending on infrastructure in a zero-emission scenario [4].

One of the many concerns associated with decarbonization, especially on the economic front, is a possible significant rise in the unemployment rate and the need for relocations. An economy heavily depends on the size of its labor force and capabilities. In the case of total decarbonization, the economy is bound to go through a large transition, including changes in the labor market. People who work in the fossil fuel industry could lose their jobs, and communities directly or indirectly related to the industry would need to acquire new skill sets, which would result in changes in employment as well. However, studies claim that systemic transition can lead to a positive net job creation rate [5, 6].

A study conducted by Treut et al. investigated the outcomes of the decarbonization strategy developed in Argentina and suggested different policies which would enable a smooth transition [7]. A similar study was conducted on China's new renewable energy policies, their impact, and the framework by Mu et al. [8]. During 2010-2015, China embarked on a five-year plan to increase renewable energy sources' capacity from 249 GW to 504 GW. In an attempt to keep up with their promise to the Paris agreement, China's policymakers are starting to introduce frameworks to boost the market for "green jobs" [8,9]. But what may work for China might not be a viable solution for democratic societies because of the practice of a free market economy in the west, where strong government involvement would be discouraged.

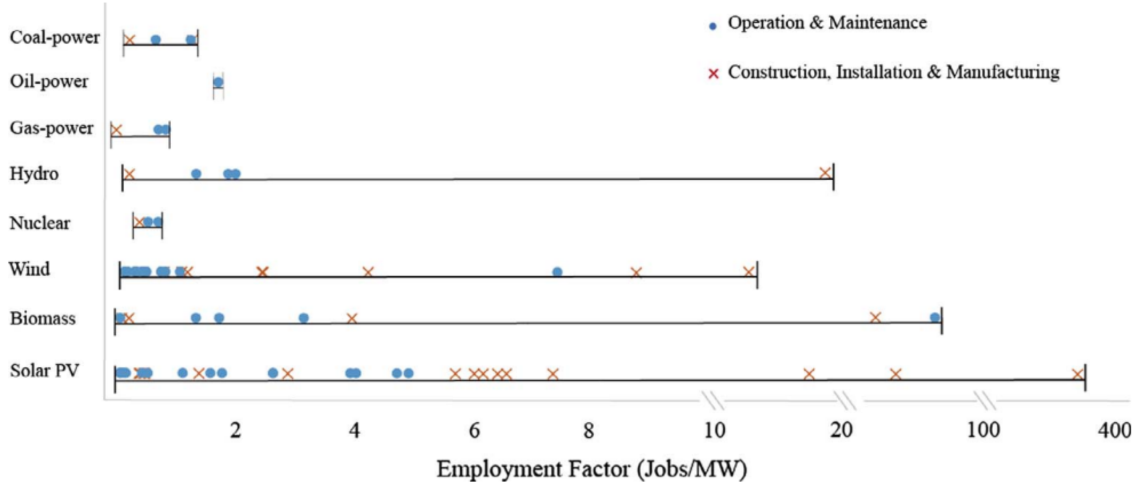


Figure 2: Summary of employment factors in existing literature [8]

Below is a discussion of a few relevant studies done on this topic. We chose to use various graphs to illustrate the points. Figure 2 shows direct and indirect jobs created by the fossil fuel and renewable industries; to better understand the direct, indirect, and induced impacts of such transitions, Mu et al. used a computable general equilibrium (CGE) method because it takes the interaction between renewable energy technologies and other sectors in the economy into account [8]. To analyze the impact, they conducted policy simulations to test out the effectiveness of Feed-In-Tariffs (FITs) financed by (i) an additional electricity consumption fee (ECF), which is currently used in China as an electricity financing mechanism, and (ii) a lump-sum tax (LST), whereas solar and wind expansion is modeled independently. This study suggests that traditional ECFs may not be the best way of financing the transitions, and an LST could be a more t cost-efficient way to tackle the problem [8].

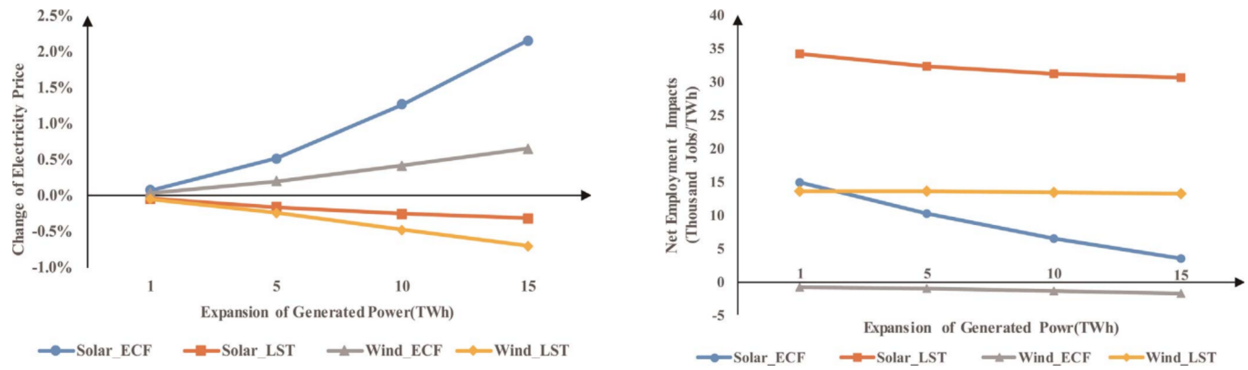


Figure 3: Change in electricity price and net employment rates associated with wind and solar policies [8]

Figure 4 shows that the direct and indirect impacts of solar and wind energy expansion did indeed bring positive growth in the job market. Currently, the labor intensity in the electricity sector is reported to be 481 jobs per TWh, which is 3.5 times higher than wind and 2.7 times higher than solar power. It is possible that the inclusion of wind and solar power will lead to a decrease in labor intensity and create new jobs in the operation and maintenance sectors. In both cases, net job creation in manufacturing and maintenance is positive, which shows that in this instance, although some people would lose jobs during decarbonization, an ample number of jobs could also be created in different fields [8].

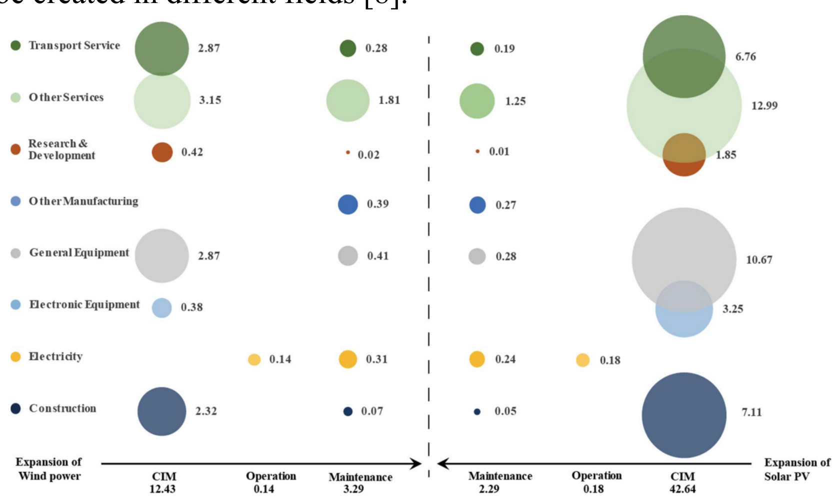


Figure 4: Employment impacts (Thousand Jobs/TW h) in CIM, operation, and maintenance stages of wind power and solar PV in China. The size of each bubble is consistent with jobs created in the corresponding sector. The numbers at the bottom of this figure stand for the total jobs created in the corresponding stage [8].

Most jobs are created in construction, maintenance, and operation because of the technical aspects of green energy (e.g., solar and wind). Also, the simulation shows net jobs will decline if the government does not offer subsidies to offset the increased cost of production in the green energy sectors until the economic and infrastructural transitions happen. Many might raise questions about the sustainability and government influence on this model. This study also emphasizes the need for aggressive expansion of the plants to compensate for the net job loss. Nonetheless, this study has drawn a positive conclusion that by spending approximately 100 billion yuan, the Chinese government may be able to address the induced negative impact. However, this study fails to determine the feasibility of such a model in a different country [8].

Truet et al. conducted a similar study using the CGE method and developed two deep decarbonization scenarios. In these scenarios, they compared results induced by the pledge set in the Paris agreement and sustainable goals adopted by the UN [7].

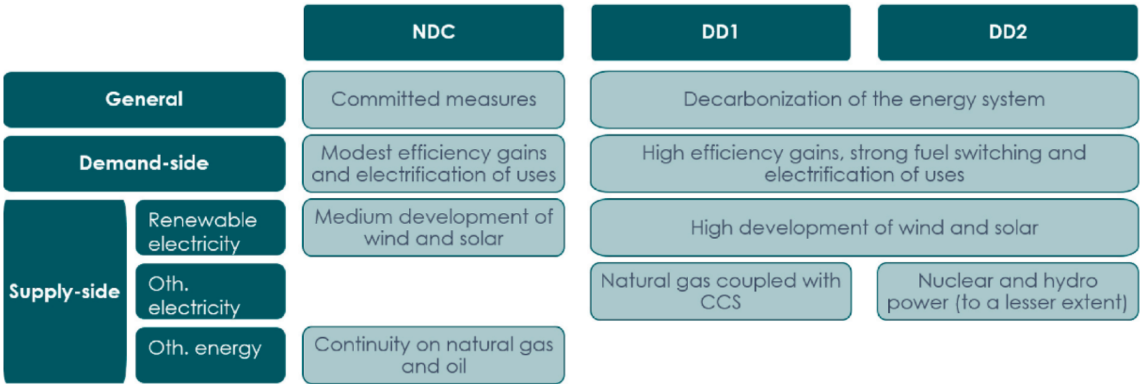
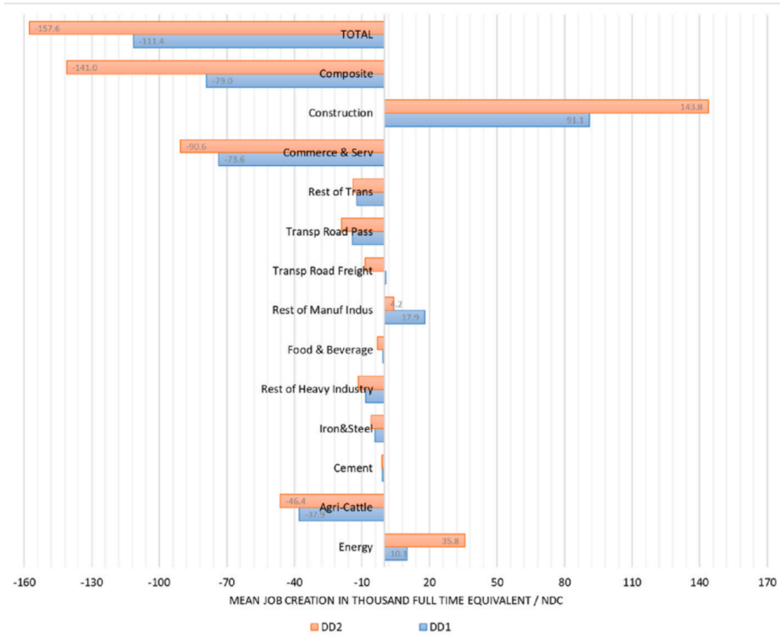


Figure 5: Main characteristics of the proposed scenarios [7]

The study concludes the sustainable goals proposed by the UN do not translate into an energy transition. Rather, it limits the diversification of fossil fuel sources, but the deep decarbonization (DD) scenarios presented by the researchers resulted in a radical transition. The study suggests no negative welfare implications are caused by the transitions, and due to relatively high production costs, net exports are predicted to decrease by 7-10%. Both DD scenarios are predicted to raise debt by +0.6ptsGDP and 1.6ptsGDP, respectively, in 2050. This study has made numerous claims which are yet to be proven sustainable. The study also supports (Figure 6) the previous findings of Mu et al., where the net job creation went up by +10-36 net employment (kFTE) on average in the energy sector and +90-144kFTE of non-relocatable jobs. Although, the researchers did predict a net job loss of -0.5-0.7% in the agriculture and transport sector. [7].



(b) Employment (kFTE)

Figure 6: Mean Job Creation [7]

This study reported that the production cost is bound to increase by 3-4% due to the higher capital cost, which eventually leads to an increase in energy pricing. This study concluded that although the DD scenarios are feasible without inducing significant negative externalities, the economy is bound to undergo structural changes, requiring a huge amount of investment from the government and private sectors. This study also concluded that decarbonization wouldn't play a major role in boosting economic growth or contraction; its implications are limited to the energy sector only [7]. There are some who might consider this wishful thinking.

One of the primary reasons behind decarbonization is the belief that it will lead to a greener and clear world, and most studies agree with it. But the benefits entirely rely on the technologies used to utilize these "green" energy sources. A few studies voiced their concerns by showing that green energy only addresses climate-related issues and ignores damages caused to the ecosystem due to the land requirements by such energy sources. It also has adverse effects like air, water, and land pollution, and by doing so, it poses some serious environmental threats-which is an important point to consider before a radical transition [10,11,12].

A recent study conducted by Fricko et al. investigated the sustainability aspect of using a large volume of fresh water to generate power. The study predicts that due to the use of freshwater in hydroelectric plants, there will be a significant amount of withdrawal, consumption, and thermal pollution, which is bound to have a long-lasting impact on the environment. The study assessed pathways developed in the global energy assessment (GEA) to understand the use of water and how decarbonization policy will utilize the resource. Figure 7 depicts that even with the climate trend, the freshwater withdrawal is going to be steady until 2100. Nonetheless, when a green energy policy is implemented, the withdrawal goes up by 611%, and thermal pollution increases by 638% [13].

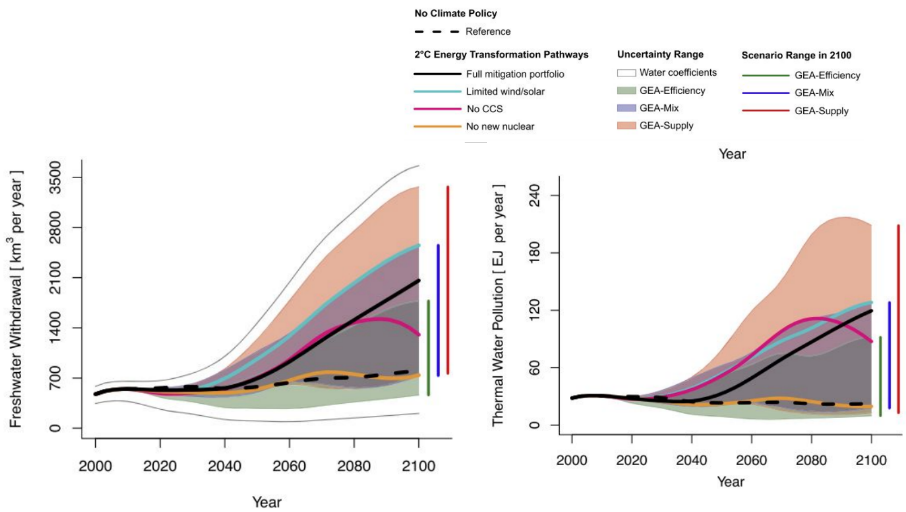


Figure 7: Impacts of using decarbonization on freshwater withdrawal and thermal pollution [13]

Many plants use fresh water as a cooling technology; however, the use of different cooling technologies, such as seawater, can possibly improve the situation. This study proposed a mandatory cooling technology for all the energy plants and predicted that it would lower the volume of freshwater used and thermal pollution in the long term. The use of such technology led to a decrease in freshwater withdrawal to 63%, which is significantly less than the previous 611%, but thermal pollution only went down to 311%. Also, the study found that the consumption coefficient related to freshwater is larger than expected, pointing toward uncertainty. There are correlations between some cooling technologies and loss of efficiency; therefore, seawater cooling might be the best alternative, which would reduce the withdrawal of freshwater without compromising the efficiency of the plants [13].

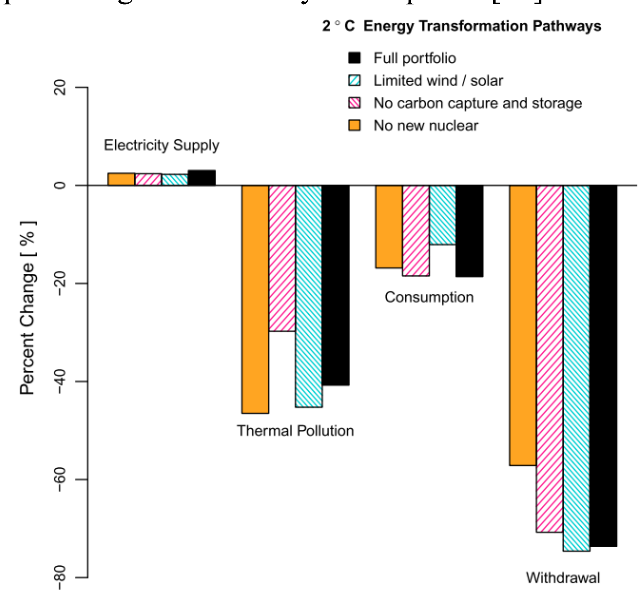


Figure 8: Cumulative impacts of adapting cooling technology [13]

Another study also shows similar results caused by hydropower plants. The study found that hydroelectric plants emit a significant amount of carbon dioxide (48–82 Tg) and methane (3–14 Tg) [14]. While hydroelectric, nuclear, etc., are promoted as environmentally friendly energy sources, in reality, such technology results in increased freshwater consumption because of the higher penetration as demand increases. Coastal currents trap most dispersed thermal plumes without distributing them to the water body. Such thermal pollution is the reason behind stress in the aquatic system since various corals and important marine lives need a steady water temperature to survive. In contrast, unsteady water discharge caused by hydroelectric dams is the reason behind non-stationary water discharge [15]. In places where hydroelectric plants are situated, agricultural lands lose value because the excessive withdrawal of fresh water leaves agricultural lands dry and unusable [13]. Hence, it is essential to be informed about the adverse effect and plan accordingly so that green energy serves its purpose without causing environmental harm.

Another dependable renewable energy source is solar power. Studies have found an association between solar energy plants and habitant loss, increase in heat emission, and disruption to wildlife [16]. One of the main concerns associated with solar energy is metal waste produced by solar plants and the use of environmentally hazardous materials during the manufacturing process [17,18]. In recent years, halide perovskite (CH3NH3PbI3, CH3NH3PbBr3, CH3NH3SnI3, etc.) PV cells are gaining popularity among scientists because of their reported higher efficiency. Pb, Sn, Br, and I are very reactive and thus can be easily released in the environment directly or indirectly. Another popular PV cell is CdTe, which leaches, and a cytotoxicity test revealed that such leaches lead to decreased body weight, increased spleen, kidney, and lung weights, mild hyperplasia of the periarteriolar lymphoid sheath in the spleen, increased protein in bronchoalveolar lavage fluid, and 4-hydroxyproline in the lungs [18]. Also, there is no silver buffer present, and the impacts of such need to be studied.

Solar Cells	Environmental Impact
Halide perovskite	Releases toxic chemicals in the environment
CdTe	Leaching, toxicity
a-Si	Leaching, Ecotoxicity
CIGS	Leaching, Ecotoxicity, Toxicity

Table 1: Environmental impact of solar cells [18]

Considering the various publications we were able to study for this paper our thoughts were that a total decarbonization may be feasible; however, complex policy packages are needed to be put in place to utilize the investments, and the governments would need to offer subsidies to reduce the burden of transitions from consumers’ shoulders. Policymakers should also be ready to face a significant increase in the unemployment rate as fossil fuel, and related industries would lay off workers. They should take into account if such models are sustainable in the long run. The question still remains “how green the green energy is” because of the potential adverse environmental impact of decarbonization. Decarbonization will undoubtedly lead to a reduction in climate issues (e.g., sea-level rise, global warming). However, depending on the kind of technology used in green energy production-there could be an adverse impact on wildlife and the environment in general. Therefore, we need to be cautious while adapting and expanding decarbonization policies.

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Dr. Raj Shah is a Director at Koehler Instrument Company in New York, where he has worked for the last 27 years. He is an elected Fellow by his peers at IChemE, CMI, STLE, AIC, NLGI, INSTMC, Institute of Physics, The Energy Institute and The Royal Society of Chemistry. An ASTM Eagle award recipient, Dr. Shah recently coedited the bestseller, “Fuels and Lubricants handbook”, details of which are available at ASTM’s Long-Awaited Fuels and Lubricants Handbook 2nd Edition Now Available (https://bit.ly/3u2e6GY). He earned his doctorate in Chemical Engineering from The Pennsylvania State University and is a Fellow from The Chartered Management Institute, London. Dr. Shah is also a Chartered Scientist with the Science Council, a Chartered Petroleum Engineer with the Energy Institute and a Chartered Engineer with the Engineering council, UK. Dr. Shah was recently granted the honorific of “Eminent engineer” with Tau beta Pi, the largest engineering society in the USA. He is on the Advisory board of directors at Farmingdale university (Mechanical Technology) , Auburn Univ (Tribology) and Stony Brook University (Chemical engineering/ Material Science and engineering). An Adjunct Professor at the State University of New York, Stony Brook, in the Department of Material Science and Chemical engineering, Raj also has over 500 publications and has been active in the alternative energy industry for over 3 decades. More information on Raj can be found at https://bit.ly/3sayVgT

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