Tough Decisions on the Road to Decarbonization

Stephen A. Roosa, Ph.D., CEM

ABSTRACT

The combustion of fossil fuels is the primary cause of anthropogenic carbon emissions. Serious climatological consequences are associated with atmospheric greenhouse gas emissions (GHG). History shows that we are increasing our use of carbon-based fuels—and the atmospheric concentrations of CO_2, methane (CH_4) and other greenhouse gases are increasing. The potential for reducing carbon emissions rests with our ability to synchronize the policies, programs, and technologies that will enable a transition to systems capable of reducing greenhouse gas emissions and increasing the use of clean energy resources. There are substantial investments associated with this process.

This article discusses international policies and strategic approaches aimed at reducing greenhouse gas emissions. Technological solutions are available to mitigate climate change. The hope is that by implementing them soon the more dire implications and consequences of climate change will be preventable.

Decarbonization creates a pathway to mitigate the more extreme impacts of climate change in the long-term. It has been identified as one of the leading trends in the energy sector.

INTRODUCTION

The environmental changes associated with greenhouse gases have been festering for a long time. Our patterns of energy use since the early 1900s have relied on the use of fossil fuels. Their use has contributed to our increasingly dire situation. It is accepted that an over-abundance of atmospheric carbon dioxide (CO_2), methane (CH_4), nitrous oxide (N2O), and other greenhouse gases (GHSs) are impacting Earth's ecosystems in detrimental ways [1]. Carbon dioxide concentrations have increased substantially since the beginning of the industrial era, rising from an annual average of 280 ppm in the late 1700s to 414 ppm in 2020—a 48% increase. Most of this increase is due to human activities [1].

The national economies of the Hydrocarbon Age are at an impasse. We are changing our landscapes because of economic development and technological advancements—terraforming them to meet the needs of agriculture, industry, urban expansion, regional transportation networks and governmental entities. Many of our cities have become “post-industrial” and are unlike anything that our forbearers might have envisioned. Cities in Brazil, Mexico, China, and India are reeling from population growth, poor development choices and environmental damage. Access to energy is the key to economic sustainability. Yet over a billion of the world’s people lack electricity.

Countries seeking economic and political control over carbon-based energy resources are at times exerting their military muscle, threatening, and waging international and regional conflicts. Examples include the rise of OPEC to control oil supplies in the late 1970s, and the Russian Federation’s cut-off of natural gas supplies to the European Union in 2022. The halt in the Nord Stream 1 pipeline meant Russian gas shipments to Europe dropped 89% and caused substantial increases in gas costs [2]. The impacts of each country’s policies and economic systems are in sum intensifying the problems associated with carbon emissions rather than resolving them. Supranational industries are using their economic muscle to press governments for favorable regulations. Despite all this, the dialogue has shifted from outright rejection of the existence of carbon-induced climate problems to the development of strategies and regulations to mitigate them. Decarbonization has been identified as one of the leading trends in the energy sector. The impacts of this ideal are becoming more noticeable in the policies, programs, and technologies that are being implemented in today’s energy sector.

INTERNATIONAL POLICIES

While local and regional responses can have powerful impacts, the policies developed by supra-national governmental organizations (e.g., the United Nations and the European Union) have offered mixed effectiveness [C]. International action to prevent additional damage to the ozone layer required cooperative and concerted efforts. Such actions evolved into the Montreal Protocol which has proved to be effective in achieving ozone reduction goals. The success of policies directed toward climate change have yielded mixed results.

Treaties such as the Kyoto Protocol (2005), Copenhagen Accord (2009), and the Paris Agreement (2016) were designed to obtain international consensus on ways to reduce greenhouse gases. The Kyoto Protocol has as its goal to stabilize atmospheric concentrations of GHG at levels that would balance anthropogenic (manmade) interference with the climate system. The Copenhagen Accord noted that the adverse effects of climate change and the potential impacts of response measures were challenges faced by all countries. Enhanced action and international cooperation on adaptation was needed to reduce vulnerabilities and to build resilience in developing countries. In the context of meaningful mitigation actions and transparency on implementation, developed countries committed to address the needs of developing countries by providing funding.

The Paris Agreement, signed by representatives of 190 countries, was an important step toward GHG policy at an international scale. Perhaps its most important near-term objective is to quickly achieve the global peaking of GHG emissions. Many of the countries participating in this agreement have made substantial gains that illustrate the achievements that have accompanied their progressive measures. To date 188 have submitted Nationally Determined Contributions (NDCs) to the United Nations Framework Convention on Climate Change (UNFCCC). Though the 2015 Paris Agreement set ambitious and seemingly achievable goals to curb emissions and adapt to global climatic shifts, the world is still on track for unprecedented climate change; bureaucratic, political, and financial hurdles have stymied thousands of the world's climate-friendly policies [4]. Many of these achievements have been due to tangible improvements in energy efficiency and transportation system.

Unfortunately, the various policy frameworks do not seem to be effective. Following two years of exceptional oscillations in energy use and emissions, caused in part by the Covid-19 pandemic, greenhouse gas emissions have since rebounded [5]. Global energy-related CO_2 emissions grew by 0.9% or 321 Mt in 2022, reaching a new high of over 36.8 Gt [5]. According to a recent study by Climate Action Tracker (CAT), if nations continue to maintain their current policies regarding the climate, the planet is heading to at least 2.4°C of warming by the end of the century [6]. The world's largest emissions increases have been due to emissions from the production of electricity and heat; these were partially offset by a decline in emissions by industry.

For the Paris Agreement to be workable, all countries must cooperatively participate. Ultimately, we need to create a pathway for the Earth's climate resilience. Policies, programs, and technologies must be implemented and synchronized to enable a transition to systems capable of reducing greenhouse gas emissions and increasing the use of clean energy resources. There are tough decisions ahead on the path to global decarbonization.

DECABONIZATION

The term decarbonization literally means the reduction of carbon. It is often included in lists that identify future trends but we are seeing it becoming policy today. The term refers to the transition to an economic system that sustainably reduces and compensates for atmospheric emissions of carbon dioxide, a potent greenhouse gas (GHG). Decarbonization has been identified as one of the top three trends in the energy sector [7]. In a broader sense, it refers to the transition away from the use of fuels and compounds that increase GHG emissions. The concept is indeed transformative because it challenges us to transition from using fossil-fuels to clean energy resources.

Gaining traction in the 1950s, the world's historical CO_2 trend shows a trajectory of emissions from combustion and industrial processes that continue to increase (see Figure 1). Though total emissions declined in 2020 due to the economic impact of COVID-19, they increased to 36.3 billion tonnes in 2021 as the world's economic situation improved. Regardless, we are already seeing a decoupling of economic growth and energy use in some developed countries.

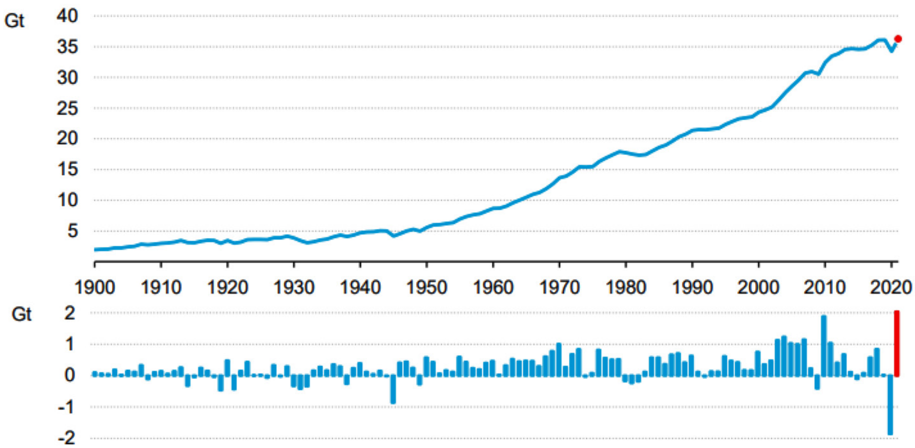

Figure 1. Total CO_2 emissions from energy combustion and industrial processes (top graph) and their annual change (bottom graph) [8].

The goal of decarbonization is to create a CO_2 emissions-free global economy [10]. This is a daunting if not seemingly impossible objective to achieve in the short-term. Long-term reductions in GHG emissions will require substantial increases in infrastructure expenditures by industrial and governmental entities. Many advanced economies have emphasized decarbonization measures in their recent economic improvement plans [11]. Given the past trajectory of greenhouse gas emissions, getting to zero emissions is a questionable goal. Regardless, we are not without tools that aid in this effort.

DECARBONIZATION STRATEGIES

How can GHG emissions be reduced? Numerous ways have been proposed to achieve decarbonization. One over-arching strategy is for countries to lower or eliminate the use of fossil fuels in combustion processes, ultimately lowering total GHG emissions (per capital emissions are show in Figure 2). As the world's population increases, per capita fossil fuel consumption would show incremental declines. Some argue that this is beginning to happen. Per capita fossil fuel consumption began to level off in 2011 and has since peaked. This has been attributed to energy conservation and efficiency improvements, fuel-switching (e.g., substituting renewables and natural gas for coal), and economic conditions. An increase in this measure was recorded in 2021 and attributed primarily to economic growth [8]. Other ways to reduce carbon emissions include using renewables, shifting to lower carbon emitting fuels, carbon capture and sequestration, electric mobility, energy efficiency, low carbon materials and emissions intelligence (tracking and managing emissions) [9].

Another solution is to expedite the transition to using energy that does not emit GHGs during combustion processes or otherwise lacks a combustion process. Realistic approaches include creating pathways to incrementally transition to clean energy. Clean energy usually refers to renewable energy plus nuclear energy since these energy resources produce negligible quantities of GHGs [12]. The vision of decarbonization is to evolve to clean energy electric grids using local generation from renewable energy sources (e.g., wind, geothermal, hydropower and solar power). Excess power can be stored for later use by using batteries (e.g., lithium-ion, sodium-sulfur, vanadium-redox, etc.), compressed air, pumped hydropower storage, or directed to a process storage solution such using water for electrolysis to create hydrogen and oxygen [13]. Another alternative is to generate electricity with package nuclear power systems [14]. In 2021 renewable energy sources and nuclear power provided a larger share of global electricity generation than coal [11]. The use of renewable energy, led by wind and solar power, has increased and accounts for 13% of total power generation. Renewable electrical generation increased by about 17% in 2021 [8]. It has accounted for over half of the increase in global power generation over the past two years [8].

Pathways to Decarbonization

Synchronizing policies, programs, and technologies and directing them toward common goals is a key to success [15]. Regardless, pathways to decarbonization are often sector specific [16]. Instituting building decarbonization measures has been proposed [11,16]. Communities have created pathways to institute clean energy programs that use energy efficient buildings and supporting electrification [16,17].

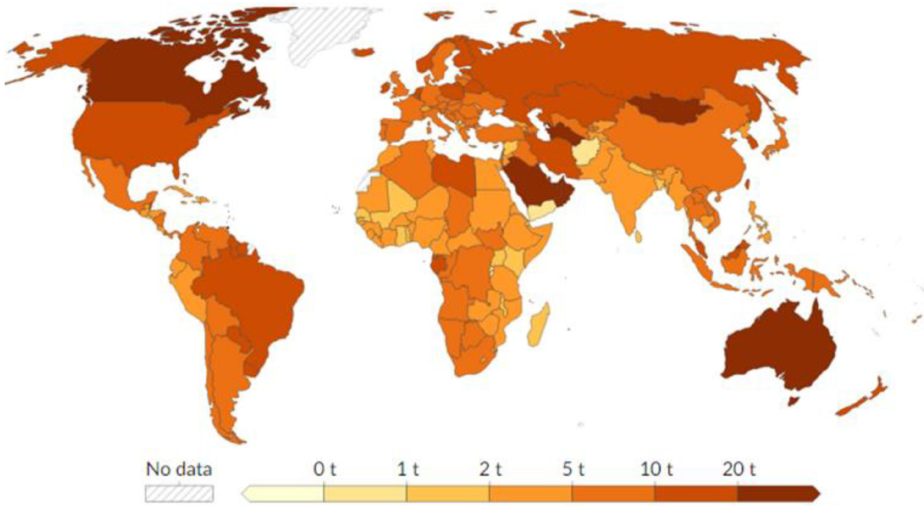

Figure 2. Per capita greenhouse gas emissions in tonnes of CO_2 equivalent over past 100 years (source: Our World in Data, 2021, https://ourworldindata.org/greenhouse-gas-emissions).

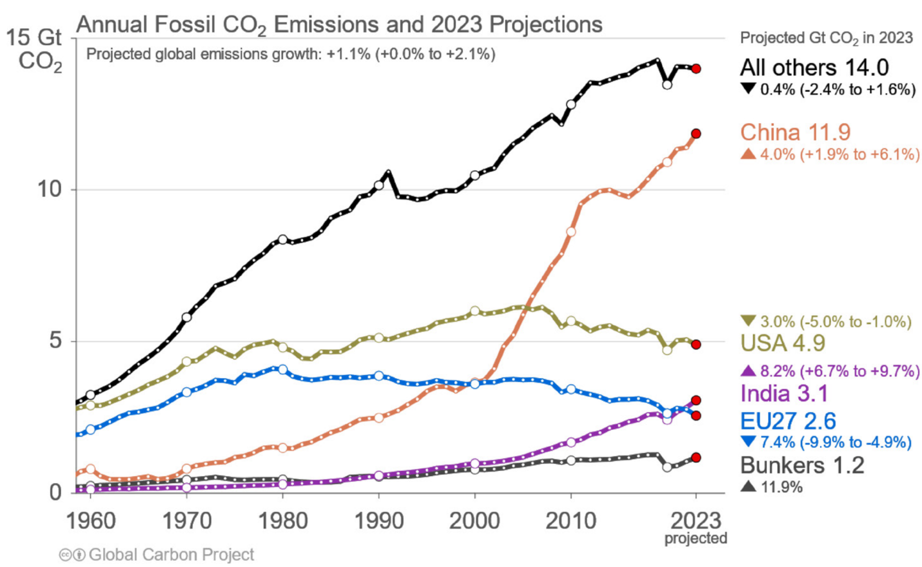

Figure 3. Annual fossil CO_2 emissions and 2023 projections (source: Global Carbon Project, Friedlingstein et al. 2023).

Technological approaches include developing net zero buildings and processes using green hydrogen for mobility applications [18]. Another approach is to convert all appliances and heating systems to operate using electricity and generate all the electricity required using renewable resources. To make this happen, industries would need to make major infrastructure changes. Key elements of an industrial decarbonization strategy would include gathering energy data, establishing emissions reporting methodologies, establishing decarbonization project generation and drivers, creating a marginal abatement cost curve, expanding electrification, and enforcing decarbonization checklists [18]. For industrial concerns, making changes to functional processes often faces formidable internal resistance.

Strategies to reduce carbon emissions will impact all sectors of the economy and costs are likely to be unevenly distributed regardless of the strategies employed. Therefore, policies that focus on reducing carbon emissions must be broadly based. A consensus must be reached. Programs must be implemented to achieve the goals established by the policies that are adopted. While policies and programs are replicable, they must be overarching in their principles, consistent in their goals, and locally adaptable. The technologies employed must be appropriate, deployable, and economically viable. Synergistic, multi-faceted approaches to resolving our energy-related facility and transportation emissions are needed. It begins with rethinking the design of our infrastructure, offering more efficient buildings and vehicles, offering more options, and greater use of renewable energy systems.

Strategies have been used effectively in the U.S. and other European Union Counties as seen from declines in emissions from the use of fossil fuels (see Figure 3). One effective way to reduce emissions is known as fuel switching. Emissions associated with fossil fuels have declined using this strategy particularly when the use of natural gas has been substituted for coal. Figure 4 indicates declines in coal and oil use in the U.S. since 2005 with corresponding increases in natural gas consumption. Total GHG emissions are reduced since natural gas combustion processes emit less CO_2. Meanwhile there have been offsetting increases in coal use in many countries including China and India.

A stabilization triangle approach to developing and implementing

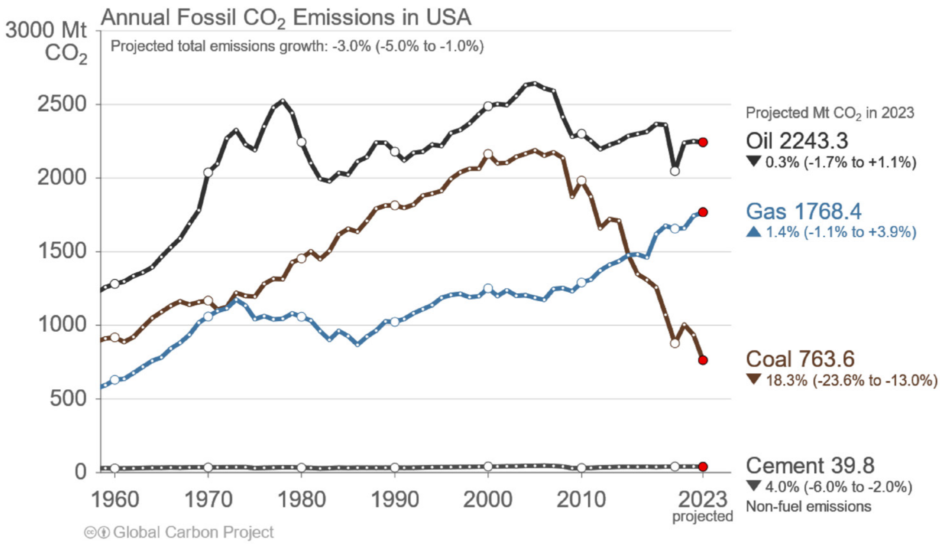

Figure 4. Annual U.S. fossil CO_2 emissions and 2023 projections (**source: Global Carbon Project, Friedlingstein et al. 2023**).

potential solutions has been adopted by individual countries and the International Governmental on Climate Change (IPCC) to address climate change solutions. It supported international agreements including the Kyoto Protocol (in force in 2005), the Copenhagen Accord (2009), and the Paris Agreement. Numerous stabilization triangle solutions, often called wedges, are being implemented on a world scale. These wedges include implementing energy conservation and efficiency initiates, fuel substitution, providing renewable and nuclear energy, energy storage systems, carbon capture and sequestration, and implementing advanced control technologies. Numerous challenges are counter to these trends to reduce carbon emissions, such as the use of fossil fuels in transportation, the large electricity requirements of central computing centers, and the energy required for the development of artificial intelligence.

Emissions reduction pathways and the implementation of strategic GHG reduction wedges help achieve the intent of the Paris Agreement. They support the international consensus to implement efforts to prevent further increases in atmospheric temperatures.

CONCLUSIONS

Has there been progress toward our GHG reduction goals? Perhaps. From 2000 to 2009 global emissions increased at a rate of 2.9% annually; from 2010 to 2019 global emissions increased at a rate of 1.0% annually, the same rate of increase from 1990 to 1999. The lower rate of emissions in the last decade is due to the implementation of climate mitigation policies and technologies, economic issues, and other factors. Between 2019 and 2023, total energy-related emissions increased around 900 Mt. Without the growing deployment of key clean energy technologies since 2019—solar PV, wind, nuclear, heat pumps, and electric vehicles—the emissions growth would have been three times larger [20]. Total emissions were estimated to be 36.8 $GtCO_2$ in 2022, and increased by 1.1% to 37.4 $GtCO_2$ in 2023 [20]. The global shortfall in hydropower generation due to droughts drove up emissions by around 170 Mt; without this effect, emissions from the global electricity sector would have fallen in 2023 [20].

The progress so far has resulted from more energy-efficient buildings, changes to transportations systems, energy efficiency improvements, fuel substitution, energy storage systems, and carbon recycling and sequestration. Renewable energy systems continue to have an important role in reducing GHG emissions. Renewables met 90% of global growth in electricity generation in 2022 [20].

Advanced economy GDP grew 1.7% but emissions fell 4.5%, a record decline outside of a recessionary period [20]. Having fallen by 520 Mt in 2023, emissions are now back to their level of fifty years ago; coal demand is back to the level of around 1900. The 2023 decline in advanced economy emissions was caused by a combination of structural and cyclical factors, including strong renewables deployment, coal-to-gas switching in the U.S., but also weaker industrial production in some countries, and milder weather conditions [20]. Total GHG emissions are increasing in developing countries including China and India.

The hope is that the more dire implications of climate change are preventable. The concept of decarbonization creates a pathway to mitigate the more extreme impacts of climate change in the long-term. It is an important tend that is shaping the transition toward a more sustainable and low-carbon future. Strategic approaches to reducing GHG emissions have been identified by researchers and newer technological solutions will be available to mitigate climate change. Many of the technologies needed to implement the solutions have been tested and proven. The key goal is to transition our economies away from using primarily fossil fuels toward clean energy resources. Knowing what solutions are workable now leads us to the next phase which is to implement the most workable solutions at larger scales.

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AUTHOR BIOGRAPHY

Stephen A. Roosa, Ph.D., MBA, CEM, BEP, CSDP, REP, CBCE, CMVP is an energy engineering professional focused on developing solutions that bridge the gaps between energy and sustainability. He is a former senior process engineer and energy manager for a Fortune 100 company. He is the president of RPM Asset Management and a senior project development engineer for Ameresco, LLC. He is a past president of the AEE and its present Director of Sustainable and Local Programs. He has taught over 100 seminars and workshops on the topics of energy management, sustainable development, renewable energy and microgrids. He has written six books, published more than 60 journal articles, and edited more than 200 published papers on topics related to energy policies, conservation, engineering, management, renewable energy, and sustainable development.

Dr. Roosa has received numerous awards during his career, including the AEE International Energy Manager of the Year Award, the AEE Energy Project of the Year, the U.S. Federal Energy and Water Management Project Award, the U.S. Army Corps of Engineers National Energy Engineers Systems Technology Award, the U.S. Department of Defense Joint Chiefs of Staff Citation for Energy Management, the AEE Distinguished Service Award, and the Honorable Order of Kentucky Colonels Medal of Distinction. He is an AEE Fellow, a Legend in Energy, and a member of the Energy Manager's Hall of Fame. Email: sroosa@aeecenter.org.