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Editorial
Mitigation of Climate Change: Crucial Energy Actions

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Abstract
Climate change is generally considered attributable to numerous causes. Human induced climate change is particularly linked to anthropogenic activities that emit greenhouse gases such as carbon dioxide to the atmosphere. The energy sector, due to its heavy reliance on fossil fuels, constitutes one of the largest carbon dioxide contributors to climate change. The mitigation of climate change requires the implementation of many measures. A great number of these are related to energy processes. In this article, the mitigation of climate change and the role played by energy actions in this task is examined. Further, measures are described that are considered crucial by the author for combatting climate change.

Key words: Mitigation, climate change, fossil fuel, greenhouse gases, anthropogenic activities

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INTRODUCTION

Climate change, stemming from global warming is attributable to numerous causes. Human induced climate change is considered by almost all of the scientific community to be particularly linked to anthropogenic activities that release to the atmosphere greenhouse gases such as carbon dioxide. The energy sector, with its reliance on fossil fuels, constitutes one of the largest carbon dioxide emitters and contributors to climate change.

Efforts directed towards the mitigation of climate change require the implementation of numerous measures. A great number of these are directly or indirectly related to energy processes.

In this article, the mitigation of climate change and, in particular, the role played by energy actions in this task is examined. Measures are also described that are considered crucial by the author for supporting efforts to address climate change.

ENERGY SECTOR

The energy sector is made up of various processes, include the following:

- Energy harvesting and production
- Energy conversion
- Energy transport and distribution
- Energy storage
- Energy utilization
- Energy recovery and disposal

The world's reliance on fossil fuels makes the energy sector one of the largest carbon dioxide emitters. Despite the emissions of greenhouse gases due to the combustion of fossil fuels, their use dominates the energy sector at present, primarily for economic reasons.

GLOBAL WARMING AND CLIMATE CHANGE

Climate change is very much driven by global warming. This, in turn, is driven by changes in the atmospheric composition, particularly increases in the concentration of the greenhouse gas carbon dioxide.

The reasons for these relations can in part be appreciated by examining the earth-sun-space energy balance. It is clear that almost all of the energy entering the earth's atmosphere ultimately returns to space. Any difference between these quantities, due to less energy leaving than entering induced by the greenhouse effect, leads to energy accumulation in the earth and its atmosphere. This manifests itself as an increase in the average temperature of the earth. In simple terms, therefore, global warming, involves a decrease in the energy output from the earth and its atmosphere, in tandem with an unchanging energy input.

CLIMATE CHANGE AND ENERGY

The main greenhouse gas is carbon dioxide, an output mainly of the combustion of fossil fuels. This occurs in many systems and devices, including furnaces, heaters and boilers, transportation vehicles, electricity generation and cogeneration facilities and numerous industrial operations.

The increasing trend over since the 1700s of anthropogenic emissions of carbon dioxide correlate well with increasing trend of the atmospheric concentration of carbon dioxide, from approximately 280 to over 410 ppm now. It is evident in the combustion reaction for any fossil fuel that carbon dioxide is an inherent output, not a waste that can be curtailed through careful engineering. That said, it is clear that engineers play an important role in any actions to mitigate climate change, given the centrality of engineering to the development of energy systems. Nonetheless, simple logic suggests that the only ways to avoid emissions of carbon dioxide are:

- To avoid or curtail the use of carbon-based fuels
- To eliminate carbon dioxide emissions, likely by utilizing some form of capture and sequestration technology

The relations between climate change and energy lead the author to suggest several energy-related actions that are crucial in efforts to mitigate climate change. These actions provide a holistic and comprehensive framework for addressing energy-related contributions to climate change in an integrated manner.

UTILIZATION OF NON-CARBON ENERGY RESOURCES

Non-carbon energy resources can mitigate in part or in whole greenhouse gas emissions. Such resources include renewable and nuclear energy.

Renewable energy of course includes direct solar radiation. But it also includes energy forms directly caused by solar radiation like bioenergy, wind energy, hydraulic energy, wave energy and ocean thermal energy. Tidal energy due to lunar and solar gravitational forces and geothermal energy due to internal heat of the earth and the natural temperatures of the ground also constitute forms of renewable energy.

Note that some renewable energy resources must be managed carefully or they may not be renewable. Biomass energy crops, for example, are renewable provided they are grown at the same rate they are harvested.

UTILIZATION OF ENERGY CARRIERS THAT SUPPORT NON-CARBON ENERGY RESOURCES

Energy carriers, sometimes referred to as energy currencies, are an important but less sometimes visible part of the energy system. They include:

- Non-chemical secondary energy forms like electrical and thermal energy (heat or cool)
- Non-conventional chemical fuels like hydrogen, methanol and ammonia
- Secondary chemical fuels, like gasoline, coke and synthetic gaseous fuels

Many energy carriers do not exist naturally, including work, electricity and hydrogen.

Energy actions to mitigate climate change require the use of energy carriers that support the use of non-fossil fuel-based energy sources. To avoid carbon dioxide emissions, it is also beneficial to use of non-carbon-based energy carriers such as hydrogen and electricity. However, many material energy carriers are utilized in a cyclic nature, so their net emissions are zero or near zero.

Hydrogen energy systems have received much attention in recent decades, in large part because they permit energy resources other than fossil fuels to be used to produce hydrogen and hydrogen-related fuels (despite the fact that almost all the hydrogen used today in industrial operations is derived from fossil fuels). Hydrogen is producible from numerous resources, using a variety of processes: Reforming of natural gas, coal gasification, water electrolysis, thermochemical water decomposition, etc.

BOOSTING EFFICIENCY

Higher efficiencies in all stages of energy systems help reduce greenhouse gas emissions. Numerous efficiency-improvement actions related to energy are possible:

- More efficient utilization of energy quantities and energy conservation
- More efficient utilization of quality of energy and better matching of energy carriers and energy demands
- Improved energy management, including the strategic implementation of energy storage and
- Fuel substitution that supports higher efficiency

Actions to improve efficiency are often addressed most effectively and comprehensively using methods based on the second law of thermodynamics, such as exergy analysis. Exergy, a measure of the usefulness an energy form or substance, is not conserved. Rather, it is destroyed or consumed due to the irreversibilities or non-idealities inherent in any real process. Thus, exergy losses occur not just through waste exergy emissions, but also in the form of internal exergy destructions or consumptions (and the latter are normally more significant than the latter). By identifying insights not observed with the more conventional energy analysis, exergy analysis quantifies meaningful thermodynamic efficiencies and losses.

By corollary, methods based on the second law of thermodynamics, like exergy analysis, often identify the available margin for design more efficient energy systems. They do this in part by clarifying upper limits to efficiency improvement.

SEQUESTRATION OF CARBON-BASED ATMOSPHERIC EMISSIONS

Capturing and sequestering emissions of carbon dioxide and other greenhouse gases constitutes a potentially useful action to mitigate climate change. This can be accomplished by capturing the greenhouse gases before they disperse in the atmosphere, although it can also involve removing such gases from the atmosphere after they have been released and dispersed. Carbon capture and sequestration technology is not mature and general agreement has not been reached on degree to which it can contribute to climate change mitigation.

To account for all greenhouse gas emissions attributable to a particular energy activity, it is essential that a life cycle approach be adopted, which examines inputs and outputs over the entire life cycle of a process. The life cycle includes not just the operating phase, but also such other phases as the manufacture and disposal of equipment.

STRIVING FOR ENERGY SUSTAINABILITY

Energy and climate change are strongly linked to sustainability, which has environmental, economic and social dimensions. Consequently, the energy-related actions for mitigating climate change can contribute to the broader objectives to achieve sustainable development and ultimately sustainability. Although numerous, the challenges faced in moving towards sustainability need to be addressed.

Table 1: Efficiency benefits of using electric heat pumps rather than electric resistance units for heating (for a fixed electrical supply rate)

Devices	Electrical power input (kW)	Heat rate delivered (kW)	Coefficient of performance	Efficiency (equivalent) (%)
Electric resistance heater	100	99	0.99	99
Heat pump (low efficiency)	100	200	2.00	200
Heat pump (medium efficiency)	100	300	3.00	300
Heat pump (high efficiency)	100	450	4.50	450
Heat pump (very high efficiency)	100	600	6.00	600

All countries need to contribute to sustainable development and efforts towards this goal have been launched, such as the implementation of the United Nations Sustainable Development Goals (SDGs) for 2015-2030. Not surprisingly, many of the SDGs relate to energy and climate change.

ILLUSTRATION

The heat pump is a fairly common technology that can significantly boost the efficiency for building heating. This is shown in Table 1, where the performances of various electrical heat pumps are listed and compared.

Also shown in Table 1 for further comparison is an alternate yet very common heating device: the electrical resistance heater.

Although electric resistance heating has a very high energy efficiency, approaching 100%, electrical heat pumps are seen to be able to provide much more heating than electrical resistance heaters and higher efficiency heat pump units exhibit superior performance. By corollary, high efficiency heat pumps can provide the same heating as lower efficiency devices or electric resistance heaters using with 50-85% less electrical power.

Of course, heat pumps can also be used for cooling by operating in a reverse mode, increasing the benefits of their applications.

There are many types of heat pumps, including air, water and ground source units, permitting a wide range of applications. For instance, a ground-source heat pump system with a large underground thermal storage system is being used by the present author's university, the University of Ontario Institute of Technology in Canada.

Given the major contributions of energy processes to climate change, this example provides but one illustration of the broad energy actions outlined in this paper. Taken together, they are intended to provide a realistic set of actions to mitigating climate change.