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Recent advances in carbon emissions reduction: policies, technologies, monitoring, assessment and modeling

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ABSTRACT

Climate change and its social, environmental, economic and ethical consequences are widely recognized as the major set of interconnected problems facing human societies. Its impacts and costs will be large, serious, and unevenly spread, globally for decades. The main factor causing climate change and global warming is the increase of global carbon emissions produced by human activities such as deforestation and burning of fossil fuels. In this special volume, the articles mainly focus on investigations of technical innovations and policy interventions for improved energy efficiency and carbon emissions reduction in a wide diversity of industrial, construction and agricultural sectors at different scales, from the smallest scales (firm or household), cities, regional, to national and global scales. Some articles in this special volume assess alternative carbon emissions reduction approaches, such as carbon capture and storage and geoengineering schemes. Given the high cost and internal/external uncertainties of carbon capture and storage and risks and side effects of various geoengineering schemes, improved energy efficiency and widespread implementation of low fossil-carbon renewable-energy based systems are clearly the most direct and effective approaches to reduce carbon emissions. This means that we have to radically transform our societal metabolism towards low/no fossil-carbon economies. However, design and implementation of low/no fossil-carbon production will require fundamental changes in the design, production and use of products and these needed changes are evolving but much more needs to be done. Additionally, the design and timing of suitable climate policy interventions, such as various carbon taxation/trading schemes, must be integral in facilitating the development of low fossil carbon products and accelerating the transition to post-fossil carbon societies.

1. Introduction

Global warming is one of the greatest threats to human survival and political stability that has occurred in human history. The main factor causing global warming is the increase of global carbon emissions. The 2007 Fourth Assessment Report (AR4) by the Intergovernmental Panel on Climate Change (IPCC) of the United Nations indicated that most of the observed warming over the last 50 years was likely to have been due to the increasing concentrations of greenhouse gases produced by human activities such as deforestation and burning fossil fuels. This conclusion was made even stronger by the Fifth Assessment Report (AR5) released in 2013. The concentration of carbon dioxide (CO_2) in the atmosphere has increased from a pre-industrial value of about 280 ppm to 391 ppm in 2011. In 2014, the concentration reached more than 400 ppm. The continuous and increasing production of carbon emissions is therefore, a matter of global concern (Yue et al., 2015). Fortunately many countries have set ambitious long-term carbon emission reduction targets, e.g. the U.S. is committed to lower carbon emissions by 17% and 83% below 2005 levels by 2020 and 2050, respectively; the UK aims to reduce its carbon emissions by at least 80% of 1990 levels by 2050; China is now committed to abate

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its emissions per unit of economic output by 40–45% of 2005 levels by 2020; India is committed to decrease its emission intensity by 20–25% by 2020; and Brazil is committed to reduce its carbon emissions by 38–42% of BAU levels by 2020.

Globally, the growth in carbon emissions is largely from industry, transport and energy supply, while residential and commercial buildings, forestry/deforestation and agricultural sectors also contribute substantial quantities of carbon dioxide, methane and other greenhouse gases. Given the increasing risks to civilization of continuing with essentially unrestrained fossil fuel burning, an important question for all is what are scientifically sound, economically viable, and ethically defendable strategies to mitigate the global warming trends and to reverse the increases and to adapt to the present and anticipated climate risks? Many relevant approaches designed to investigate ways to reduce carbon emissions and to mitigate the impacts of climate change are included in about 90 articles contained in this special volume (SV).

2. Carbon emission reduction potentials in diverse industrial sectors

Reduction of fossil carbon emissions from diverse industrial sectors is central to efforts to reduce fossil carbon emissions due to the large material's flows they process and to the large quantities of energy they consume. If the energy is used inefficiently, this will lead to higher carbon emission levels. It becomes necessary to base the economic, the energy and the environmental policies on the efficient use of resources, in particular on energy efficiency (Robaina-Alves et al., 2015). Carbon emissions are generated in almost all activities of industrial sectors, extraction of materials from the earth's crust, production, procurement, inventory management, order processing, transportation, usage and end-of-life management of used products. However, as aggregate carbon emissions continue to rise, necessary improvements in industrial practices are lagging behind (Stål, 2015). Fortunately, some new carbon emissions reduction technologies, if effectively applied sector-wide, promise to help societies to make progress in alleviating the growing climate change crises (Slowak and Taticchi, 2015). Except for technical innovation, the design and timing of policy interventions is crucial for reducing innovation barriers and improvements in energy efficiency (Ruby, 2015). The authors of the articles in this SV investigated carbon emissions reduction potentials in a wide diversity of industrial sectors as highlighted in the following sections.

2.1. The iron and steel industry

Iron and steel production is one of the major sources of anthropogenic CO_2 emissions. Targeting a limitation of the global mean temperature increase in the range of 2.4–3.2 °C could result in drastic increases of the CO_2 prices if policies are developed to internalize the currently externalized impacts of CO_2 in the near future. Morfeldt et al. (2015) showed that significant energy efficiency improvements of current steel production processes, such as top gas recycling, can only meet the binding climate target if combined with carbon capture and storage (CCS). Moreover, a binding climate target tends to induce a regional differentiation of prices, indicating that regions such as China, India and South Korea may have difficulties meeting their domestic demand for steel, due to the high CO_2 price and their high dependence on fossil fuels for energy production.

China is the biggest iron and steel producer in the world. In 2012, it produced 658 Mt of pig iron and 716 Mt of crude steel, representing 59% and 46% of the world's production, respectively. The iron and steel industry in China accounted for 10% of total CO_2 emissions of China, therefore, the low fossil–carbon transition of the iron and steel industry is vital for meeting China's CO_2 emission reduction targets. Among different pathways to achieve CO_2 emissions reduction, more attention must be paid to industrial symbiosis, a system's approach which is designed to build upon win-win synergies between environmental and economic performances through physical sharing of ‘waste’ energy, exchanging of waste materials, by-products and infrastructure sharing among co-located entities. For China's integrated steel mills (ISMs), Yu et al. (2015a) showed that: 1) the three of the most effective symbiotic measures for CO_2 abatement were blast furnace gas recycled on site as fuel and/or sold off-site, coke oven gas recycled on site as fuel and/or sold off-site, and blast furnace slag sold to cement producing companies; 2) utilization of gaseous and solid waste/byproducts far outweighed the use of sensible heat in terms of their contributions to CO_2 abatement, which indicated the abundant potentials in sensible heat recovery; 3) cleaner production inside an ISM contributed more to CO_2 abatement than symbiotic measures with other enterprises did.

2.2. The cement industry

Cement is the basic and most widely used building material in civil engineering, the quantity of which has increased dramatically because of vast and rapid urbanization. The cement industry is also one of the most significant carbon emitters. This sector accounted for about 1.8 Gt of CO_2 emissions in 2006, approximately 7% of the total anthropogenic CO_2 emissions worldwide (Gao et al., 2015). Ishak and Hashim (2015) reviewed the CO_2 emissions of all stages of cement manufacturing, including raw materials preparation, clinker production, combustion of fuels in the kiln and the production of the final cement products. They found that 90% of CO_2 emissions from cement plants were generated from clinker production while the remaining 10% was from raw materials preparation and the finishing stage of producing cement. They also reviewed various CO_2 emissions reduction strategies, including energy efficiency improvements, waste heat recovery, the substitution of fossil fuel with renewable energy sources, the production of low carbon cement and CCS. In addition, the use of supplementary cementitious materials, such as fly ash, silica fume, copper slag, sewage sludge, ground-granulated blast furnace slag, are often promoted as ways to reduce carbon emissions (Liu et al., 2015b; Crossin, 2015; Yang et al., 2015a).

China is the biggest producer and CO_2 emitter in the global cement industry. The cement industry accounts for 14.8% of total CO_2 emissions from China, thus it is a critical sector within which to help China to meet its national 40–45% carbon emissions reduction target (Chen et al., 2015a). Based on data from fifteen cement plants in China, Gao et al. (2015) showed that replacing carbonate-containing materials with non-carbonate materials and by changing the clinker ratio were the main ways to reduce CO_2 content in raw meal and process emissions, e.g. sulphoaluminate cement manufacture in a modern cement plant can give CO_2 emissions reductions of up to 35% per unit of mass of cement produced, relative to ordinary Portland cement manufacture.

2.3. The rubber industry

During all stages in the manufacturing processes of rubber products, large quantities of energy, water and other natural resources are consumed. Among rubber products manufacturing processes, the rubber material milling process, the extruding process and the rolling process all have a relatively high electricity consumption rate. Dayaratne and Gunawardena (2015) investigated three rubber-band manufacturing factories and revealed the