Benefit-cost analysis of SF6 emissions mitigation in the power industry

Overview

The potent greenhouse gas sulfur hexafluoride (SF6) is widely used in gas-insulated switchgear (GIS) equipment in the power industry. With the growing electricity demand and the continual integration of renewable energy into the grid, GIS installations, and consequently, SF6 emissions are projected to rise. Although efforts have been taken to reduce SF6 emissions from GIS in many countries, low-carbon alternatives for SF6 were not available until recent years. Thus, to date, there has been no comprehensive analysis on the economic feasibility of replacing SF6 in high-voltage GIS equipment. We fill the gap by constructing a scalable and flexible benefit-cost analysis (BCA) framework to evaluate the net social benefit of three SF6 replacement schemes. Using the Chinese power industry data, we find that despite the high global warming potential of SF6, if the leakage rate is well controlled, the environmental benefit from replacing SF6 is outweighed by the high investment cost of the low-carbon alternatives. However, with the projected increase of the social cost of carbon and the anticipated reduction in equipment costs, if leakage control is not sufficiently enforced, it is socially desirable to fully replace SF6 in the future.

Background

SF6 is one of the most potent greenhouse gases (GHGs). According to the IPCC (AR5) reports, SF6 has a 100-year global warming potential (GWP) of 23,500 and an atmospheric lifetime of up to 3200 years. Research has shown that global emissions of SF6 have increased by about 24% in the past decade and are expected to rise with the growing electricity demand and electrical equipment installations (Simmonds et al., 2020).

SF6 is widely used in high-voltage gas-insulated switchgear (GIS) equipment in electric grid systems all over the world because of its excellent arc-quenching (extinguishing an electric arc) and dielectric (insulating electricity) properties. Increasing electrification, especially in developing economies, has lead to the rapid growth in the manufacturing and installation of GIS equipment. For example, the average growth rate of new GIS equipment in China is around 10% from 2015-2020. Consequently, the consumption and emissions of SF6 also increased. Recent studies have shown that SF6 emissions from electric equipment use account for 80% of total SF6 emissions globally (Rabie et al., 2020). Moreover, with the growing integration of renewable energy sources, a wave of GIS equipment increase is expected to take place in developed countries, especially with the development of offshore wind power. How to address the increase of SF6 in GIS with renewable energy transition has been overlooked in the existing literature.

Methodology

In this paper, we systematically analyze the economic feasibility of mitigating SF6 emissions in the power industry by adopting alternative insulating gases in the GIS equipment. We fill the gap in the literature by providing a scalable and flexible BCA framework that incorporates the private benefits and costs of firms to implement SF6 replacement schemes and the social benefits and costs if such replacement takes place. Because of the significant uncertainty in future technological development, policy enforcement, and the social cost of carbon (SCC), we use Monte Carlo simulations to estimate the range of net benefits and to conduct sensitivity analyses.

Specifically, we consider three replacement schemes, namely the Equipment Replacement scheme (replacing the SF6 GIS intervals entirely with SF6-free GIS intervals at the current year), the Gas Replacement scheme (retrofitting the SF6 GIS intervals to be compatible with using eco-friendly insulation gases at the current year), and the Green Investment scheme (investing in new SF6-free GIS intervals when building new substations or when the current intervals retire). The three schemes are constructed to reflect different levels of urgency in treating SF6 emissions.

For each scheme, we consider the private cost and benefit of the grid companies and the social cost and benefit. We assume that the firms do not have borrowing constraints thus the costs and benefits can be fully smoothed over the lifetime of the equipment. Additionally, all costs and benefits are normalized to the interval level and are constructed to reflect the characteristics of the corresponding scheme described above.

Case study and Results

To illustrate how the BCA framework can be used, we apply the framework to consider a specific eco-friendly insulation gas mixture (C4F7N/CO2 mixture) and use the primary data collected in the Chinese power industry on 126kV and 252kV GIS equipment to conduct a case study. The choice of the C4F7N/CO2 mixture stems from both theoretical research and industry practices. The reason to choose China is that China has the world's largest power industry in terms of electricity generation capacity and annual electricity consumption. Moreover, the composition of electrical equipment using SF6 as insulation gas in China is representative of that in other countries. Thus, China is an important market to consider when evaluating cost-effective ways to reduce SF6 emissions.

Our preliminary result shows that in the Chinese context, under the current level of equipment cost and SCC, the total cost of replacing SF6 in all three schemes are orders of magnitudes higher than the total benefit. Take 126kv GIS intervals, for example, replacing one GIS interval yields a total benefit of $3658 over a 30-year time horizon while its total cost is $118800. The high cost is driven by the high equipment and monitoring cost of the alternative insulation gas. The low total benefit is mainly due to the low SF6 leakage rate in GIS equipment, because of stringent industry standard on the equipment leakage rate. This result is robust under other schemes and specifications.

The sensitivity analyses show that if the costs of SF6-free GIS intervals and the corresponding monitoring equipment decrease considerably in future years, and that the SCC increases from the current level of $40/tC to $200/tC, then we can anticipate that the future benefit of replacing SF6 may outweigh its cost. In other words, to achieve zero-carbon emissions by 2050, the timing of policies to be implemented is crucial. The cost-effective policy in the short-run is to enforce leakage monitoring of SF6 and subsidize R&D for alternative insulation gases and equipment. In the long-run, investing in SF6-free GIS equipment can be socially beneficial.

Conclusions

Existing literature on SF6 emissions has focused on the aggregated level of SF6 emissions (Billen et al., 2020; Rabie et al., 2018; Simmonds et al., 2020; Fang et al., 2013). The projections made on the SF6 emission trend are based on generalized scenarios and do not reflect the benefits and costs to society. Thus, the literature fails to identify the practicality of mitigation measures in specific sectors. We use a bottom-up approach and focus on one specific but representative sector for SF6 emissions. The BCA framework can help firms to identify the most cost-efficient scheme to replace the use of SF6 in the power system and help regulators to design the appropriate policy instrument that maximizes social welfare. Although policies to ban the use of SF6 in high-voltage gas-insulated electrical equipment are implemented or initiated in many countries (e.g., EU), we argue that enforcing leakage monitoring and investing in R&D of alternative for SF6 is more cost-effective in the short-run.

References

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