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Assessing application potential of clean energy supply for greenhouse gas emission mitigation: a case study on General Motors global manufacturing

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ABSTRACT

Greenhouse gas (GHG) emissions from global manufacturing companies are significant due to the high percentage of fossil fuels consumed in current energy structure. Clean energy technologies are widely recognized for their cleanliness in power generations and accordingly are promising as alternative energy supply for GHG mitigation from global manufacturing. However, deploying clean energy technologies at a global scale requires multi-attribute decision-making and currently there is a lack of information for assessing the application potential of various clean energy systems. This paper presents a mathematical approach based on cost benefit analysis to evaluate the application potential of such clean energy systems as solar photovoltaic, wind, hybrid solar-wind, and hydrogen-based fuel cells to partially supply the electricity needs of global manufacturing to reduce the facility GHG emissions. A case study is conducted on six selected production sites from GM's global production locations, with the future trend of the results analyzed till 2035. The analysis results reveal that the optimal selection and deployment of a clean power system are dependent on such factors as location, time, technology and scale. The highest cost benefit result is obtained on wind power system deployed in Bochum, with 15.5 tons of $CO_{2,eq}$ mitigation potential per \$1000 cost input. The number will be increased to 15.73 and 19.96 tons of $CO_{2,eq}$ per \$1000 cost input in 2020 and 2035, respectively. The models and results presented in this study could be useful in decision support of optimal selection and deployment of clean energy system by global manufacturers in future.

1. Introduction

Industrial productions such as automotive manufacturing require significant amount of energy inputs for the process operations (Unander et al., 1999; Yuan et al., 2006; Gutowski et al., 2006). As current global energy supply is mainly produced from fossil fuels, the energy consumed in industrial productions generates huge amount of greenhouse gas (GHG) emissions which are of grave concerns worldwide due to their global warming effects (the Intergovernment, 2007). In general, energies consumed in industrial productions are from two categories: direct consumption by burning such fossil fuels as coal, natural gas, oil, etc., on-site for supporting industrial process operations, and indirect consumption by using grid electricity which is usually generated from a mix of energy sources including fossil fuels and renewable energies.

From both direct and indirect sources, the amounts of GHG emissions from industrial productions are significant. Take General Motors (GM) as an example, statistical data shows that the GM manufacturing facilities in U.S. alone consumed more than 5.54×10^{16} J of energy in 2007 which led to generations of 6.26 million metric tons of CO_2 emissions (General Motors Company, 2008). As a whole, the industrial sector in the U.S. produced 28.3% of the total 6702 Million Metric Tons of CO_2 equivalent GHG emissions in 2011, higher than any other economic sectors including transportation, commercial, residential and agriculture (U.S. EPA, 2013). In global scale, the CO_2 emissions from global industrial sector will grow significantly in this decade from 15,165 Million Metric Tons in 2010 to 18,081 Million Metric tons in 2020 (IPCC, 2007). Concerned on the huge amounts and the associated adverse impacts on global warming, industrial GHG emissions are

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always under a priority consideration for emission mitigation by industrialized countries and international communities.

Within the international framework of Kyoto Protocol, many countries have adopted certain types of climate policy, agreements and incentive programs for GHG emission mitigation and monitoring, including UK Climate Change Agreement, German Agreement on Climate Protection, Finland's Agreement on the Promotion of Energy Conservation in Industry, Dutch Long-Term Agreement, Danish Agreement on Industrial Energy Efficiency, etc (IPCC, 2007). These agreements, in nature, provide governmental pressure and regulatory threat for industrial companies to act on their GHG emissions mitigation and controls.

In general, there are two effective ways in reducing the GHG emissions from industrial facilities: improving energy efficiency, or using clean energy supply. In the past decades, improving energy efficiency was mainly adopted by industry for reducing the GHG emissions because it can also reduce the utility costs from the industrial operations. For example, GM's U.S. facilities have conducted a total of 1753 projects from 1991 to 2007 for energy efficiency improvements and conversions of energy sources by using lower GHG emitting fuels such as switching from coal to natural gas for the operation of boilers, which has led to a GHG reduction of over 17 million metric tons CO_2 equivalent (General Motors Company 2008).

However, after decades of continuous improvement, it is difficult to further reduce CO_2 emissions of industrial productions through energy efficiency improvement and conservation, because industrial productions are energy-driven and a baseline of energy input is always required to operate a production system. A potential solution to this dilemma is to use clean energy technologies such as solar photovoltaic, wind, fuel cells, etc., to partially supply the power needs of industrial productions, so as to further reduce the GHG emissions from industrial facilities (Yuan and Dornfeld, 2009; Zhai et al., 2011).

Clean energy technologies are recognized for their cleanliness during power generations and are promoted for use worldwide (Bilgen et al., 2004). In the past years, clean energy technologies were limited in electricity generations mainly because of their high economic costs (Brown, 2001). With continuous technology improvement and cost decreasing in the past decades, the application of clean energy power systems becomes increasingly feasible when compared with conventional grid power supply in terms of tradeoffs between economic cost and environmental benefits.

However, a rigorous literature review found that past research were mostly focused on economic and environmental impact assessment of clean energy systems. For solar photovoltaic (PV), Branker et al. provided a detailed review of solar PV levelized cost of electricity (Branker et al., 2011); Azzopardi and Mutale conducted a life cycle analysis of solar PVs (Azzopardi and Mutale, 2010), and Tsoutsos et al. performed an investigation on the environmental impacts of solar energy systems (Tsoutsos et al., 2005). For wind, European Wind Energy Association published a guide on wind technology, economic performance and future wind power (European Wind Energy Asso, 2009); comprehensive environmental impacts of offshore wind energy are presented by Koller (2006); challenges of onshore wind power development are reported by Han et al. for China (Han et al., 2009). Besides solar and wind, fuel cell stationary power systems using hydrogen fuels were also researched as a clean and renewable technology. Zoulias and Lymberopoulos provided a techno-economic analysis of standalone hydrogen fuel cell based power system (Zoulias and Lymberopoulos, 2007). Neuhoff reported economic reviews of large-scale deployment of hydrogen energies for electricity generations (Neuhoff, 2005).

While the past research on the economic and environmental performance analyses have greatly enhanced the large-scale deployment of clean power systems for electricity generations, there are few studies on the tradeoffs of economic cost and environmental benefits of the clean energy supply for reducing GHG emissions from global industrial productions such as GM' automotive manufacturing (Yuan and Dornfeld, 2009; Zhai et al., 2011). Currently there is a lack of methods and data support for decision-making in optimal selection and deployment of clean power systems for GHG mitigation of large scale industrial productions in a global scale. In this paper, a mathematical approach is developed for quantifying the cost benefit of clean energy supply, to support decision-making in assessing the application potential of various clean energy technologies for partially supplying the power needs of large-scale global industrial facilities. A case study is conducted on a generic assessment of the application potential of four clean energy supply systems including solar PV, wind, hybrid solar-wind, and fuel cell stationary power systems on the global production facilities of GM. It is expected that this study would be useful for global industrial manufacturers in decision-making and strategy-planning of employing clean energy technologies to mitigate their GHG emissions in future.

2. Method

Using clean energy supply for GHG emission mitigation from global industrial productions requires complex decision-making processes. Since a global manufacturer such as GM usually has production sites at many locations around the world, and there are a number of clean energy technologies available on the commercial market for power generations, employing clean energy supply for GHG mitigation needs to consider multiple factors such as the feasibility of GHG mitigation for a specific production site, local geographic conditions for a clean energy deployment, cost of clean power systems, amount of GHGs to be reduced, scale of the production, future trend of the clean energy technology and cost change, etc.

Considering the major factors of industrial concerns on the application of clean energy systems in industrial productions, the application potential of various clean energy power systems for greenhouse gas emission mitigation can be quantitatively assessed based on a cost benefit analysis. The cost is the unit cost of the electricity generated from the clean energy systems, and the benefit is the amount of GHG emissions reduced. In this study, four common clean energy systems including solar PV, wind, hybrid solar-wind and fuel cells are selected for analyzing and benchmarking their application potentials through connecting to local power grids to partially supply the electricity needs of industrial production facilities. Fig. 1 shows the generic scheme of the cost benefit analysis structure for assessing the application potential of these four clean energy supplies in manufacturing industry.

For assessing the application potential of a clean energy supply in GHG emission mitigation of industrial productions, the first step is to identify the feasibility of the clean energy supply at a specific geographic location. Since clean energy technologies such as solar PV, wind, fuel cells, etc., all generates GHG emissions from their life cycles, application of the clean energy supply needs to consider the amount of GHG emissions from the life cycle of the clean energy power systems. For effective GHG emission mitigation, the amount of GHG emissions from the life cycle of a clean energy system must be lower than that from the grid power supply, based on the same amount of power delivery. Here we employ the GHG emission factors of grid power supply at each location and the life cycle GHG emission factors of each clean energy system for the feasibility analysis. Such GHG emissions as CO_2, CH_4, N_2O, etc., from both grid