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What is energy efficiency and emission reduction potential in the Iranian petrochemical industry?

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ABSTRACT

In this study, the prospects of energy efficiency potential, clean development mechanism (CDM) and carbon income up to and beyond 2012 are investigated in the petrochemical industries of Iran as a major oil-producing country. This paper is to address four questions of: (1) the GHGs emission in Iranian petrochemical complexes, (2) the most energy-consuming processes, (3) units with the highest energy efficiency potentials and (4) potentials of CDM or similar carbon projects based on post-2012 scenarios. The petrochemical processes are investigated in two categories of non-polymeric and polymeric productions. Based on capital expenditure, economic saving, simple payback period, CO_2 equivalent emissions, and the level of technology transfer, the attractiveness of energy efficiency measures is assessed and CDM potentials are investigated. Meanwhile, the impact of the recently deregulation of national energy-prices is examined. The results reveal that the three main non-polymeric (ammonia, urea and methanol) processes in Iran offer the most opportunity for energy efficiency improvement and carbon-market potentials followed by the polymeric processes in units with outdated technology. The studied petrochemical units indicate over 2.53 million tons CO_2-eq/year potential reduction in GHGs emission and natural gas conservation of 1100 million-m^3/year. Nonetheless, more detailed energy-auditing for the entire Iranian petrochemicals is required for a comprehensive analysis.

1. Introduction

The petrochemical industry is responsible for 70% of the chemical industry's expenditures on fuels and 40% of the expenditures on electricity (Neelis et al., 2008). The primary petrochemicals could be divided into non-polymeric (ammonia, urea, methanol, etc.) and polymeric products. The two polymeric classes are olefins (ethylene, propylene and butadiene) and aromatics (benzene, toluene and xylenes). Oil refineries produce olefins and aromatics by fluid catalytic cracking of petroleum fractions. Chemical plants produce olefins by steam cracking of natural gas liquids like ethane and propane. Aromatics are produced by catalytic reforming of naphtha. Olefins and aromatics are the building blocks of end-use processes for a wide range of materials such as solvents, detergents, and adhesives. Olefins are the basis for polymers and oligomers used in plastics, resins, fibers, elastomers, lubricants, and gels (Matar and Hatch, 2000).

The largest petrochemical industries are located in the USA and Western Europe; however, major growth in new production capacity is in the Middle East and Asia including Iran (Cefic, 2011). The issue of energy efficiency and GHGs emission reduction are amongst the top priorities in this industry.

GHGs emission in petrochemicals was examined by various researches including Gielen et al. (2002) who worked on CO_2 emission reduction for Japanese petrochemicals. They suggested a number of options for emission reduction including the introduction of biomass feed stocks, new catalytic production processes and changes in waste handling that could reduce the emissions by 7.7%. The use of flue gas for CO_2 enhanced oil recovery in the Middle East was explored by Iijima and Kamijo (2003). The study results showed that CO_2 recovery and compression costs from boilers are 16 to 22 US$/ton, which is comparable to the CO_2 trading price in Europe. Freed et al. (2005) analyzed non-energy uses of fossil fuels as petrochemical feed-stocks in the USA and their GHG emissions. Neelis et al. (2007) approximated the theoretical energy saving potentials for the petrochemical industry using energy balance in 68 key processes in Western Europe. It recommended for more detailed analysis by taking into account thermodynamic, economic and practical considerations to identify technical and economic

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energy-saving potentials. Ren et al. (2009) studied the production costs of petrochemicals from oil, natural gas, coal and biomass from 2030 to 2050. It was found that the effect of CO_2 emissions costs for coal and biomass are high and for the oil and gas-based routes are relatively moderate. Charmondusit and Keartpakpraek (2011) conducted eco-efficiency evaluation of the 31 factories in petroleum and petrochemical group of Thailand.

Hayashi and Krey (2007) assessed the large-scale efficiency measures in heavy industries including oil & gas and ammonia in India and Brazil. They indicated that the potentials strongly depend on the project-specific and country-specific context. Also, the non-polymeric petrochemicals were discussed by Rafiqul et al. (2005) by investigating the energy efficiency improvements in ammonia production. Considerable improvements in specific energy use and CO_2 emissions were found in the ammonia production scenario, yet under the assumption of high oil and gas prices, a partial switch to coal based technologies is expected which notably lowers the CO_2 efficiency. Ren et al. (2008) investigated the energy use and CO_2 emissions and production costs in steam cracking and methane to olefins. They stressed that while several possibilities for energy efficiency improvement do exist, none of the natural gas-based routes is likely to become more energy efficient or to lead to less CO_2 emissions than the steam cracking routes.

Kosugi et al. (2005) conducted an economic analysis of CDM projects for natural gas use in combined heat and power (CHP) facilities of China in various industries including oil and gas sector. They concluded that in some CHP projects, the value of CO_2 emission reduction credit offsets the CHP capital price. Also, Lybaek (2008) investigated market opportunities for future CDM projects in Asia based on combined heat and power production with similar results. Niederberger and Spalding-Fecher (2006) worked on demand-side energy efficiency under CDM projects and concluded that the CDM is only making a very small contribution to promotion of energy efficiency (approximately 140 kt CO_2-eq per year), despite the significant potential for improvement in developing countries worldwide. Branco et al. (2011) studied the abatement costs of CO_2 emissions in the Brazilian oil refining sector. Their findings revealed that refineries face high abatement costs.

The issue of taxation was highlighted by Lee et al. (2007), who worked on the effects of carbon tax on petrochemical-related industries of Taiwan. Gomes et al. (2009) reviewed the impact of CO_2 taxation in new refineries of Brazil. Their findings indicated that for CO_2 prices higher than US\$100/tCO_2, refineries could reduce their emissions by increasing the consumption of natural gas to produce hydrogen.

In Iran several studies have been conducted on the above-mentioned issues including Abbaspour et al. (2006), who presented scenarios for the reduction of greenhouse gases in oil sector of Iran. Soltanieh et al. (2009) concluded that with one ton of CO_2 injection, there will be from 2 to 8 barrels of enhance-oil recovered via CDM projects. Mirbagheri et al. (2010) explored the removal of urea and ammonia from petrochemical industries for reuse in a waste water treatment in Iran at pilot scale. Sekhavatjou et al. (2011) investigated the GHGs emission minimization through processes improvements in Iranian oil industries. Their results showed that the injection of produced methane from anaerobic reactors of wastewater treatment plant to waste incineration furnace will save about 1.75 million m^3 of flare gas. Also, Zangeneh et al. (2011) studied the CDM opportunities for conversion of carbon dioxide to valuable petrochemicals through increasing carbon efficiency in certain processes such as methanol synthesis and methane stream reforming or modifications in catalyst processes. However, an overall study of energy consumption, efficiency and carbon potentials in Iranian petrochemicals has never been conducted. Due to the abundance of energy resources and low prices of fossil fuels in Iran as a major oil producing and exporting country, the energy efficiency and carbon market potentials have been mostly ignored by the top management. Albeit, the 2011 deregulation of energy prices and the drastic increase in energy costs for industrial sectors of Iran has prompted an urgent need to re-examine these issues more seriously. The objective of this research is to investigate the potential of energy efficiency improvement and incentives like carbon market potential for the Iranian petrochemical industries based on the most recent available data and information in this regard. The similarities in the level of technology and types of equipment used in the petrochemical units worldwide could make the results of this research beneficial to other developing countries.

Table 1
GHGs emission factors (kg of GHG per TJ of consumed fuel).

Fuel	CO_2	CH_4	N_2O
Natural gas	56,100	1	0.1
Fuel oil	77,400	3	0.6

Source: IPCC (2006).

2. Methodology

1. The specific energy consumption (SEC) in the petrochemical units of Iran is calculated based on the following equation:

$$\text{SEC} = \text{total energy consumed(MJ)}/\text{total manufactured product(ton)};$$

2. The fuel consumed in various forms is measured in MJ/year unit (natural gas is the dominant fuel in Iranian petrochemicals, followed by limited use of fuel oil).
3. The GHGs emission factors used are shown in Table 1.
4. The energy carriers produced inside the unit from the incoming fuel or electricity to the unit are not included in the calculations, to prevent double counting.
5. The consumed electricity is either provided by the national grid network or inside the complex in MJ/year. The electricity is assumed to be equivalent to the electricity generated by a gas power plant with 30% efficiency.
6. The consumed steam is either produced inside or outside the complex in MJ/year based on the pressure and flow rate of the steam provided by a boiler with 80% efficiency.
7. The consumed air from any source in MJ/year is assumed to be produced by a compressor with 80% efficiency.
8. 1 m^3 of consumed cooling water in MJ/year is assumed to require 0.33 MJ of energy for its production.
9. The actual energy conservation potential for each petrochemical unit is calculated based on the difference between the operation and design SECs.
10. The theoretical energy conservation potential for each petrochemical unit is calculated based on the difference between the unit's operation SEC and the proposed SEC for the establishment of similar new unit.
11. The CDM potentials are calculated according to the accepted methodologies relevant to petrochemical industries and the actual available data.
12. Three scenarios for secondary certified emission reductions (SCERs) are assumed as current market price (€11), realistic post-2012 price (€17) and optimistic post-2012 price (€25); and
13. Three scenarios for natural gas prices in Iran are assumed as 2010 price (0.011€), 2011 price (0.047€) and post 2012 price (0.1€) per m^3.
14. Capital expenditure, economic saving and simple payback period for selected energy efficiency projects in both non-polymeric and polymeric processes are determined based on available data and expert opinions.