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Optimal deployment of renewable electricity technologies in Iran and implications for emissions reductions

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ABSTRACT

In this paper, special focus is paid to the long-term adoption of renewable electricity technologies and their implications for emissions reductions in Iran. MESSAGE, as a bottom-up energy supply optimization model, is used to assess the lowest-cost technology options. The potential impacts of transitioning to a renewable electricity supply are quantified, and the investment requirement to achieve a low-carbon generation mix is estimated. Alternative scenarios are defined to evaluate the impact of fossil fuel prices, the carbon tax and government incentives on the utilization of renewable resources, national renewable targets, and emissions reductions. The prioritization of non-hydro renewable energy sources under different circumstances shows that wind is the most promising technology, followed by solar PV (photovoltaic), solar thermal and biogas. The findings demonstrate that the carbon tax would not individually be an effective strategy to reduce emissions. However, the carbon tax coupled with direct renewable subsidies would be more cost-effective, especially while fossil fuel prices are low. In the case of higher fossil fuel prices, the cost-effectiveness of carbon taxes at reducing emissions is not significantly influenced by the level of renewable subsidies.

1. Introduction

The potential of renewable electricity technologies to reduce GHG (greenhouse gas) emissions and enhance the security of the energy supply has been the center of attention in long-term power sector analysis (e.g. [1–9]). Most renewable energy technologies are in their development phase, and their generation cost is still the major barrier to widespread market penetration [10,11]. Therefore, it is of interest to determine the optimum contribution of renewables to meet the electricity demand under different circumstances, as characterized by increased fossil fuel prices, environmental externalities and technological development. It is also interesting to explore how renewable energy utilization can be affected by efficient environmental and economic incentives in the long run.

Energy system models are commonly used to study the contribution of renewable technologies to fuel supply mixes and emissions reductions. These models are capable of addressing the possible influences of fossil fuel costs and renewable incentives on the energy supply structure, resource conservation, and investment requirements (see, e.g. [12–24], for an overview).

This study uses the MESSAGE[1] model as a detailed bottom-up technology-specific model to identify the appropriate renewable technology options in Iran and the implications of renewables' diffusion on the investment requirement and emissions reductions from 2015 to 2045. The future structure of power generation in Iran is an interesting case study because it has the following characteristics:

- The long-term electricity demand in Iran is expected to grow rapidly [25], necessitating an extensive investment to meet the growing demand in the few next decades. Moreover, the steep growth in the domestic consumption of NG (natural gas) and petroleum products along with the limited supply capacities, especially in cold seasons, might lead to fuel supply shortfalls.
- Fossil fuel consumption has imposed a great financial burden on the country and has led to disastrous air pollution. The total CO_2

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[1] Model for Energy Supply Strategy Alternatives and their General Environmental Impacts.

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emissions increased by more than 2.8-fold from 1990 to 2010, making Iran one of the top ten producers of CO_2 in the world [26]. Hence, renewable energy resources have been regarded as a way to improve the environmental quality.

- The Iranian power sector could be of interest under the CDM (Clean Development Mechanism) because the CO_2 emissions that are sourced from the power sector have increased sixfold over the last three decades and currently account for approximately one-third of the total CO_2 emissions in the country [27,28].
- Iran is among the world's largest oil and gas reserve holders [29]. In addition, Iran has significant potential for renewable energy sources, including hydro, wind, solar, biomass and geothermal power. Despite the presence of abundant renewable energy potential [30–33], the current power sector almost completely relies on fossil fuels [27]. Hence, the Iranian government has set a target of 10% non-hydro renewable electricity generation by 2025 [34]. For each unit of saved fossil fuels – either through energy efficiency improvements or substitution by renewables – the country can achieve higher revenues via fossil fuel export.

A few recent studies have investigated the future perspectives of renewable energy in the power-generation sector. Nejat et al. [31] compared the recent development of renewable energy in Iran with global trends. Mousavi et al. [35] evaluated the competitiveness of wind power generation in Iran. Previous energy system optimization studies on the long-term evolution of the Iranian power sector mainly addressed the role of R&D in the process of technology spillover for solar PV (photovoltaic) [36]; impact of innovative activities on the market penetration of fuel cell, wind turbine and solar PV [37]; and power generation expansion planning in a restructured energy supply system [38]. However, the conditions under which the power system can meet the national renewable target have not been fully investigated. In addition, the cost-effectiveness of the renewable-supporting policies in terms of renewable subsidies and carbon taxes in Iran has remained unexplored. Thus, the present paper has two main objectives. First, it attempts to construct alternative scenarios to demonstrate the optimal strategies for replacing conventional fossil fuel power plants with renewable technologies in Iran. In this context, the conditions under which the national renewable target can be achieved are quantitatively assessed. The second objective is to provide insight into the cost-effectiveness of carbon taxes and direct incentives for renewables (individually and combined) at reducing CO_2 emissions.

In Section 2, the evolution of the Iranian power sector over the past two decades is reviewed. The methodology and model structure of the power supply system in Iran are described in Section 3. Section 4 provides the main assumptions, data sources and scenarios. The main results are given in Section 5, and the paper is concluded in Section 6.

2. Overview of the electricity supply sector in Iran

Fig. 1 shows the past trends of the power plant capacity and total gross electricity generation. To meet the growing demand for electricity, the power sector increased fivefold from 13 GW in 1986 to 65 GW in 2011. During this period, the total capacity and electricity generation increased by 6.7% and 7.5% per year, respectively. The difference in the growth rates stems from the higher utilization of combined cycle power plants that have a higher capacity factor. Electricity generation relies almost completely on fossil fuel power plants, with a total share of 95% in 2011 [27]. The hydropower installed capacity reached approximately 8.7 GW in 2011 (i.e., approximately 13% of the total installed capacity). The corresponding hydroelectricity generation is 12 TWh, which is approximately 5% of the total generation of 240 TWh.

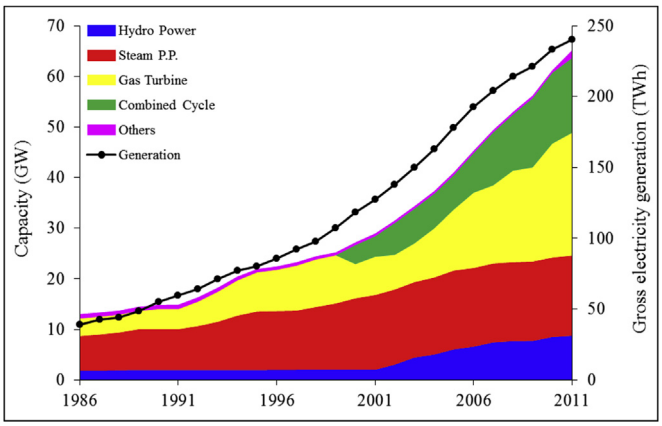

Fig. 1. Installed capacity and electricity generation trends in Iran [27,28].

The average efficiency of thermal power plants improved from 35.1% in 1999 to 37.8% in 2011 [28], mainly due to the higher utilization of more efficient combined-cycle power plants. The share of steam turbine power plants decreased over the last decade, although they still plays an important role in total electricity generation (39% of total electricity generation in 2011). The total installed capacity of gas turbine facilities increased 2.5-fold during the same period.

As shown in Fig. 2, fuel consumption has gradually shifted from petroleum products to NG. As a result of the growth in electricity demand and in the consumption of fossil fuels in the power sector, CO_2 emissions from the power sector have increased sixfold.

3. Methodology

The electricity supply system of Iran is modeled using the MESSAGE model. MESSAGE is a bottom-up energy supply optimization model that is based on the reference energy system, starting from resources and passing through different production processes, conversion technologies, transmissions and distributions to meet final/useful energy demand. MESSAGE was originally developed at the International Institute for Applied Systems Analysis. The International Atomic Energy Agency improved MESSAGE to facilitate its application [39].

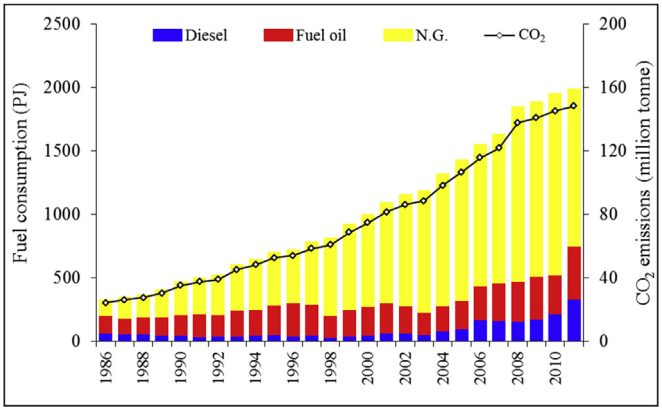

Fig. 2. Fuel consumption and total CO_2 emissions in Iran's power sector [27,28].