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Substitution effect of renewable portfolio standards and renewable energy certificate trading for feed-in tariff

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HIGHLIGHTS

- The substitution effect of RPS and REC trade for the FIT was calculated and analyzed.
- A multi-region power market model was proposed and developed.
- REC trade can reduce the government's expenditure on subsidies for renewable energy.
- FIT subsidy provides guarantees of the local power sectors' profit.
- RPS, REC trade and FIT subsidy need to be considered together.

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ABSTRACT

The Feed-in Tariff (FIT) has been successfully used to promote the development of renewable energy; nevertheless, it may cause financial burden on the governments at the same time. Compared with FIT, Renewable Portfolio Standards (RPS) and the Renewable Energy Certificate (REC) trading have been considered to reduce the government's expenditure caused by the subsidization. To examine the effectiveness of RPS and REC trading, the development of renewable energy and the environmental and economic benefits under different policies have been quantitatively investigated by using a multi-region power market model and China has been chosen as a case study. The obtained results show that: (i) REC trading can efficiently reduce the government's expenditure on subsidies for the development of renewable energy; (ii) Compared to FIT, RPS and REC trading will reduce the power sectors' profit; and (iii) RPS and REC trading may not be enough to achieve the target on renewable energy especially when the capital cost is high, therefore, RPS, REC trade and FIT subsidy should be implemented as complementary policies, not independent.

1. Introduction

Growing concern regarding climate change requires reducing greenhouse gas emissions and promoting the development of renewable energy, in which policies are playing a key role. To date, the most common and successful policies include Feed-In Tariffs (FITs) and Renewable Portfolio Standards (RPS) [1]. The impacts of FITs and RPSs have been widely studied [2–6]. FITs are regarded as more efficient because they provide long-term financial stability for investors [7]. However, the fast growing of the government's expenditure on subsiding renewable energy has long been regarded as parts of the social welfare change [8] without considering the public's willingness-to-pay, resulting in heavy financial burdens for governments all over the world. In Spain the FIT for PVs stopped in 2012 due to generous tariffs, overcapacity and tariff deficits. And in other EU countries, the FIT schemes also have been sharply reduced partly due to the financial recession [9]. Recent studies in China have also clearly shown different opinions of public's willingness [10,11] about current FIT, which is so high that tens of billions RMB subsidies have not been delivered in a timely manner in recent years. In order to relieve the financial pressure caused by subsidies, RPS and REC trade are alternatives for jurisdictions. Different from the FIT policy that pays a fixed price for renewable power generation, RPSs incentivize generators to produce a minimum proportion of eligible renewable power in their supply mix. Meanwhile, by linking eligible renewable energy to Renewable Energy Certificates (RECs), power utilities are required to obtain enough RECs in order to

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Nomenclature

Subscripts

D representative days (3 typical days are used)
H time series $(1-8)$
R,R' regions (Northeast, North, Shandong, East, Fujian, South, Chuanyu, Central, Northwest and Xinjiang)
NG technologies not eligible for RPS (Coal, Gas, Nuclear and Hydro)
RG technologies eligible for RPS (PV and Wind)

Parameters

$NGBPP_{NG}$ regulated benchmark power price of NG power (billion RMB/GWh)
$RGFIT_{RG}$ feed-in tariff of RG power (billion RMB/GWh)
RPS_R RPS target for region R (%)
DR discount rate (%)
$NGFC_{NG}$ fixed cost for new NG capacity (billion RMB/GW)
$RGFC_{RG}$ fixed cost for new RG capacity (billion RMB/GW)
$NGVC_{NG}$ fuel cost for generated NG power (billion RMB/GWh)
$NGMC_{NG}$ operation and maintenance cost of installed NG capacity (billion RMB/GW)
$RGMC_{RG}$ operation and maintenance cost of installed RG capacity (billion RMB/GW)
$RGCF_{D,H,R,RG}$ maximum hourly capacity factor of RG power (%)
$INING_{R,NG}$ initial NG capacity (GW)
$INIRG_{R,RG}$ initial RG capacity (GW)
NGT_R regional maximum total installed capacity of NG power (GW)
RGT_R regional maximum total installed capacity of RG power (GW)
$NGUPCF_{NG}$ upper limit of annual capacity factor of NG power (%)
$NGLOCF_{NG}$ lower limit of annual capacity factor of NG power (%)
$NGUP_{NG}$ upper limit of hourly capacity factor of NG power (%)
$NGLO_{NG}$ lower limit of hourly capacity factor of NG power (%)
$RAMPUP_{NG}$ maximum ramp up rate of NG power (%)
$RAMPDN_{NG}$ maximum ramp down rate of NG power (%)
$DEM_{D,H,R}$ regional hourly power demand (GWh)
$TEF_{R,R'}$ interregional transmission efficiency (%)
$TVC_{R,R'}$ variable cost of interregional transmission (billion RMB/GWh)
$TRC_{R,R'}$ interregional transmission grid capacity (GW)

Variables

$newng_{R,NG}$ new installed NG capacity (GW)
$newrg_{R,RG}$ new installed RG capacity (GW)
$ngpp_{D,H,R,NG}$ hourly generated NG power (GWh)
$rgpp_{D,H,R,RG}$ hourly generated RG power (GWh)
$ppf_{D,H,R,R'}$ hourly power purchase from region R' (GWh)
$pst_{D,H,R,R'}$ hourly power sold to region R' (GWh)
$recpf_{RG,R,R'}$ annual REC purchased from one region (GWh)
$recst_{RG,R,R'}$ annual REC sold to one region (GWh)
$powpri_{D,H,R,R'}$ interregional power trade price (billion RMB/GWh)
$recpri_{RG,R,R'}$ interregional REC trade price (billion RMB/GWh)

Abbreviation

RPS Renewable Portfolio Standard
FIT Feed-in tariff
REC Renewable Energy Certificates
LPS Local Power Sector

meet the regulations. RECs can be traded and therefore bring economic incentives for cost-effective renewable production, which is not covered by the government. This paper is to study the effectiveness of using RPS and REC trading to replace FIT, and their synergistic effects on government expenditure, power utilities' profits and regional renewable energy development. Therefore, the authors proposed a model, which can be used for all nations to quantify the substitution effects of RPS and REC trade for FIT. As a case study, the model has been applied to China, who has just announced a REC trading system in 2017, following the first national RPS targets published by the National Energy Administration in 2016 with detailed 2020 targets at province level [12].

Many studies have been done to investigate the effect of RPS and FIT on promoting the development of renewable energy. However, from different perspectives, different conclusions may be obtained. From the viewpoint of renewable energy industries, FIT, which can provide a stable and profitable market, is more favorable than RPS, which may create a market uncertainty and lower overall profit [13–15]. On the contrary, from the viewpoint of social welfare, a RPS is more preferred because it introduces market competition into the renewable energy field [16]. However, few of these studies focus on the government's fiscal interests. Since renewable power and non-renewable power are homogeneous, it is difficult to pass the cost of renewable power onto consumers by the market. Thus, the government has to afford the expenditure directly.

The RPS policy and REC trading have also been widely examined. Mack et al. [17] and Berendt [18] have argued that the lack of liquidity of the existing REC markets in the U.S. leads to volatile and reduced-value markets for renewable energy certificates and ultimately increases the cost of renewable energy. Perez [19] found that a 25% out-of-state REC allowance can capture most of the economic benefits, and further increasing REC trading flexibility contributes only slightly. These studies provide evidence of the efficiency of a free trading market for REC. However, empirical evidence from Yin [20] showed that allowing free trading of RECs can significantly weaken the impact of RPS for the regions lacking renewable resources. Such contrary opinions put a question mark on whether REC trading is suitable for all situations when adopting an RPS.

To analyse the effect of FIT and RPS with/without REC trading, many models have been developed, which can be divided into three types:

(i) Computable General Equilibrium (CGE) models: for example, Morris [21] revised Emissions Prediction Policy Analysis (EPPA) model, which is a multi-region, and multi-sector recursive-dynamic representation of the global economy. In the EPPA model, different electricity generation technologies are modeled as different sectors in order to investigate the impact of RPS policy on the power mix. However, the time step used in the CGE models is usually a month or a year, and therefore, the impact of the intermittence of renewable electricity generation on the hourly operation of the power system cannot be well considered;
(ii) Optimization models: for example, Perez et al. [19] utilized a power planning model to optimize the portfolio of transmission and generation investments. However, in such models, both the electricity price and the REC price are set as exogenous. The power generators, retailers and consumers are price-takers rather than players in the market, which means that their behaviors have no impacts on electricity price and REC price;
(iii) Complementarity market models: for example Tanaka [22] developed an analytical dominant firm-competitive fringe model to account for market power, and Chen et al. [23] presented an equilibrium market model with both analytical and numerical results