No. 11 KNOWLEDGE EXCHANGE *Series* June 2007 ESMAP

Scaling Up Renewable Energy in China:

Economic Modeling Method and Application

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Many countries wishing to scale up grid-based renewable energy (RE) introduce policies that set national targets. But such policy decisions must be based on a solid analytical framework that evaluates the optimum economic quantity of grid-based generation that RE sources can produce. Based on these calculations, an optimal mix of policy instruments can be selected to achieve those targets. This note highlights China's successful application of this economic modeling method.

Introduction

Globally, grid-connected renewable energies (REs) are a growing niche within the energy sector. REs complement conventional energy generation effectively in several respects. First, they can offer the least-cost option for grid-connected generation on a life-cycle cost basis. Second, their reduced negative environmental effect translates into positive externalities at both local and global levels. Third, by diversifying sources of grid-based electricity generation, they increase energy security and reduce vulnerability to volatile fuel prices. As of 2005, RE generation capacity totaled 932 gigawatts (GW), nearly 23 percent of total electric power capacity (4,100 GW) (table 1).

Table 1. Capacity Additions to Renewable Energy Generation, 2005

Power source	*GW added*	*GW at end of year*	*Growth rate (%)*
Large hydropower	12–14	750	1.5–2
Small hydropower	5	66	8
Wind turbine	11.5	59	24
Biomass	2–3	44	—
Geothermal	0.3	9.3	3
Solar PV (grid)			
GW	1.1	3.1	55
homes	200,000	650,000	—
Solar PV (off-grid)	0.3	2.3	15
Solar thermal	~0	0.4	—
Ocean (tidal)	~0	0.3	—

Source: REN21, 2006.

ESMAP is a multi-donor trust fund managed by the World Bank Energy, Transport, and Water Department (ETW) that promotes the role of energy in poverty reduction and economic growth in an environmentally responsible manner. Its work applies to low-income, emerging and transition economies and contributes to the achievement of internationally agreed development goals.

Many countries, both developing and developed, are introducing policies to encourage greater RE use. As a logical step to stimulate RE investment and development, an often used approach is setting national targets. But the policy decision to set a target for an economically optimum amount of RE is hardly easy and should not be based on arbitrary criteria. To the contrary, such a decision should be backed by a solid analytical framework that evaluates the optimum economic quantity of grid-based generation that can be produced from RE sources, and then determines the most effective policy instruments to attain those targets.

Encouraging China's Scale-up

In China, coal-fired electricity generation still accounts for 70 percent of grid capacity and 80 percent of total generation, despite the country's sizeable RE potential. China has considerable experience with both large- and small-scale hydropower technology, as well as significant untapped potential in biomass, landfill gas, and wind power.

To support China in establishing RE targets and shaping and implementing enabling legislation to attain these goals,[1] the World Bank and the Global Envi-

[1] China's Renewable Energy Law became effective January 1, 2006.

ronment Facility (GEF) are financing the China Renewable Energy Scale-up Program (CRESP).[2]

The method used to design CRESP had to answer three basic questions:

- How much RE is justified with and without considering externalities?
- How is the target best achieved for the country and why?
- Other than economic efficiency, how do various policy options perform (e.g., in terms of employment, supply diversification, or practical application); what criteria should be considered in this evaluation?

Bottom-up Modeling Approach

To discover China's optimum economic quantity for RE-based grid-power generation, a bottom-up modeling approach was adopted. Provincial supply curves were estimated and then aggregated at a national level.[3] Starting with an analysis of the provincial cost of coal-based power generation and the elaboration of a provincial database of RE-based power-generation projects, a provincial supply curve was developed for each of China's 31 provinces and municipalities, relating the cost per kilowatt hour to the level of electricity production. As part of the analysis, the cost of coal-based power generation was broken down into production and environmental costs (box 1, step 1).

From the provincial supply curves, the model extrapolated a national supply curve, from which it computed three levels of RE-based electricity production:

- Baseline resulting from the continuation of business-as-usual trends, with pricing based on financial parameters (Q_{BAU});

[2] Approved in 2005, CRESP is a five-year project with a total project cost of US$228.82 million.

[3] In smaller countries, a national-level analysis would suffice.

Box 1. Modeling Renewable Energy's Share of Grid Power

Step 1: Calculating the Optimum Economic Quantity

1. Determine the production cost of coal (yuan per kWh).
2. Calculate the environmental damage cost of coal using the benefit transfer or other method.
3. Combine these costs to determine the social cost of coal generation.
4. Establish the provincial database of RE projects and key assumptions.
5. For each provincial RE project, determine the unit cost of electricity, including the *capacity penalty*.*
6. Estimate cost reductions for all RE sources by the target date.
7. Create provincial supply curves for RE-based generation.
8. For each provincial supply curve, establish three RE production quantities:
   - Q_{BAU} = business as usual
   - Q_{ECON} = at an RE cost per kWh equivalent to the economic cost of coal (excluding social cost)
   - Q_{ENV} = at an RE cost per kWh equivalent to the economic cost of coal (including social cost)
9. To arrive at a national Q_{BAU}, Q_{ECON}, and Q_{ENV}, sum all provincial *avoided cost* curves.**
10. Conduct sensitivity testing and risk analysis; verify all assumptions in selected provinces during the CRESP pilot phase.

* The increased cost of an RE project per kWh (because the capacity factor or percentage of time that power is available for dispatch differs from that of conventional power generation).

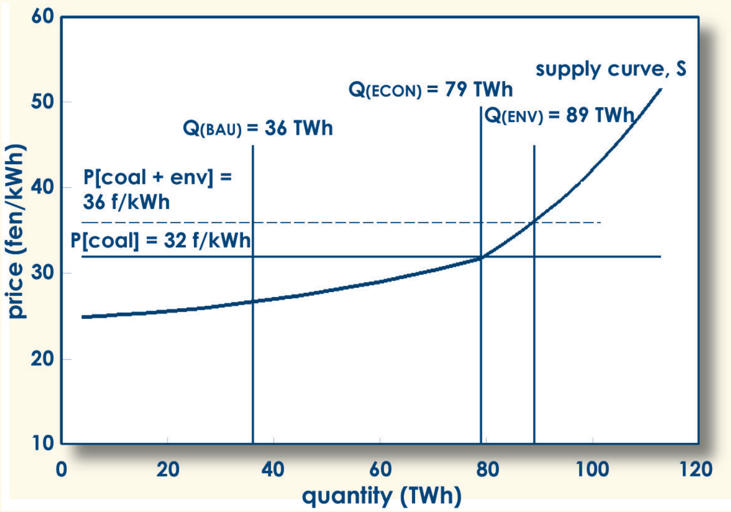
** Calculated by subtracting the production cost of coal from each point along the provincial supply curve; at point Q_{ECON}, the avoided cost equals zero.

Step 2: Determining the Most Effective Policy Instruments

1. Review international best practices for policy instruments.
2. Evaluate both quantity- and price-based options.
3. Determine the financial effects of both systems on key stakeholders.
4. Reconcile economic and financial flows.
5. Make a preliminary recommendation on the most effective policy instruments to achieve the economic optimum.
6. Identify any data or other limitations of the analysis to be addressed in the CRESP pilot phase.

Source: ASTAE, 2006.

Figure 1. China's Renewable Energy Supply Curve



Source: ASTAE, 2006.

- Quantity produced by all RE projects with a unit-generation cost less than or equal to that of coal, including only economic production costs (QECON); and
- Quantity produced by all RE projects with a unit-economic-generation cost less than or equal to that of coal, including the economic cost of environmental externalities (QENV).

The resulting calculations estimated that, under business-as-usual conditions, the incremental level of RE generation between 2000 and 2010 would be 36 terawatt hours (TWh)—significantly below the quantity that would be economically viable on a strict production-cost-only basis (79 TWh); and even lower than that resulting from the inclusion of environmental externalities (89 TWh) (figure 1).

Achieving the Optimal Policy Mix

To meet China's national targets, the next step was to select the most appropriate policy options. Two types of policy instruments could have been used: i) quantity-based instruments in the form of set targets and a subsequently market-determined price or ii) price-based instruments in the form of a set price tariff leading to a market-determined quantity (box 2).

While quantity- and price-based policies have an equal effect in theory, their outcomes may differ in practice. Therefore, the method had to assess the financial effect of the two alternatives on each region, RE technology, and various stakeholder groups in order to determine the optimal policy mix (box 1, step 2).

Early on in the analysis, the price-based feedlaw system was ruled out. Because of China's regional variation in RE endowment, coal production costs, and externalities, design of such a policy would have been too complex, requiring excessive administration to enforce. The quantity-based Renewable Portfolio Standard would have allowed the market to determine both the price and technology mix more appropriate to each region.[4] But regions with higher RE costs and fewer financial resources might have had trouble achieving targets on their own.

A system of Tradable Green Certificates (TGC), similar to the Clean Development Mechanism, would allow provinces with higher RE costs to meet their targets by investing in lower-cost provinces. Thus, it was determined that the optimum policy mix to achieve QENV (89 TWh) was the Renewable Portfolio Standard with inter-provincial trade (TGC). This configuration would reach a net present value of Y 36.01 billion (US$4.35 billion), 15 percent less than that without TGC. With input from this policy analysis and other

Box 2. Examples of Quantity- and Price-based Policy Concepts

Renewable portfolio standard: Legislation requires the production of an agreed-on quantity of electricity from a portfolio of RE sources by a given target year, with penalties for underperformance. Rents accrue to producers, and costs are recovered from consumers.

Non-fossil fuel obligation: Generators using RE in England and Wales bid competitively to receive a premium price of electricity funded by a levy on electricity sales to final consumers.

Feedlaw system: The term is derived from the original German electricity feed-in law, which provided producers a price guarantee using specified RE sources. Under this system, the government sets a feedlaw price. Utilities are required to accept wind energy production from all technically-qualified producers and pay the feedlaw price. Rents accrue to developers/equipment producers, and costs are recovered from consumers.

Feedlaw/bidding system combination: The feedlaw price provides developers a guaranteed off-take price, but bidding is required for the right to develop RE sites. Rents accrue to producers/government. Costs are recovered from consumers.

Source: ASTAE, 2006.

[4] Chinese law permits both the feedlaw and Renewable Portfolio Standard systems; its regulations provide a feed-in tariff for biomass, but a bids-based concession is used for wind.

consultations, China has adopted a goal of scaling up RE for power generation to 15 percent of total electricity generation by 2020, up from 7 percent in 2005.

Policy Trade-offs

As expected, the policy is far from neutral; it produces winners and losers at many levels. The net benefit of reaching the target would amount to savings of about 1 percent of the national cost of power generation (Y 8.6 billion [US$1.04 billion] annually) and a 5-percent reduction in overall air pollution. It would also result in a net increase in employment and a small increase in GDP. But at the regional level, western provinces well-endowed in small-scale hydropower resources would win over other provinces with poorer-quality RE resources (e.g., Shandong and Jiangsu). Similarly, consumers would save Y 23.7 billion (US$2.86 billion), but the coal industry would suffer net losses; conversely, the construction industry in western provinces would be enhanced. With the elimination of coal subsidies, the central government would enjoy a net tax gain from increased revenue.

With regard to the technology mix, 75 percent of economically optimum production would come from new small-scale hydropower and 13 percent from retrofitted ones; the remaining 12 percent would be derived from biomass and landfill projects. Because of China's well-established, small-scale hydropower construction industry and the nascent stage of its wind generation, wind power would not be economical. A specific policy targeted at the wind-energy sector, comprising a mix of feed-in price to ensure manufacturers recover their costs and bidding to maintain competitiveness, could be expected to lower costs by 30 percent over the 2000–10 period and develop the industry.

Conclusion

Any successful RE scale-up program requires a solid economic basis from which to determine rational targets and policies to optimally develop RE resources. The China case shows that a well-designed program determines national targets based on financial and economical viability, with and without considering local and global externality cost/benefits. It also includes the selection of an appropriate stimulating mechanism (e.g., TGC) and policy options (e.g., feed-in tariffs or Renewable Portfolio Standard).

The economic modeling method applied in China succeeded in helping to develop policies for setting RE targets. The same approach was used in Croatia and South Africa, and is currently being applied in Serbia.[5]

[5] In Croatia, the analysis led to the GEF Renewable Energy Resources Project, which includes a contingent loan facility to assist project development; in South Africa, the analysis led to the Renewable Energy Market Transformation Project, which will support solar water heating for commercial use and provide assistance to meet the government's 2013 target of 4 percent electricity demand (10,000 GWh electricity generation) from RE sources (www.worldbank.org/retoolkit).

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About this publication: The ESMAP *Knowledge Exchange Series* shares results of recent energy sector work to catalyze discussion and learning among energy policy makers and practitioners.

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The ESMAP *Knowledge Exchange Series* is produced by the Energy Sector Management Assistance Program, World Bank.

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