The Green Effect

THE NEED TO DIVERSIFY AWAY from fossil fuel generation due to concerns over energy security, fuel price volatility, and the climate challenge is driving the deployment of nonconventional renewable (wind, small hydro, solar, tidal, geothermal, and in some cases waste) or "green" energy worldwide (in this article, these will all be termed "renewable energy"). Developed countries have seen renewable energy as a key tool for emission reduction as well as for energy independency, eventually reducing reliance on oil, gas, and coal imports. In developing countries, renewable sources have been largely limited to conventional hydro plants. Over the past decade, the primary objective of increasing the population's access to electricity has combined with budget constraints to prevent these countries from making renewable energy a priority. This situation is, however, changing; renewable energy has begun the new decade with a fast penetration in these countries, due to increasing awareness about the crucial role of clean energy supply and pressure to go along with to worldwide efforts in this direction.

The general enthusiasm for renewable generation has motivated the development of specific mechanisms for its implementation. These are needed because renewable generation is still not competitive enough to enter the market on the same

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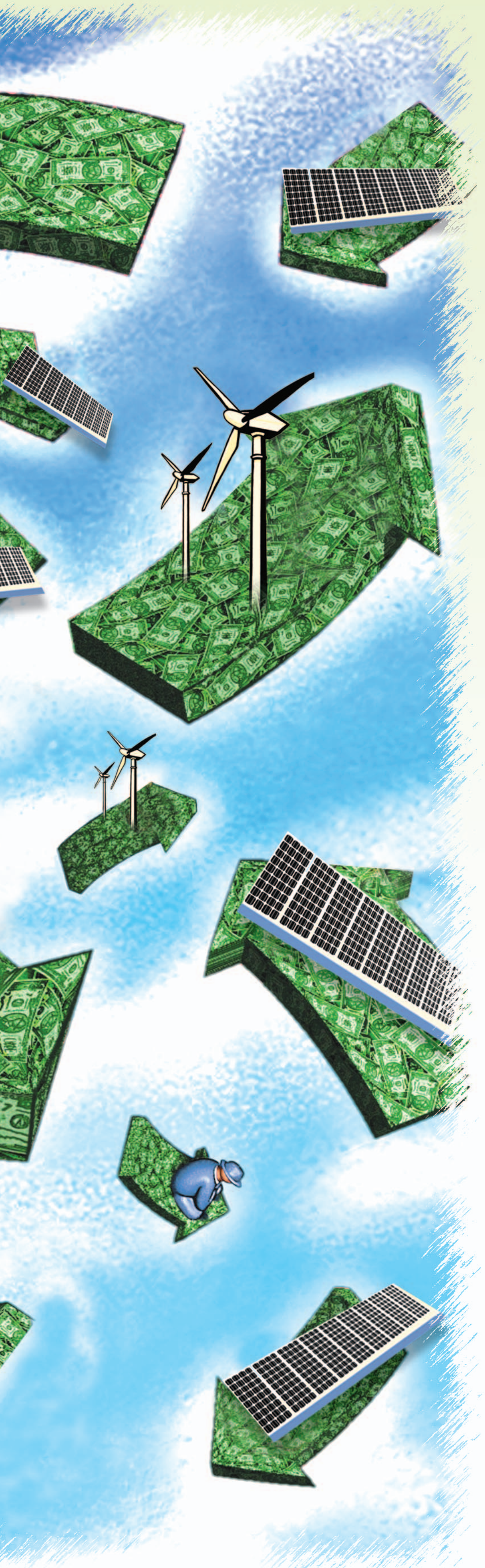

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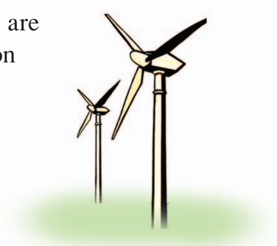
Economic and Market Impacts of Renewable Energy Development in Spain, Germany, and Latin America

footing as other generation technologies. Table 1 compares investment levels and average generation costs for different technologies. Although technological changes that can alter the picture are expected over the next 20 years, most renewables currently lag conventional energy (nuclear, hydro, and conventional gas and coal) in terms of economic competitiveness.

Support Schemes

Four main mechanisms have been used to promote renewable energy worldwide:

- ✔ **Feed-in tariffs:** Consumers are obligated to acquire renewable energy at a predetermined (usually administratively set) price or premium on energy spot prices. Feed-in tariffs have been the most applied mechanism worldwide; their effectiveness in fostering renewables in countries such as Denmark, Germany, and Spain is well known.
- ✔ **Quotas and tradable green certificates:** Minimum shares of renewable energy are imposed on consumers or producers, followed by penalties for noncompliance. This mechanism is applied in fewer countries than feed-in tariffs. In some markets the trading of the quota is allowed, and a green certificate market is created. Quotas mechanisms are applied in Chile and parts of the United States. The Netherlands has pioneered the use of green certificates, and they are also used in the United Kingdom, in a few other European countries, and in certain parts of the United States.
- ✔ **Auctions:** a competitive bidding process is organized to buy a given quantity of renewable energy, and winners are selected based on the lowest price offered. Auctions were initially applied in Europe (the United Kingdom and Ireland), and more recently they have been used in Latin America.
- ✔ **Fiscal incentives and tax credits:** These are subsidies such as exemptions or rebates on taxes, tax refunds, charges or special financing, or depreciation conditions. They have been used practically everywhere renewable energy has been developed, as a complementary support mechanism.



By Luiz A. Barroso, Hugh Rudnick, Frank Sensfuss, and Pedro Linares

table 1. Investment and generation cost per technology (OECD countries). (Source: IEA 2010.)

	2008		2030	
	Investment (US$/kW)	Generation (US$/MWh)	Investment (US$/kW)	Generation (US$/MWh)
Nuclear	1600–5900	42–137	3200–4500	55–80
Hydropower	1970–2600	45–105	1940–2570	40–100
Biomass	2960–3670	50–140	2550–3150	35–120
Wind-onshore	1900–3700	50–234	1440–1600	70–85
Geothermal	3470–4060	65–80	3020–3540	55–70
CCS coal	3223–6268	67–142	1400	94–104
Combined cycle LNG	520–1800	76–120	900	78
CSP	3470–4500	136–243	1730–2160	70–220
Wind-Offshore	2890–3200	146–261	2280–2530	80–95
Tidal	5150–5420	195–220	2240–2390	100–115
Solar PV (Central Grid)	5730–6800	333–600	2010–2400	140–305

The application of these mechanisms (or combinations of them) has resulted in the construction of significant renewable capacity worldwide. Wind power has benefited the most: worldwide wind capacity jumped from 24 GW in 2001 to 160 GW in 2009. This concrete achievement shows that renewable energy is here to stay and will have an increasing penetration in all electricity markets in an emission-constrained future.

On the other hand, the development of renewable energy entails a significant economic effort in terms of support incentives, operational costs, grid reinforcements, and backup infrastructure. A less discussed topic has been its economic and market impacts. Depending on the physical system's characteristics—for instance, the degree of operating flexibility—and on market design aspects such as the importance of market prices in driving investment, the impact can be positive or negative. For example, the dispatch priority and the very different merit curves produced by renewables have a direct impact on the expected value of market prices and their volatility, which ultimately might affect the profitability of existing power plants. The massive application of specific support schemes could significantly alter the market space for other new entrants, including other renewables like conventional hydroelectricity. On the cost side, setting the feed-in-tariff to deliver a desired amount of renewables has proven to be challenging: a high price can lead to overinvestment, while a price set too low can lead to underinvestment. Overall, worldwide enthusiasm for renewable energy development postpones discussions about its impact on the market—for better or worse.

This article contributes to this discussion by assessing some general market and economic impacts of renewable generation in some electricity markets. We selected three different experiences: Spain, Germany, and Latin America (specifically, Brazil, Chile, and Peru). Motivated by the need to diversify away from fossil fuel generation, Germany and Spain are developed countries with high levels of global greenhouse-gas emissions; they have experienced an aggressive development of renewables (mostly wind) for the last six years, based on feed-in tariffs. Latin America, on the other hand, is a developing region in which hydropower has a strong presence. This makes the existing energy matrices already renewable; the difference is that it is not "green" energy but "blue" hydro energy. The power sector of this region contributes very little to greenhouse-gas emissions. The strong and persistent wind flows, rich fertile soil, and thousands of sunny hours a year provide significant potential for several types of renewable energy in addition to wind. These include cogeneration from sugarcane bagasse and small hydropower plants. In addition, hydro reservoirs can easily smooth out production fluctuations of intermittent (wind and solar) or seasonal (biomass) energy sources, thus providing an operational flexibility that facilitates their economic integration. In other words, hydro reservoirs play the role of "energy warehouses" that can "store" other types of energy, such as wind, solar, and biomass, in addition to water. Financial constraints, however, pose several challenges in the design of the support mechanism. Some countries have opted for energy auctions while others have opted for a quota system. The different characteristics of these selected experiences will provide the reader with a broad (but concise) overview and analysis of renewable development and its potential market and economic impacts.

The Spanish and German Experiences

Spain and Germany are two examples of enthusiastic countries that have developed specific mechanisms for an aggressive implementation of renewable generation, forcing their introduction through direct subsidies paid by consumers. Both countries have been effective in achieving a high penetration of renewables and reducing emissions, at a cost that has been significant. We analyze the two cases and review the support schemes used and the resulting developments; we also assess the challenges each country faces.

Spain

The promotion of renewable generation in Spain has been driven by three major policy goals: reducing greenhouse-gas emissions, decreasing the reliance on imported fuels, and fostering a domestic industry able to generate jobs. Indeed, according to different studies, renewable electricity in Spain has reduced total Spanish greenhouse-gas emissions by 5% and total power sector emissions by 20%. The equivalent reduction of energy imports is about 8 million tons of oil equivalent (Mtoe), or 7% of the total energy imported. Finally, renewable electricity is assumed to generate between 90,000 and 110,000 jobs (0.5% of the total) and 0.6% of the Spanish GDP. The positive contribution of renewables to achieve these goals is recognized by most political forces, and in fact renewable energy promotion in Spain has been (at least until very recent times—see below) backed by all of them since the first major renewable electricity support plan in 1994.

table 2. Premiums for renewables in Spain (€/MWh). (Source: Comisión Nacional de Energía, 2010.)

	2004	2005	2006	2007	2008	2009
Solar	332.52	340.40	374.06	392.14	388.74	429.33
Wind	28.08	28.92	37.37	36.35	35.97	42.75
Small hydro	31.72	29.31	36.06	35.61	31.69	42.71
Biomass	30.54	27.87	35.17	46.71	52.06	73.10
Waste	22.65	20.29	33.18	37.48	35.84	61.10

The Spanish Support Scheme

In 1994, Spain established its first feed-in tariff system, which has since been the major support mechanism for renewable electricity in the country. The system has been adjusted over time. In 1998, an option was included so that renewable energy producers could bid in the wholesale market (and were incentivized to do so). They received the market price, plus a premium. Since then—and this is an interesting feature of the Spanish support system—a large share of wind power plants has bid in the market (93% of all wind plans in Spain in 2007 and 2008, although this number has since been reduced due to lower market prices).

In 2004, another modification guaranteed receiving the feed-in tariff or the premium for the whole economic lifetime of the power plant (usually with a decreasing factor). In addition, balancing payments were required from some of the renewable producers. Another important change was the increase of the maximum size of solar photovoltaic (PV) plants able to receive the maximum premium, which jump-started the building of large (up to 100-kW) PV plants. In 2007, the system was again modified by the introduction of a cap-and-floor system for renewable energy producers bidding in the wholesale market.

The system has—in principle—a quantity control built into it: when the renewable electricity targets are achieved, the premium was not discontinued. Nevertheless, this was not accomplished for solar PV. The target was 500 MW, and it has clearly been exceeded, with more than 2,500 MW of capacity added in one year. The same has happened with solar thermal plants. As for the amount of the premiums, Table 2 shows the average premium received per MWh. It should be added that for solar PV the premium in 2010 was reduced to 240 €/MWh.

It should also be mentioned that it was not only feed-in tariffs that promoted the installation of renewable electricity plants. This was accompanied by an obligation to distribution system operators to purchase all renewable production, except under technical limitations (e.g., grid congestion). And—sometimes more important—the active role played by regional governments helped to create favorable investment and licensing conditions.

Growth in Renewable Electricity Generation in Spain

This support system has—at least for some technologies—proven to be very successful in promoting growth. Spain has become one of the world's leaders in renewable energy installed, particularly for wind and solar energy. Currently, renewable electricity plants produce more than 56,000 MWh per year (more than 20% of the total national electricity demand). Figure 1 shows the evolution of Spain's renewable installed capacity.

This success has not spread among all technologies, however. As mentioned earlier, wind energy (and also solar in recent years) has experienced very significant growth; wind currently provides an average of 15% of the country's total electricity demand. But other potentially large sources, such as biomass, have not been developed as expected. The major reasons for this have to do with nontechnical barriers, such

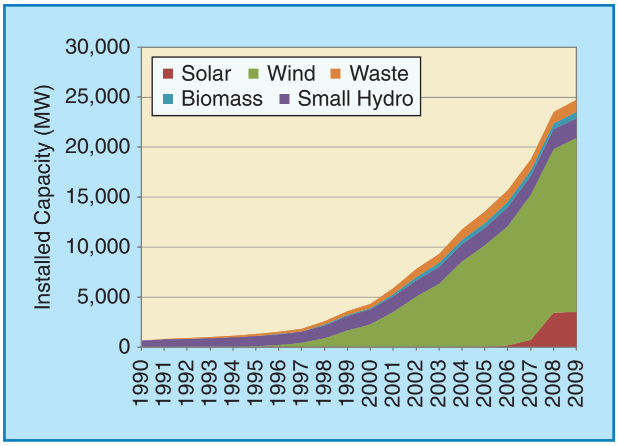


figure 1. Renewable installed capacity in Spain (MW). (Source: Comisión Nacional de Energía, 2010.)

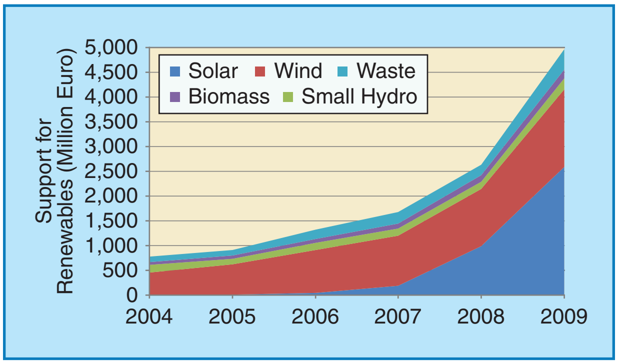


figure 2. Monetary support for renewables in Spain. (Source: Comisión Nacional de Energía, 2010.)

as logistic problems or contractual issues, and not with the level of economic support.

Impacts on the Spanish System: Costs, Prices, and Emissions

This large development of wind and solar energy has of course come at a far from negligible monetary cost for consumers. This should be balanced against the reduction in system costs because of reduced fuel consumption and also against nonmonetary benefits such as security of supply, environmental improvements, and R&D improvements. Nevertheless, the significant support received by solar energy and the large amount of wind energy produced have both contributed to a relevant fraction of the total electricity tariff. In 2009, the total national support for renewables was €4.6 million (17% of the total cost of the power system in Spain). As shown in Figure 2, more than half of this amount corresponds to support for solar energy (the fastest-growing of the renewables). Many deem the support received by solar excessive, given that the large reduction in PV panel costs was not accompanied by a reduction of the premium.

It is illuminating to put these numbers in context, comparing them against each technology's share of electricity demand. As shown in Table 3, the impact of the various renewables on system costs is not proportionate to their share of electricity demand, with solar accounting for most of the imbalance. The figure for solar corresponds mostly to PV, which overshot the target for 2010 as mentioned before, at very high premiums. A similar situation is expected to occur

table 3. In Spain, renewable energy's share of system costs and of total electricity demand for 2009. (Source: Comisión Nacional de Energía, 2010.)

	Share of Total System Costs (%)	Share of Electricity Demand (%)
Wind	6	15.2
Small hydro	1	2.3
Biomass and waste	3	1.1
Solar	10	3

with solar thermal, for which a very large installed capacity has been authorized, again at a very high premium.

In addition to the cost impact—which currently may be the most significant—renewable energy promotion schemes have had other effects on the power system. One of the most studied has been their impact on wholesale market prices. As may be expected, given that most renewable electricity is bid at a null price, increasing the share of renewables should decrease market prices. We can offer some considerations about this.

First, this is not completely a social benefit; it is partly a transfer from producers to consumers, which potentially creates cost-recovery problems. (This is already happening with gas combined cycles in Spain, though it is not totally the fault of renewable penetration, as we discuss below.) Nevertheless, there may be some cost reductions associated with lower fuel consumption. Second, the impact should only be a short-term one; in the long term, the signal for investment is reduced, and therefore power becomes scarcer and prices should increase. Third, the existence of market power may counteract this effect. All in all, this impact is very dependent on the configuration of the power system, and it is therefore necessary to carry out specific analyses in order to quantify it.

Studies carried out by Spanish experts, for example, have estimated market price reductions of 11.7%, 8.6%, and 25.1% in Spain in 2005, 2006, and 2007, respectively. This outcome is, however, very dependent on the role played by combined cycle gas-fired generation and its take-or-pay contracts. If combined gas-fired generation sets the marginal price most of the time even with renewable penetration, then prices should not change much. In fact, this is what will probably happen in the medium term, even with respect to new entry, as there is currently an overcapacity of gas-fired generation in Spain. It is difficult to attribute this to the growth in renewables, since that growth was already planned. It is therefore unrealistic to expect any new investment in power generation until at least the 2020–2025 time frame, if demand behaves as predicted. Renewables are thus probably not deterring any new entry by themselves.

A very relevant issue is how the growth in renewable electricity (particularly nondispatchable renewable capacity) affects economic dispatch, reserve requirements, and prices. Very little has been published in Spain about this issue. The general idea is of course that intermittency should increase volatility, risk, and reserve requirements. But if we assume the overcapacity in gas-fired generation and the existence of large hydro and pumping potential, then these effects can be mitigated. An initial estimation by specialists (Comillas-IIT) shows that the cost of additional reserves is more than compensated for by the reduction in fuel costs and is in fact not very significant.

As for emissions reductions, renewables are assumed to avoid between 18 and 24 Mt of carbon dioxide (CO_2) (20% of the power system emissions and 5% of total Spanish emissions). In addition, renewables also reduce NO_x and SO_2 emissions due to the replacement of fossil fuels. Some estimates point to a 5% reduction in NO_x and 3% reduction in SO_2 emissions.

Challenges and Perspectives in Spain

The Spanish renewable support system is currently at a crossroads. It is being challenged at the political level because of its impact on the electricity tariff (very sensitive in a pre-election year), with the government talking of removing the premium or reducing it significantly (even retroactively for some technologies). The system is also starting to approach technical limitations for grid integration, with some wind production being curtailed in off-peak hours (this can of course be solved with appropriate grid management). A careful analysis should be performed before any quick decisions are made, however.

It may be said that the support system has worked reasonably well for wind energy: it has developed a balanced and consistent growth at a contained cost and has also developed a solid industry framework. The support has been quite ineffective in promoting biomass or small hydro, however. This is probably due to nontechnical, noneconomic barriers. In the case of solar energy, the system was probably poorly designed; this has resulted in explosive growth, potentially large inefficiencies, and little industry development.

The future requires further increases in renewable electricity production in order to comply with European Union (EU) targets. Indeed, renewable electricity is expected to contribute to 42% of total electricity demand for 2020. This may be achieved either by increasing renewables or by reducing demand. It seems that the latter alternative may be more affordable and also presents other advantages. As for the former, two issues seem critical. The first is developing an effective and efficient (lower-cost) support system. This may require being more selective about technologies and designing different support systems for different technologies (for example, thinking once again about auctions). An added complexity for Spain is the interaction between national and regional governments, which may require a specific approach when designing the support system. Second, there is a need to advance the integration of intermittent energy sources into the system. Here several courses of action could be considered; improving interconnections is probably the most relevant.

Germany

German support for renewable electricity generation pursues several goals. As in Spain, increasing renewable electricity generation is part of a long-term strategy focused on greenhouse-gas reduction and a sustainable electricity supply. In the German context, support for technological progress in order to reduce the future costs of renewable generation is another goal. A third goal—and one with particular importance in the public debate—is the creation of a competitive renewable technology industry with positive employment effects.

The German Support Scheme

The increasing importance of renewable electricity generation is the result of an effective support policy by the German government. In 1989, after a long period of R&D support, the German government initiated direct support of renewables with a “100-MW Wind” program that provided capital grants for investments in wind power plants. In the years that followed, a number of additional support policies were added.

The core of the German support scheme is a guaranteed feed-in tariff system that started up in 1991 following the introduction of the Electricity Feed-In Law in 1990. This law required public utilities to buy electricity generated by renewable technologies at a fixed percentage of the retail price of electricity. In 2000, that law was succeeded by the Renewable Energy Act. The new law required public utilities to buy electricity generated by renewables at a given price. Minor revisions of the new law took place in 2004 and 2006. In 2009, another revision took place that adjusted some tariffs and reorganized the mechanism for the cost pass-through and the transactions carried out by the transmission system operators (TSOs). The TSOs are obliged to buy the renewable electricity generation at the fixed tariffs. They must then sell the renewable electricity generation on the spot market. Consumers pay the cost difference.

In addition to the feed-in support, several other support schemes stimulated the development of renewables in Germany. Among these are several programs for the provision of soft loans with reduced interest rates or schemes providing capital grants. A prominent example is the ongoing Environment and Energy Saving Program, which started up in 1990 and has played an important role in the financing of wind energy projects.

Growth in Renewable Electricity Generation in Germany

The ongoing support has stimulated quick development of renewable electricity generation in Germany. Starting with 17 TWh of production in 1990 (representing a 3% share of total consumption), renewable electricity generation in Germany rose to 93.5 TWh in 2009 (a 16% share of total consumption). In terms of electricity generation growth, wind energy and biomass are the most important technologies. In terms of installed capacity, wind energy dominates. In 2009, installed wind energy capacity in Germany reached 25.8 GW; it was followed by the quickly growing PV sector, with an installed capacity of 8.9 GW. Figure 3 shows the development of the installed capacity of renewable electricity generation in Germany.

The official 2010 EU renewables target for Germany of 12.5% share of total power consumption is likely to be exceeded by more than 4%. The effectiveness of feed-in

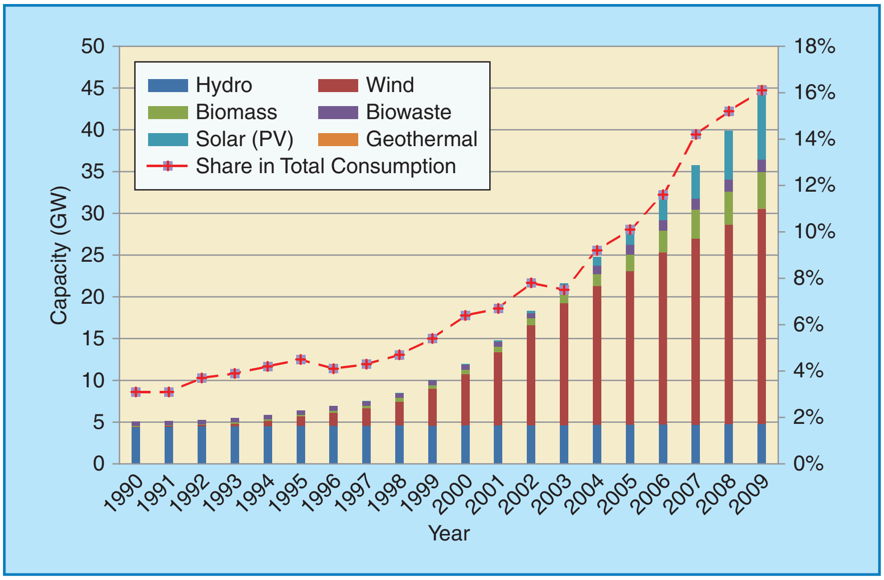


figure 3. Installed capacity of renewable electricity generation technologies in Germany. (Source: Working Group on Renewable Energy Statistics.)

financial load on the system. The cost of the support scheme must be paid by electricity consumers. Companies with a high share of electricity cost in their production cost can apply for a reduced support payment of €0.5/MWh. All consumers without this privilege must pay the remaining cost of the support. In 2009, the support cost reached €4.6 billion, resulting in an average payment for consumers of €1.1/MWh. Figure 5 provides an overview of the components of household electricity prices in Germany.

The quick growth of PV and the introduction of additional tariffs for small-scale biomass are important components of the increase in the projected net cost of the support scheme. The fee for consumers reached €20.5/MWh in 2010. For a typical household, this fee accounts for about 8% of the electricity price. It is expected that the tariffs for PV will be reduced between 11% and 16% in July 2010. The popularity of PV in Germany and the fear of destroying the German PV industry complicate the debate on cutting of PV tariffs, however. Despite the cuts, sustained growth of renewable electricity generation and low spot market prices are likely to lead to further growth in the fee for consumers over the next few years. It remains to be seen whether this rising cost will endanger the popularity of renewables in Germany.

systems for the support of wind energy—defined as the capability of utilizing the existing potential for renewable generation—is also supported by a study prepared for the European Commission (see Figure 4), which compared the ability of various national support schemes for onshore wind to make use of existing generation potentials.

Impacts on the German System: Costs, Prices, and Emissions

The growth in German renewable electricity generation due to the feed-in support scheme has led to an increase of the

Electricity generation from fluctuating energy sources has become an important issue for electricity markets. Feeding in renewable electricity reduces prices on the spot market. In the short run, lower prices shift profits from the supply side to the demand side of the market. According to a recent study by the German Federal Environment Ministry, this effect was approximately €3.6 billion to €4 billion in 2008. As the power plant portfolio adjusts to the increasing amount of renewable electricity generation, this number will likely be reduced. But the reduction of electricity prices at times of high renewable production is likely to prevail. This price effect must be taken into account in the design of market-based support schemes.

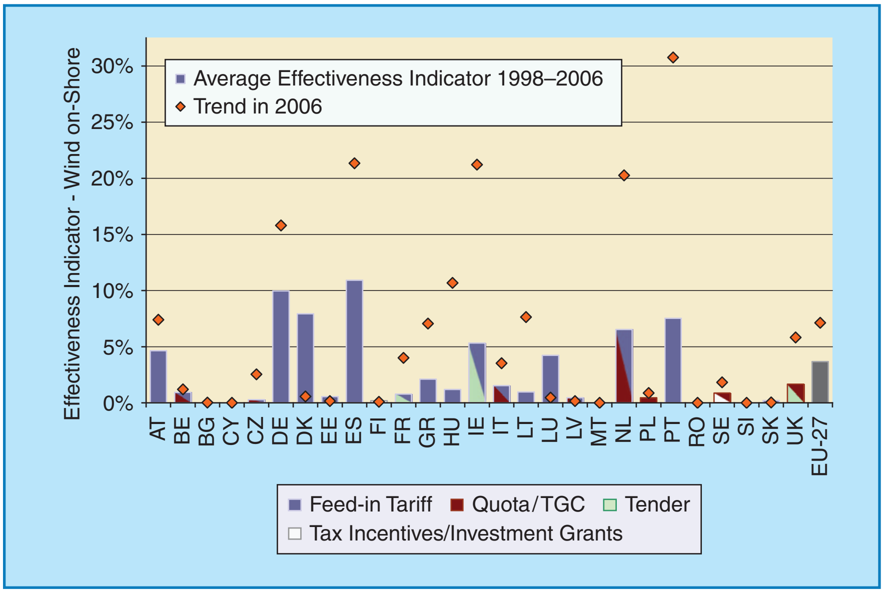


figure 4. Effectiveness of national support schemes for wind energy in Europe. (Source: Ragwitz et al., 2007.)

Due to the price effect, the spot market value of electricity generated by wind energy is below the average market price. Premium systems must take this into account in order to avoid unintended losses for wind generators.

An issue that has garnered much public attention is the occurrence of negative prices on the German spot market. In times of low demand and high renewable generation, spot market prices have sometimes reached high negative values of up to €–500/MWh. The reason for these market results is that TSOs were obligated to sell renewable electricity generation with unlimited bids on the market. This may have supported speculation of market participants against the bids of the TSOs. As a result, several measures have been taken to reduce the risk of negative prices that increase the cost of the support scheme (as when TSOs must pay to sell electricity). In times of low demand and high renewable generation, TSOs are now allowed to limit their bids. In rare cases, this can lead to renewable production being curtailed in order to avoid incurring additional costs to the support scheme due to extreme price events. Since the system has not yet reached its limit in integrating renewable generation, it is important that both flexible generation (i.e., the shutting down of plants) and demand are bid into the market at reasonable prices. Due to the high concentration of the market in terms of base load generation (four players own almost all the base load generation units), it remains to be seen whether new entrants and market "learning," e.g., by increased awareness of market participants, will be sufficient to achieve reasonable market outcomes in situations with low demand for conventional capacity.

One key goal of the support for renewable electricity generation in Germany is to reduce CO_2 emissions. In the year 1990, hard coal and lignite accounted for 56.5% of electricity generation, followed by nuclear (27.7%) and gas (6.5%). In 2009 the share of lignite and hard coal was reduced to 42.8%. Nuclear faced a decline to 22.6%, while the share of gas grew to 12.9%. Recent studies on the impact of renewable electricity generation on plant dispatch show that renewable electricity generation in Germany replaces mainly electricity generation by hard coal power plants. Based on these findings, the German government has attributed a savings of 74 Mt CO_2 equivalent to renewable electricity generation in 2009. Leaving out older large hydro plants, supported renewable generation saved 55 Mt CO_2 equivalent. As a result, renewable electricity generation plays an important role in Germany's achievements in terms of greenhouse-gas reduction.

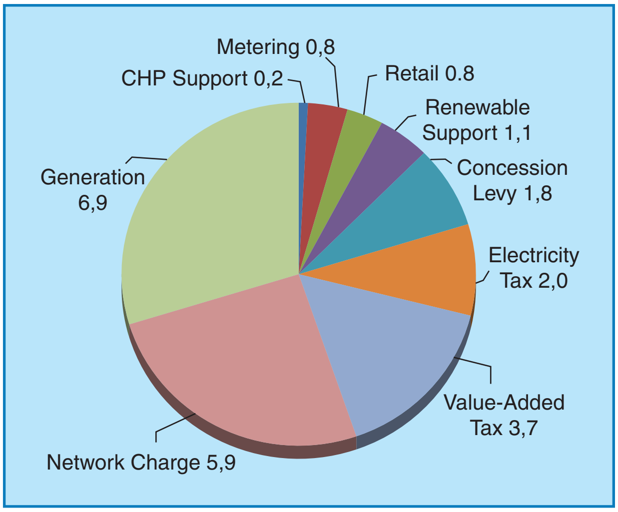


figure 5. Components of electricity prices for households in Germany in 2009 (euro cents/kWh). (Source: Agentur für Erneuerbare Energien.)

Challenges and Perspectives in Germany

Although the German support scheme has been very successful in the past, it faces new challenges as the government pursues an ambitious strategy to further increase the share of renewable electricity generation. As the economic crisis has led to lower CO_2 emissions and electricity prices, it is obvious that sustained support is necessary in order to achieve further growth of renewable generation in the next few years. The official target is for renewables' share to reach at least 30% by 2020. A goal of 80% in the year 2050 has been discussed. In order to deal with these amounts of fluctuating generation, the integration of electricity markets in Europe and the growth of the corresponding grid infrastructure will be crucial. Taking these targets and the development of the past few years into account, it can be stated that renewable generation in Germany has left its marginal status behind.

As a consequence of the growing amount of renewable electricity generation and the financial volume of the system, a careful and efficient evolution of the support scheme has become much more important. In the short run, the growing amount of renewable generation is stimulating a debate as to how renewable electricity generation should be sold into the electricity market. The current solution—TSOs selling all the renewable electricity on the spot market—leads to a situation in which the TSOs become very important players in that market. This was not an intended result of the EU's policy of unbundling the electricity sector. The situation is even more undesirable since market signals cannot be passed through to the actual owners of renewable generation units. This endangers the electricity markets' ability to steer investment decisions, e.g., regarding storage.

To address this problem, an addition to the existing support scheme based on premiums with price indices is under discussion. Such a change could stimulate generators of renewables to sell the electricity directly on the market. Some organizations oppose this idea and prefer an approach based on complex time-dependent tariffs or a tendering procedure for the marketing service (currently carried out by the TSOs). At the very core of the debate in Germany is the struggle between the pioneers of renewable

Four main mechanisms have been used to promote renewable energy worldwide: feed-in tariffs, quotas and tradable green certificates, auctions, and fiscal incentives and tax credits.

generation and the established generation companies they battled for many years. Having fought to bring renewables online, these pioneers have a vision of a decentralized system with many small players and a deep mistrust of an electricity market dominated by a few players. It remains to be seen which way will be chosen in a debate that concerns the fundamental design of renewable support and the electricity sector as a whole.

Latin America: Quota Mechanisms and Energy Auctions in a Hydro-Based Region

Latin America has one of the cleanest energy matrices in the world, mainly due to its intensive use of hydropower for electricity generation and sugarcane ethanol for transportation. Installed hydro capacity in the region exceeds 150 GW, 22% of the global total, but taps only 30% of the region's hydro resources. The region is uniquely well placed in terms of renewable resources: sugarcane production is massive in Brazil but is also developed in many other countries in the region, such as Colombia and Guatemala. In addition to ethanol, which is economically competitive with oil at US$35 per barrel, bioelectricity—cogeneration from the sugarcane bagasse—has become a significant and competitive source of power. Due to the significant number of river basins, small hydros plants are in use almost everywhere. Last but not least, wind power is emerging as the fourth asset of the region's renewable portfolio, with a potential but not yet installed capacity of close to 350 GW that is mostly concentrated in Brazil (140 GW) and the Central American countries and Mexico (another 140 GW jointly). Yearly wind power load factors are constant and high: 40–45% on average in Brazil and Peru. The sunny areas of the region will allow solar power to emerge in a next wave.

While the "conventional" renewables have a major share in the region, a small but significant penetration of nonconventional renewables (wind, small hydro, solar, tidal, and geothermal) has also occurred, mirroring the dynamics in the developed world. Costa Rica stands out as the country with the highest wind penetration: 7% with respect to its installed capacity. All the other countries in the region have wind penetrations of 2–3% or less. These renewables have different attributes in Latin America than in other countries, however, and that makes them interesting generation options:

- ✔ Their construction time is short—around 18 months, in contrast to five years for "regular" hydro. This allows flexibility with respect to the introduction of new capacity, which is valuable as a hedge against load growth uncertainty.
- ✔ New "regular" hydro plants may be larger projects than those developed so far. In April 2010, for example, Brazil auctioned the concession and a long-term contract for Belo Monte, an 11,233-MW hydro plant in the Amazon. It will become the world's third-largest such facility. Because this type of plant costs several billion dollars, the number of qualified investors is limited, which reduces the competition for contracts. In contrast, renewables are smaller plants with smaller investments costs, a fact that increases the number of potential investors.
- ✔ The lack of a coherent policy for environmental licensing often leads to delays for such large plants, which can affect supply reliability. A paradoxical effect of these barriers to the development of hydropower is that hydro-rich countries like Brazil have been forced to build more than 10,000 MW of coal- and oil-fired plants in the past few years. A similar trend is taking place in Chile. In contrast, renewable generation is usually spread out over several plants with smaller capacities, which provides a "portfolio" effect and thus a hedge against project delays.
- ✔ Substituting locally available renewable energy for generation fired by imported oil, gas, or coal could save foreign currency expenses and confer the advantage of site-specific energy resources to cope with old and critical needs such as rural electrification.

The downside of the renewable energy resource scenario in Latin America is the same as in other parts of the world: its higher economic cost as compared with standard generation options. More expensive electricity necessarily implies less competitive conditions for countries relying heavily on exports to the developed world. Given those conditions, countries in the region are not incorporating feed-in tariffs but are trying other competitive mechanisms to stimulate renewable investment.

Mechanisms for Introduction of Renewables

Brazil, Chile, Costa Rica, Ecuador, Mexico, Panama, Peru, and Uruguay are the countries in Latin America with some sort of explicit support scheme. Technology-specific auctions (and competitive bidding for specific projects) and, more recently, quota mechanisms have been the primary support schemes used, instead of European-style feed-in tariffs and premiums, which are only applied in Ecuador and Argentina. Tax credits and fiscal incentives are, however, present everywhere.

Figure 6 illustrates the main mechanisms used in the region. Sometimes different mechanisms are combined—tax credits and energy auctions, for example. Below we assess the Brazilian, Peruvian, and Chilean cases.

figure 6. Renewable energy support mechanisms in Latin America.

Brazil

The installed capacity of the Brazilian power system is 106 GW, of which some 75% is hydroelectric. In 2002, Brazil started to develop a support mechanism for renewable energy through a specific program, Proinfa. This first mechanism was essentially a feed-in tariff designed to contract 3,300 MW of wind, biomass, and small hydro (plants with a capacity smaller than 30 MW). Each technology had a different feed-in tariff and was given first priority for 1,100 MW. The energy produced by participating plants is purchased by Eletrobras (the holding company for power utilities owned by the federal government) through 20-year contracts. Eletrobras then resells the energy to all consumers, in proportion to actual consumption (formally, a levy is paid by all consumers). The consumers are then entitled to shares of Proinfa energy in their contract portfolios. The average price paid to Proinfa wind farms for 2010 is about US$140/MWh (actual prices depend on reference load factors). Even though at this moment most of the wind power produced in the country comes from Proinfa, the program has been criticized for having a distorted economic rationale and failing to provide economic signals for efficiency and technological improvement. Proinfa also required that at least 60% of each project's equipment be locally produced. This turned out to be a serious obstacle for the expansion of wind power because Brazil had just one local equipment supplier at that time. Not all technologies met their quotas, and some volumes were transferred from one technology to another to meet the total target of 3,300 MW. A little more than 3,300 MW was acquired via the Proinfa program. This program was effective in fostering the renewable energy industry in Brazil on a larger scale, but it had several implementation difficulties and was successfully delayed until concluded in 2010.

Since December 1996, there have also been specific incentives for the sale of renewable energy through contracts in the free market. These incentives take the form of discounts on transmission and distribution tariffs for consumers who purchase energy through contracts that are backed up by nonconventional renewable energy. In practice, this is a cross-subsidy on the "wires" cost, paid by captive consumers and received by free consumers who purchase renewable energy. This mechanism did stimulate the development of sugarcane cogeneration and boost the development of small hydros, but the price-quantity risks embedded in a financial contract with a commitment to firm energy delivery prevented the aggressive expansion of wind power generation.

In 2008, a new incentive mechanism was tested and put in place. Brazilian regulation allows the use of contract auctions as a backstop mechanism for the development of specific technologies, driven by energy policy decisions. The fixed cost of this energy is paid by all consumers through a charge, but the consumer is not assigned a share of the contracted energy in his portfolio of contracts as happens with Proinfa. Instead, this energy is used as insurance (or physical energy reserve) for the system. As this energy is not formally assigned to consumers as a forward contract, the spot revenue it makes at the spot market is reassigned to consumers and deducted from the fixed payment. Consumers in effect become investors in merchant plants (paying fixed amounts and collecting the resulting spot revenues).

Since 2008, technology-specific contract auctions have thus been the main mechanism in Brazil for fostering nonconventional renewables. The first auction was carried out in August 2008, to contract new energy from the cogeneration of sugarcane bagasse (bioelectricity) for delivery in 2011 and 2012. The motivation for this decision arose from Brazil's ethanol "boom" of 2006–2007, which fostered an expansion of sugarcane production and the installation of hundreds of new ethanol mills that should begin operations between 2009 and 2012. Sugar and ethanol production require both steam and electric power, which are produced through the combustion of bagasse, the residue left after the sugarcane is crushed during syrup extraction. This use of bagasse as a fuel makes possible the production and sale of electric energy surpluses during the harvest period, e.g., by the use of more efficient (higher-pressure and higher-temperature) boilers.

Hence, in order to use the expansion of ethanol production for the benefit of the power sector, a special "reserve" auction was carried out to contract new energy from these plants. Some 2,400 MW (gross capacity) were acquired in 15-year contracts for an average price of US$80/MWh (minus the income from the short-term market). The net capacity for the power sector is about 1,500 MW.

In December 2009, a similar auction to contract wind power for delivery in 2012 was held. The motivation for this auction was to take advantage of lower equipment costs due to the 2008–2009 world financial crisis and to jump-start the development of this technology in Brazil on a larger scale. The product offered to potential investors—a 20-year energy contract with delivery starting in 2012—includes a very specific accounting mechanism designed to provide investors a fixed payment (for financing purposes) while managing the quantity-price risk and incentivizing (or penalizing) production above (or below) a given firm energy threshold. Wind projects representing 13,000 MW registered for the auction, which contracted some 1,800 MW of capacity for an average—and surprisingly competitive—energy price of US$77/MWh (21% below the initial auction price). A diverse mix of investors (local and foreign private generators, along with manufacturers and government-owned companies) won the contracts, and three new wind turbine factories are to be built.

Peru

With a 6-GW power system (50% of which is hydroelectric), Peru has also adopted technology-specific contract auctions. In February 2010, a procurement auction was applied to contract renewable energy. About 150 MW of wind power were competitively contracted at energy prices averaging US$80/MWh. Contracting of 160 MW of small hydro and 90 MW of solar plants was accomplished as well, for average prices of US$60/MWh and US$220/MWh, respectively. These energy prices had discounts of 27% (wind) and 18% (solar and small hydro) with respect to the auction price cap; the winning investors were for the most part private foreign companies. The duration of the contracts is 20 years, and delivery is scheduled for three years ahead. These plants are also entitled to regulated capacity payments (about US$12/MWh on top of the energy price).

Chile

Chile, with 13 GW of installed capacity (40% of it hydroelectric), has followed a different path than Brazil and Peru. The country uses energy contract auctions that do not discriminate between technologies. No matter that a wind farm won a 275-GWh/year, 15-year contract for a price of US$93/MWh (a separate capacity payment is also offered). This was, however, under a condition of tight supply with little competition. Beginning in 2004, the route Chile followed to incorporate renewables involved the creation of transmission cross-subsidies. Other agents were to absorb the transmission payments corresponding to use of the network by nonconventional renewable generation. These subsidies were not enough to spark any change, however, and it was decided in 2008 to modify electricity regulations so as to create a quota system that would force renewable energy into Chile's energy matrix. The new regulations were motivated by the desire of the government and of politicians to participate in the green energy drive of the developed world, although Chile's contribution to global warming is almost nil. The regulations obligated power traders, distribution companies, and generators that make energy withdrawals from the system on behalf of consumers to certify that at least 10% of the energy traded comes from nonconventional renewable energy that is self-produced or purchased from other generators. It establishes an initial obligation of 5% from January 2010 until 2014; from then on, there will be an increase of 0.5% annually until the target of 10% is reached in 2024. In case the requirement is not met, noncompliant traders will pay a fine of approximately US$28 for each noncompliant MWh. If the noncompliance is repeated within a three-year period, the fine becomes US$42/MWh. In order to comply with the nonconventional renewable energy law, heavy renewable investment would have to take place over the next years. Mini hydro (hydro plants with capacities smaller than 20 MW), wind, and biomass are seen as the most economically attractive alternatives for the country.

Further regulatory changes have been made in Brazil, Peru, and Chile in order to facilitate renewable network integration. For example, Brazil has supported cooperative planning of an integrated transmission and distribution network. Tax incentive programs have also been implemented in most countries, as well as direct subsidies to preinvestment assessments. A reduction of 75% on the income tax during the first ten years of operation and special financing conditions have also been put in place in Brazil.

Results and Market Impacts

Despite the support mechanisms adopted in Latin America, overall nonconventional renewable penetration is still small. Some interesting analysis of its potential impacts can nevertheless be performed.

The storage capacity provided by hydro reservoirs makes balancing costs and negative prices due to plants' production variability less relevant. The reason is the "smoothing out" capability they offer. In some countries, such as Brazil, the seasonality in the renewable production actually brings economic benefits. For example, the sugarcane cogeneration season occurs only during the harvest period, which in turn coincides with the dry season for hydroelectric plants. In other words, there is a natural complementarity between hydroelectric generation and bioelectricity. In economic terms, this means that the energy produced by biomass power plants has a greater value than was originally imagined because energy spot prices in the harvest period are higher than the annual average. The same behavior is observed for wind plants, whose production pattern is complementary to

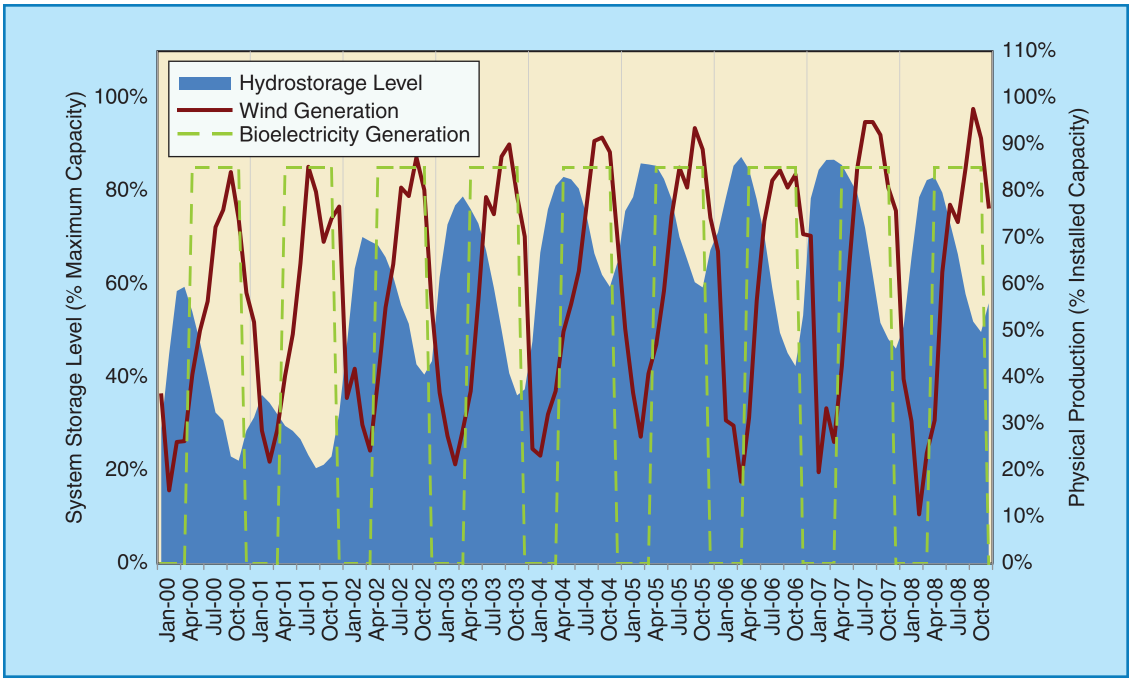


figure 7. Historical hydro storage and wind and bioelectricity production patterns in Brazil.

hydro storage levels in some parts of the country. Figure 7 illustrates this by showing historical hydro storage data along with typical physical production patterns for wind and bioelectricity (sugarcane cogen) plants. A complementarity between wind and bioelectricity with hydro can be observed, and the effect of wind generation and sugarcane cogeneration on spot energy prices could well be to reduce rather than increase them. So far, the amount of capacity in the system from these plants is still too small to permit us to measure and observe this effect. In addition, spot energy prices in Brazil, Chile, and Peru are related to water values formed by the averages of future water opportunity costs for several hydrological scenarios, a fact that smooths out the immediate impact of renewables on prices.

table 4. Overall costs of the main support mechanisms in Brazil.

	Proinfa			Technology-Specific Auction ("Reserve Energy" Auction)		
	MW	GWh/year	US$/MWh	MW	GWh/year	US$/MWh
Wind	1,423	3,740	154	1,800	6,596	80
Small hydro	1,191	6,260	96	–	–	
Bioelectricity*	779	2,661	77	2,379	4,800	84
Impact on Costs						
Total capacity (MW)	3,393			4,179		
Total energy (GWh/year)	12,661			11,397		
Average cost (US$/MWh)	109			82		
Total cost (millions of US$/year)**	1,381			933		
Net impact on tariffs (US$/MWh)***	3.8			1.6		

Values as of April 2010; prices include taxes. Exchange rate: 1 BRL = US$1.85. (Source: Eletrobras, EPE, Aneel, ONS, and PSR.)
*Installed capacity includes self-consumption. In the auction case, energy values correspond to the excess energy sold to the grid at the auction. More excess energy from the new plants will be available to be sold to the free market at future auctions.
**Gross cost, i.e., total (fixed) cost paid by the consumers.
***For the auction case, it is the net cost, i.e., it includes estimates of yearly spot revenues collected by consumers.

On the cost side, Table 4 provides a summary of the prices, volumes, and costs resulting from the two main Brazilian support mechanisms. One can observe that although the annual costs of both outcomes is practically the same (around US$1 billion), the energy auction scheme delivered about 20% more total capacity, with an average energy cost and an expected tariff impact that were about 25% and 60% smaller, respectively. In the case of bioelectricity, more-efficient plants were acquired through the auction scheme, and not all new plants contracted have sold their total surplus capacity in the auction. Some 2,700 GWh/year of energy from these plants (about 40% of the total energy available to the grid) is still available to be sold in future auctions or directly to free consumers.

In the Peruvian system the annual cost to remunerate the winning projects of the auction carried out in 2009 is about US$140 million: about 15% of the Brazilian costs for the renewable auction, for a contracted energy volume that is 85% smaller.

Although it is still early to judge the impact of renewables on investment and prices in Chile, preliminary assessments indicate that over 20 years, the fulfillment of the quota system would involve a higher installed capacity and investment (about 5% and 7% higher, respectively) than without the requirement. This is to be expected everywhere, since high-plant-factor technology, such as coal-fired generation, would need to be replaced by lower-plant-factor technology, such as wind. On the other hand, total operation costs over 20 years would be 3% lower, due to the replacement of fossil fuel–based generation with generation whose variable cost is almost nil. The total economic effect (total investment and total operational cost) for the quota application would amount to a 3% increase over the 20-year period. In terms of effects on the market, the annual average marginal cost would increase by 5%, mainly due to the use of alternative fuels, such as liquid natural gas (LNG), to replace generation in low-wind conditions. For a quickly developing country, the last effect must be taken seriously. Electricity is an important component of the production costs of Chilean products in a globalized market, imposing an additional tax, lessening competitiveness, and resulting in lower economic growth.

Although a very important annual average emission reduction of approximately 16% would be obtained in Chile by fulfilling the quota, the resulting higher electricity cost would affect less protected social segments. Some impact on emission reduction is expected in Peru as well, but in Brazil the overall impact will be small because of the dominance of hydroelectric generation. In Brazil, the power sector accounts for less than 3% of the country's total emissions; deforestation is the main contributor.

Perspectives and Challenges

In a region with the potential for such a wide variety of renewables, there is still much room for renewable development. Energy auctions have proven to be an interesting path towards renewable implementation. They provide an indirect way to discover feed-in tariff prices, and the long-term contracting reduces risk aversion and facilitates project financing. In principle, auctions keep the advantages of feed-in tariffs (income certainty) but manage to stimulate the right amount of investment. The design of a relevant set of guarantees (financial, technical, and operational) is essential, however, in order to avoid the experiences of bidders that have bid too aggressively in order to win contracts that later could not be fulfilled. This raises the question of the effectiveness of contract guarantees. Brazil and Peru have announced additional renewable auctions (focusing on wind, small hydro, and biomass) for 2010. The 2009–2019 indicative ten-year generation expansion plan in Brazil has announced a strong preference for renewable sources to complement mainstream hydro in the system expansion. Several other Latin American countries (Mexico, Guatemala, and Costa Rica) have announced plans to develop renewables aggressively.

In Chile, however, it is not yet clear that the long-term quota will be easily achieved. Investors in renewable technology from all over the world were attracted to Chile's quota mechanism. A large number of projects have submitted environmental applications. In the Chilean scheme, however, the spot energy prices and standard auctions of energy contracts are the main price mechanisms for fostering renewable penetration. This has limited the achievement of the quota requirements, particularly by nonincumbent investors. For example, the production variability of wind results in a difficulty in establishing adequate energy contracts to obtain financing based on project cash flows. The exposure to spot prices creates market risks in energy contracts, causing limited secured flows with which to ensure sufficient funding (this same challenge is observed in Brazil for wind trading with free consumers). The alternative of direct energy sale to the spot market is also not attractive, as it does not allow financial flows to ensure revenue stability for the debt service. Capacity payments in Chile for most renewables are also low, due to their unreliable peaking capacity. In the end, renewable projects may not materialize—not because of technological innovation or cost competitiveness barriers but because financial instruments and the tools available are insufficient to finance projects. Today this constitutes the main obstacle to investment.

This challenge was also observed in Brazil until the auction product was developed. The investments that have materialized in Chile to date—and those under construction—have been developed by major incumbent generators using corporate finance, with guarantees from a parent company, and using particular opportunities that the market has provided. Nevertheless, there has been a gradual learning process on the part of banking and investment funds, which have begun to look forward to these projects. If the financing challenges are not overcome soon, it is possible there will be a drop-off of wind projects approved or presented by nontraditional developers. Those developers are clamoring for the introduction of a feed-in tariff, having concluded that the quota system is insufficient. A further negative development is that suppliers are transferring the quota responsibility to consumers, which either pay the penalty through prices or develop their own renewable sources of energy, as is happening with certain large mining complexes that do so as part of their sustainability programs.

Overall Conclusions

In a carbon-constrained era, the development of both clean and efficient electricity is critical for all countries, and this has clearly been the driver for the countries analyzed in this work. It is still too early to identify the best support mechanism or to assess a cost-benefit index for renewables, but with the massive application of support schemes worldwide, market cost impacts and wealth transfer between segments should be studied carefully, given their relevance as demonstrated by the experiences described in this article.

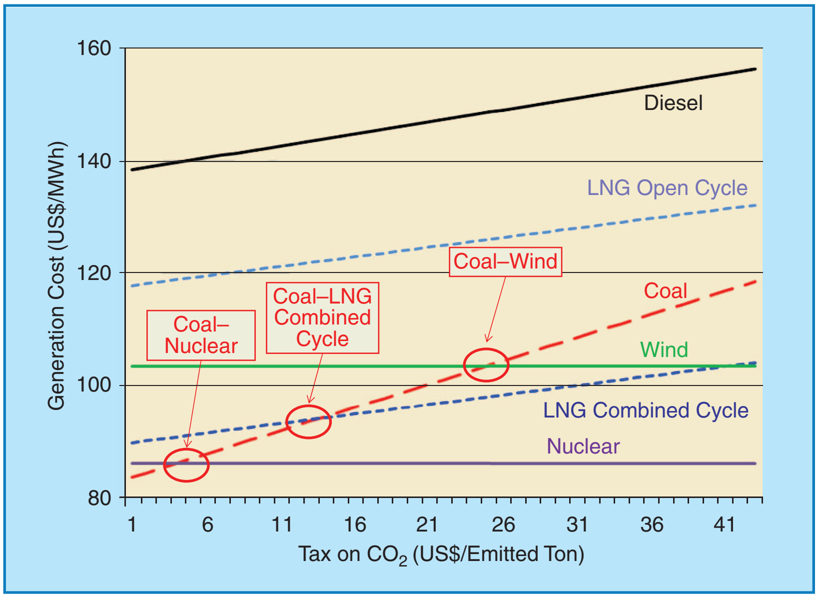


figure 8. The effect of carbon taxes on the cost of various generation technologies in Chile, as of 2009. (Source: Systep.)

An economic decision that may change the development of renewables worldwide is the introduction of carbon taxes. A carbon tax is a tax on the carbon content of fuels, translating into a tax on the CO_2 emissions from burning fossil fuels for electricity generation. A carbon tax might increase the competitiveness of renewable technologies as compared with the traditional fossil fuel ones, although this will depend largely on the price and market context. As an example, Figure 8 shows—for Chile and with the present cost of technologies—how a growing carbon tax can make coal-fired generation more expensive and thus wind energy more competitive than coal and LNG. This may not be the case in other countries, depending on their energy matrices.

Carbon taxes also have the advantage of being technology-neutral. They can thus promote energy efficiency as well as low-carbon technologies such as nuclear and carbon capture and storage. But a relevant question being posed internationally is whether carbon taxes are really the best tool for reducing emissions and coping with global warming. Their limited political acceptability will eventually prevent them from being a standalone, effective mechanism for reducing emissions. Most researchers agree that carbon taxes should be coupled with other policy measures—in particular with support policies for renewable or low-carbon energy alternatives—in order to be effective. These include support for R&D, removal of energy subsidies, and, eventually, direct renewable electricity support systems such as those reviewed in this article.

Whether as a result of carbon taxes or direct support policies, the contribution of renewable energy to the power supply will only increase in the future. The effects on markets, costs, investment, and wealth distribution will be correspondingly greater. Careful analysis and regulation will be required to adapt to this new environment in order to make the greater penetration of low-carbon technologies compatible with the adequate functioning of power systems and competitive markets worldwide.

For Further Reading

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