Chapter 9

Renewable Energy Technologies: Mitigation Potential and Operational Strategies

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Abstract

The future economic development trajectory for India is likely to result in rapid and accelerated growth in energy demand, with attendant shortages and problems. Due to the predominance of fossil fuels in the generation mix, there are large negative environmental externalities caused by electricity generation. Power sector alone has a 40% contribution in the total carbon emissions. In this context, it is imperative to develop and promote alternative energy sources that can lead to sustainability of energy-environment system. There are opportunities for renewable energy technologies (RETs) under the new climate change regime as they meet the two basic conditions to be eligible for assistance under UNFCCC mechanisms: they contribute to global sustainability through GHG mitigation; and, they conform to national priorities by leading to development of local capacities and infrastructure. This increases the importance of electricity generation from renewables. Considerable experience and capabilities exist in the country on RETs. But a number of techno-economic, market-related, and institutional barriers impede technology development and penetration. Although at present the contribution of renewable electricity is small, the capabilities promise the flexibility for responding to emerging economic, socio-environmental and sustainable development needs. This paper discusses the renewable and carbon market linkages and assesses mitigation potential of power sector RETs under global environmental intervention scenarios for GHG emissions reduction. An overall energy system framework is used for assessing future role of renewable energy in the power sector under baseline and different mitigation scenarios over a time frame of 35 years, between 2000 to 2035. The methodology uses an integrated bottom-up modelling framework. Looking into past performance trends and likely future developments, analysis results are compared with officially set targets for renewable energy. The paper also assesses the CDM investment potential for power sector renewables. It outlines specific policy interventions for overcoming the barriers and enhancing deployment of renewables for the future.

9.1 Introduction

There are myriad of technologies for electricity generation in India reflecting the diversities in resource endowments across the various regions, regional development patterns, fuel transportation infrastructure, demand characteristics and socio-environmental aspects. Coal remains the mainstay of electricity generation due to vast indigenous resources and constitutes about three-fifths of the country's power generation capacity. Large hydropower at present has about one-quarter share, and has shown a declining trend over the past decade. Its growth has remained restricted primarily due to a number of socio-environmental barriers. Gas-based power has grown very rapidly in the last decade to almost one-twelfth of total generation capacity due to lower capital requirements, shorter construction periods, and higher efficiencies. Nuclear capacity is about 3% of the total (Shukla et al., 1999).

RET capacity, (renewables in this paper include small hydro, wind, cogeneration and biomass-based power generation, and solar technologies and exclude large hydropower), aggregating 3000 MW as on December 2000, has a 3% share in the overall generation capacity and a one percent share in the overall generation (CMIE, 2000). The present estimated potential of renewables in the country is estimated at 100,000 MW (MNES, 2000-2001). TABLE 9.1 shows the installed capacities of the technologies vis-à-vis their estimated potential.

TABLE 9.1 Progress of RETs for electricity generation

Technology	Cumulative installation as on 31st December, 2000	Estimated potential
Small hydro (MW)	1341	15,000
Wind (MW)	1267	45,000
Biomass and cogeneration (MW) +	308	19,500
Solar PV (MW) #	47 MWp	
Solar thermal (MW)	*	

Note: The potential for solar energy is estimated at 20 MW/km^2

+ Estimation of the biomass and cogeneration potential is at 16000 MW and 3500 MW respectively. The installed capacity of biomass-based combustion power is 63 MW and cogeneration based power generation capacity aggregates to 210 MW. Installed capacity of biomass gasifiers is 35 MW
# Among the total installed capacity, grid-interactive solar power for peak load shaving in urban centres and providing voltage support in rural areas aggregates 1.04 MW
* A 140 MW integrated Solar Combined Cycle Power Plant (ISCCPP) is being implemented at Mathania in Jodhpur, Rajasthan.
Source: MNES Annual Report, 2000-2001

The energy scenario in India, especially the power sector, is characterized by growing demand-supply gap, inherent inefficiencies, distorted pricing mechanisms, weak institutional structure, environmental unsustainability and socio-political influences. The pace of rural electrification has been slow and there are about 80,000 villages in the country that await electrification with a large number of them located in economically backward and remote areas. The future economic development trajectory is likely to result in rapid and accelerated growth in energy demand, with attendant shortages and problems. The growing energy consumption is likely to lead to increasing emissions of gases, compounding the pollution problems at the local level and increasing GHG emissions. For instance, a long term projection (Shukla and Pandey, 1999) of the business-as-usual scenario over a 40-year period (1995-2035) indicates that energy consumption shall treble; electricity generation shall rise by 5.4 times; coal shall continue to be the main source of fuel and carbon emissions shall go up by 3.6 times. In this context, it is imperative to develop and promote alternative energy sources that can lead to sustainability of the energy system. Although at present the contribution of renewable electricity is small, the capabilities promise the flexibility for responding to emerging economic, socio-environmental and sustainable development needs.

9.2 Evolution of India's renewable energy programme

The Indian renewable energy programme was launched primarily as a response to the perceived rural energy crisis in the 1970s. It was initiated with a target-oriented supply push approach and primarily sought to develop niche applications, such as in rural areas where grid electricity was unavailable. It started with the creation of CASE (Commission on Additional Sources of Energy) in 1980, and then the DNES (Department of Non-conventional Energy Sources) in September, 1982. DNES was converted into a full-fledged Ministry (Ministry of Non-conventional Energy Sources, or MNES) in July 1992, making India the only country in the world with a ministry dedicated to promoting RETs (MNES, 1999-2000).

In the early 1980s, the technologies were not mature and there was little international experience in implementation. However, renewables were promoted as a panacea to the energy problems, pushed mainly by cash subsidies, and doing 'too much too soon' resulted in unrealistic expectations leading to failures (Sinha, 1993). Limitations were imposed by targets and the allocated budgets and in some cases like wind, poor technology selection led to failures. In the early 90s the emphasis shifted from purely subsidy-driven dissemination programmes to technology promotion through commercial route, as part of the overall reforms process, with fiscal and financial incentives embodied such as subsidised interest rates, capital subsidies, tax concessions, duty waivers and accelerated depreciation. By 1998, a multi-pronged strategy led to the development of the world's largest SPV lighting programme, fourth largest wind power programme, and second largest biogas and improved stove programmes. The push policies adopted since the 90s have been successful in creating a fairly large and diversified manufacturing base, and an infrastructure (technology-support groups and facilities, as well as the nodal agencies) to support RET design, development, testing, and deployment. But commercialisation of the technologies have been limited by providing financial incentives like subsidies, low reliability of the devices, lack of remunerative tariffs for RET-generated electricity, and a lack of consumer-desired features (in terms of the services and the financial commitments) in the design and sales-package. Distortions in the energy and electricity prices and non-internalisation of the socio-environmental externalities have adversely affected the competitiveness of RETs compared to conventional energy sources. Lack of R&D focus has posed a barrier towards bringing down technology costs. Overall, the programmes have failed to develop an orientation towards commercialisation and energy service delivery along with non-establishment of adequate marketing, sales and servicing infrastructure. The indivdual RETs are briefly discussed here.

9.2.1 Small hydropower

Hydro based power generation upto 25 MW capacity, classified as small hydropower, has been one of the earliest known renewable energy sources, in existence in the country since 1897 (TEDDY, 1999-2000). The present installed capacity is 1341 MW (MNES, 2000-2001) and estimates of MNES place the potential at 15,000 MW. More than 8000 MW up to 15 MW capacity have been identified through more than 4000 sites in different states of India (TEDDY, 1999-2000). A large potential of this technology exists in remote hilly areas, and therefore penetration of small hydropower would lead to rural electrification and local area development. India has a well-established manufacturing base for small hydro equipments. Programmes that involve local capacity building and demonstration, training and awareness programmes will accelerate technology adaptation and maintenance. Some states have taken up initiatives for community-based run-of-the-river hydel projects, but a long road lies ahead to tread the path of success and solve the rural energy crisis in the country.

Small hydropower development has been impeded by a number of barriers. Investment costs for small hydropower development are substantially high due to terrain inaccessibility and lack of suitable transportation linkages in remote hilly areas. Places with high potential have low demand for power, that in turn implies high investment costs for setting up of transmission networks in difficult terrain. A number of institutional barriers such as inadequate state plan allocation, lack of coordination among planning and implementing agencies, delays in the clearances and allotment of private sector projects, low priority of the State Electricity Boards to take up the projects, and lack of clear policy for private sector participation have slowed down progress in this technology. Programmes that involve local capacity building and demonstration, training and awareness programmes will accelerate technology adaptation and maintenance.

9.2.2 Wind power

Wind power generation capacity has reached nearly 1267 MW with an aggregate generation of about 6.5 billion units of electricity. India is positioned among the top five countries in wind power installation after Germany, USA, Denmark and Spain. Private investment constitutes a substantial 95.5% of the total capacity and the rest are demonstration projects. Out of the total energy generated, about 80% consumption is for captive purposes while the rest is sold to the grid. Estimates by the MNES place the realisable wind energy potential in India to be 45,000 MW (MNES, 1999-2000). Technical potential is estimated to be 10,000 MW, assuming 20% grid penetration, which is expected to go up with the augmentation of the grid capacity in potential states. The latest projections by MNES plan additional 10 GW of renewable capacity by 2012 (MNES, 2000-2001). It is envisaged that around 60% of this capacity or 6000 MW may come from wind power.

The Indian wind energy programme was initiated in 1984 and for more than two decades Government programmes alone drove the demand for wind power. Wind energy sector was liberalised for private participation in 1992 that altered the competitive advantage of wind power and generated significant demand ‘pull’ by the private sector. During the course of technology adaptation, implementation experiences have lowered costs of wind power and enhanced manufacturing and servicing capacity have lowered the risk. There is a strong indigenous manufacturing base for wind power equipments accounting for about 80% of the total equipments. After a period of explosive growth that pushed India’s wind energy utilization up to the world’s third highest, investment fell sharply from mid-1996 to the end of 1998. Technical problems were encountered as decline in California’s wind energy programme had led to dumping of wind power equipments to India that often had associated quality problems in equipments. The unsustainability of the financial incentives for promoting wind power development manifested itself in sharp decline in wind power capacity growth. Low capacity utilisation (the assessment was based on 20% utilisation, but in most cases they were found to be lower) raised generation costs. The scale of operation of was often constrained by operational problems in matching the availability (supply) with the load duration curve. Attractiveness of private investment in wind power projects declined with the imposition of MAT (Minimum Alternate Tax) that lowered tax-credit benefits, lowering of corporate income tax by the Union Government, withdrawal of third-party sales in some states and fluctuating and inconsistent policy regime across States. (Rajshekhar et al., 1999). Sustainable development of wind power will require addressing the economic, technical and institutional barriers being faced. Cost reductions, improved technical performance and financial incentives, and global conventions and mechanisms could create conditions for the rapid spread of wind power systems (Ravindranath et al., 2000).

9.2.3 Biomass-based power generation/cogeneration

Biomass, consisting of woodfuels, crop residues and animal dung, continues to dominate energy supply in rural and traditional sectors, having about one-third share in the total primary energy consumption in the country. Cogeneration technology, based on multiple and sequential use of a fuel for generation of steam and power, aims at surplus power generation in process industries such as sugar mills, paper mills, rice mills, etc. The aggregate biomass combustion based power and sugar-cogeneration capacity by the end of December 2000 was 273 MW, with 210 MW of cogeneration and the rest biomass power. In the area of small-scale biomass gasification, a total capacity of 35 MW has so far been installed, mainly for stand-alone applications. The combined potential of biomass and sugar-cogeneration based power generation is estimated to be 19.5 GW. The cogeneration potential from bagasse in existing 430 sugar mills is alone about 3.5 GW (TEDDY, 1999-2000). Power generation systems can range from small scale (5-100 kW), medium scale (1-10 MW) to large-scale (about 50 MW) (Ravindranath and Hall, 1995) applications. A national biomass power programme is being implemented, the main objectives of which are to establish techno-economic feasibility of power generation from biomass materials (Ravindranath et al., 2000).

A shift in the perspective with respect to biomass energy strategies will be necessary to treat biomass as a competitive and modern energy supply source, reorient technology policy, integrate biomass policy with development and environment policy and support development of competitive energy markets using biomass technologies. For setting up of large-scale biomass based electricity generation technologies, the most important issue is ensuring a *continued and reliable supply* of biomass, especially woodfuels. That in turn raises critical issues related to land availability and enhancing productivity through technological interventions. Growth in cogeneration capacity is constrained by large incremental investment requirements, channeling of sugarcane bagasse for alternative uses e.g. for paper production, technical barriers in upgradation of existing sugar mills and installation of power generation systems, and synchronisation and feeding of electricity to the grid. Enhanced utilization of biomass, information dissemination programmes to promote usage, technology transfer, coordination among institutions and subsidy to biomass technologies will enhance technology penetration in the short-term. Some of the medium term measures would be development of scale economy based technologies, R&D of conversion technologies, removal of distortions in energy tariffs and institutional development. In the long run, infrastructure related to biomass energy usage needs to be adequately developed along with institutions and policies for competitive biomass energy service markets.

9.2.4 Solar technologies

Solar photovoltaic (SPV), with an aggregate peak capacity of 47 MWp, contribute at present around two and a half percent of the power generation based on RET in India (MNES, 2000-

2001). Solar Thermal Power Generation potential in India is about 35 MW/km^2 Estimates indicate 800 MW/year potential for solar thermal based power generation in India during the period 2010 to 2015, with worldwide advancements in the parabolic trough technology (TEDDY, 1999-2000). A project for setting up of a 140 MW integrated solar combined cycle power project has been initiated at Jodhpur in Rajasthan. It comprises of 35 MW solar thermal component based on parabolic trough collectors and 105 MW power generation based on naphtha/gas.

In the early nineties, SPV programme developed two distinct components: (i) a socially oriented dissemination programme implemented by state nodal agencies with MNES subsidies; and (ii) a market-oriented scheme implemented by the Indian Renewable Energy Development Agency (IREDA) with financial assistance from international agencies. At present, the indigenous manufacturing base for SPV systems is small and about 80% of the silicon wafers are imported (MNES, 1999-2000). Technology penetration is restricted primarily due to their extremely high investment costs that is estimated to be Rs.20 crores/MW for SPV and Rs.11 crores/MW for Solar Thermal (Ramana, 1998). Electricity generation costs from SPV on a life cycle basis is over 10 times higher compared to coal-fired thermal power. Besides, a number of transaction costs are involved in technology commercialisation such as expensive and time consuming project identification; challenging project implementation in a number of small-scale installations; high costs of credit collection and risks associated with marketing, contracting and information collection; conducting promotion campaigns and creating after sales service infrastructure; quality control measures, cost of co-financing, conducting feasibility studies and developing business plans. All of these raise the cost of the delivered energy. Studies on the penetration of solar technologies for off-grid solar power systems in developing countries such as India, Indonesia and Sri Lanka reveal that access to credit in the rural areas is one of the single most important factors influencing the diffusion of solar home systems (Miller and Hope, 2000). Some of the key policy lessons derived from World Bank experiences are ensuring flow of rural credit through appropriately designed channels by selection of credit organisations having a strong network in rural areas, offering long-term loans to entrepreneurial start-up companies which becomes critical to rapid development of market infrastructure, phasing out of import duties on PV modules, and providing supply side grant for the rapid development of a market infrastructure for technology dissemination.

9.3 Assessing mitigation potential

9.3.1 Analytical framework

The assessment of future paths for analysing the role of renewable energy in the power sector is carried out within an overall energy system framework. Renewable energy options for power sector are integrated with the overall power sector technology strategy assessment, embedded in the energy system. This paper assesses renewable energy trajectories under future scenarios over a 35-year time period from 2000 to 2035 and the consequent policy implications.

The methodology uses an integrated bottom-up modelling framework that has an energy system model, end-use sector models and a demand projection model that separately projects demands for 37 end use services. These bottom-up models have very detailed representation of technological options in energy supply and enduse sectors in terms of costs, fuel inputs and emission characteristics. MARKAL (Market Allocation), which is an energy systems optimization model (Fishbone and Abilock, 1981; Berger et al., 1987; Shukla, 1996), decides for each period the energy and technology mix while minimizing the discounted capital and energy cost. Energy enduse sectors are broadly categorised as industries, transportation, agriculture, residential and commercial. Each individual sector is analysed individually using AIM/ENDUSE model (Asian-Pacific Integrated Model– End-use Component) (Morita et al., 1994; Morita et al., 1996; Kainuma et al., 1997) that selects the technology mix within each end-use sector while minimizing the discounted costs of capital, energy and materials. Soft-linkage between supply and demand side takes place by providing technology mix for each end-use sector as an input to MARKAL together with exogenous bounds on technology penetration. Demand model for projection of enduse energy services uses logistic regression method (representing transition from high growth to saturation) based on past sector level consumption data as well as estimates, if available, from other detailed studies for some future years along with expert opinion on the future trajectories of these sectors. Similar representation is commonly used for technology penetration in the energy and environment context (Edmonds and Reilly, 1983).

9.3.2 Scenarios

Carbon mitigation potential assessment for RETs in the power sector examines renewable energy options for electricity generation under a baseline scenario and global environmental intervention scenarios. The scenarios are based on internally consistent and reproducible set of assumptions about the key relationships and driving forces of change, which are derived from an understanding of both history and current situation and describe relationships between important drivers of resource availability, productivity and technological change (IPCC, 2000). Important exogenous model specifications for these scenarios include the demand trajectories derived from overall macro-economic projections, investment constraints, discount rate, energy supply limitations, energy prices, technology costs and performance parameters, bounds on technology penetration, and environmental characteristics.

<u>Baseline:</u> This scenario presumes continuation of current energy and economic dynamics and provides a reference for comparing the impacts of policies or alternate futures. It assumes what is often called a "business-as-usual" dynamics and serves as a benchmark for assessing carbon mitigation potential of renewable energy trajectories under global environmental intervention futures. Overall macroeconomic projections are based on an assumption of GDP growth rate of 5% in terms of CAGR (compounded annual growth rate) over a period of next 35 years (2000-2035) with a declining trajectory of 6% growth in initial years to 4% in later periods. Structural changes in the economy are represented by rising share of commercial sector and declining agricultural sector share. Among energy forms, coal supply continues to dominate but imported natural gas consumption increases steadily with the domestic gas reserves likely to be exhausted by 2015. This scenario presumes no policy interventions for GHG emissions control other than normal non-market and long-term policy interventions related to energy and technology.

<u>Global environmental interventions (GEI):</u> The ultimate objective of the UNFCCC is to achieve stabilization of GHG concentrations in the atmosphere at a level that would prevent dangerous anthropogenic interference with the climate system (IPCC, 1996). Rising energy demand has lead to rapidly rising trend of energy emissions from India, with high carbon intensity. Although the per capita carbon emissions for India are quite low at present (about 20 times lower than US per capita emissions), total annual emissions exceed 200 Mt of carbon.

Opportunities for RETs under the new climate change regime arise as they meet two basic conditions to be eligible for assistance under UNFCCC mechanisms- a) they contribute to global sustainability through GHG mitigation and, b) they conform to national priorities by leading to development of local capacities and infrastructure. This paper assesses the impact of energy system responses to global carbon market signals on power sector RETs. At present, the only mechanism for developing country participation in the global emissions limitations regime is through the CDM defined in the Kyoto Protocol under UNFCC. This is a voluntary mechanism for promoting GHG emissions mitigation projects that offers potential benefits such as access to global carbon market for emissions reduction trading, technology transfers, improvements in local environment and share of surplus from CDM projects (Audinet et al., 2000). Our analysis for mitigation potential assessment is constructed around five sub-scenarios with different levels of cumulative mitigation targets. These targets are set on reductions over cumulative emissions in the baseline scenario over 2000 to 2035. The mitigation targets aim at 5, 10, 15, 20 and 25% reduction over cumulative baseline emissions. We refer to the 5% reduction target as low mitigation, 15% one as medium and 25% as high mitigation scenarios respectively.

9.4 Results

9.4.1 Technology Trajectories

Baseline projections: Baseline results show that while the economy grows around sevenfold in the 35-year period between 2000 and 2035, there is a five-fold increase in electricity demand and generation capacity almost triples. Coal continues to dominate the capacity mix, but with declining share from 60% at present to 50% in 2035. Natural gas based capacity share increases substantially from present 7% to one-fifth of total capacity in 2035, mainly due to rising competitiveness of natural gas based technologies. Large hydro maintains around one-fifth share in the overall capacity. Nuclear share rises from the present 2% to 5% in 2035.

Renewables exhibit a thirteen times increase in capacity during the period from 2000 to 2035 (**Fig. 9.1)**, with their share in total power generation capacity increasing from present 3% to 6% in 2035. Performance improvements in technologies are reflected in generation share increase from less than 1% at present to around 5% in 2035. Latest projections by MNES plan additional 10 GW of renewable capacity by 2012, which is likely to constitute 10% of the overall power generation capacity additions (MNES, 2000-2001). Our baseline scenario results project a capacity addition of only 60% of this value, i.e. around 6 GW of renewable capacity additions in next 12 years. Capacity increases are constrained by a number of barriers, with investment availability being a major one. Wind power capacity doubles in 2010, increases by 2.5 times in 2020 and attains 5 GW capacity in 2035. A technology push policy along with R&D thrust and learning innovations enhances short and medium term penetration. But long-term penetration is driven by development of indigenous manufacturing capabilities and increasing competitiveness of wind technology. Biomass and cogeneration technology capacities increase substantially, with their combined capacities reaching around 4 GW by 2015, and 10 GW by 2035, accounting for 50% of the total renewable capacity. High conversion efficiency coupled with low investment requirements in cogeneration technology leads to large part of the potential being exploited in the next decade.

Small hydro capacity grows at an average annual rate of 9%, and increases its share from 9% at present to about one-fifth share. Solar technologies increase their capacity shares from the present 2% to close to 10% by 2035, with the aggregate capacity of SPV and solar thermal capacity attaining close to 2 GW capacity by 2035.

Global Environmental Interventions (GEI): Global environmental interventions lead to significant shifts in renewable energy trajectories from baseline and alter their contribution in the overall generation capacity (TABLE 9.2) and **(Fig. 9.2).** With tightening of carbon emission mitigation requirements, the share of renewables in the overall generation capacity increases progressively.

TABLE 9.2 Renewable capacities across scenarios (GW)

Scenarios	**2015**	**2025**	**2035**
Baseline	8	15	22
GEI			
Low mitigation	10	18	28
Medium mitigation	12	25	41
High mitigation	18	35	58

Even a weak mitigation scenario drives renewable capacity up by 5% over baseline as early as 2005. The capacity rise in the short-term (in 2015) under this regime is more than 10% over baseline, with progressive increase to an additional one-fifth capacity by 2025 and more than one-third increase in capacity in the long-term (2035). But a medium mitigation scenario drives capacity up by one-third over baseline by 2005. Stricter mitigation requirements in later time periods accelerate growth in renewables and lead to about 45% capacity increase in 2015, 60% increase over baseline in the medium term (2025) and almost doubling of the capacity in the long-term (2035). A strong mitigation scenario significantly alters the technology mix for electricity generation that increases the renewables capacity by more than half in the next 5 years, doubles capacity by 2015 and leads to three times increase in capacity of renewables by 2035 **Figs. 9.3a to 9.3d** show the capacity projections of individual renewable technologies. Analysis results reveal that under GEI scenarios, emerging competitiveness of wind power drives capacity up substantially as compared to baseline (**Fig. 9.3b**). Cogeneration is an attractive mitigation option and offers large opportunities for potential exploitation through appropriate policies and implementation mechanisms in the short-term. Weak and medium mitigation scenarios result in 30 to 40% increase in capacity in short-term over baseline. Medium-term capacity increase is about one and half times over baseline capacity under weak and medium mitigation scenarios and almost doubles under a strong control regime. Biomass contribution to mitigation increases progressively over time, with a large potential being realised in later years that is initiated with the setting up of a biomass fuel supply market and advancements in biomass combustion and gasification technologies (**Fig. 9.3c**). By 2025, capacity increases by one and half to two times over baseline under medium and strong mitigation scenarios respectively. A strong mitigation regime can initiate the early setting up of a commercial fuelwood market and enhance technological competitiveness. Global environmental interventions drive up small hydro capacity by about 1.5 to 2.5 times over baseline by 2015 (**Fig. 9.3a**). There is a significant increase in penetration of solar technologies over baseline under medium and strong mitigation scenarios in the long-term (**Fig. 9.3d**). This is driven by setting up of a global carbon market that triggers enhancement of technological competitiveness by learning experiences, technology transfer mechanisms, and international co-operation in R&D.

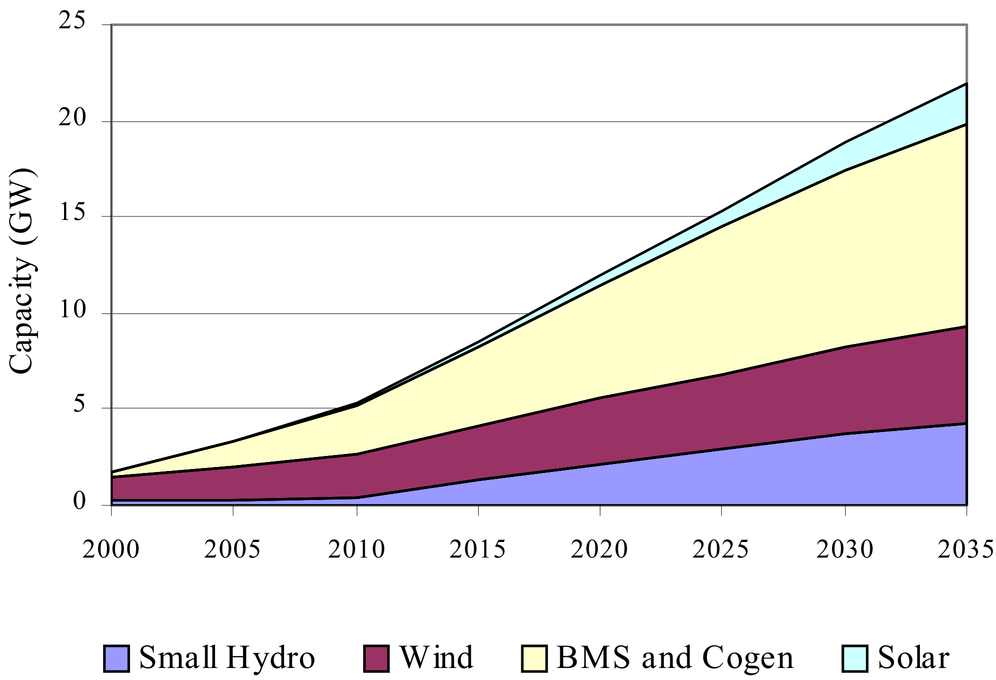

Fig. 9.1 Capacity projections of renewables in baseline scenario (GW)

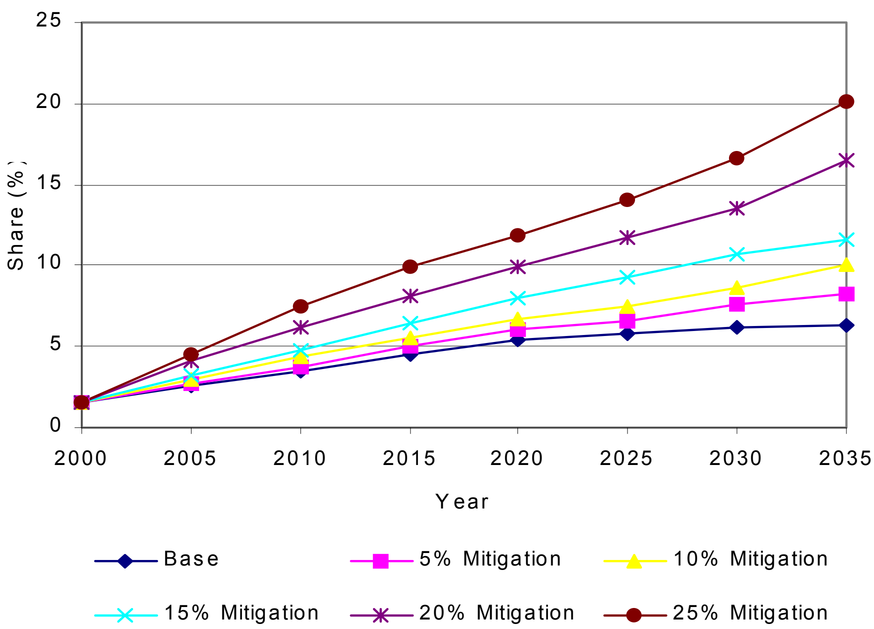

Fig . 9.2 Share of renewables as percentage of total capacity

9.4.2 Renewable and carbon market linkages

Cumulative mitigation potential of RETs ranges between 12 to 15% of the overall power sector cumulative mitigation potential. As for power sector share in the overall energy system, estimation is about 55 to 70%, across different mitigation scenarios. The carbon supply curves (**Fig. 9.4)** represent the cumulative mitigation of carbon emissions by RETs across five mitigation sub-scenarios. Mitigation potential of RETs reveals some distinct patterns. Biomass and cogeneration technologies have more than 60% share in the total mitigation by RETs. They offer cheap mitigation opportunities and their potential is easiest to realise. Wind share is restricted to 15% of the total by all renewable technologies. Most of the wind sites having high potential get tapped in early years, and exploitation of more difficult sites in later periods results in low capacity utilisation and slowing down of mitigation opportunities. Though solar share increases in the long-term with stricter mitigation requirements, but its share in overall mitigation is limited to about 5%.

9.4.3 Marginal mitigation costs

Potential opportunities for carbon mitigation in India arise in the context of a functioning global carbon market. The global carbon price signals determine the long-term optimal emission trajectories. **Fig. 9.5** shows the marginal cost trajectories under different mitigation scenarios for the entire energy system, as derived from the analytical framework used in this paper. These marginal costs reflect expectations about global carbon price trajectories that drive mitigation targets. The marginal cost increases with time as cheaper mitigation options, such as demand side improvements in the energy system, are exercised early on and costlier energy supply side interventions take place later. Demand side options such as agricultural pumpset efficiency improvements, and efficient residential lighting systems offer no-regret mitigation choices. Supply side options are associated with large investment requirements, long life times of the technologies, and complexities in decision-making processes. Our analysis estimates the contribution from renewables in the power sector (TABLE 9.3). Under weak mitigation scenario, average mitigation costs are less than $5/t of C till about 2015. In the long-term, say by 2035, this scenario has average costs below $40/t of C and the cumulative contribution from power sector renewables is estimated at about half a billion dollar. Under a medium mitigation scenario, average mitigation costs are less than $50/t of C till 2025 and it almost doubles over the next decade. Cumulative revenue generation over a 35 year period is almost 3 billion $. A strong mitigation scenario results in substantial increases in the mitigation costs even in the short-term due to costly energy supply side interventions. Average mitigation costs are as high as $50/t of C by 2015 and reach around $180/t of C in a period of 35 years. Under this scenario, cumulative contribution from power sector renewables approaches 10 billion $ over the same period.

9.4.4 CDM potential estimation

CDM is the only participatory mechanism for developing country Parties in project activities, as specified in the Kyoto Protocol UNFCCC. This paper estimates the contribution from potential CDM projects for RETs in the power sector (TABLE 9. 4).

TABLE 9.3 Average mitigation costs, average contribution and cumulative contribution from renewables in power sector

Scenarios		2015	2025	2035
5% Mitigation	Average cost[a] ($/t of C)	4	18	37
	Average contribution[b] ($/t of C)	2.6	3.5	8.1
	Cumulative contribution[c] (Billion $)	0.03	0.14	0.57
15% Mitigation	Average cost ($/t of C)	26	48	97
	Average contribution[b] ($/t of C)	3.1	6.2	20.9
	Cumulative contribution (Billion $)	0.15	0.66	3.23
25% Mitigation	Average cost ($/t C)	50	97	178
	Average contribution[b] ($/t of C)	7.6	12.7	26.8
	Cumulative contribution (Billion $)	0.66	2.68	9.18

[a] The Average cost estimation is for a period of 5 years, i.e. the cost for 2015 is the average of the estimated cost over the period 2010-2015

[b] The Average contribution estimation is for a period of 5 years, and the time period coincides with that for average cost estimation. The average contribution estimation for each five year period is the difference between the estimated average cost for that period and global carbon price, that is reflected in the marginal cost trajectories.

[c] The starting period for cumulative contribution estimation is 2005.

TABLE 9.4 CDM contribution by renewables in power sector (2000-2012)

Scenarios	Mitigation (Mt of C)[+]	Revenue (Million $)	Contribution (Million $)	Unit contribution ($/t of C)
5% Mitigation	11	38	14	1.3
15% Mitigation	30	710	104	3.5
25% Mitigation	58	2573	434	7.4

+The carbon mitigation estimation is based on assessment of the emission trajectories under baseline and mitigation scenarios.

The cumulative carbon mitigation potential during the period 2000-12 depends upon the long-term optimal emission trajectories, which in turn is dependent on global carbon price expectations. Close to 10 Mt of mitigation during 2000-12 under a 5% scenario can provide net earnings of around 14 million $ with a total revenue earning of close to 40 million $. Around 50 Mt of mitigation between 2000 and 2012 results in more than a billion $ revenue flow, with the revenue generation almost doubling under 60 Mt cumulative mitigation during the same period. The net contribution varies over a wide range between close to 15 million $ under low mitigation to more than 400 million $ under high mitigation scenario.

TABLE 9.5 shows the contribution from RETs under different mitigation scenarios. Biomass and cogeneration have a 60 to 80% CDM contribution, while having only 30 to 40% share in the additional capacity build-up over baseline. As compared to this, wind with a 40% share in the additional capacity build-up among renewables, has a less than 10% share in CDM contribution. While solar technologies have a 2% share in the additional capacity build-up, their share in CDM contribution is close to 1%. Small hydro technologies have higher availability than wind and solar technologies with contribution share ranging between 20 to 25%, while having a 20 to 30% share in additional capacity.

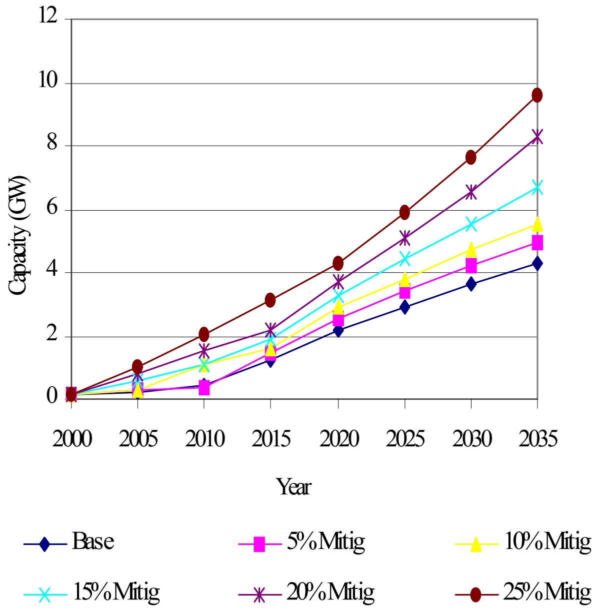

Fig. 9.3a Small hydro capacities

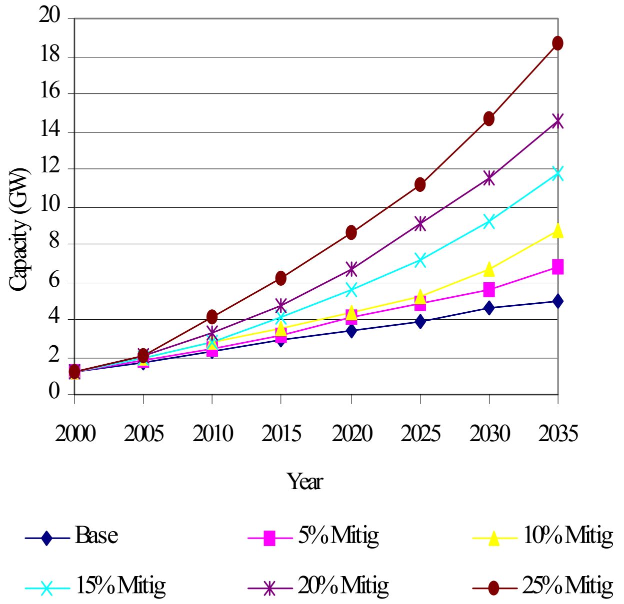

Fig. 9.3b Wind capacities

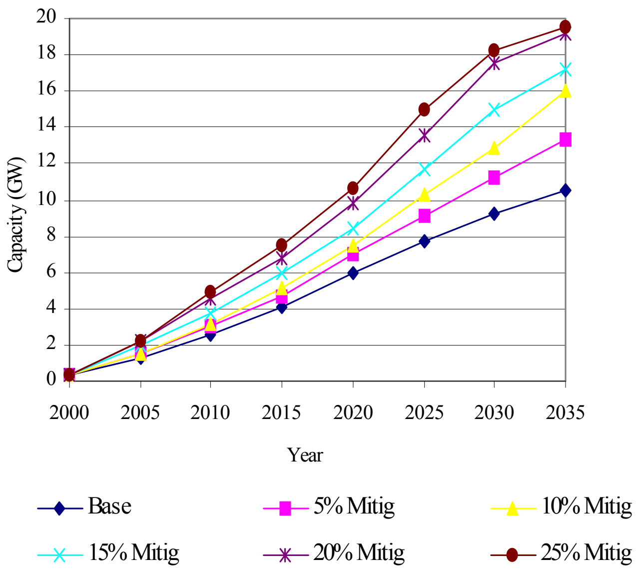

Fig. 9.3c Biomass and cogeneration capacities

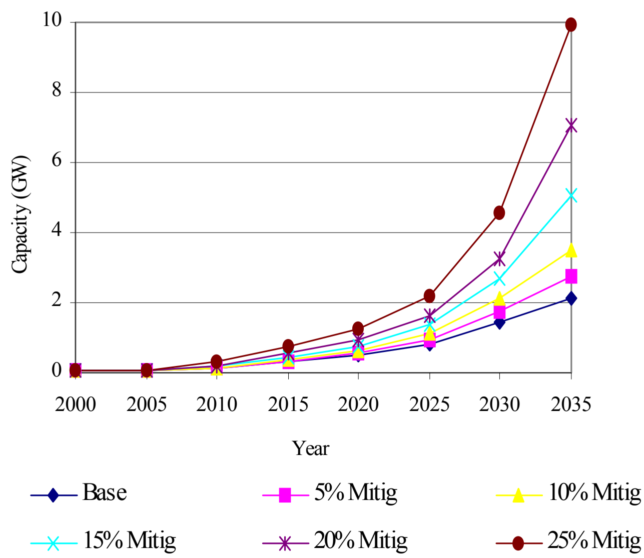

Fig . 9.3d Solar capacities

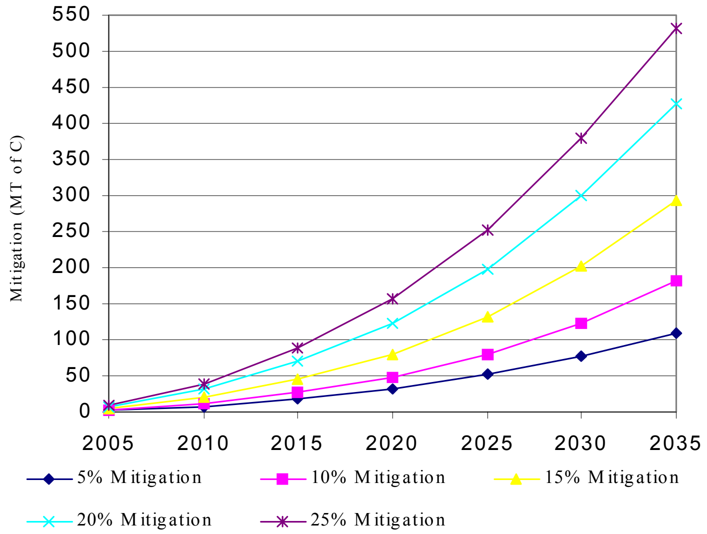

Fig. 9.4 Carbon supply trajectories for renewables

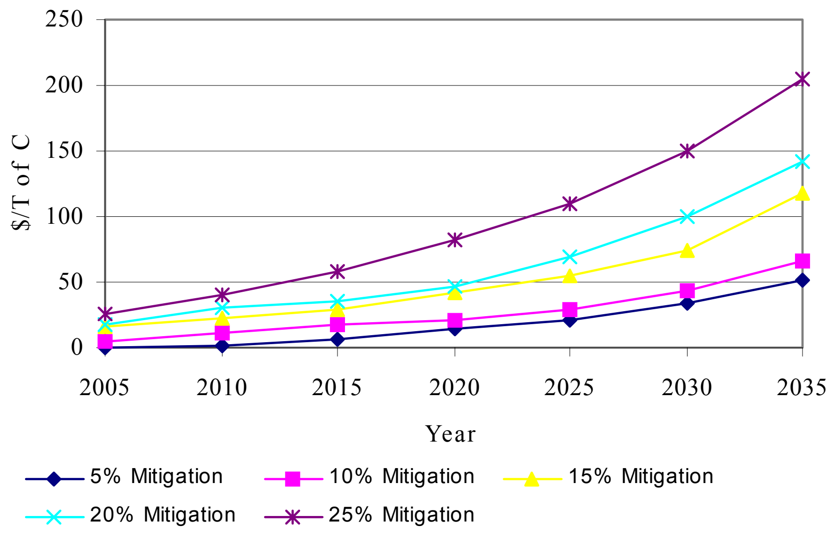

Fig. 9.5 Marginal cost of carbon mitigation

Therefore in response to global environmental interventions and emerging possibilities of setting up of a global carbon market in which developing countries like India could participate, substantial investments in biomass and cogeneration technologies within the next decade would offer economic mitigation opportunities. The analysis presumes that biomass is grown in a sustainable manner, which affirms its carbon neutrality. Some of the other related issues in this context are structuring of policy incentives for private participation and investments in cogeneration for which an attractive potential exists in many industries, advancements in biomass conversion technologies, setting up of biomass supply infrastructure and development of market mechanisms for trading, and adopting sustainable agricultural practices.

TABLE 9.5 CDM contribution from RETs

Technologies	**CDM contribution (Million $)**				
	5% Mitigation	**10% Mitigation**	**15% Mitigation**	**20% Mitigation**	**25% Mitigation**
Small hydro	2.3	10.9	20.2	45.9	107.9
Wind	0.4	4.6	6.1	14.5	40.1
Biomass and cogeneration	11.3	36.3	77.2	157.8	280.4
Solar	0.05	0.2	0.6	1.7	5.5

9.4.5 Investments in Renewable Energy Technologies (RETs)

It is interesting to compare relative shares of RETs in carbon mitigation vis-à-vis their investment shares across different mitigation scenarios (**Fig. 9.6** and **Fig. 9.7**). While biomass and cogeneration technologies have a 60 to 80% share in total mitigation, they have relatively lower share in investments ranging between a quarter to 40% of the total. Contrast this with solar technologies that have only a 3 to 6% share in mitigation, while their investment shares range between one-fifth to a third of the total. Wind power having high investment costs and low capacity utilisation has a 10 to 15% share in mitigation, while having 20 to 25% share in investments. Policies and measures targeted at recycling the net contribution from emissions reductions, due to specific sectoral interventions, back to these sectors can help in lowering mitigation costs and ensure sustainability of the regime. Some external financing mechanisms may be necessary in initial periods for undertaking mitigation activities and lowering the overall burden of costs on various contributing sectors. Analysis shows that recycling of net contribution from 100 Mt of carbon mitigation over a period of next 35 years can lead to close to a billion $ saving in investments. If India were to mitigate about 90 Mt of carbon by RETs alone in the power sector by 2015, revenue recycling could save 3 billion dollars in investment. The medium-term (2000 to 2025) savings in investment range between half a billion to 6 billion dollars for 50 to 250 Mt of carbon mitigation respectively. Long-term reductions in investments are quite substantial. There is an investment saving of about 7 billion dollars by recycling of the contribution from close to 300 Mt of carbon mitigation over 2000-2035, while for a billion tonne of carbon mitigation over the same period the investment saving is 17 billion dollars.

<u>Investment potential in RETs under CDM:</u> Renewable energy contribution in carbon mitigation offers investment opportunities through mechanisms such as CDM under the functioning of a global carbon market (**Fig. 9.8**). Depending upon the long-term mitigation

trajectory, CDM investment potential for the period 2000-2012 ranges between 1 to 7 billion \$. Following the *additionality* criteria under the Kyoto Protocol, a 6.5 Mt of carbon mitigation over baseline emissions between 2000-2012 under a 5% cumulative mitigation scenario entail a CDM investment potential of 1 billion \$. A mitigation of 60 Mt of carbon over the next 12 years has an investment potential of 7 billion \$. Biomass and cogeneration technologies have the highest share in CDM investment (30 to 40% share) under low to medium mitigation scenario (5 to 15% mitigation scenarios) as they offer a large and relatively cheap potential that can be easily exploited as compared to other RETs. The investment in these technologies can range between less than half a billion dollars to more than two billion dollars across mitigation scenarios. Stricter mitigation requirements (20 to 25% cumulative mitigation over baseline emissions), necessitate high investments in technologies such as wind and solar. Close to 50 Mt of mitigation by RETs over 2000-2012, has an investment potential of more than a billion for wind alone. Around 60 Mt of mitigation target over the same period doubles the investment potential in wind to more than 2 billion dollars. Investment potential in solar technologies under this scenario reach about a billion dollar that has a 13% share in the total RET investment potential. Small hydro maintains close to one-third share in investments across all mitigation scenarios.

9.5 Barriers in renewable energy development and penetration

Despite the progress in renewable energy, a number of barriers restrict its development and penetration. Some of these are the relatively higher investment requirements for RETs, intermittent electricity generation characteristics from renewable resources leading to their low reliability in meeting power demand, need for effective back-up power supply options that increases costs, lack of full cost pricing in determining cost of competing energy supplies and non-internalization of environmental externalities. Renewable energy development is impeded under conditions of electricity markets undergoing transition when high discount rates and competition on short-term electricity prices within a regulatory framework disadvantage projects with high capital costs but low running costs, such as renewable electricity systems. In addition, non-cost barriers also inhibit the greater use of renewable energy. This is particularly the case with the imperfect flow of information and the lack of integrated planning procedures and guidelines. Some of the barriers for development and penetration of RETs, broadly classified as economic and technological barriers; market-related barriers and institutional barriers are presented (TABLE 9.6).

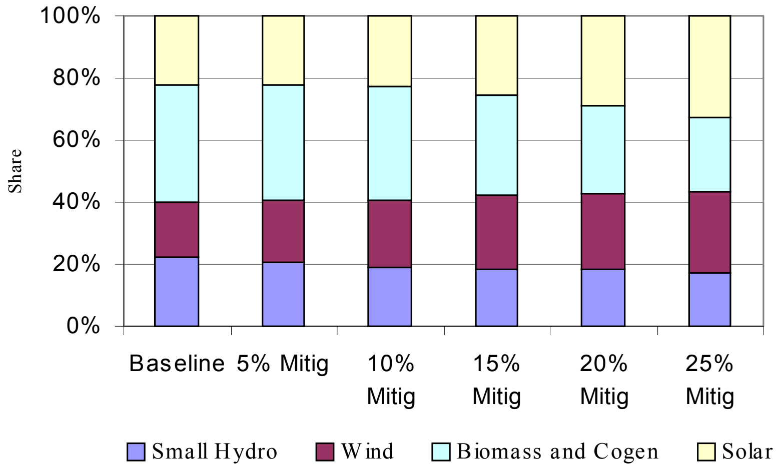

Fig. 9.6 Technology shares in cumulative investment (2000-2035)

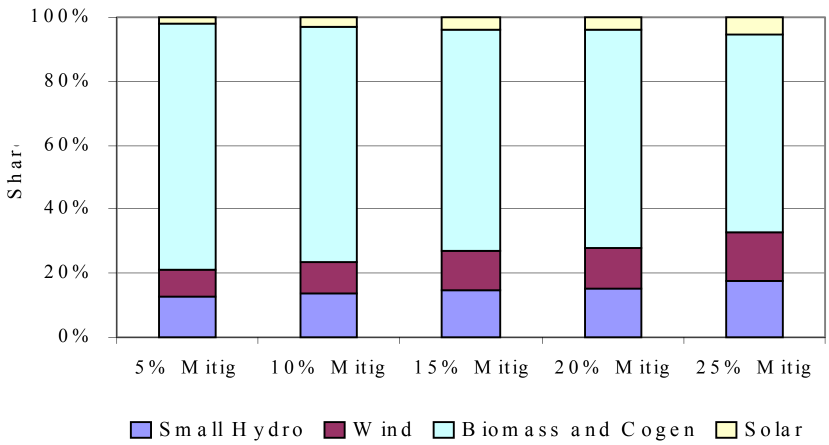

Fig . 9.7 Technology shares in cumulative mitigation (2000-2035)

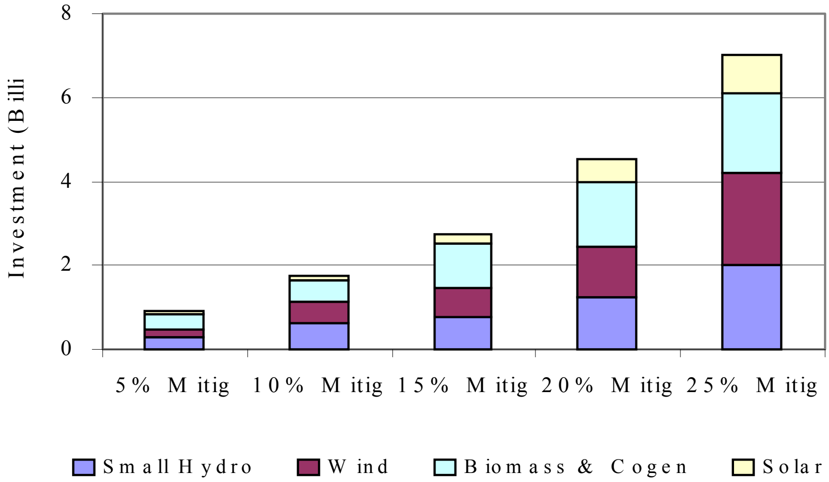

Fig . 9.8 Investment potential in RETs under CDM (Billion $)

9.6 Conclusions and operational strategies

A variety of issues are linked to an operational strategy formulation for renewable energy. The strategy needs to be integrated with energy market liberalization and withdrawal of direct government interventions and its deployment needs to be enhanced from 'energy services' delivery perspective. These translate into incorporating renewable energy strategy into development programmes to promote decentralised applications. Redefinition of public-private role in renewable energy development would imply increased private participation and industry collaboration in R&D for rapid commercialization of RETs and market infrastructure development. International cooperation in R&D and technology transfer mechanisms through emerging instruments such as CDM need to be established. Many renewables are in a classic chicken and egg situation - financiers and manufacturers are reluctant to invest the capital needed to reduce costs when demand is low and uncertain, but demand stays low because potential economies of scale cannot be realised at low levels of production. Renewables need to gain confidence of various parties by establishing a strong track record, performing to expectations, and improving their competitive position relative to conventional fuels. Faster diffusion of RETs would necessitate improved reliability of technologies and introduction of consumer-desired features (in terms of services and financial commitments) in the design and sales package. Setting up of Market Based Instruments (MBIs) such as Green Pricing Schemes for renewable electricity with tradable renewable energy certificates could be adopted. Energy market development incorporating full cost pricing of energy forms, adopting net-metering schemes by incorporating avoidance costs for T&D in the electricity supply price from renewables and internalisation of socio-environmental externalities in pricing of energy services will go a long way in enhancing competitiveness of renewables.

Future target setting and establishment of a renewable energy portfolio needs to be integrated with overall energy sector and power sector targets. Renewables should be included in the Electricity Bill and incorporated in the regulatory proceedings/mechanisms at the centre and states. The baseline scenario projections should be based on past trends and most likely future developments. Specific interventions need to be clearly outlined for achieving penetrations beyond baseline projections, as shown in the analysis under results of different scenarios. At present, MNES has projected a 10,000 MW renewable energy capacity by 2012 for which our analysis results indicate that investment requirements would approximate 8 billion $. Looking into the past performance and likely future developments under baseline, it is unlikely that such investment requirements would be mobilised unless some specific interventions take place. Our analysis results for baseline project around 8,000 MW renewable capacity by 2015 and a 15,000 MW capacity by 2020. Results also indicate that the 10,000 MW capacity target set for renewable energy by 2012 match very closely with the projections for medium mitigation scenario. An average 25$/t of C price offers around 15 Mt of cumulative carbon mitigation potential by 2015 from renewable energy in the power sector (medium mitigation scenario in our analysis). This leads to renewable capacity achievements close to MNES targets by 2012. Analysis in this paper indicates that India's participation in a global carbon market for 15 Mt mitigation target offers an investment potential of about 3 billion $ under the CDM or any other alternative mechanisms that may come into effect for participation of developing countries in global climate change interventions. Under this scenario, the CDM investment potential forms a substantial 40% of the total investment requirements with a net earning potential of close to 150 million $ from renewable energy CDM projects in the power sector. Some technology specific measures that would form a part of renewable energy operational strategies are outlined here.

TABLE 9.6 Barriers in renewable energy development and penetration

Small hydro power

Economic & technological	Market related	Institutional
➢ High Investment requirements ➢ Remote and dispersed availability of potential ➢ Demand/supply mismatch ➢ Intermittent supply of water; sharing for irrigation- need for back-up technologies raises costs ➢ Power off-take problems due to Grid instabilities	➢ High risk perception of private investor to serve rural market and set up decentralised applications ➢ Subsidy on fossil fuels and irrational electricity tariff structure hinder development ➢ Non-internalisation of socio-environmental externalities in energy pricing affect competitiveness	➢ Lack of information, training and awareness programmes ➢ Non-uniform and unstable policies across states ➢ Non-inclusion in the regulatory framework ➢ Inadequate allocation from state plans and low priority for utilities to take up projects ➢ Low level of capacity building and mobilisation of community participation ➢ Lack of orientation towards providing energy services for decentralised and rural applications

Wind power

Economic & technological	Market related	Institutional
➢ High Investment requirements ➢ Dispersed nature of potential- difficulties in tapping wind energy resource. ➢ Low peak coincidence factor that leads to problems in matching wind availability with load duration curve ➢ Power off-take problems due to Grid instabilities ➢ High reactive power requirements for start-up	➢ Higher charges may be imposed under wheeling contracts on intermittent generators ➢ Fluctuating generation costs create problems in cost recovery under fixed power purchase terms ➢ Subsidy on fossil fuels, non-internalisation of socio-environmental externalities and irrational electricity tariff structure hinder development	➢ Non-availability of infrastructure such as land and access to T&D networks ➢ Long-term un-sustainability of programmes based on fiscal and financial incentives ➢ Not integrated in power sector reforms ➢ Non-uniform and unstable policies across states deters investors

Biomass and cogeneration power

Economic & technological	Market related	Institutional
➢ Inconsistencies in nature of biomass fuel lead to difficulties in conversion ➢ Uncertainties in technological performance ➢ Technical barriers in upgradation of existing sugar mills for cogeneration, synchronisation and feeding electricity to grid ➢ Alternative uses for cogeneration fuel like paper production ➢ Large fund requirements in setting up of commercial biomass fuel (fuel wood) market for afforestation programmes, harvesting and transportation of the fuel.	➢ Unreliable fuel supply ➢ High transaction costs in setting up of biomass fuel market ➢ Difficulties in marketing and pricing of forest products pose challenges for Fuel wood market creation. ➢ Non-remunerative tariff for power export from sugar mills	➢ Land requirement for large-scale biomass cultivation may compete with foodgrain production ➢ Non-uniform and unstable policies across states ➢ Non-inclusion in regulatory framework ➢ Lack of orientation towards providing decentralised, rural energy services ➢ Low replicability of demonstration projects

Solar power

Economic & technological	Market related	Institutional
➢ Very high Investment requirements ➢ Low level of technological maturity ➢ Non-standardisation of technologies leading to low level of reliability ➢ Need for storage/backup technologies for supply during night-time raises costs ➢ Low Peak Coincidence factor ➢ Inadequate maintenance & servicing skills	➢ High-risk perception of private investor ➢ Large pre-investment risks associated with the costs of marketing, contracting and information collection ➢ Trade barriers imposed by high import duties for PV modules. ➢ Subsidy on fossil fuels, non-internalisation of socio-environmental externalities and irrational electricity tariff structure hinder development	➢ High transaction costs in technology commercialisation ➢ Difficulties in technology dissemination due to inadequate marketing infrastructure and sales and services networks ➢ Not integrated in power sector reforms ➢ Difficulties in availability of finance and providing micro-credit access, especially for rural areas ➢ Low replicability of Demonstration projects

9.6.1 Small hydro

Small hydropower development could be integrated with regional development plans, especially for stand-alone systems. Decentralised power generation from stand-alone small hydro sources occurring in remote hilly areas could be taken up as part of rural electrification and poverty alleviation programmes along with upgradation programme of water mills. Measures such as speeding up clearances of private power projects, de-licensing power generation from small hydro and providing investment support would encourage private participation. Adopting a bottom-up approach for technology dissemination would entail setting up of demonstration, training and awareness programmes for community empowerment and local capacity building. A critical issue is providing micro-credit and funding access from decentralised banks.

9.6.2 Wind

Measures need to be undertaken for better operation and maintenance of wind power systems and better technological performance leading to improved capacity utilization. Wind power supply option needs to be included in utility's unit commitment approach. Ensuring grid stability for reliable power off-take will lead to better capacity utilisation. Encouraging private participation would require establishing uniform and stable policy regime across states regarding third-party sale, fixing of tariffs, wheeling and banking of power. Interventions for environmental sustainability enhance wind power penetration. Baseline projections need to be redefined in light of investment requirements and a preparedness plan developed for accelerated penetration under carbon mitigation scenarios.

9.6.3 Biomass and cogeneration

Biomass energy development needs to be integrated with environment and development policies such as wasteland development programmes, poverty alleviation, and rural employment generation programmes. For centralised power generation applications, it is necessary to set up a commercial fuelwood market for ensuring a continuous and reliable fuel supply. Setting up of biomass energy projects would entail empowering local communities and undertaking capacity building programmes. Farmers' co-operatives could be set up in catchment areas for management of plantations. Other issues include increased R&D in advanced biomass conversion technologies such as integrated cycle conversion technologies, and development of advanced manufacturing capabilities for transition from demonstration and pilot-plant stages to commercial stage. For cogeneration projects, power supply needs to be ensured from sugar mills to utilities by using supplementary fuels at the time of non-operation of sugar mills.

9.6.4 Solar

Solar power programmes need to be integrated with regional development and rural electrification programmes. This would involve mobilising community participation in decentralised system development by local capacity building, training and awareness building programmes, and assistance in income generation schemes as part of their economic and social welfare. Technology transfer would be facilitated by removal of trade barriers such as high import duty on PV modules. A critical issue is development of sustainable business plans for ensuring replicability of demonstration projects. Setting up of market infrastructure would involve strong sales and services networks for providing the energy service. Sustainable financial arrangements are critical for success of SPV programmes with a network for micro-credit access. Local financiers should be encouraged to assume part of the credit risk to ensure post project sustainability and replication. Small private dealers could be encouraged to work with local micro-finance organizations or partner with large credit firms.

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