

CO₂ Emissions Mitigation Potential of Solar Home Lighting Systems in India

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ABSTRACT: The clean development mechanism (CDM) of the Kyoto Protocol (KP) provides industrialized (Annex-I) countries with an incentive to invest in emission reduction projects in developing (non-Annex-I) countries to achieve a reduction in carbon dioxide (CO₂) emissions at lowest cost that also promotes sustainable development in the host country. Solar home lighting systems (SHSs) could be of interest under the CDM because they directly displace greenhouse gas (GHG) emissions while contributing to sustainable rural development, if developed correctly. In this study an attempt has been made to estimate the CO₂ emissions mitigation potential of SHSs projects under CDM in India. It is observed that annual CER volumes could reach 0.5 to 1.4 million by 2012 and 3.7 to 9.0 million by 2020. This would require that the government sets the subsidy level for SHSs at a level that allows them to become viable with the CER revenue. From a macro-economic point of view this makes sense if the sustainability benefits are deemed sufficiently high to warrant promotion of this project type.

Keywords: Kyoto Protocol, Clean Development Mechanism, Solar Home Lighting Systems, India

1. INTRODUCTION

The KP to the United Nations Framework Convention on Climate Change (UNFCCC) has opened the market for trading in GHG emissions credits. The CDM has been set up to assist Non-Annex-I countries in achieving sustainable development by promoting GHG reduction projects that generate emission credits (or CERs) for Annex-I countries [1]. There is tremendous interest among Indian project promoters, financing institutions, and other stakeholders in the opportunities emerging out of the CDM. By April 2008, there were 1033 CDM project activities registered by the CDM Executive Board (EB) and they are expected to produce more than 1.25 billion CERs before the end the KP's first commitment period in 2012 in which 333 CDM projects are located in India (cdm.unfccc.int).

India, being a tropical country, is blessed with plenty of sunshine. The average daily solar radiation varies between 4-7 kWh/m² for different parts of the country [2]. There are on an average 250-300 clear sunny days in a year [3]. In spite of the limitations of being a dilute source and intermittent in nature, solar energy has the potential for meeting and supplementing various energy end use activities. SHSs are presently being promoted in India as a domestic lighting option for rural households with no access to grid electricity [3]. The large-scale acceptance of SHSs will depend upon a variety of socio-techno-economic factors. Since the initial cost of the SHSs is relatively higher as compared to other domestic lighting options particularly for low income households in rural areas, the financial viability of an investment on SHS is expected to play a crucial role in its diffusion.

SHSs could become relevant for the CDM because they directly displace GHG emissions

and contribute to sustainable rural development. In this study, an assessment of the theoretical CO₂ mitigation potential of SHSs under CDM has been made. The paper is set out as follows. Section 2 provides some salient features of the Indian programme on the promotion of SHSs. A brief detail of SHS is given in section 3. The discussion how the CDM could mobilize the diffusion of SHS and the estimation of the CO₂ mitigation potential of SHS is discussed in sections 4 and 5 respectively. Section 6 presents a method for the estimation of the potential number of SHS. Section 7 presents the forecast diffusion levels of SHSs under an optimistic CDM and business-as-usual scenario. Section 8 concludes.

2. PROGRAMME ON SHSs IN INDIA

India has one of the world's largest programs for deployment of renewable energy products and systems. Of the total 11,273 MW of renewable energy projects installed in India by December 2007, wind energy contributes 7,845 MW, hydro power 2,046 MW, biomass power and co-generation 1,326 MW, waste to energy 55 MW and solar photovoltaic (SPV) account for 2 MW (grid-interactive) [3]. The key drivers for renewable energy are large untapped potential, demand-supply gap, concern for environment; need to strengthen India's energy security, pressure on high-emission sectors from their stakeholders, and solution for rural electrification. There is an immense scope and potential for the use of SPV technology in India. Fig 1 presents the details of sector-wise use of SPV modules installed so far [3].

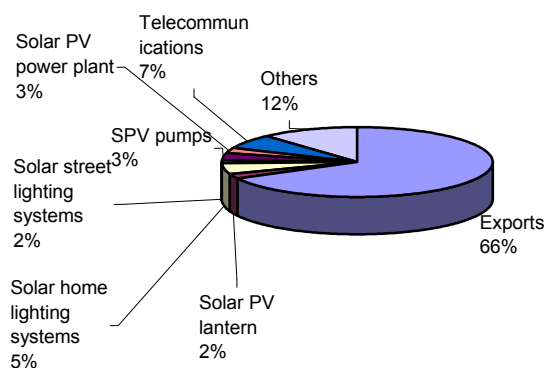


Fig 1. Sector-wise use of solar PV modules (335 MWp capacity; 1.4 million SPV systems)

The Ministry of New and Renewable Energy (MNRE) has made sustained efforts for the deployment of photovoltaic systems in rural areas. A large amount of experience has been gathered on technical, economic, social and management issues. An analysis of the experience shows that SPV technology can be a viable alternative to extension of grid lines to electrify villages, especially in remote and difficult areas [4-5]. The overall reliability of SPV systems is better than the reliability of conventional power supply in rural areas. Applications like SHSs are useful in even those areas which have intermittent electricity supply. A vast number of applications pursued so far have contributed in a significant way to the process of commercialization of photovoltaics in India. Fig 2 presents the annual production and growth of Solar cell and PV module.

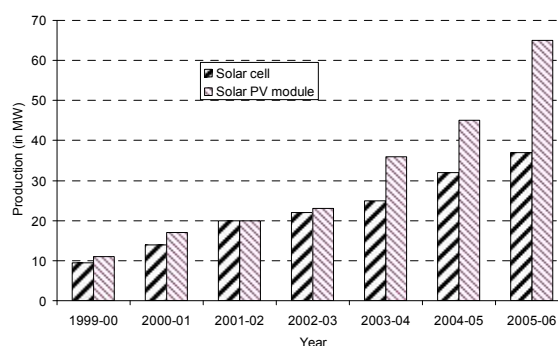


Fig 2. Annual production and growth of solar cell and PV module

The Ministry has laid down detailed specifications of all the SHSs and other systems that are being promoted under the programme. Only those systems, whose prototype has been tested and approved by the authorized test centres as per the specifications are to be accepted for supply under the programme. Five different configurations of SHSs are being promoted by the Ministry: 18Wp PV module (one 9W CFL), 37Wp PV module (Two 9W CFLs or one 9W CFL and a fan) and 74Wp PV module (Four 9W CFLs or two 9W CFL and a fan/TV). Subsidies amount to 50-60% of the investment cost of the system. Despite better favorable conditions for support of SPV products the response to the government programmes to promote SPV systems is poor. Dissemination of SHSs is the most popular SPV systems promoted under the Government programme, but only 363,399 SHSs have been installed so far [3]. Fig

3 presents the time variation of cumulative number of SHSs installed in India.

The key elements of a sustainable rural photovoltaic market include customer satisfaction, affordability, dealer profitability, and effective supply and service chains [6]. There is a limited access of SHSs to the end users. Moreover, barriers such as stiff competition from subsidized conventional energy and lack of technical support for installation and maintenance impede the penetration of these systems [7-10].

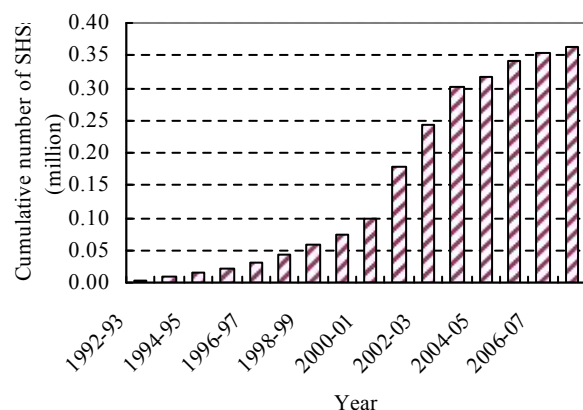


Fig 3. Time variation of cumulative number of SHSs installed

3. SOLAR HOME LIGHTING SYSTEMS

Table 1. Different models of solar home systems commonly used in India

Model	Specification	Basic price (€)	MNES subsidy (€)	User's share (€)
Model – I	18 W _p module, 1 light	103	56	47
Model – II	37 W _p module, 2 lights	181	102	79
Model – III	37 W _p module, 1 light, 1 fan	195	102	93
Model – IV	74 W _p module, 2 lights, 1 fan	323	186	137
Model – V	74 W _p module, 4 lights	318	186	132

4. CDM RULES FOR SMALL SCALE SHS PROJECTS

Small-scale renewable energy and energy efficiency projects are helping to meet the needs of rural people in developing countries, alleviating poverty and fostering sustainable development. However, the low emission reductions per installation are making it difficult for such projects to derive value from participating in CDM. Negotiators of the Marrakesh Accords [11] as well as the CDM EB recognized this problem and adopted simplified

The home lighting systems are powered by solar energy using solar cells that convert solar energy directly to electricity. The electricity is stored in batteries and used for the purpose of lighting whenever required. These systems are useful in non-electrified rural areas and as reliable emergency lighting system for important domestic, commercial and industrial applications. The solar home lighting system is a fixed installation designed for domestic application (see: Fig 4). The system comprises of Solar PV Module (Solar Cells), charge controller, battery and lighting system (lamps and fans). The solar module is installed in the open on roof/terrace - exposed to sunlight and the charge controller and battery are kept inside a protected place in the house. The solar module requires periodic dusting for effective performance. Table 1 presents the different models of SHSs commonly used in India along with their specifications and price (www.mnes.nic.in).

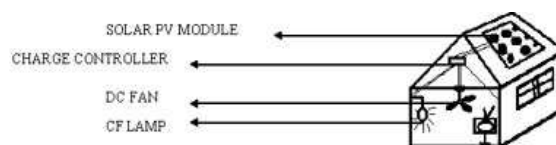


Fig 4. Schematic diagram of a SHS

CDM modalities and procedures for qualifying small-scale projects with regard to renewable energy small scale projects with a maximum output capacity equivalent of up to 15 MW.

Fig 5 presents the number of different project size categories of the 3285 CDM projects submitted until 1st April, 2008 of which 978 projects have been registered by the CDM EB and 85 projects were requesting registration (<http://cdm.unfccc.int>). Out of the 978 projects registered by the EB, 322 projects were located in India. Only 4 projects involve SHSs in which

only one project ‘photovoltaic kits to light up rural households’ from Morocco has been registered by the CDM EB until 1st May 2008. Two projects from India and one project from Bangladesh were at the validation stage in the same period.

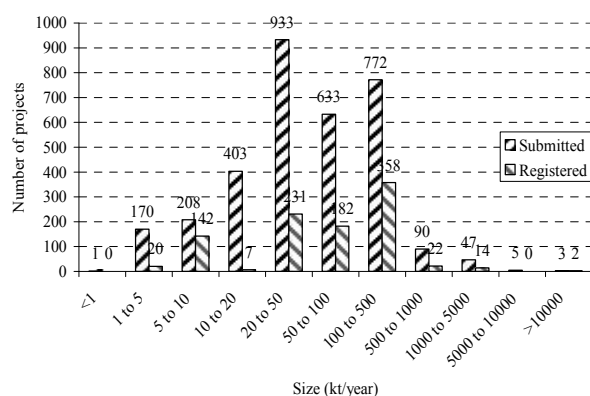


Fig 5. Size categories of submitted and registered CDM projects (Source: cdm.unfccc.int)

4.1 Baseline

The quantification of climate benefits of a project - i.e. the mitigation of GHG emissions-is done by means of a “baseline”. A baseline describes the (theoretical) emissions that would have occurred in case the CDM project was not implemented. The amounts of CERs that can be earned by the project are then calculated as the difference of baseline emissions and project emissions. The selection of the baseline will have a big impact on the amount of emission reductions that can be credited to the installation of SHSs. The CO₂ emissions mitigation benefit associated with a SHS depend upon the type/amount of fuel saved. A SHS usually replaces kerosene in the rural areas of the country [12]. To estimate the CO₂ mitigation potential of SHSs under CDM in the country the small scale methodology I.A *Electricity generation by the user* in its version of 30th September 2005 [13] has been used.

4.2 Additionality

To maintain the environmental integrity of the Kyoto Protocol, CDM credits are given only for activities that would otherwise not be expected to occur [14]. The ‘additionality’ criterion for the CDM is a key to ensure that CDM projects lead to real and additional emission reductions. Even

in the hypothetical case of an off-grid situation where lifecycle costs of the SHSs would be cheaper than all other alternatives, the high upfront investment cost to a rural household in acquiring a SHSs would still be a barrier to widespread market penetration. In terms of costs per kWh in grid connected areas, costs of SHSs will be higher than grid electricity by an order of magnitude and such projects thus be additional at any rate.

4.3 Monitoring

Monitoring under small-scale rules consists in an annual check of all systems or a sample thereof to ensure that they are still operating. Since the installations of SHSs are often widely dispersed in sparsely populated and difficult to reach areas, monitoring costs could make CDM participation prohibitive if each household with a system is visited. Simple and efficient sampling procedures are therefore required. There are two variables that need to be monitored and verified in order to correctly establish emission reductions from SHSs according to small-scale methodology I.A: number of systems operational in the field, and estimated fuel savings per available system.

5. CO₂ MITIGATION POTENTIAL OF SHSs UNDER CDM IN INDIA

The annual CO₂ mitigation potential of a SHS would depend on the type and amount of fuel replaced by SHS. In India, about 56% of Indian households use electricity for lighting, the rural-urban disparity is quite prominent. 43.5% of rural households have access to electricity while the rest rely on kerosene. In contrast, about 87.6% of the urban households use electricity for lighting. According to Census, 2001, 85 million households were without access to electricity in the country, 92% of whom resided in rural areas [15]. In rural India, even in the electrified households, people continue to depend on other energy sources, chiefly kerosene, for lighting which is basically due to poor reliability and quality of the existing supply. Therefore, in this study, it is assumed that due to irregular supply of electricity in most part of India rural households having electric connection will also use SHSs during black hours.

The annual CO₂ emissions mitigation by use of a SHS can therefore be estimated as

$$CE_{sl} = H_{sl} SF_k \left[CV_k CEF_k FCO_k \left(\frac{44}{12} \right) \right] \quad (1)$$

where H_{sl} represents the annual number of hours of illumination provided by a SHS, SF_k the specific kerosene consumption (in l/hr) in the hurricane lantern, CV_k the calorific value of kerosene (in MJ/l), CEF_k the carbon emission factor of kerosene (in kg/MJ), and FCO_k the fraction of carbon oxidized during kerosene combustion.

What is now the financial attractiveness of a SHS based CDM project? The monetary benefits associated with a SHS depend upon the monetary value of kerosene saved which is the product of annual fuel savings and the price of the fuel saved and the difference in investment costs between the common hurricane lantern and the SHS. The difference between the cumulative present value of the benefits (due to the substitution of the kerosene and the avoided costs of hurricane lantern replacement at the end of its technical lifetime, if this ends before the end of technical lifetime of the SHS) and the costs (i. e. capital cost and annual repair and maintenance

cost) is the net present value (NPV) of the investment on the SHS. To estimate the NPV of SHS based project background parameters have been taken from references [12, 14, 16]. In India, kerosene is sold for domestic use under a quota system, which is heavily subsidized [17]. Therefore two prices, subsidized price (0.19 €/litre) and market price (0.37 €/litre) of kerosene has been used for the estimates presented in this study. It is observed that under the scenario with kerosene price of 0.37 € per litre the NPV of an investment in the SHSs is attractive (Table 2), whereas with the subsidized price of kerosene (i. e. 0.19 € per litre) the NPV is not attractive, thus showing additionality for the CDM. The break-even price of CERs has been estimated at 46 € in case of SHSs. While the use of SHS would cost more than current CER prices on the world market that lie between 5 and 15 € depending on the quality of the project, the use of SHSs would only require a relatively limited amount of subsidy to make them viable CDM projects. This however, does not include other barriers to project implementation such as the fear of users not to receive maintenance in case of breakdown and the unfamiliarity of the SPV technology.

Table 2. Financial attractiveness of an investment on SHS in India depending on kerosene price and subsidy rates and CER revenues

Indicators	Unit	Kerosene price and subsidies		
		Price of kerosene: (0.19 €/litre)	Price of kerosene: (0.37 €/litre)	Price of kerosene: (0.19 €/litre + 37% subsidy)
Simple payback period	Years	18	6.8	8.5
Benefit to cost ratio	---	0.6	1.2	1
Net present value (NPV)	Rs	-95	45	0
Cost per CER	€	46	---	---

6. POTENTIAL OF SHS SYSTEMS IN INDIA

The potential of SHSs essentially depends on availability and accessibility of solar radiation, and affordability of the user to invest in a SHS. Using the above mentioned factors, the total potential number, of SHS (N_{shs}) can be estimated as

$$N_{shs} = \xi_l \sum_{i=1}^n N_i \{ \xi_{2i} \xi_{3ri} \} \quad (2)$$

where N_i represents the total number of households in the i^{th} state, ξ_l the fraction of households living in the geographical areas with

adequate solar radiation availability, ξ_{2i} the fraction of total households living in the rural areas of the i^{th} state, and ξ_{3ri} the fraction of households above the poverty line in rural area in the i^{th} state.

Sufficient solar radiation is necessary for all devices based on solar energy. In this study only the area with daily solar radiation greater than 4 kWh/m² have been considered for potential estimation of SHSs. Ideally, detailed solar radiation data for each location should be used in evaluating the potential of these technologies. On a macro level, seven north-eastern states and the northern states of Jammu and Kashmir, Himachal

Pradesh and Uttaranchal in India can be given low priority in the process of identification of niche areas for installation of SHSs. As already shown in Table 1 the market price of a SHS varies from 103 € (for Model-I) to 323 € (for Model-IV). It is expected that with high volume production and induction of new and improved technologies should lead to reduction in costs of SPV modules [18]. As the price of SPV modules will be further reduced due to learning effect the capital cost of the SHSs is expected to decrease. Moreover, the economics of SPV systems is expected to be attractive with the increase in the price(s) of commercial fuel(s) substituted by these systems. MNRE provides a capital subsidy of 56 € (for Model-I) to 186 € (for Models-IV&V) on the purchase of SHSs. In addition to this some state government also provides additional subsidy to the user. Therefore, in the case of SHSs it is also assumed that all households above poverty line can afford to purchase a SHS. For the estimation of the CO₂ mitigation potential of SHSs in this study the commonly used designs of SHS (Model – II) have been used. However, in practice households can use other designs as per their requirement and affordability for domestic lighting.

The use of the framework presented in the earlier section(s) requires detailed data on a variety of input parameters. Table 3 presents the distribution of households in rural area of India. The state-wise population below poverty line in the rural area is also given in the same table. Using equation (2) the estimated potential of SHSs in India has been estimated to be 97 million (Table 3). It is observed that out of 138 million rural household in India 97 million households can use SHSs. It may be noted that Uttar Pradesh has a highest potential of SHSs (14 million) followed by Andhra Pradesh (11 million) and Maharashtra (9 million).

Using equations (1) and (2) the theoretical maximum CO₂ mitigation potential of SHSs can be estimated as

$$CDM_{spv,l} = \left[\xi_l \sum_{i=1}^n N_i \{ \xi_{2i} \xi_{3ri} \} \right] \left[H_{sl} SF_k \left\{ CV_k CEF_k FCO_k \left(\frac{44}{12} \right) \right\} \right] \quad (3)$$

Table 3 present the theoretical mitigation potential of SHSs in India. The CO₂ mitigation of SHSs has been estimated at 23 million CERs annually. Table 3 also gives a breakdown according to states. It may be noted that Uttar Pradesh has the maximum mitigation potential (3.4 mt CO₂) followed by Andhra Pradesh (2.6 mt CO₂), Maharashtra (2 mt CO₂) etc.

7. DIFFUSION OF SHSs IN INDIA

Empirical studies have shown that in a variety of situations the growth of a technology over time may conform to an S-shaped curve, which is a combination of simple and modified exponential curves [19]. The S-shaped curves characterized by a slow initial growth, followed by rapid growth after a certain take-off point and then again a slow growth towards a finite upper limit to the dissemination [20]. Therefore, a logistic model is used to estimate the theoretical cumulative number of SHSs considered in the study at different time periods. The use of SHSs within the electrified households is still questionable in near future. It may be possible that people will no longer use the SHSs once they will get grid connection. Using the development path of China as an analogy it is assumed that in the year 2019 India will achieve 100% rural electrification. It may be noted that after getting the reliable electricity supply through the grid the households will no longer buy the SHSs. However, users who already have the SHS will use it upto the useful lifetime of the system.

Fig 6 represents the projected time variation of the cumulative number of SHSs using the logistic model considered in the study. Two cases such as standard scenario (SS) and optimistic scenario (OS) are presented. The values of the regression coefficients using logistic model have been estimated by regression of the time series data for the installation of SHSs (Fig 3) extracted from the annual reports of the MNRE. In the optimistic scenario it is assumed that, in the past, if the diffusion of SHSs would have been driven by the market forces instead of subsidies then the cumulative number of installation of SHSs would be three times more than the actual level [21-23]. Our results indicate that in India, even with highly favorable assumptions, the dissemination of SHSs for domestic lighting is not likely to reach its maximum estimated potential in another 20 years. But all these time periods are not

relevant for the CDM whose current endpoint is 2012 and which may only be able to live longer if post-2012 negotiations retain an emission target based policy regime. However, CDM

could be used as a tool to foster the dissemination of SHSs in the country. It could accelerate the diffusion process.

Table 3. Estimated potential and theoretical mitigation potential of SHSs in India

State	No. of households in rural India (million)	State-wise population below poverty line in rural India (%)	Estimated potential of SHSs (million)	Theoretical mitigation potential (million CERs)
Andhra Pradesh	12.4	11.1	11.0	2.65
Assam	4.3	40.1	2.6	0.62
Bihar	12.3	44.3	6.9	1.64
Chhattisgarh	3.3	37.1	2.1	0.49
Delhi	0.2	0.4	0.2	0.05
Goa	0.1	1.3	0.1	0.04
Gujarat	6.1	13.2	5.3	1.27
Haryana	2.6	8.3	2.4	0.58
Jharkhand	3.7	44.3	2.1	0.50
Karnataka	6.9	17.4	5.7	1.36
Kerala	5.0	9.4	4.5	1.08
Madhya Pradesh	8.0	37.1	5.0	1.21
Maharashtra	11.3	23.7	8.6	2.06
Orissa	6.6	48.0	3.4	0.82
Punjab	2.9	6.4	2.7	0.65
Rajasthan	7.1	13.7	6.2	1.48
Tamil Nadu	8.2	20.5	6.5	1.57
Uttar Pradesh	20.4	31.2	14.0	3.37
West Bengal	11.4	31.8	7.8	1.87
Total			97.1	23.30

Source: <http://www.censusindia.net/>

Source: <http://www.agricoop.nic.in/Statatglance2004/EcoIndicator.pdf>

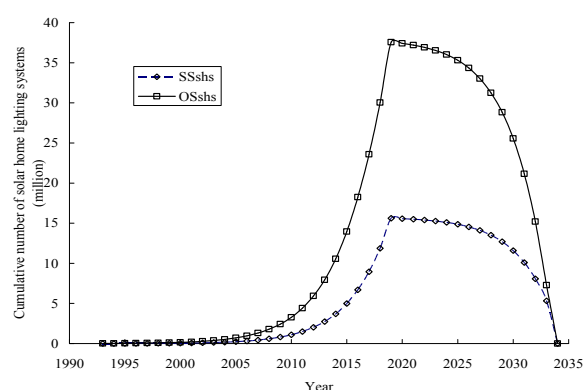


Fig 6. Time variation of cumulative number of installation of solar home lighting systems in India using Logistic model

The projected values of the cumulative number of SHSs and likely CER generation using the logistic model are presented in Table 4. It may be noted that with the current trend of dissemination of SHSs in the country around 2 million SHSs could be installed up to the end of

first crediting period in the SS scenario whereas in the OS scenario around 6 million SHSs could be installed. Upto the year 2020, more than 15 million SHSs are expected to be installed that would generate more than 3.5 million CERs in the SS scenario whereas in the OS scenario, more than 37 million SHSs are expected to be installed that would generate around 9 million CERs.

8. CONCLUSIONS

Our estimates indicate that, there is a vast theoretical potential of CO₂ mitigation by the use of SHSs for domestic lighting in India. The theoretical potential number of SHSs has been estimated at 97 million. The annual CER potential of SHSs in India could theoretically reach 35 million tonnes. Under more realistic assumptions about diffusion of SPV technologies based on past experiences with the government-run programmes, annual CER volumes by 2012 could reach 0.5 to 1.4 million and by 2020, 4 to 9

million. CDM could help to achieve the maximum utilization potential more rapidly as compared to the current diffusion trend if supportive policies are introduced. However, it is

questionable whether such a policy would be an optimal use of scarce resources, given the fact that CDM projects in other sectors are much more attractive.

Table 4. Projected values of the cumulative number of SHSs and associated CER generation

Year	Projected values of the cumulative number of SHSs (million)		Projected values of the cumulative installed capacity of SHSs (MWp)		Projected values of the annual CER generation (million)	
	SS	OS	SS	OS	SS	OS
2008	0.6	1.8	22.1	66.0	0.1	0.4
2012	2.0	5.9	75.1	219.7	0.5	1.4
2016	6.7	18.3	247.8	675.5	1.6	4.4
2020	15.6	37.4	575.8	1384.2	3.7	9.0

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