Available online at www.sciencedirect.com
SCIENCE DIRECT®

RENEWABLE
& SUSTAINABLE
ENERGY REVIEWS

PERGAMON Renewable and Sustainable Energy Reviews 7 (2003) 83–98
www.elsevier.com/locate/rser

# Potential of Kyoto Protocol Clean Development Mechanism in transfer of clean energy technologies to Small Island Developing States: case study of Cape Verde

N. Duic, L.M. Alves, F. Chen *, M. da Graça Carvalho

*Research Group on Energy and Sustainable Development, Instituto Superior Técnico, Av. Rovisco Pais, 1049-001 Lisbon, Portugal*

Received 31 October 2002; accepted 5 November 2002

**Abstract**

The developed countries committed to greenhouse gases reductions under the aegis of the Kyoto Protocol of the United Nations Framework Convention on Climate Change will, in order to reduce the cost of meeting their commitments, depend on cheaper reductions elsewhere. The reductions will be materialised through several mechanisms of the Kyoto Protocol: the Emission Trade, Joint Implementation and Clean Development Mechanisms. The Mechanisms will carry a strong financial incentive for the dissemination of clean energy technologies, including renewable energy technologies and especially technologies that increase the efficiency of energy transformation and consume. This paper concentrates on the case typical of more than 30 Small Island Developing States, that all have a common situation of relatively low carbon intensity and high price of fossil fuel based economies, and on how the Clean Development Mechanism is expected to influence the transfer of clean energy technologies under the aegis of the Kyoto Protocol. The paper shows, by assessing a case of a small island, that although the emission reduction on global scale is small, there is great potential for establishing a strong market presence of renewable energy technologies in developing countries. A typical small island electricity generation is heavily dependent on Diesel engines, expensive and polluting, but still the most appropriate on such a small scale. This paper studies implications of different scenaria of development of electrical energy system on the island of Santiago, Cape Verde. An estimate of electricity demand for the period until 2030 is given. Baseline scenarium based on Diesel capacity is compared to a renewable energy scenario envisaging 30% of the elec-

* Corresponding author. Tel.: +351-218417592; fax: +351-218475545.
*E-mail address:* cfz@navier.ist.utl.pt (F. Chen).

1364-0321/03/$ - see front matter 
doi:10.1016/S1364-0321(02)00062-X

tricity generated by the wind power, and the other supply side efficiency scenario replacing Diesel capacity with combined cycle. The declining price of clean energy technologies is taken into account. The possible influence of the Clean Development Mechanism is assessed. The potential for financing the technology transfer is quantified and its influence on different electricity system planning scenarios estimated.


*Keywords:* Kyoto protocol; Clean development mechanism; Islands; Transfer of clean energy technologies

**Contents**



## 1. Introduction

In the course of the last two decades it became clear that the carbon dioxide concentration in the atmosphere has significantly increased since the early 19th century, which may, due to the greenhouse gas effect, cause significant global warming in the coming decades. Acknowledging that, the United Nations have started a mitigation process at the "Earth Summit" in Rio de Janeiro in 1992 with the UN Framework Convention on Climate Change (UNFCCC). The process was later continued by yearly Conference of the Parties sessions starting in 1995. The Kyoto Protocol to the UNFCCC was signed in 1997 at the third such session. The Convention is signed and ratified by 186 countries, while Kyoto Protocol is signed and/or acceded by a total of 120 countries and ratified by 96 countries representing 37% of the GHG emissions of the Annex I Parties [1,2]. The Protocol will enter into force on the 90th day after the date on which not less than 55 Parties to the Convention, incorporating Annex I Parties which accounted in total for at least 55% of the total carbon dioxide emissions for 1990 from that group, have deposited their instruments of ratification, acceptance, approval or accession.

The Kyoto Protocol carries legally binding greenhouse gas (GHG) emission targets for the so-called Annex I (to the UNFCCC) parties, or more precisely, Annex B (to the Protocol). Those, mainly developed countries and economies in transition are obliged to reduce their overall GHG emission level by at least 5% below 1990 levels during the commitment period 2008–2012. The Kyoto Protocol allows Annex B parties to meet these commitments partly by achieving emission reductions abroad, enabling them to improve the cost-effectiveness of emission reduction, because reducing GHG emissions at an emission source in another country may be cheaper than doing so domestically. There are three cross-border emission reduction mechanisms that Annex B can apply in order to reduce the cost of their commitments: Emissions Trading (ET), Joint Implementation (JI) or Clean Development Mechanism (CDM). Within the Annex B region a country may purchase assigned amounts (AAs) by means of ET, or emission reduction units (ERUs) from JI projects conducted in another Annex B country. An Annex B party may also buy certified emission reductions (CERs) from developing countries by means of CDM projects. Policy makers in Annex B countries have to decide how much money to invest in which of the flexible Kyoto mechanisms, depending on estimate which mechanism will be most effective and efficient.

Several studies find that the marginal costs of GHG emission reduction vary greatly among the UNFCCC parties [3–5]. Since the process of global warming is caused by the total accumulation of greenhouse gases in the atmosphere, it does not matter where these pollutants are emitted or reduced. If parties could use these cost differences, the overall costs of mitigating climate change would be reduced by half compared with domestic action only [3,4]. The paper [6] estimated the potential demand and supply of GHG emission reduction projects with a main emphasis on the supply of CDM projects from developing countries (DCs). It is concluded that the demand for GHG emission reduction projects from Annex B countries, including domestic actions in Annex B countries, JI projects, Emission Trading and CDM projects in total will be between about 500 and 1300 MtC in 2010. Jepma et al. [7] analysed the potential market for project-based international cooperation within the framework of the Kyoto Protocol. With the help of existing cost data, it is shown that the scope for cost savings by using the project-based flexible instruments of the Protocol is considerable, and that a multibillion dollar carbon credit market can emerge.

Although there are several functioning carbon markets [8], that traded more than 10 $MtCO_2e$, and expected to quadruple in 2002, they will only properly develop after 2008 [9]. Until then the market will only partially be able to help the policy makers to make strategic investment decisions that have to be taken in the short term, especially since CERs that accrue from CDM projects before 2008 could be banked in order to use them for the commitment period 2008–2012. Zhang et al. [10] suggested that public funds could be used to complement private investment via the CDM, thus enhancing market functions of such an investment. The Kyoto Protocol was analysed [11] from the perspective of developing countries. The literature on the Protocol's impact indicates that Annex B countries will benefit from an emissions trading regime and the benefit is highest when non-Annex B countries are also included in the trading system.

Several environmental economists claim that emission reduction entitlements from ET will be more environmentally sound and cheaper than those from JI or CDM [12–14]. However, contrary to their findings, some authors are arguing that JI and CDM will be more effective, efficient and politically acceptable than ET in implementing the Kyoto protocol [15–18]. This paper will argue that the CDM may add to economic viability of projects that are already economically sound, while facilitating the Technology Transfer of clean energy technologies to Small Island Developing States. Another paper [19] analysed the capacity of the proposed mechanisms of the Kyoto Protocol to promote investment in renewable energy technologies (RETs). The results show that RETs have great capacity to contribute to other aspects of sustainable development and vast technical potential to reduce GHG emissions. Appropriate public–private linkage would be necessary in order to bring the CDM into full play.

This paper will show how the Clean Development Mechanism could function in the case of a small insular developing country, Cape Verde. The country belongs to the group of Small Island Developing States (SIDS) and the group of the Least Developed Countries (LDC), in a low carbon intensive economy based on an expensive small-scale energy system [20]. In order to simplify the example, only one of the energy systems will be taken into account, the biggest one, the electricity generation on the island of Santiago. That system will be assessed in detail, giving profound knowledge of the influence of the potential CDM project. The results could then be used in similar cases.

## 2. The case of Santiago, Cape Verde

Cape Verde is a small island country situated in the Atlantic Ocean, off the West African coast. It has a population of 450,000 spread over nine islands. The population is very young with a high birth rate of 33 per thousand and low mortality rate of seven per thousand, but with the fertility rate, still high–four born children per woman, starting to fall. Since the islands are not managing to provide employment opportunities for the demographic population growth emigration is widespread. Due to the uneven development of different islands there is also important internal migration, mainly from rural areas to urban areas on main islands, Santiago and São Vicente, and also to the island of Sal because of its international airport and tourism developments.

Subsistence farming is the main occupation for most of the rural population, currently half of the population. The rural areas are saturated and it is presumed that the new population stemming from the demographic growth in rural areas will migrate to urban areas or abroad.

Internal migrations will follow the patterns of economic growth, which is relatively hard to predict. A very strong employer in Cape Verde is the administration, and since only a limited level of decentralisation is predicted, the capital Praia will be the strongest magnet for the surplus coming from the saturated rural areas. Tourism is creating another set of growth centres, depending on infrastructure, transport, health level and attraction of certain places. Sal already has strong attraction in the international airport, the best tourist infrastructure already in place and a currently relatively small number of inhabitants. Neighbouring Boavista has started to develop its great tourist potential. Santo Antão, Fogo and Brava might develop a rural tourist industry if they become more accessible. The tourist arrivals to Cape Verde were 83,000 in 2000, growing by 24% from the previous year. Tourism is already making 4% of GDP. The island of São Vicente and its main town Mindelo was for a long time the economic powerhouse of Cape Verde, but it is now losing its prestige. Nevertheless, it is still expected to attract rural surplus from northern islands of Santo Antão and São Nicolau.

The island of Santiago, where the capital Praia is located, already holds 55% of the population of Cape Verde, and will pass 60% in 2030. Most of this growth will continue to go to Praia as it has since independence created job opportunities in the capital, so Praia will pass the 150,000 mark by 2010 (30%) and 300,000 by 2030 (50%) unless there is a strong investment in decentralisation.

Cape Verde has a relatively high nominal GDP per capita of 1330 USD (2000) [21], but a significant part of it is due to remittances from migrant workers, which means that when the links start to wither, the main income source will disappear. The purchase power parity based GDP was estimated to be 4860 USD/capita in 2000 [22].

The lack of natural resources is partially assuaged by a relatively high level of literacy (74%) [22], which is reaching developed countries' levels for the population younger than 20, and a nearly general spread of elementary education. The comparative advantage of a well-educated population is currently used mostly for labour export.

The GDP growth has averaged 5.5% between 1985–89, 3.8% between 1990–94, and has recently picked up to 7.5% between 1995–99. Nevertheless, such exceptional growth is mainly due to the capital inflow induced by the privatisation. The long-term growth is expected to average a more conservative 4.7% until 2004, according to World Bank [21]. For the purposes of the CDM analysis this paper assumed growth of 4.5% between 2005–09, 4% between 2010–14, and 3.5% until 2030, still a high rate for a country without any absolute advantage.

One of the most important growth sectors will be the production of desalinised water, which will grow 20 fold between 1996 and 2012, to 7.6 million $m^3$ per year, due to lack of water resources. Desalinisation will then create a strong growth in electricity demand.

## 3. Electricity generation

Apart from the island of São Vicente the electricity production in Cape Verde was until recently being developed locally, without understanding the positive effects of grid connection. The electricity consumption per capita has grown only from 55 kWh in 1980 to 104 kWh in 1996 [23] with the island of Santiago having per capita consumption of 220 kWh in 1996 and 326 kWh in 2000. That is expected to grow to 720 kWh in 2010 and 2700 kWh in 2030. Such exponential growth will be caused by further electrification of the island, strong growth of the population due to demographic growth and net immigration, already reaching the limits of water resources that will have to be replaced more and more by desalinised water and general economical growth.

Currently only 39% of the Santiago island population is connected to the electricity grid, mainly in the capital Praia. That is expected to grow to 68% in 2010 and 92% in 2030. Certain parts of the hard to reach and poor rural population will most probably be left out of the electrification, but that might change as the poor rural population increasingly moves to towns while the richer population builds second homes in rural zones. The ELECTRA plans are much more optimistic, planning to connect 98% of the population of the city of Praia, 37% of rural part of the Praia district, 86% of population of São Domingos, 70% of Santa Catarina district, 69% of Santa Cruz, 88% of São Miguel and 79% of the population of the Tarrafal district. It is hard to say how that can be done in such a short period of time. This paper has predicted a progress in electrification rate shown in Fig. 1.

There are at the moment more than ten independent electricity grids on the island of Santiago, but the process of extending the Praia based network all over the island has started in 1999 by connecting São Domingos. Even though this paper has predicted connecting Assomada only in 2010, now it seems that the new owner of the electricity utility ELECTRA will push for connection sooner. We have assumed the connection of Pedra Badejo in 2015, Calheta in 2017 and Tarrafal in 2020 reaching the northernmost end of the island. We have not assumed connecting Santiago with neighbouring islands Maio and Fogo before 2030, since most probably such connections would not yet be commercially viable, considering the relatively low demand on those two islands.

Judging from the growth in demand and problems in covering it by production, with high loss of load probability in the Praia network, any new capacity built automatically creates new demand. With the conservative growth forecast the main Santiago electricity network spreading from Praia will have to satisfy the demand of 200

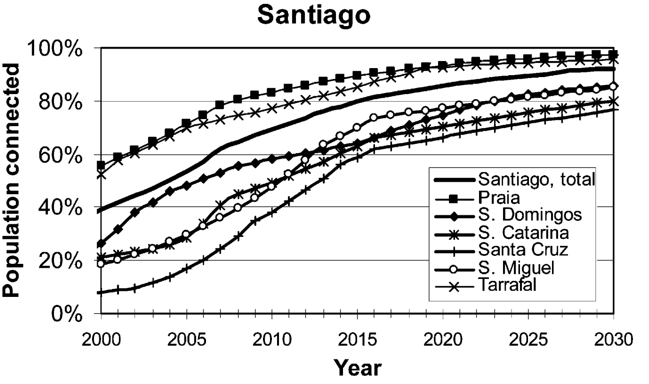


Fig. 1. Expected electrification rates, island of Santiago, per district.

GWh in 2010 and 1100 GWh in 2030. That demand will stay relatively stable during around the year since there are no strong seasonal changes, while the daily variations will be somehow damped by the desalinisation influence.

The peak load in the main network will nevertheless grow from 10.6 MW in 2000 to 33 MW in 2010 and 200 MW in 2030. Table 1 shows basic electricity demand data. Currently, the demand in the main network is covered by two power plants, one in Praia, with 10 MW of Diesel capacity, and the new power plant of Palmarejo, with one Diesel block of 4400 kW already in production in 2000, and another one planned for 2002.

According to the study done in 1997 [24] that demand will mostly be satisfied by the Diesel capacity, with 1.8 MW of wind power already planned for 2003. Such an approach is based on the fact that although some islands of Cape Verde have superb wind conditions, this is not true for most locations on the island of Santiago. Already installed, 900 kW of wind power at San Felipe close to Praia has given the average wind velocity of 8.6 m/s, which might look high by European standards, but with considerably higher investment costs, that yields an electricity price that is only on the edge of economic viability.

The baseline scenario, based on the latter study, envisages installation of eight Diesel blocks of 4 MW between 1999 and 2008 to cover the demand. In the beginning such a block will be more than 20% of the network installed capacity, but since there is an urgent need of increasing capacity and there is a large hidden demand that will reveal only with the growth of installed capacity, such a situation is justified by the lower cost of unit capacity for bigger units.

After the year 2008 the units installed were of 6.6 MW, 12 between 2009 and 2020, and 28 between 2021–30. After 2018 it might be cheaper to install larger blocks than 6.6 MW, but the logic of Patou's study [24] was followed.

The total installed capacity connected to the main grid will reach 53 MW in 2010 and 260 MW in 2030, nearly all of it Diesel.

Diesel has several advantages for Cape Verde. It is a relatively simple technology that has been used for a long time in Cape Verde and in similar situations, there is local know-how in operating and maintaining Diesel plants and infrastructure for

Table 1
Electricity production and consumption in Santiago

| | 2000 | 2010 | 2020 | 2030 |
|---|---|---|---|---|
| Electrification rate, % | 39 | 68 | 85 | 92 |
| Demand, main netw., GWh | 69 | 200 | 521 | 1100 |
| Demand, Santiago, GWh | 77 | 212 | 521 | 1100 |
| Peak load, main network MW | 10.6 | 33 | 86 | 204 |
| Consumption, main network kWh/capita | 560 | 860 | 1500 | 2700 |
| Consumption, Santiago, kWh/capita | 326 | 720 | 1500 | 2700 |
| Consumption, main network kWh/person connected | 1004 | 1140 | 1740 | 3000 |
| Consumption, Santiago, kWh/person connected | 833 | 1040 | 1740 | 3000 |

fuel handling already in place. The main disadvantage for Cape Verde is the highly oscillating price of fuel, which is currently very high and which is the most important ingredient in the price of electricity produced from that technology. The ecological concern is more of a global reach, since Diesel technology has a relatively high intensity of GHG per unit product.

There are many different ways in which emissions of GHG could be reduced, but we have decided to concentrate on two technologies that are relatively commercial, readily available and large scale in GHG reduction. The first is wind power, for which Cape Verde (though not the island of Santiago) has superb conditions and relatively good experience and popularity among local stakeholders. The second is combined cycle electricity production, aimed at increasing the efficiency of fossil fuel technologies. That technology although fully commercial in developed countries has its drawbacks for Cape Verde. It is relatively complicated technology to maintain that would require building up of local know how from scratch. It is still not economically viable at this level of load, but it will get viable in several years time. It would require setting up a system of supply of completely new fuel; the best of all liquid fuels would be kerosene. Judging from comparable cases in other countries that have already passed the threshold of viability there will be no combined cycle application unless there is some external help in reducing the barriers, possibly from the UNFCCC process.

The wind scenario envisages the production of 30% electricity from wind power starting from 2006. After the second phase of wind power installation has been accomplished in 2003, there would be construction of 2.4 MW each year between 2004 and 2008 and again in 2010 resulting in nearly 20 MW of installed wind power by 2010. During the decade 2011–20 another 34 MW would be put into exploitation bringing the total to 55 MW, including the decommissioning of Danida I. By the year 2030 the total installed wind capacity on the island of Santiago would reach 118 MW. That would enable the production of around 30% of electricity from wind and to reduce the emission of $CO_2$ from electricity production by the same percentage. The main drawback of this scenario is that installing wind turbines will not significantly reduce the Diesel capacity needed to satisfy the reserve. The wind was taken into account for guaranteed supply with only 4% of its power. The reserve was taken into account in the same way as in the baseline scenario, having in reserve at least the two largest blocks (N-2 criteria) and at least 15% of installed capacity, whichever criterion is larger. Such an approach would significantly increase the electricity supply security, since now the Praia system is run with N-1 criteria at the most. Fig. 2 shows the change of the installed capacity for three scenaria.

The problems of grid stability are not addressed here, but the installation of variable pitch wind turbines with synchronous generator has recently become off-the-shelf technology, permitting, with some additional equipment, high instantaneous penetrations of wind electricity. The model envisaged no energy rejection and load factors based on historical values.

The third scenario builds on the 30% wind scenario, but tries to increase the efficiency of fossil fuel technology by applying the combined cycle (CC). It is clear from the market supply of gas turbines that their price starts to fall after the turbine

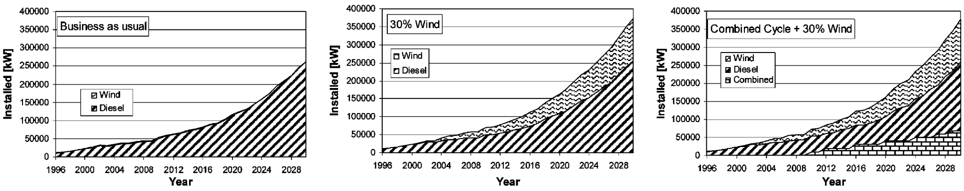


Fig. 2. Installed capacity for three scenaria—wind does not reduce significantly the installed diesel capacity needed.

power passes the 5 MW mark. In conjunction with the steam turbine, which normally makes one third of the total power of the combined cycle power plant, 10 MW blocks where chosen for the Santiago network. The first block would be built only when that falls to only 15% of the installed power, which is forecast to happen only in 2010. From then on, CC blocks would be used for base electricity production, which for Praia network accounted for 77% of the total production in 1997. If the average wind capacity is put to 37% of its nominal, as the previous experience shows, and with the expected LDC curve for the Santiago network, the average maximum production that could be covered from CC if installing CC to cover all base load, would be up to 67%. The actual electricity production by the combined cycle restrained in the described way would be around 47%. Since desalinisation will only increase its share of electricity consumption, and can be used as a demand equaliser, the base load share could only increase, though that was not taken into account. New combined cycle 10 MW blocks will be needed to cover the base load in 2012, 2016, 2020, 2024, 2027 and 2029, bringing the total to 70 MW.

Diesel capacity will be used to cover the peak production and to cover the reserve needed to satisfy both N-2 and 15% criteria. As in two previous scenarios in the beginning the blocks of 4 MW are installed, in all eight until 2008. After that year the blocks of 6.6 MW are installed, but with much lower frequency than in previous two scenarios. Only five are installed until 2020, seven less than in the baseline scenario and six less than 30% wind scenario. Between 2021 and 2030 a further 23 6.6 MW blocks are planned for installation, five fewer than in the baseline scenario and 30% wind as well. In the end of the observed period in 2030 there would be 190 MW of Diesel capacity in use. Fig. 2 shows the change of the installed capacity for three scenarios and Fig. 3 electricity production per technology.

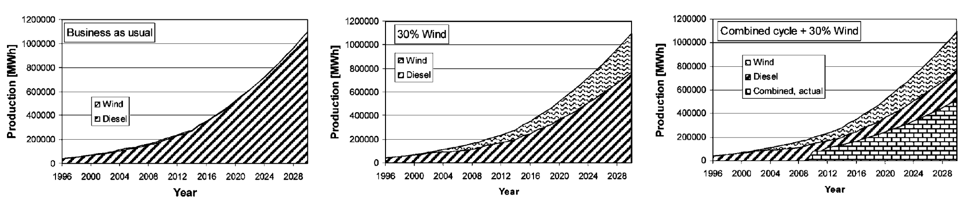


Fig. 3. Electricity production for three scenaria.

## 4. The influence of clean development mechanism

In the year 2000 electricity production on the island of Santiago is expected to have emitted some 50 kt of $CO_2$. In the case of baseline that would increase threefold by 2010, further to 388 kt in 2020 and to 825 kt in 2030. The 30% wind share in electricity production would decrease that for 30 and 47% of combined cycle share in the electricity production would reduce it further by 15%, as shown in Fig. 4.

In the case that such a reduction of GHG emission is facilitated through the Clean Development Mechanism (CDM) of the UNFCCC process, that might result in a significant amount of emission certificates that could then be traded or used by the investor country. It was assumed here that the baseline scenario can be used as CDM baseline, and all the savings from that level can be used as tradable certificates. It was also assumed that all emission reduction was linked to investment made from an Annex B country, which in the case of Cape Verde is practicable, since the power utility Electra is partly owned by Portuguese power utility EDP.

It is expected that the price of certificates will reach 5–15 €/t$CO_2$e when the budget period starts. OECD has predicted that the price of reducing the emission in case of completely free trade of certificates would be 25 €/t$CO_2$e [3], while [4] and [25] assume the price of traded emission of 17 €/t$CO_2$e. The price used in this paper is the average mitigation price in case of free trade (25 €/t$CO_2$e) to show potential CDM value of emission reduction as shown in Fig. 5.

The main advantage of the Diesel technology in Cape Verde is that there is infrastructure already in place. That causes that the investment cost of kW Diesel power is only 600 € (Table 2), while the investment cost of Wind kW is nearly double its cost in for example Denmark, due to high connection and infrastructure costs, or 1325 €/kW. The investment cost of the combined cycle is estimated at 850 €/kW, which is more than technology range of 450–650 €/kW [26]. On the positive side, it is envisaged to run combined cycle blocks on kerosene, which is already handled by Cape Verde.

For the average load factor of 45% the electricity produced from Diesel engine is estimated to cost 8 EU¢/kWh. The wind electricity cost is estimated at 9 EU¢/kWh, which is due to a much higher investment cost. The cost of electricity from the

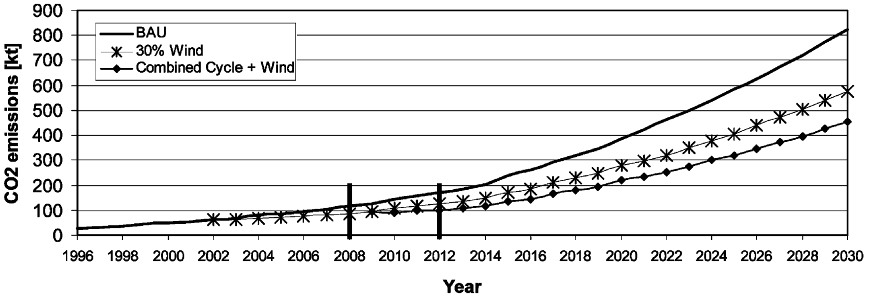


Fig. 4. $CO_2$ emissions for the three scenaria.

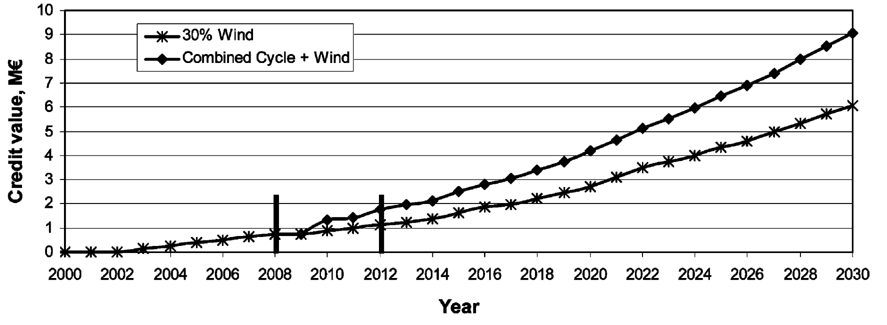


Fig. 5. Potential CDM value based on estimate of 25 €/t$CO_2$ (based on OECD study in case of emission trading).

Table 2
Price of different technologies for electricity production

| Technology | Investment cost €/kW | Electricity cost EU¢/kWh |
|---|---|---|
| Diesel | 600 | 8 |
| Wind | 1325 | 9 |
| Combined cycle | 850 | 6 |

combined cycle kerosene fired 10 MW blocks is guessed to be 6 EU¢/kWh based on an 80% load factor.

Costwise, two more scenarios were taken into account. The wind technology price has fallen rapidly during the last two decades [26]. A continuous technology price fall of 1.5% yearly was assumed during the following 30 years. The first scenario is the same as 30% wind scenario but with declining prices, and the second is like the combined cycle scenario with 30% wind plus the declining prices for wind technology.

The price of electricity produced from Diesel engines is adjusted for the load factor, since Diesel has to be kept idle while there is wind, in order to keep the guaranteed reserve capacity. In the case of 30% wind scenario that will increase the price of Diesel electricity to 9 EU¢/kWh, while for the combined cycle scenario the price will eventually increase to 12 EU¢/kWh, since Diesel capacity is used for peak loads only, with load factors of less than 20%.

As can be seen from the comparison of average electricity production price on Figs. 6 and 7, none of the low $CO_2$ scenarios are economically viable. With current technology prices wind is not economically viable on the island of Santiago. The combined cycle will theoretically become viable on its own after the installed power reaches 70 MW, but not in combination with wind (Fig. 7). With the potential value of CDM taken into account there is a chance of economic viability of the combined scenario, which is also the best from the $CO_2$ emissions point of view.

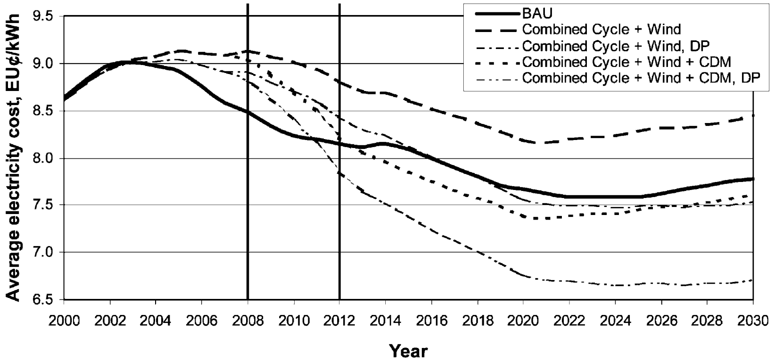


Fig. 6. Average (5 year moving average) electricity cost for wind 30% scenaria; BAU—baseline scenarium; DP—declining prices of wind technology of 1.5% yearly; CDM—potential influence of Clean Development Mechanism at 25 €/t$CO_2$

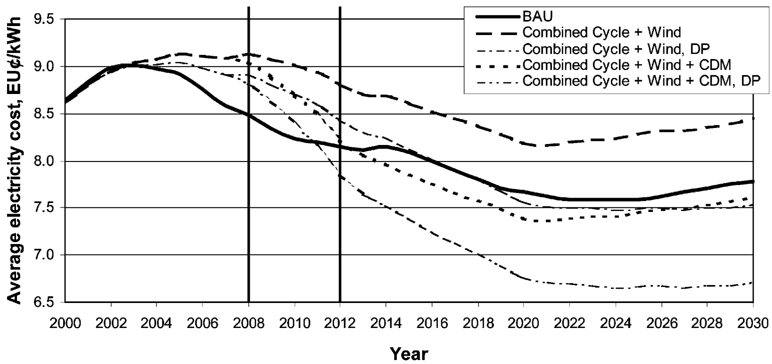


Fig. 7. Average (5 year moving average) electricity cost for combined cycle/wind scenaria; BAU—baseline scenarium; DP—declining prices of wind technology of 1.5% yearly; CDM—potential influence of Clean Development Mechanism at 25 €/t$CO_2$.

Assuming only a 1.5% yearly price decline of wind technology during the next 30 years, wind will still not become economically viable on its own, but with the help of CDM it could. A decline of 3% would make it viable without CDM in 2012. The fifth scenario, the best from the point of view of $CO_2$, could become viable with the relatively small price per tonne of carbon through the CDM process, and would get economically viable after 2016 even without CDM.

## 5. Implications to SIDS

Due to the relatively high price of electricity produced from Diesel, and small electricity systems, the island states offer excellent potential to CDM linked technology transfer, although on a small absolute scale. The potential depends on the magnitude of the isolated area electricity system, being limited to an island, or a part of an island, or to a country. One more important factor is that in most of these islands, which are often the least developed countries, the small isolated electricity systems do not function 24 h per day, and the loss of load probability is high. That makes intermittence of renewable electricity sources more acceptable.

For very small isolated systems, up to several kW, photovoltaic power can be competitive, especially if the Diesel fuel is expensive to deliver. In the case of small electricity grids wind electricity production will be competitive or close to being competitive with Diesel electricity. The competitiveness depends very much on the need to build up reserve Diesel capacity to have a back up when there is no wind and the difficulty of handling the fuel. In cases when there is a small difference between the electricity prices coming from Diesel and wind, the Clean Development Mechanism can add significantly to the attractiveness of investing into wind energy, by reducing the wind electricity price by 5–10%. The problem with wind energy in such small grids is that units installed have to be relatively small, compared to the newest technology (wind turbines of up to 2 MW currently). Although very small grids can depend on only one wind turbine, backed with a Diesel generator, in any of the possible regimes, wind-Diesel to parallel, if necessary, if one wants to reduce loss of load probability in systems, blocks of more than 15% of the total installed power should not be considered. That adds to the investment cost, plus the fixed cost of the wind field, which will in such a situation only have several small wind turbines. Together with higher transportation and installation costs, wind electricity will typically cost at least double than the price in Denmark. The problem of small and inefficient units will be avoided for systems bigger than 2 MW, since then the units of 250 kW can be used. Those are already highly efficient units offered by many producers.

When the electricity system reaches 70 MW of installed power, allowing for the installation of 10 MW units, then it should be viable to install combined cycle blocks for covering the base load. That could earn a significant amount of CDM credits, since the combined cycle is more efficient. Depending on fuel, the combined cycle could earn even more, if natural gas is used, but most of islands do not have such sources of gas. Therefore kerosene must be used, which has a similar carbon intensity to Diesel fuel. Kerosene is relatively practical since the most of islands already have storage and handling in place due to the air transport.

## 6. Additionality and baselines

A CDM project activity is additional if anthropogenic emissions of greenhouse gases by sources are reduced below those that would have occurred in the absence of the registered CDM project activity [1]. The baseline for a CDM project activity is the scenario that reasonably represents the anthropogenic emissions by sources of greenhouse gases that would occur in the absence of the proposed project activity. The baseline for this paper is based on “emissions from a technology that represents an economically attractive course of action, taking into account barriers to investment" [1], which is Diesel for electricity sector in Cape Verde. It can be argued that the baseline will not significantly change for Cape Verde during the lifetime of the technology taken into account in this paper, wind and combined cycle, and that a crediting period of seven years should be selected, "which may be renewed at most twice, provided that, for each renewal, a designated operational entity determines and informs the executive board that the original project baseline is still valid or has been updated taking account of new data where applicable" [1]. There is also the possibility to fitting into a category of small-scale CDM project activities, but the details are still under consideration by the UNFCCC CDM Executive Board.

## 7. Conclusions

Small islands, as well as isolated regions, have to take a particular path to the development of their electricity power systems, bound to the limits of geography and unable to profit from economies of scale. But that disadvantage, that makes electricity produced on small islands much more expensive than in big connected grids, can be turned into an advantage through the Clean Development Mechanism. The environmentally friendly electricity producing technologies are either not far from being economically viable, or are viable already, but not being built because of barriers to new technologies, and those are the marginal cases in which CDM could make a difference. There are several technologies that could be helped by CDM induced technology transfer. A renewable one, wind energy, and supply side efficiency technology, combined cycle are discussed in this paper, but that is not an exhaustive list. The case study of island of Santiago, Cape Verde, including the five scenarios of development of electricity production is shown with the potential influence of CDM, as well as the influence of declining prices of renewable energy technologies. The first scenario is baseline, which means mainly Diesel. The second conceives of the wind harnessed for the production of 30% of electricity. The third scenario replaces part of the Diesel capacities by the combined cycle technology. The fourth scenario is the same as the second with declining prices of wind technology, as the fifth is the same as the third scenario with declining prices. The wind scenario would reduce $CO_2$ emissions by a third, and introducing combined cycle by a further 15%, in all there is a potential of nearly halving emission from the baseline.

With current technology prices wind is not economically viable on the island of Santiago. The combined cycle will theoretically become viable on its own after the installed power reaches 70 MW, but not in combination with wind. With the potential value of CDM taken into account there is a chance of economic viability of the third, combined scenario, which is also the best from the $CO_2$ emissions point of view. Assuming only a 1.5% yearly decline of wind technology during the next 30 years, the wind will still not become economically viable on its own, but with the help of CDM it could. A decline of 3% would make it viable without CDM in 2012. The fifth scenario, the best from the point of view of $CO_2$, could become viable with a relatively small price of tonne of carbon through the CDM process. There is a large, nearly 50%, GHG reduction potential, from the baseline. There is clear additionality for wind energy and combined cycle. There is a strong contribution to the host's country sustainable development needs. Similar results were obtained for a much smaller electricity system of the Island of Santo Antão, Cape Verde [27], showing the scalability of the approach.

## Acknowledgements

The authors would like to acknowledge the Portuguese Ministério da Ciência e Tecnologia for the financial support for the scholarships of Dr. Neven Duic, Dr. Luís Alves and Dr. Fengzhen Chen as part of the programme Praxis XXI.

The financial support of DGDEV and DGTREN of the European Union and the Portuguese Direcção Geral da Energia are also acknowledged. The content of the publication is the sole responsibility of its authors, and in no way represents the views of the European Commission or its services.

## References

[1] UN framework convention on climate change site, http://www.unfccc.de/
[2] Hyvarinen J. In defence of the Kyoto Protocol, IEEP, London, 2000.
[3] OECD study Meeting the Kyoto targets. COM/ENV/EPOC/CPE (99)76, 1999.
[4] E3M Lab, Capros P, Mantzos L. The economic effects of EU-wide industry-level emission trading to reduce greenhouse gases. Results from PRIMES energy systems model, 2000.
[5] Kram T, Hill D. A multinational model for $CO_2$ reduction—defining boundaries of future $CO_2$ emissions in nine countries. Energy Policy 1996;24(1):39–51.
[6] Halsnaes K. Market potential for Kyoto mechanisms—estimation of global market potential for co-operative greenhouse gas emission reduction policies. Energy Policy 2002;30(1):13–32.
[7] Jepma CJ, Gaast W. On the potential of flexible instruments under the Kyoto Protocol. International Journal of Environment and Pollution 1998;10(3-4):476–84.
[8] The Economist, Greenhouse gases—cost free, January 22, 2000.
[9] European Commission, Green Paper on GHG emissions trading within the EU—COM (2000) 87, 2000.
[10] Zhang ZX, Maruyama A. Towards a private-public synergy in financing climate change mitigation projects. Energy Policy 2001;29(15):1363–78.
[11] Painuly JP. The Kyoto Protocol, emissions trading and the CDM: An analysis from developing countries perspective. Energy Journal 2001;22(3):147–69.
[12] Tietenberg T. Relevant experience with tradable entitlements, combating global warming: study on a global system of tradable carbon emission entitlements, United Nations, New York, 1992. p. 37-54.
[13] Zhang ZX, Nentjes A. International tradable carbon permits as a strong form of joint implementation. In: Skea J, Sorrell S, editors. Pollution for sale: emissions trading and joint implementation. Cheltenham: Edward Elgar; 1999. p. 322–42.
[14] Tietenberg T, Grubb M, Michaelowa A, Swift B, Zhang ZX. Greenhouse gases emissions trading: defining the principles, modalities, rules and guidelines for verification, reporting and accountability, Geneva: UNCTAD, 1998.
[15] Philibert C. Emissions trading and developing countries. OECD, 1999.
[16] Philibert C. The Clean Development Mechanism: An economic approach to "environmental additionality". UNEP, 1998.
[17] Philibert C. How could emissions trading benefit developing countries. Energy Policy 2000;28(13):947–56.

[18] Woerdman E. Implementing the Kyoto protocol: why JI and CDM show more promise than international emissions trading. Energy Policy 2000;28:29–38.
[19] Wohlgemuth N, Missfeldt F. The Kyoto mechanisms and the prospects for renewable energy technologies. Solar Energy 2000;69(4):305–14.
[20] Briguglio L. Small island developing states and their economic vulnerabilities. World Development 1995;23(9):1615–32.
[21] Cape Verde at Glance, World Bank data, published on: http://www.worldbank.org/data/countrydata/aag/cpv—aag.pdf
[22] The human development report 2002, UNDP, http://www.undp.org/hdro/report.html
[23] The human development report 1999, UNDP, http://www.undp.org/hdro/report.html
[24] Patou M. Programme de développement à moyen terme du sous—secteur de l'électricité géré par l'entreprise publique d'électricité et d'eau ELECTRA, Cap Verte, 1997.
[25] Capros P, Georgakopoulos P, Van Regemorter D, Proost S, Schmidt TFN, Koschel H, Conrad K, Vouyoukas EL. Climate technology strategies 1-2. Mannheim: Physica-Verlag, 1999.
[26] Eliasson B. Renewable Energy: Hydro, Wind, Solar, Biomass, Geothermal, Ocean: Status and Prospects. Baden-Dattwil, Switzerland: ABB Corporate Research Ltd. EUREC Agency, 1998.
[27] Duic N, Alves LM, Carvalho MG. Kyoto Protocol objectives by promoting the technology transfer to small island developing countries: Santo Antão, Cape Verde. CD Proc. of the International Conference on New and Renewable Energy Technologies for Sustainable Development, Madeira 2000, p. 9.